GEOCHEMICAL SEDIMENTARY EVOLUTION DURING PROCESS OF MANGROVE FOREST FORMATION, DEVELOPMENT AND DEGRADATION IN RED RIVER MOUTH (ON EXAMPLE OF GIAO THUY MANGROVE FOREST, NAM DINH PROVINCE)

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Introduction

In tropical littorals, thanks to coastal sedimentation, low tidal mudflats tend to be elevated into high tidal mudflats, which are more favorable for keeping and storing mangrove seeds (Hoekstra, 2000) [10]. But when the mudflats become higher than the spring tide level, mangrove forest (MF), which is under dominant influence of fresh water, begins degrade. In several coastal regions of Vietnam, the degradation of mangrove forest is also caused or intensified by human making aquacultural ponds. Environmental variations during the process of formation, development and degradation of mangrove forests are recorded in the sediment profiles of these regions in the manner of sedimentary, geochemical and nutritional tendencies. Interpretation of these geochemical records in coastal sediment will be a contribution to reconstruct the environmental evolution of the process of mangrove forests formation, development and degradation in the Red River mouth, (Giao Thuy mangrove forest), Nam Dinh province (Figure 1).

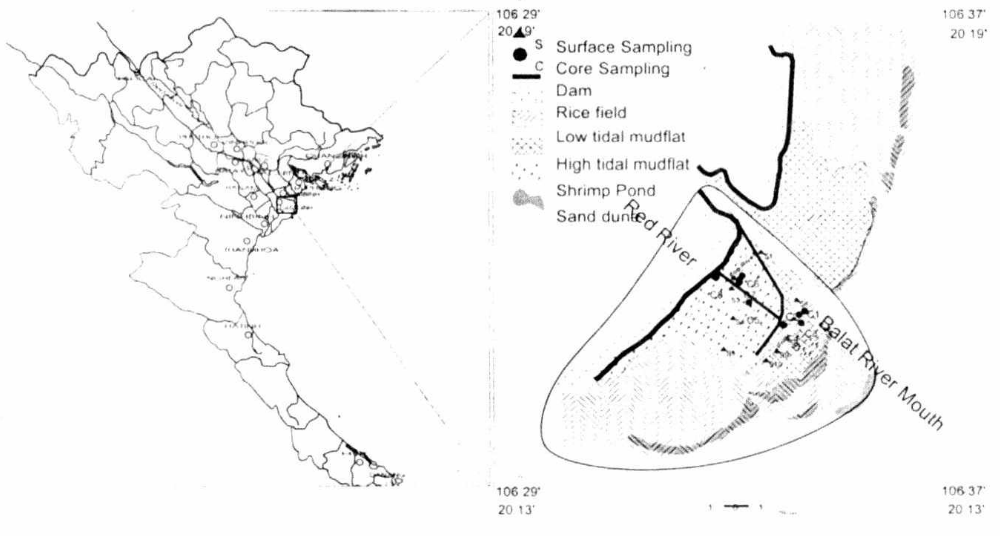


Figure 1. Study area and sampling sites

1. Materials and Methods

In order to obtain such environmental changes during the process of mangrove forest formation, development and degradation, lineal system for observation and sample collection were set across sedimentary environments such as low tidal mudflats, high tidal mudflat with mangrove forest, degraded mangrove forest in shrimp ponds, tidal channel, irrigated drainage and so on. They are different each from others in geomorphology, mangrove system, hydraulic dynamic, water circulation, water permanence, anthropogenic impacts and geochemical characteristics. The samples were taken on the surface, bottom sediments and at relatively homogeneous intervals along 1m50 depth of seven cores (Figure 1). The samples were preserved according to requirements of relevant analytical methods, then homogenized and pretreated for analyzing grain size, minerals, major and minor elements, nutrients and geochemical indices.

Grain size was determined by Laser Diffraction method on Master Seizer equipment of Malvern Instruments Ltd, UK (sizes of 0.1–2000μm) and Vietnamese sieve system (sizes of more than 2000μm). Using this data, on the basic of classification system of the British Geological Survey, the sediments were classified. X-ray diffraction method was used for determination of mineral composition on Bruker (Germany) X-ray diffractometer. Chemical compositions were analyzed by mass method, volume method and photometric titration method. Atomic absorption spectroscopy method on AAS Mark II Nippon Jarrell Ash and Shimadzu AAS was used for determination of Ca, Mg, Mn, Na, K, Cu, Pb, Zn, Co, Ni, Cr, Cd. Kjedald method was used for determination of N, potassium dichromate titration method for determination of $C_{organic}$ and humic. Geochemical indices such as Fe^{2+}, Fe^{3+}, Fe^{2+}_{HCl}, Fe^{2+}_{pyrit}, S_{total}, $S_{reduction}$, S_{pyrit} were determined by Vonkov-Octramov method .

2. Results and discussion

2.1. Differentiation in Sedimentary Deposition Condition

In Giao Thuy coast (Figure 1), 3 distinctive sedimentary environments - low tidal mudflat, high tidal mudflat with mangrove forest and shrimp ponds, differing in geomorphology, hydrdynamic, water circulation, water permanence, mangrove ecosystem and anthropogenic impacts were identified (Table 1), reflecting the formation, development and degradation of mangrove forest.

Table 1. Characteristics of differentiation in sedimentary deposition conditions

Parameters	Type of Environments		
	Low tidal mudflats (MFs are forming)	***Mangrove forests*** *(MFs are developing)*	***Shrimp ponds*** *(MFs are degrading)*
Hydraulic dynamic	Strongest	Medium	Weakest
Water circulation	Best	Medium	Worst
Submergence	22-24 hours per day	6-8 hours per day	24 hours per day
Mangroves	None	High density	None or little
Human activities	Weakest	Medium	Strongest

• *Low tidal mudflats* form among succeeding generations of sand dunes, ranging in water depth of 4 m to mean tide level. Sediments are almost permanently under sea water and affected predominantly by tide rather than by river and human activities.

• *Mangrove forests* composed of mainly *Aegiceras, Bruguiera, Acanthus, Kandelia, Sonneratia, Rhizophora*, are developing on high tidal mudflats- the area laying higher than mean sea level and lower than high tide level. There are two level of mangrove trees: upper (2-4m) and lower (0,5-1,2m). The mangrove forest sediments are temporally under water at alternative time in day according to tide regime and are affected by tide, river and human activities.

• *Degradation of mangrove forest* mostly occurs in extensive shrimp ponds, where sedimentary environments are enclosed by small dykes higher than high tide level. Due to drainage regime, input water is much stronger than output one, water circulation in ponds is limited. Sediments in ponds are permanently under water and often structurally disturbed by shrimps. Once for three years, sediments of 20 cm thick in shrimp ponds are dredged and taken out for the sanitation of shrimp pond.

• Based on the lithological records, the sediments in these three environments could be classified as silt, mud, sandy silt and sandy mud of tidal flat facies of upper Thai Binh formation (Q_2^3tb amb, mb) with silt accounts for 60- 70% and fine sand accounts for less than 5%. X-ray diffraction analysis results show that the main minerals in the sediments are quartz (42.59-52.09%), feldspar (9.77-11.85%), illite (18.15-20.07%), chlorite (11.36-13.44%), kaolinite (7.50-20.88%). The above mentioned sedimentary environments are different in grain size and mineral composition. The parameters are changed against depth but not so much.

2.2. Geochemical records of sediments

Differentiation of the sedimentary environments leads to differentiation of the geochemical differentiation of the related sedimentary formations.

- *Geochemical records of sediments in low tidal mudflats*

Geochemical indices of low tidal mudflats (Fe^{2+}_{HCl}= 0.04-0.07%, Fe^{2+}_{Pyrite}=0.29- 0.61%, Fe^{2+} = 0.35 -0.52%, S_{Pyrite} =0.05 -0.08%, $S_{Reduction}$ = 0.07 - 0.10%, S_{total} = 0.15 -0.19%) characterize for a combination of weak oxidation environment and weak reduction environment. Getting down cores, the oxidation index Fe^{3+} decrease (Figure 2), relevant to increasing reduction after top down the sedimentary depth whereas concentration of Fe^{2+} is almost unchanged and concentrations of S_{pyrite} as well as other sulfurs are significantly rising (Table 2). That is possibly due to the formation of pyrite in deep sediments from Fe and sulfurs (Cu N.D.,1996; 1998) [2, 3]. Concentrations of nutrients in low tidal mudflats sediment are rather high (humic: 0.89 -1.71%, $C_{Organic}$: 0.52- 1.00%, N: 0.06 - 0.09%, P_2O_5: 0.17- 0.21%) with the highest concentrations are reached at the depth of 60cm. The concentrations (ppm) of Cu (106- 147), Zn (110- 143), Pb (79- 110), Cr (84- 96), Ni (48- 53) and Co (26-29) (Table 2), that are 1.3 -100 times higher than those in low tidal mudflat sediments of Nga Son coast (Nhuan et al, 1996) [9], showing a great loading of heavy metals, especially industrial elements (Cu, Pb and Zn) from the Red River. That minor heavy metals are enriched at the depth of 60cm together with nutrients may be related to absorbability of organic materials.

- *Geochemical records of sediments in mangrove forests*

The high tidal mudflats with mangroves are characterized by environmental fluctuation between weakly oxidation and weakly reduction. The sediments have rather high concentrations of Fe^{3+} (0.21- 0.44%), Fe^{2+} (0.02- 0.03%), Fe_{HCl} (0.19- 0.24%), Fe_{Pyrite} (0.03- 0.08%), S_{Pyrite} (0.03- 0.09%), $S_{Reduction}$ (0.05- 0.12%), S_{Total} (0.11- 0.19%). Downward the cores, reduction indices such as Fe^{2+}, Fe_{HCl}, Fe_{Pyrite}, S_{Pyrite}, $S_{Reduction}$, S_{Total} increase gradually, reflecting the reduction condition of the environment. Being supplied from mangrove ecosystem, the nutriment concentrations of mangrove forest sediment are high: (humic: 0.71%-15%, P_2O_5: 0.16-0.2%, N: 0.05-0.08%, $C_{Organic}$: 0.41-0.9%). N and P_2O_5 concentrations tend to rather slightly change after depth (variation coefficient V<21%), whereas humic and $C_{Organic}$ concentrations tend to increase to wards the surface and accumulate intensively at the surface layer of sediments.

Table 2 : The sedimentary and geochemical indices of low tidal mudflat, mangrove forest and shrimp pond in Giao Thuy coastal region, Nam Dinh province

	Low tidal mudflat			**Mangrove forest**			**Shrimp pond**		
	Surface part	*Lower part*	*Average*	*Surface part*	*Lower part*	*Average*	*Surface part*	*Lower part*	*Average*
Geochemical indices (%)									
Fe^{2+}_{Pyrite}	0.04	0.07	0.06	0.03	0.06	0.05	0.13	0.10	0.11
Fe^{2+}_{HCl}	0.27	0.50	0.45	0.19	0.22	0.21	0.34	0.26	0.29
Fe^{3+}	0.37	0.46	0.45	0.44	0.26	0.32	0.17	0.26	0.23
Fe^{2+}	0.02	0.03	0.03	0.02	0.03	0.02	0.03	0.03	0.03
S_{Pyrite}	0.04	0.08	0.07	0.03	0.07	0.06	0.15	0.12	0.13
$S_{Redution}$	0.06	0.09	0.09	0.05	0.10	0.08	0.18	0.15	0.16
S_{Total}	0.13	0.18	0.17	0.11	0.18	0.15	0.28	0.24	0.25
Nutrients (%)									
P_2O_5	0.17	0.20	0.17	0.20	0.17	0.18	0.15	0.16	0.16
Humic	0.89	1.47	0.97	1.45	1.06	1.17	0.73	1.05	0.94
$C_{Organic}$	0.52	0.85	0.57	0.85	0.62	0.68	0.43	0.61	0.55
N	0.06	0.08	0.06	0.07	0.06	0.07	0.05	0.06	0.05
Minor elements (ppm)									
Cu	140	107	119	147	112	121	88	89	89
Pb	108	77	90	132	96	107	61	100	87
Zn	133	110	119	170	113	129	87	97	93
Co	28	26	27	27	25	25	18	22	20
Cr	94	87	89	101	83	88	72	86	82
Ni	52	47	49	55	45	48	40	44	42
Cd	3	2	3	3	2	3	2	2	2

The concentrations of heavy metals (Cu: 68-158 ppm, Pb: 61-144 ppm and Zn: 85-178 ppm) in mangrove forest sediment are high, especially on the surface layer. Accumulation of such heavy metals as Cu, Pb and Zn in sediments of mangrove forest is stronger than in Holocene younger sediments. It may be resulted from industrial utilization of Cu, Pb and Zn in the Red River delta.

- *Geochemical records of sediments in shrimp ponds.*

The concentrations of reduction indices (Fe_{Pyrite}, $Fe_{Siderite}$, Fe^{2+}, S_{Pyrite}, $S_{Reduction}$, S_{Total}) are in range of 0.08-0.34% with variation coefficient less than 24%. Sulfur concentrations in this sediment are about 0.06-0.31%, 10 - 30 times less than those of sediments in shrimp ponds of Bach Dang estuary, where the aquaculture movement is older and stronger (Nguyen Duc Cu, 1996).[2]. After Nguyen Duc Cu et al (1996; 1998), [2, 3] high accumulation of sulfurs and pyrite often relates to the degradation of mangrove's roots in the reduction environment by anaerobic bacteria. This process converts SO_4^{2-} accumulated in mangrove's root and in sea water into pyrite and other sulfurs (Aplin et al, 1994) [1], causing low aquaculture productivity. Nutrient records in the shrimp pond sedimentary environment show that humic concentrations range from 0.73 to 1.26%, $C_{Organic}$: 0.43- 0.74%, P_2O_5: 0.15- 0.16%, N: 0.04- 0.07% and irregularly distributed (V = 22.45- 29.65%), intensively dispersed on surface as a sign of mangrove forest degradation. The concentration of heavy metals in the shrimp pond sediment is higher than those in sea-clay sediments: Zn (87- 99ppm), Cu (88- 91ppm), Pb (87- 99ppm), Cr (72- 87ppm) and Co, Ni, Cd (<50ppm) (table 2),. Concentration of Cu, Pb, Zn, Co, Ni, Cd and Cr decreases upward and extremely rapidly in 25cm-thick surface layer.

This shows that the ability of the surface coarser sediment layer to keep and store heavy metals as well as other toxins is considerably low. Similar phenomena have been recorded in sediments of Bohai Bay, China (Zohang et al, 2002) [11]. Once these components can not be kept in the sediment, they may diffuse into the water environment or be absorbed by the shrimp pond ecosystem.

2.3. Geochemical sedimentary evolution in the process of mangrove forest formation, development and degradation

Based on the combination of observation evidences and records of lithology, geochemistry, mineralogy and nutrimentlogy, geochemical evolution picture of sediments in relationship with the mangrove forest formation, development and degradation of Giao Thuy coast has been reconstructed.

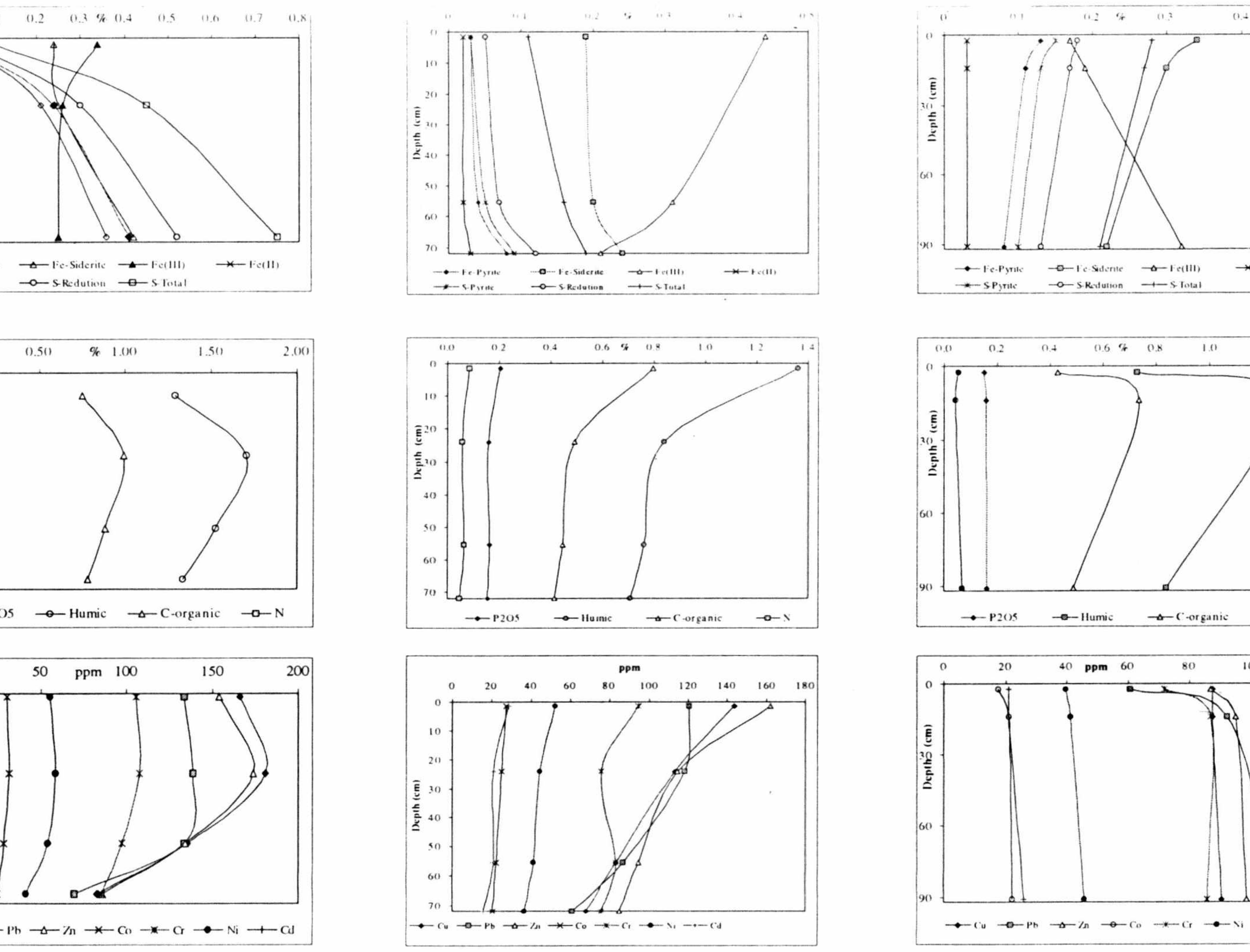
- *Formation and development of mangrove forest*

In tropical littorals, sedimentation makes low tidal mudflats get higher to become high tidal mudflats which are more favorable for mangrove seeds to develop (Hoekstra, 2000) [10]. In their return, the formation and development of mangrove forests, as a sedimentary trap, make the coastal environment more favorable for depositing of sediments. Sedimentation rate in mangrove forest tends to be higher than 7 cm per year

(Hoekstra, 2000)[10]. The transformation of low tidal mudflat without mangroves into high tidal mudflat is characterized by a little increase in concentration of Fe_{pyrite}, S_{total}, S_{pyrite}, $S_{reduction}$ thanks to accumulation of mangrove root as the main source of sulfurs. The quicker increasing sulfur concentration profile after depth in comparison with high tidal mudflats proves that formation of mangrove forest could also accompany with more oxidation process than the process of sedimentation on low tidal mudflat. The transformation also accompanies with accumulation of nutrients (N from 0.06% to 0.07%, P_2O_5 from 0.17% to 0.19%, humid from 0.97% to 1.41%, $C_{organic}$ from 0.57% to 0.83%) and heavy metals (Cu from 279 to 294ppm, Pb from 216 to 265ppm, Zn from 267 to 340ppm, Cr from 189 to 202ppm, Ni from 103 to 109ppm and Cd from 5 to 6ppm). The formation of mangrove forest on tidal mudflats is characterized by enrichment of fine sediment, (clay minerals and organic materials) that increases capacity of the ecosystem to store heavy metals (Table 2).

- *Degradation of mangrove forest*

Limitation of sediments supplying, water circulation, cutting mangroves for making shrimp pond and massive destroying their roots as well as removing bottom sediments lead to the degradation of the mangrove ecosystem. Geochemical transformation of mangrove forest into shrimp pond is characterized by increase of reduction indices such as Fe^{2+}, Fe^{2+}_{HCl}, Fe^{2+}_{pyrite}, S_{total} (from 0.21 to 0.28%), $S_{reduction}$ (from 0.13 to 0.18%), S_{pyrite} (from 0.07 to 0.13%) and decrease of oxidation index Fe^{3+}. In the shrimp pond, from lower to upper parts, sulfur concentrations in the sediments increase quickly, differing from the mangrove forest sediments. Highly chronological and horizontal accumulation of sulfurs during mangrove degradation, perhaps is caused by massive destruction of mangrove roots in the shrimp pond. The degradation of mangrove ecosystem is accompanied with dispersion of nutrient: N from 0.07 down to 0.05%, P_2O_5 from 0.19 down to 0.06%, humic from 1.41 down to 0.94%, $C_{organic}$ from 0.83 down to 0.55%. The rapid decrease of nutrient concentrations in upper sedimentary layer of shrimp ponds may be related to removing the sediments with mangrove root during shrimp pond construction. Lower concentrations of heavy metals in shrimp pond sediment in comparison to mangrove forest sediments (Table 2) shows that the degradation of mangrove forest is characterized by dispersion of these elements. Therefore the destroying of mangroves during shrimp pond construction, not only decreases area of mangroves forest but also makes the sedimentary environment degraded geochemically and ecologically. Consequently, it would be difficult to restore the sedimentary environment, to maintain high productivity of aquaculture and to replant mangrove forest.



idal mudflat Mangrove forest Shrimp pond

ical distribution of geochemical indices of sediments during the process of formation, development and degradation of ma

To prevent degradation of sedimentary environment and to keep sustainable development of mangrove forest, some measures could be proposed as follows: i) aquaculture activities could be started only in the naturally degrading mangrove forest area- an area of mangrove of about 40 years (a natural cycle of formation, development and degradation of mangrove forest in the Red River mouth is estimated about 40 years); ii) wise use of mangrove forest and surrounding tidal mudflats should be guaranteed by laws, policies and effective management (community-based and users-based management, co management, ecosystem approach for management, etc.).

3. Conclusions

1. In the coastal region of Giao Thuy district, Nam Dinh province, the formation, development and degradation of mangrove forests take place in 3 distinctive sedimentary environments: low tidal mudflat without mangrove, high tidal mudflat with mangrove and shrimp ponds. The changes in hydrodynamic conditions, water circulation, human activities...leads to geochemical differentiation of sedimentary environment and formations.

2. The formation and development of mangrove forests are geochemically characterized by accumulation of fine sediments, clay minerals and nutrients (N from 0.06 up to 0.07%, P_2O_5 from 0.17 up to 0.19%, humid from 0.97 up to 1.41%, $C_{organic}$ from 0.57 up to 0.83%) and heavy metals (Pb from 97 up to 105ppm, Zn from 123 up to 127ppm...). The formation and development of mangrove forests, making sedimentary environment more favorable for storing toxic elements, contribute much to the protection of marine environment.

3. Degradation of mangrove ecosystem accompanied by accumulation of coarse sediments, pyrite, quartz, feldspar and sulfurs (S_{pyrit}: 0.07-0.13%, S_{total}: 0.21-0.28%, $S_{reduction}$: 0.13-0.18%). Degradation of mangrove ecosystem is also characterized by the dispersion of nutrients (N from 0.07 down to 0.05%, P_2O_5 from 0.19 down to 0.06%, humid from 1.41 down to 0.94%, O_{rganic} from 0.83 down to 0.55%) and toxic heavy metals (Cu from 119 down to 89ppm, Pb from 105 down to 87ppm, Zn from 127 down to 94ppm). Once the shrimp ponds degraded, it would be difficult not only to maintain high productivity of aquaculture, but also to replant mangrove forest.

4. To prevent degradation of sedimentary environment and to keep sustainable development of mangrove forest, some measures could be proposed as follows: i) Aquaculture activities could be permitted only in the naturally degrading mangrove forest area (mangrove of over 40 years old). ii) Rational use of mangrove forest and surrounding tidal mudflats should be guaranteed by laws, policies and effective management.

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TẠP CHÍ KHOA HỌC ĐHQGHN, KHTN & CN, T.XX, Số 3, 2004

TIẾN HOÁ ĐỊA HOÁ TRẦM TÍCH TRONG QUÁ TRÌNH HÌNH THÀNH, PHÁT TRIỂN VÀ THOÁI HOÁ RỪNG NGẬP MẶN KHU VỰC CỬA SÔNG HỒNG (LẤY VÍ DỤ HUYỆN GIAO THUỶ, TỈNH NAM ĐỊNH)

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Từ những dấu ấn địa hoá được ghi lại trong các thành tạo trầm tích khác nhau ở khu vực ven cửa sông Hồng, bức tranh tiến hoá địa hoá trầm tích trong mối quan hệ với sự hình thành, phát triển và thoái hoá rừng ngập mặn (RNM) được khôi phục. Quá trình hình thành và phát triển RNM được đặc trưng bởi sự tăng cao hàm lượng các hợp phần dinh dưỡng (N từ 0,06 lên 0,07%, P_2O_5 từ 0.17 lên 0.19%, mùn từ 0.97 lên 1.41%, $C_{hữu\ cơ}$ từ 0.57 lên 0.83%), và hàm lượng các nguyên tố vi lượng (Pb từ 97 lên 105 ppm, Zn từ 12 lên127 ppm...), phản ánh vai trò của RNM trong việc lưu giữ độc tố, bảo vệ môi trường biển. Sự thoái hoá RNM bị cường hoá do hoạt động đắp đầm nuôi tôm, dẫn tới sự tích tụ cao của pyrit và sunfua (S_{pyrit}: 0.07-0.13%, $S_{tổng}$: 0.21-0.28%, $S_{khử}$: 0.13-0.18%), giảm hàm lượng dinh dưỡng (N từ 0.07 xuống 0.05%, P_2O_5 từ 0.19 xuống 0.06%, mùn từ 1.41 xuống 0.94%, $C_{hữu\ cơ}$ từ 0.83 xuống 0.55%) và phân tán các nguyên tố vi lượng (Cu từ 118.6 xuống 88.6ppm, Pb từ 105 xuống 87ppm, Zn từ 126.9 xuống 93.5ppm). Khi RNM bị phá huỷ để đắp đầm nuôi tôm, sự thoái hoá môi trường trầm tích không những dẫn đến suy giảm năng suất thuỷ sản mà còn gây khó khăn cho việc tái trồng rừng. Để hạn chế sự thoái hoá môi trường trầm tích RNM cần áp dụng mô hình sử dụng khôn khéo và quản lý bền vững RNM.