VNU Journal of Science, Earth Sciences 23 (2007) 235-243

Quaternary sedimentary cycles in relation to sea level change in Vietnam

Tran Nghi*, Nguyen Thanh Lan, Dinh Xuan Thanh,
Pham Nguyen Ha Vu, Nguyen Hoang Son, Tran Thi Thanh Nhan

College of Science, VNU

Received 20 November 2007; received in revised form 15 December 2007

Abstract. Vietnam has over 3200 km shoreline which extends from north to south of the country. Sea level changes were principal factors influenced on sedimentary environment and compositions. In Quaternary, cycles of sea level change and tectonic movement were main factor that created Red River delta, Nam Bo plain and Central plain. There are 5 sedimentary cycles corresponding to 5 cycles of sea level change of the Red River delta and Nam Bo plain. Sedimentary cycles were characterized by sedimentary coefficients such as: grain size, clay content, index of cation Fe^{2+}/Fe^{3+} exchange, pH variation from the start to the end of cycles. They are represented by fluvial terraces, marine terraces, marine notches and peat layers. In central littoral plain, the relationship between sedimentary cycles and sea level is represented by five sandy cycles and distribution of coral terraces in shallow sea.

There are 5 generations of ancient shoreline zones, which correlated with glacial and interglacial periods in Vietnamese continental shelf: the shoreline in 30 m water depth is correlated with (Q_2^{1-2}). Up to 60 m water depth is correlated with (Q_1^{3b}-Q_2^{1}) and 100-120 m water depth is correlated with $Wurm_2$ glaciation (Q_1^{3b})(?). In 200-300 m water depth correlated with $Wurm_1$ glaciation (Q_1^{3a})(?), at 400-500 m water depth correlated with Riss glaciation (Q_1^{2b})(?), at 600-700 m water depth correlated with Mindel glaciation (Q_1^{2a})(?), and at 1000-1500 m water depth correlated with Gunz glaciation (Q_1^{1})(?). As such Quaternary sea level changes in mainland and continental shelf interacted and quite distinctive form each other by pendulum rule.

Keywords: Quaternary sedimentary circles; Red River Delta; Cuu Long River Delta; Sea level change.

1. Introduction

Vietnam has over 3200 km shoreline which extends from Mong Cai in the north to Ha Tien in the south. Sea level changes had influenced on sedimentary environment and compositions and the evolution sedimentary cycle of Red River Delta, Cuu Long River Delta and Central Coastal plains. These cycles were distinguished by absolute age dating include: thermo-luminescence age, ^{14}C dating from wood and shells. Geomorphological characteristics and sedimentary coefficients were used together

* Corresponding author. Tel.: 84-4-5587059
E-mail: trannghi@vnu.edu.vn

with absolute ages to analyze the cause - effect relationship between development of sedimentary cycles, sea level changes, and tectonic movement in Quaternary.

2. Methodology

There are many research projects have undertaken by Vietnamese scientists on Quaternary sea level change, especially in Late Pleistocene to Holocene. However, the identification of transgression and regression phases and lithofacies analysis based on quantitative approaches such as material compositions, geochemical environmental coefficients,... have just applied by Tran Nghi, Mai Thanh Tan and other workers in 2000, 2001 [6, 8]. Therefore, in this paper, we will use the same approaches to analyze the cause - effect relationship between lithological characteristics and lithofacies associations in relation to transgression and regression phase and tectonic movements: fluvial and marine terraces in mainland and in continental shelf that are distributed in different height and depth and compare them to the transgression and regression system of ancient shorelines.

For investigating mechanism of sedimentary evolution of Red River Delta, Cuu Long River Delta and Central plains, it is necessary to define the cause - effect correlation between lithology, sea level change, and tectonic movement. The sedimentary environment has major role in governing petrological compositions in term of lithofacies - paleogeography. The transgression phase is characterized by marshy, lagoonal and deltaic environments. Meanwhile, regression phases created coarse - grained materials of proluvial - aluvial environments. Therefore, the relationship between sedimentary cycles and sea level change is determined by changing of facies association according to time and space. The end of a cycle is marked by a weathering period to form laterite - bearing, yellow to red sediments.

Absolute age (Ka)	Geological age		Vietnam (Tran Nghi)		North West Europe		British	Alper (Penk)	Italy	Middle East	Poland (Sapherlevin)	Russia (Lakovlep)	North of America (East)	Archaeology	
			Sedimentary cycles	Regression ⇄ Transgression	Stratigraphy	Regression Transgression								Human species	Cultural periods
	HOLO-CENE		Q_2^3 ?		Holocene	Flandrian Transgression	Holocene Transgression	Holocene Transgression	Holocene Transgression	"Nizza" Transgression	Holocene Transgression	Transgression Mogine	Holocene Transgression		Mesolithic and Neolithic
10	PLEISTOCENE	Late	Q_1^{3b}-Q_2^3			Regression	Regression	W_2		Regression	Baltic Glaciation	Astakop-vandai	Viskosine (2)	Modern human	Upper
			Q_1^{3b} ?		Weich-sebian	Transgression Regression	Khanstanton	W_1-W_2? W_1	Pantinian	Regression	Muzur Vacsava II Deglaciation	Mologo sek nhim Kalinin	V_1-V_2 Viskosine (1)	Nean-dectane	Middle
			Q_1^{2b-3a} ?		Eemian	Transgression	Upper Ixla Khocnen	R-W_1		Tyrhenian	Mazoves II	Mikulin Odinsop		Pre Nean-dectan and pre Sapien	Lower
125		Middle			Saalian	Regression	Dzippin	Riss		Regression	Vacsava I	Dnheprop			
			Q_1^{2a} ?		Holsterian	Transgression	Lower Khocnen	M-R		?	Mazoves I	Likhvin			
					Elsterian	Regression	Logestophoc Glaciation	Mindel		Regression	Krakop	Acient glaciation 1,2			Early
700		Early	Q_1^{1b} ?		Cromeriam complex	Transgression	Cromerian	G-M	Cromerian	Roman crotorian	Sandomir	Acient deglaciation			
900					Menapian	Regression	Crue	Gun	Cassia	Siciian	Laroslap	Acient glaciation			
			Q_1^{1a} ?		Waal			D-G						Heidel-berg species	
1.6					Eburonian			D		Emilian					
	PLIOCENE				Tiglian										
2-2.5 Ma					Practiglian										
					Reuverian										

Paleolithic

Fig. 1. Comparison of sea level change - glacial - interglacial - sedimentary cycles and geological age [9].

The main methods used in this paper are:

- *Petrological analysis method* was carried out using thin sections, made by cementing epoxy of unconsolidated sands.

- *Granulometric analysis* of sand was used by sets of sieve or pipet of different fractions and then granulometric parameters (Sorting - So, Asymetric coefficient - Sk, average grain size - Md) were obtained by a PC software.

- *Geochemistry environmental coefficients* of sediments was measured by specialized meter and then obtained: pH, Eh, Kt, Fe^{2+}/Fe^{3+}... These pH - alkaline - acid index, Eh - redox potention index, Kt = $(Na^+ + K^+) / (K^{2+} + Mg^{2+})$ exchanging cation coefficients were applied in lithofacies association analysis and reconstruction of paleogeographical landscape.

3. Transgression - regression cycles of Red River Delta, Cuu Long River Delta, Central plain in Quaternary

Red River Delta (RRD) and Cuu Long River Delta (CLRD) are the biggest plains in Vietnam. Developing history and sedimentary evolution of both deltas have closely related with sea level changes in Quaternary in which regression were according Gunz, Mindel, Riss, $Wurm_1$, $Wurm_2$ glacial phases and transgressions were correlated with interglacial phases and Flandrien transgression.

Five sedimentary cycles in RRD and CLRD were correlated with 5 stratigraphic formations: in early Pleistocene (Q_1^1), Middle - Late Pleistocene (Q_1^{2-3a}) , Late Pleistocene (Q_1^{3b}), late part of Late Pleistocene - Middle Holocene (Q_1^{3c}-Q_2^2) and Late Holocene in each delta (Fig. 1-6) [2]. The beginning of a cycle was related with coarse grained size pebbles, sands proluvial and alluvial facies sediment what is mainland origin and the ending was related with fine grained size silt, clay deltaic and lagoonal facies.

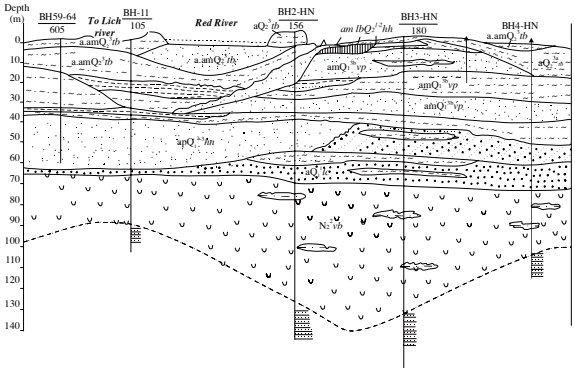

Fig. 2. Litho - facies cross section in the center of Red River Delta [3].

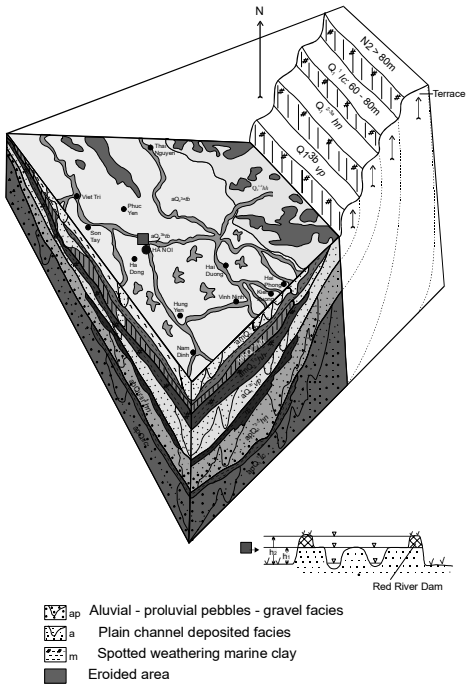

Fig. 3. Block diagram of alluvial facies in Red River Delta [11].

The first sedimentary cycle (Early Pleistocene, Le Chi Formation in RRD and Trang Bom Formation in CLRD) are characterized by coarse grained size sediment with content of pebbles - gravel increased from 15 to 20.8% in RRD and 13.8% in CLRD [2]. The ending of cycles was correlated with interglacial phase, silty clay deltaic - marshy facies (Md=0.1-0.5 mm in RRD and Md=0.018-0.439 mm in CLRD).

During maximum sea level rise, erosion - accumulation terraces of 55-70 m high in NE of RRD were formed. Meanwhile, lithofacies association of sandy barriers and lagoonal facies is the main feature in Central coastal plain from Quang Binh Province to Mui Ne - Phan Thiet, Binh Thuan Province.

The second sedimentary cycle from Middle - Late Pleistocene (Hanoi Formation in RRD and Thu Duc Formation in CLRD) is comprised by thick pebble - gravel layer (10-80 m) of mountainous river and proluvial facies (Md=0.2-1 mm in RRD and Md=2.3 mm in CLRD [2]). By the end of this sedimentary cycle, rock composition composes of clayish marshy and clayish silt deltaic facies in Thanh Hoa plain, RRD, CLRD, and ancient sandy bars, tombolo lagoonal facies in Central plain.

The third sedimentary cycle corresponds to Late Pleistocene (Vinh Phuc Formation in RRD and Cu Chi or Moc Hoa in CLRD), which contains coarse and medium grained sands of river bed facies and passing upwards into sand levee facies, silty clay flood plain and clay marshy, greenish lagoonal facies. In Central plain, late Pleistocene transgression phase created big volume of white quartz sandy bars. However, these white sand have became yellow sand due to infiltration weathering.

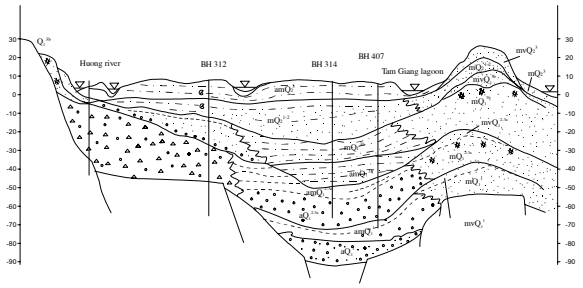

Fig. 4. Litho - facies cross section of Thua Thien Hue Plain [4].

The fourth sedimentary cycle was formed during period from Latest Pleistocene to Early - Middle Holocene (Hai Hung Formation in RRD and Tan Thanh or Binh Chanh Formation in CLRD). This sequence is characterized by Flandrien transgression sedimentary facies complex and composed of sandy silt of deltaic facies, clay silt rich in organic material and peat of marshy facies. These layers were covered by grey - greenish clay of lagoonal facies. The coastal plains in Central Vietnam, from Nghe An to Binh Thuan provinces, compose of a combination of coastal sandy bars and lagoons occuring inside sandy bars. The associations of tombolo and bay was quite typical in South Central Vietnam, especially in Khanh Hoa Province.

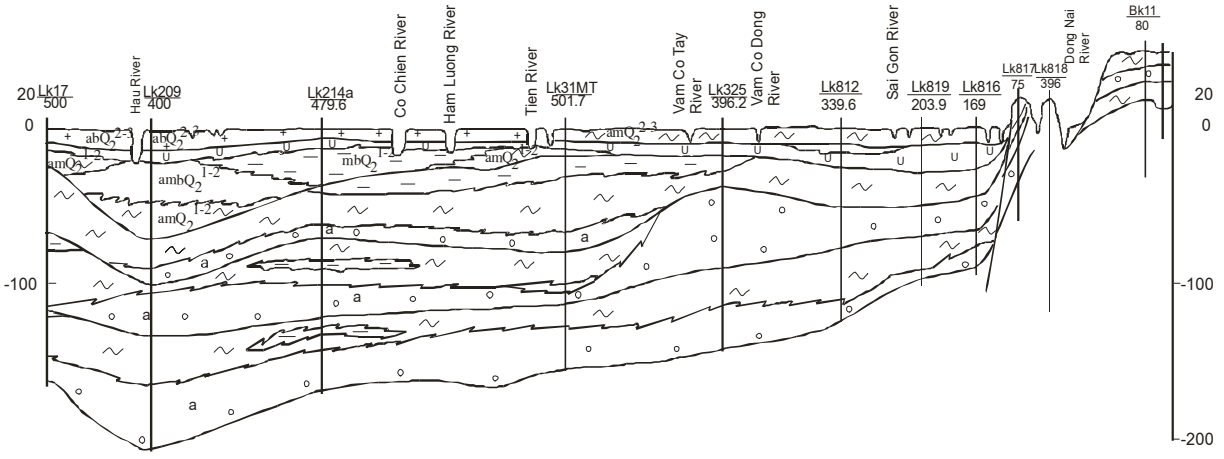

Fig. 5. Sedimentary cross section in Cuu Long River Delta [9].

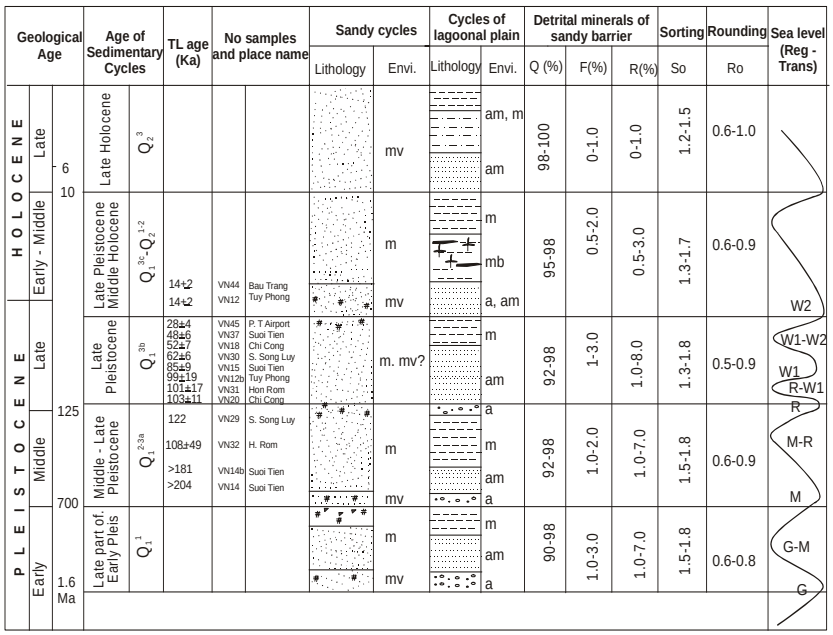

Fig. 6. Comparison of thermoluminescence ages of quartz sandy barrier and sedimentary cycles in Binh Thuan Province, Vietnam [9].

The fifth sedimentary cycle was formed in Late Holocene regression phase (Thai Binh Formation in RRD and Can Gio Formation in CCRD). This cycle is dominated by sands, silts, clay alluvial facies in upper part and silt, clay deltaic plain, grey clay marshy and sand silt clay deltaic front facies in lower part. Besides, Late Holocene eolian sediments have been formed by wind reworking old sandy formation. In addition, the fifth cycle was also eolian sediment in sandy bars and sandy dunes in CLRD.

4. Thermoluminescence age of red sandy cycles in Phan Thiet - Binh Thuan provinces

The coastline of South Central Vietnam is dominated by extensive sandy coastal barrier successions of Early Pleistocene, Middle - Late Pleistocene, Late Pleistocene and Late Pleistocene to Early - Middle Holocene and Late Holocene.

The first cycle: an angular tektite layer covered alternative red and white - yellow sand barrier of Early Pleistocene. Probably, this red sand succession should have age older than the age of tektites (i.e. before 700 Ka) [1]. The comparison of these successions with glacial and interglacial in the world (Fig. 1) corresponds to interglacial Gunz - Mindel.

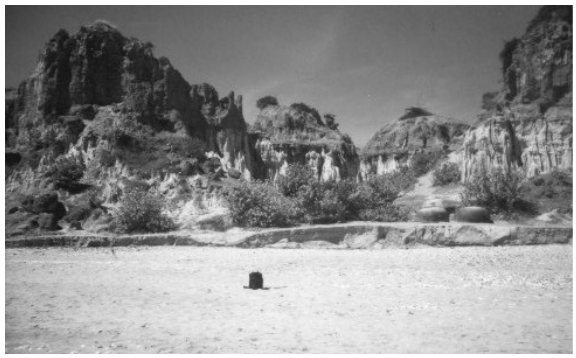

Fig. 7. The sequence of red sand and light grey sand, Chi Cong, Binh Thuan Province, Vietnam [7].

The second cycle, composing of 2 rhythms, was possibly equivalent to older grey - white, well cemented sand barrier of Middle Pleistocene age (Q_1^{2a}) (TL age of >204 Ka [1]). Moderate cemented red sand barrier of Middle - Late Pleistocene are dominated by inner barriers. The

sandy samples yielded an age of 103±11 Ka, 101±17 Ka [1], possibly equivalent to stage 5 of last interglacial sensulato of the Oxygen Isotope record.

The third cycle comprises by a series of red and yellow sand successions of barriers dominated in coastal zone of South Central Vietnam from Phan Thiet to Tuy Phong. This cycle over lies of Middle - Late Pleistocene sandy barrier successions the boundary between second cycle is exposed and third cycle in Hon Rom, Chi Cong, Suoi Tien and Song Luy. The alternation of red sand and yellow sand rhythms related to sea level change and infiltration weathering in late Pleistocene.

Sample VN31 yielded an age 101±17 Ka [1].

Sample VN31 yielded an age of 101±17 Ka, and VN32 - an age of 108±49 Ka (Hon Rom) [1]. This age range belongs to Late Pleistocene cycle which are suggestive of deposition during stage 5 (sensulato) of the Oxygen Isotope record.

The fourth cycle composed of two rhythms: an eolian red sand dunes of Late Pleistocene (sample at Phan Thiet airport yielded a TL age of 28±4 Ka) correlated with stage 2 and 3, and white sand barriers oxygen isotope to be equivalent with last glacial maximum (W_2) of Early - Middle Holocene.

The fifth sandy cycle reworked Holocene quartz sandy barrier to form sand dune during 3 Ka to present. The South Central coastal zone between Phan Thiet and Tuy Phong is dominated on surface by light yellow active dune fields due to reacting of wind, possibly correlated with Holocene regression and sea level rise.

5. Cycles of coral reef in relation to sea level change in coastal zone and shallow sea of Central Vietnam area

Coral reefs occur in 3 locations in shallow sea of South Central Vietnam (Fig. 8).

Middle - Late Pleistocene coral reefs, which were calcified, occur in Hon Do - Ninh Thuan. This layer is covered by red sand. Late Pleistocene coral reef terrace is distributed in 20-25 m water depth. Middle Holocene coral reef terraces are located in 1 - 2 m water deep yield and age of 5000 year BP by C^{14} dating.

Distribution of calcified coral reefs in comparison with red sand (19 Ka) showed that: this layer could have been formed in Middle - Late Pleistocene transgression and Vinh Phuc transgression that created red sand and coral reef in 20 - 25 m water depth. The red sand layer covers the coral.

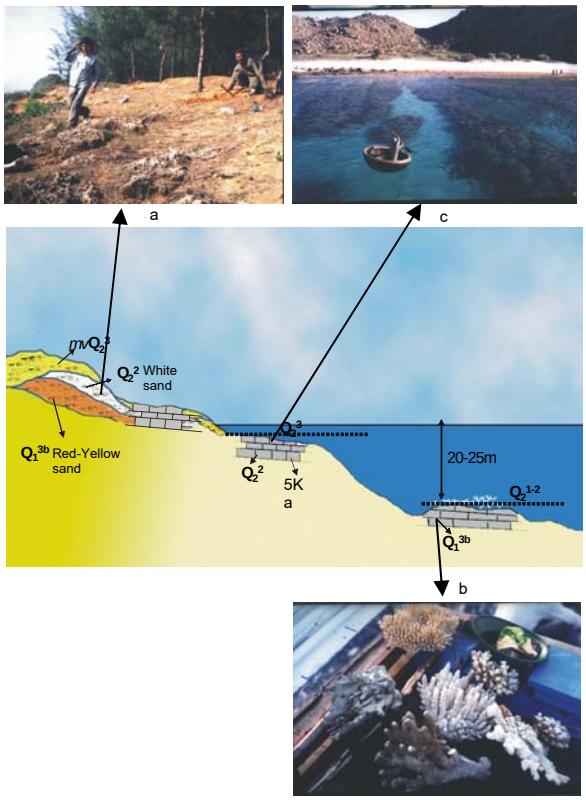

Fig. 8. Development periods of coral in South Central area (Hon Gom Peninsula).

The coral terrace in 20 - 25 m water depth was formed in Flandrian transgression. This was the second sea level stands in Holocene and it is correlative to ancient shorelines. The coral reef at 1-2 m water depth, formed in Early - Middle Holocene, is correlated with white sand in Cam Ranh and Hon Gom.

Fig. 9. Laterite gravel in bottom sediment in SW Eastern Sea.

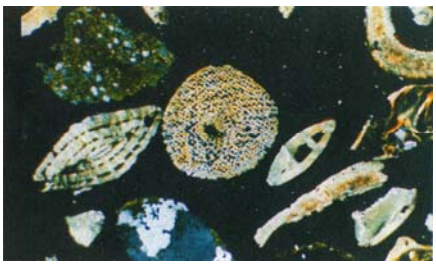

Fig. 10. Foraminifera, diatomea, quaczite fragments and fragments of dacite rock in bottom sediments in SW of Eastern Sea.

Fig. 11. Weathering spotted clay in Late Pleistocene sediment in SW of Eastern Sea.

6. Quaternary shorelines in bottom of continental shelf of Vietnam

6.1. Ancient shorelines

The well-sorted and well-round ancient sandy bars distributed parallel to modern shoreline.

Well-round laterite gravels are situated in sea bottoms far from modern coastline. This layer is covered by spotted clay layer which contained laterite curdles.

Concentration of coarse - grained terrigeneous sediment and moderate to well - roundness bioclasts [9].

Location of ancient shoreline in continental shelf [8]:

- In 30 m water depth correlated with (Q_2^{1-2}).
- In 60 m water depth correlated with (Q_1^{3b}-Q_2^{1}).
- In 100-120 m water depth correlated with $Wurm_2$ glaciation (Q_1^{3b}).
- In 200-300 m water depth correlated with $Wurm_1$ glaciation (Q_1^{3a}).
- In 400-500 m water depth correlated with Riss glaciation (Q_1^{2b}).
- In 600-700 m water depth correlated with Mindel glaciation (Q_1^{2a}).
- In 1000-1500 m water depth correlated with Gunz glaciation (Q_1^{1}).

6.2. Relationship between marine terraces and sedimentary cycles in the sea bottom

In Quaternary, appearance of fluvial and marine terraces in mainland and continental shelf are the results of uplift - subsidence movements and transgression - regression phases. Five ancient marine terraces on mainland and 6 on continental shelf [9] from Pleistocene to Holocene ages can be identified.

These terraces have symmetric relation, it means that the oldest marine terrace on mainland is at highest elevation (highest point) and the oldest marine terrace on continental shelf is at lowest elevation (deepest point) (Fig. 12). The marine terraces on mainland and continental shelf of the same age were formed in the same sedimentary cycle. These periods extended from Pleistocene to Holocene. Thus, sea level changes combined with uplift activities on mainland and subsidence in sea bottom characteristic marine terraces systems had produced.

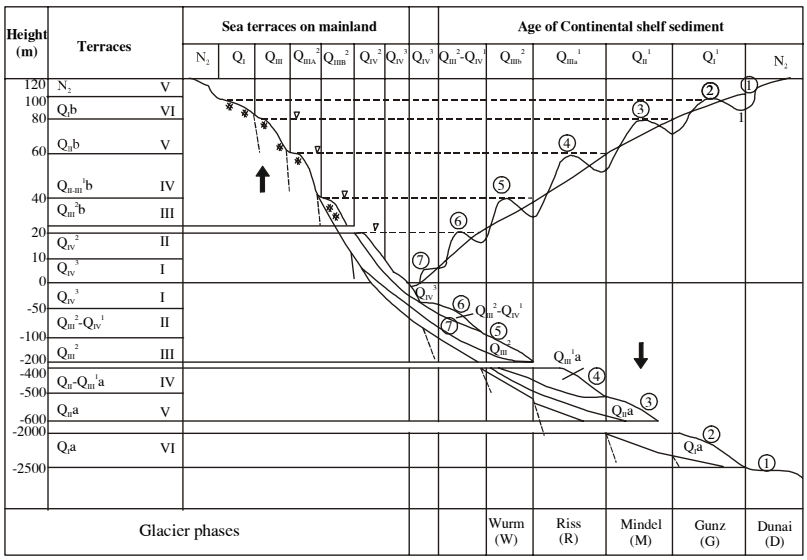

Fig. 12. Relationship between sea terraces and Pliocene - Quaternary sedimentary cycles in continental shelf of Vietnam [10].

7. Conclusions

In Quaternary, cycles of sea level change and tectonic movement cycles are the main reasons, which create Red River Delta, Cuu Long River Delta and Central plain. There are 5 sedimentary cycles corresponding to 5 cycles of sea level change in Red River Delta, Cuu Long River Delta, and Central plain. In Central littoral plain, the relationship between sedimentary cycles and sea level change is characterized by 5 sandy cycles and distribution of coral terraces in shallow sea.

There are 5 generations of ancient shoreline zones, which can be correlated with glacial and interglacial phases in Vietnamese continental shelf: at 30 m water depth correlated with Q_2^{1-2}; at 60 m water depth correlated with Q_1^{3b}-Q_2^{1}; at 100-120 m water depth correlated with $Wurm_2$ glaciation Q_1^{3b}; at 200-300 m water depth correlated with $Wurm_1$ glaciation (Q_1^{3a}); at 400-500 m water depth correlated with Riss glaciation Q_1^{2b}; at 600-700 m water depth correlated with Mindel glaciation Q_1^{2a}; and at 1000-1500 m water depth correlated with Gunz glaciation Q_1^{1}. These ancient shorelines correlated with marine terraces and 6 sedimentary cycles in continental shelf.

References

[1] V.M.W. Colin, G.J. Brian, Tran Nghi, M.P. David, et al., Thermoluminescence ages for a reworked coastal barrier, southeastern Vietnam: a preliminary report, *Journal of Asian Earth Sciences* 20 (2002) 535.

[2] Nguyen Huy Dung et al., *Neogene - Quaternary stratigraphical division and Nam Bo plain structure research*, Department of Geology and Mineral Resource, Hanoi, 2003 (in Vietnamese).

[3] Tran Nghi, Ngo Quang Toan, Characteristics of sedimentary circles and history of Quaternary geology of Red River Delta, *Journal of Geology* 206-207 (1991) 31 (in Vietnamese).

[4] Tran Nghi, Circles of marine transgression, regression, and formation history of Central plains in Quaternary, *New discoveries in archeology in 1995 year*, Hanoi, 1996 (in Vietnamese).

[5] Tran Nghi, Evolution of coastal sandy formations in Central Vietnam in relationship

with the oscillation of sea level in Quaternary. Project *Marine geological research and Geophysics (II)*, Institute of Oceanography, Hanoi, 1996.

[6] Tran Nghi, Nguyen Dich Dy, Dinh Van Thuan, Vu Van Vinh, Ma Kong Co, Trinh Nguyen Tinh, Phan Thiet red sands - material composition, provenance, mechanism of formation and evolution in relation with sea level changes and neotectonics, Proceedings of *The first scientific conference*, Hanoi University of Science, 1998 (in Vietnamese).

[7] Tran Nghi et al., Environment and mechanism of red sand formation in Phan Thiet Province, *Journal of Geology* 245A (1998) 31 (in Vietnamese).

[8] Tran Nghi, Mai Thanh Tan, Doan Dinh Lam, La The Phuc, Dinh Xuan Thanh, Nguyen Dinh Nguyen, Characteristics of Pliocene - Quaternary lithofacies - paleogeography in shelf of Vietnam, *Journal of Sciences of the Earth*, 23 (2001) 35 (in Vietnamese).

[9] Tran Nghi, Mai Thanh Tan, Dinh Xuan Thanh, Nguyen Thanh Lan, The sea level change problem in Quaternary based on sedimentary research in littoral and shallow sea from Nha Trang to Bac Lieu, Proceedings of Scientific conference *Geotechnics and Marine Geology*, Da Lat, 2003 (in Vietnamese).

[10] Tran Nghi, Textbook on sedimentology, VNU Publishing House, Hanoi, 2003 (in Vietnamese).

[11] Tran Nghi, *Textbook on marine geology*, VNU Publishing House, Hanoi, 2005 (in Vietnamese).