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Palynological investigation from a deep core at the coastal area of the Red River Delta, Vietnam

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Abstract. Palynological study in a deep core (69.5 m depth) in the coastal area of the Red River Delta, Vietnam provides evidences on vegetation change in the regional area in about 12000 years before present. This research aims to reconstruct the vegetation development and paleoenvironmental changes in the Red River Delta, Vietnam during the Holocene. These data show that the region supported a Fagaceae-Coniferous, especially *Quercus, Pinus* và *Castanopsis*, similar to contemporary vegetation described in Vietnam and southeast China. Tropical broadleaf forest dominated at the time right after 12.000 BP. At the same time, *Scyphiphora hydrophyllaceae* is the dominant wood species in the back mangrove forest at the studied area. After this time, the climate became warmer although there were several periods with colder climate in between.
Keywords: palynology, paleoecology, Red River, pollen, spore, paleoenvironment.

1. Introduction

Whereas the Late Quaternary vegetational history of large parts of the world is fairly well documented and palynological studies in the Red River Delta are numerous, little attention has been paid to the Holocene vegetation history of North-Vietnam [1-3]. Most of the available palynological studies in Vietnam were focused on characterize the sedimentary strata in regional geological mapping [4] and in archaeology [5, 6]. Using pollen records and other microfossil records for Holocene palaeogeography reconstruction, sea level change, and climate history [7-12] was still limited and only reached a low temporal resolution. Recently, Li et al. [13] presented a detailed and well-dated reconstruction of Holocene climate change in the Red River delta. More records are need to advance our standing of vegetation succession. This research aims to reveal the vegetation development and paleoenvironmental changes in the Red River Delta, Vietnam during Holocene. Our reconstructions, which are primarily based on pollen analyses, are intended to contribute to understanding ecological processes.

2. Physical conditions of the studied area

2.1. Geological setting

The Vietnamese catchment of the Red River Delta occupies approximately 10,000 km^2 and consists of a 5,600 km^2 large delta plain

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bordered by a mountainous region composed of Precambrian crystalline rocks and Paleozoic to Mesozoic limestones [14]. The most important mountain ridge, Hoang Lien Son, is a south-eastern extension of the Himalayas extending from Yunnan (China) into northern Vietnam and forms a vast area of uplands of 1600-2000 m high with peaks reaching 2500-3000 m above sea level (a.s.l) (fig. 2.1), including the highest mountains of mainland Southeast Asia (Fan Si Pan, 3143 m, and Lang Kung, 2913 m).

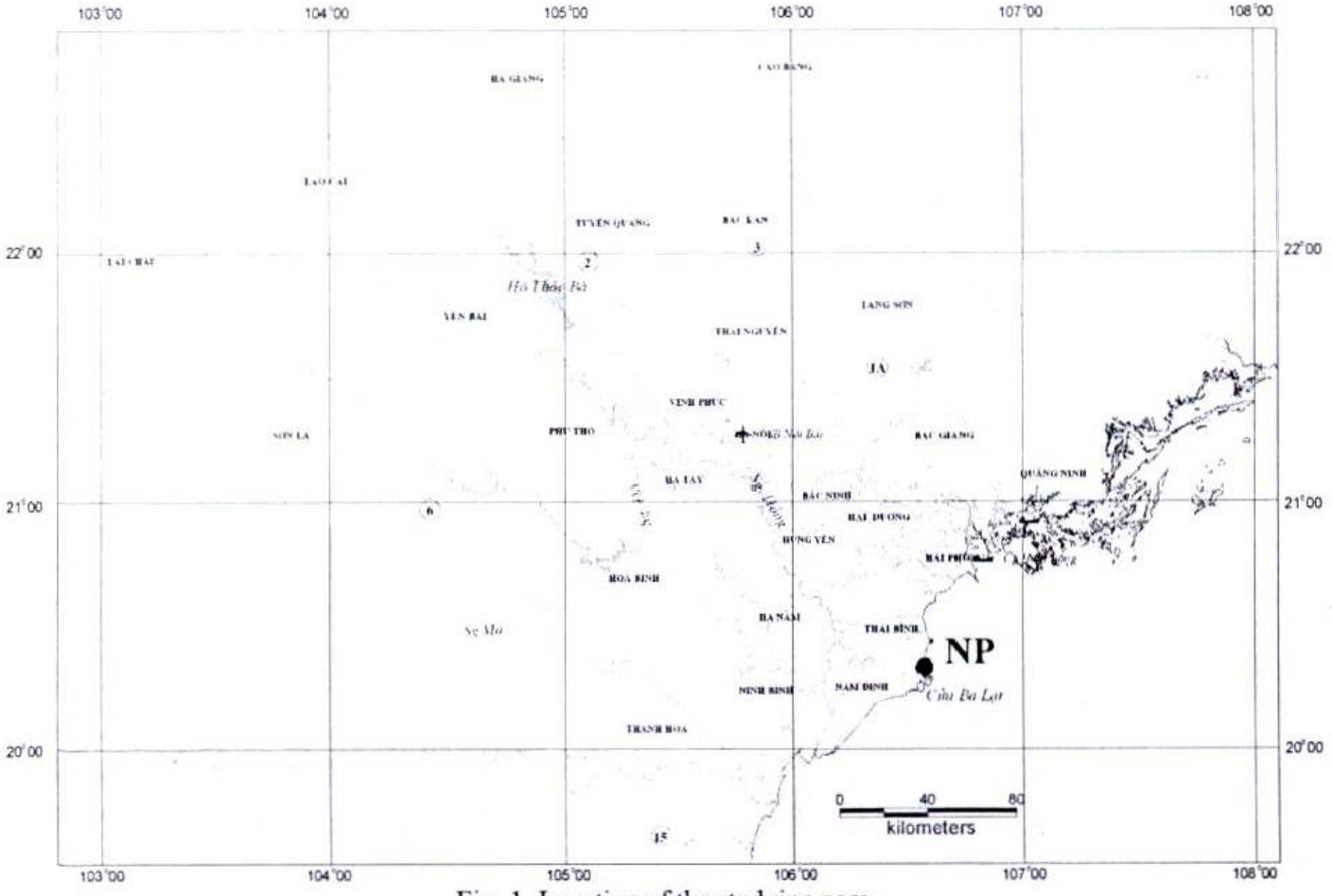


Fig. 1. Location of the studying core.

Deep borehole data show that the Quaternary sediments often overlay the older sediments uncomformably. They covers a large part of the study area but their thickness increases from the edge to the centre of the delta. The Late Pleistocene sediments are alluvial, marine or alluvial-marine. The late Pleistocene sediments are colorful motley and show signs of long-time weathering. This weathered surface is quite common over a large area of the Red River Delta from Hanoi to the coastal zone. The surface sediments are mainly Holocene and mainly composed of sand, sitlty clay, clayey silt. They are generally divided into two stratigraphical units: the Hai Hung formation (Q_2^{1-2}) and the Thai Binh (Q_2^3) formation [14].

2.2.Climate

The study area has a tropical everwet monsoon climate with a hot (31-33° C) and rainy summer from May to September and a colder (15 – 18° C) dry winter from November to March. In spring and autum, climate is more comfortable but these seasons are short. In July and August rain showers are of 500-600mm per month cause the river level to rise up to 2-3m

higher than the land surface because of dykes. In winter average rainfall is about 30-50mm per month. In the mountain area, temperature depends on elevation.

2.3. Vegetation

Because of its complex abiotic conditions, the Northern part of Vietnam has a very diverse vegetation. This diversity is not only attributable to the large number of endemic species, but also to the fact that the area is a meeting point of the floras of China, the Himalaya, and Malaysia. The highlands of the Hoang Lien Son ridge form the south-eastern part of the Sikang-Yunnan floristic Province of the Holarctic floristic kingdom. This Province constitutes a very important boundary area of the Holarctic and Paleotropic realms with numerous tropical, subtropical and temperate connections. As at the same time local endemism is very high, the Sikang-Yunnan floristic Province has one of the richest and specific indigenous floras of mainland Asia [15].

The Red River catchment area can be subdivided into the following altitudinal vegetation zones [15]:

The *tropical lowland* (0-100m a.s.l.) is cultivated everywhere. The vegetation consists of mainly herbs and shrubs. All zones higher than 100 m a.s.l. are called the *uplands*.

The *tropical midland* (100-700m a.s.l.) was formerly characterized by a primary vegetation of closed tropical evergreen broad-leaved forests on hills and mountain foothills. At present, this forest type is completely extinct and replaced by agricultural fields and secondary plant communities, including highly degraded open forests, bamboo stands, shrubs, and grasslands [16].

In the *Subtropical submontane belt* (700-1600m) annual mean temperature is about 15^0C -20^0C, the temperature of the coldest month below 15^0C, the minimum even below 0^0C during some days. The vegetation is dominated by Fagaceae, Lauraceae, Theaceae, Ulmaceae, Magnoliaceae, Juglandaceae, and Rosaceae. *Keteleeria davidiana* (Pinaceae) is present [16], whereas Dipterocarpaceae, *Erythrophleum fordii* (Leguminosae), and *Lagerstroemia tomentosa* (Lythraceae), which are characteric for lower altitudes, are less common. On flat areas and on gentle slopes, especially of low and middle elevation, warmth loving, broad-leaved species like *Castanopsis* sp., *Cinnamomum* sp., *Dipterocarpus retusus, Hopea molissima, Madhuca pasquieri, Syzygium* sp., *Vatica* sp. and warmth loving *Lithocarpus* and *Quercus* species form the 35-45 m high first stratum. Along the ridge tops and on the upper parts of mountain slopes, especially on the drier, steeper slopes, the coniferous *Dacrycarpus imbricatus* appears as a co-dominant tree, whereas along the dry steep summits of ridges this species may even be mono-dominant. Accompanying species of the second stratum (25-30 m high) are the warmth-loving, broad-leaved trees *Artocarpus* sp., *Canarium* sp., *Cryptocarya* sp., *Dillenia* sp., *Eberhardtia aurata, Elaeocarpus tonkinensis, Elaeocarpus* spp., *Gironniera subaequalis, Litsea* sp., *Michelia* spp., *Nephelium milliferum, Xanthophyllum urophyllum*, and a large palm *Livistona chinensis* [17].

In the *Temperate submontane belt* (1600-2400m) annual mean temperature is about 10-15^0C, the mean temperature of the coldest month below 10^0C, and the minimum temperature often below 0^0C. Species of warm temperate temperature conditions appear including *Alnus*, *Betula*, *Acer*, and *Carpinus*. They are found together with the gymnosperms

Dacrydium, *Cedrus*, *Cephatotaxus*, *Cryptomeria*, and *Fokiena* [16]. On gentle slopes, especially in the low and middle parts of mountain slopes, broad-leaved evergreen and deciduous trees occur, such as *Archidendron*, *Cryptocarya*, *Eberhardtia*, *Exbucklandia*, *Lithocarpus*, *Litsea*, *Magnolia*, *Manglietia*, *Michelia*, *Rehderodendron*, *Rhoiptelea*, *Schima*, *Symplocos* etc., accompanied by the conifer *Fokienia hodginsi* on drier, steep slopes [17].

The *Temperate montane belt* (2400m) has a snow cover in winter. Next to shrub species of Fagaceae and Ericaceae, gymnosperms of cold temperate climate occur like *Abies pindrow* and *Tsuga yunnaensis* [16].

Deforestation and degradation have destroyed most primary forests of the Hoang Lien Son area and far beyond and botanical investigations in this region are urgently required for the organization of conservation areas to protect the remaining primary plant communities that have world wide significance as centers of plant diversity [15].

3. Materials and methods

The studying core is located in the Balat mouth at 106°33'48''E, 20°19'08''N (fig. 1). The core is 69.5m depth, mainly consists of clay and silty clay (detail description in fig. 2)

60 samples of the core in the interval of 50 cm was collected. 0.5 cm^3 from each sample was extracted for pollen analysis. Sample preparation followed standard methods [18] and included addition of a known amount of Lycopodium clavatum spores to calculate pollen concentrations [18], treatment with HCl and KOH, sieving over a 120 μm and a 7-8 μm sieve, treatment with HF, acetolysis (7 min), and mounting in silicon oil.

Pollen and spores were identified with and named after [4], Huang [19], Wang et al. [20, 21], Thanikaimoni [22] and Yulong Zhang et al. [23] and checked with a modern reference collection of some typical representatives of the Vietnamese flora and with the reference collection of the Institute of Botany and Landscape Ecology, Greifswald University.

Pollen types are in the text displayed in SMALL CAPITALS in order to differentiate them clearly from taxa [24]. The unidentified pollen grains consist of corroded or otherwise damaged grains and those grains for which no matching type could be found in the literature or in the reference collection. In general, the number of unidentified pollen types is low.

The results of the analyses are presented as relative values (in which the pollen frequencies are expressed as percentages of a pollensum) and as concentrations values (grains/cm^3).

To avoid (extra) local overrepresentation for the borehole samples, a pollensum of types attributable to taxa that are currently absent from the lowlands and restricted to areas over 100 m a.s.l was chosen. Also the pollen types attributable to taxa that currently often grow along river banks are excluded from the pollensum because also they may show overrepresentation. Generally, about four slides per sediment spectrum were analysed to reach a pollen sum of 80 - 200 grains. Pollen percentage calculations were carried out with the Excel program; the diagrams are constructed with Tiliagraph and Tiliaview [25, 26]. The diagrams divided into site pollen zones, based on the changes in the curves of dominant or characteristic pollen types. Pollen types were assigned to ecological groups using the 'Flora of Viet Nam' [27, 28]; the 'Vietnam forest trees' [29]; the 'Some basic characters of Vietnam flora' [30]; the 'Flora Malesiana' [31]; the 'Mangrove Ecology' [32].

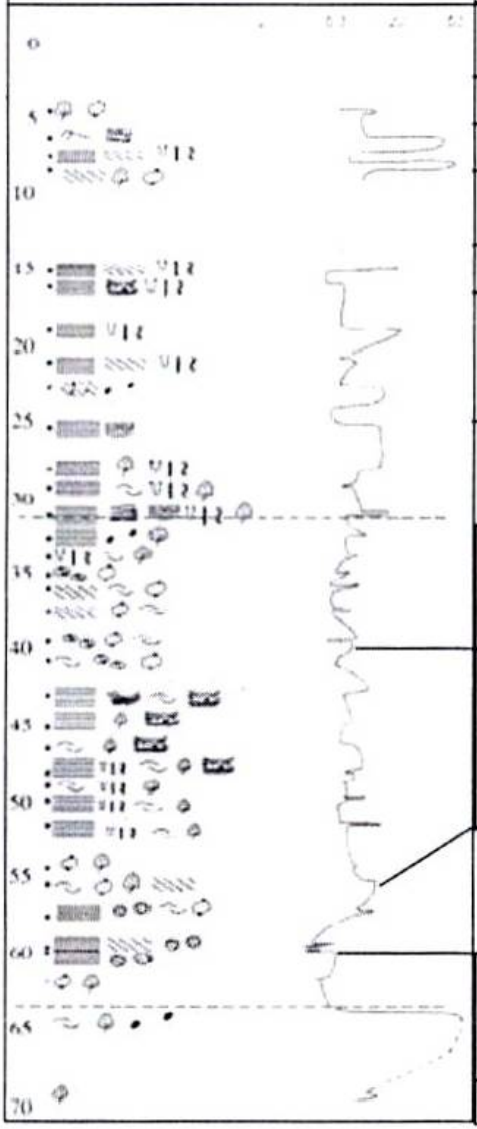
C14 dating

Only one samples of wood and other plant remains collected at the depth of 62 m were ^{14}C

AMS dated at the Leibnitz Laboratory of Kiel University (Prof. Dr. Piet Grootes) and calibrated with CALIB rev 4.3 [33]. For the calibration of the carbonates a regional correction (Δ R) was applied of -25 ± 20 years following Southon et al. [34]. The ages are expressed as cal yr BP (BP = 1957). The calibrated result of the sample showed the date of 12031 B.P.

Coordinates	**Altitude**	**Date of sampling**
106°33'48"E, 20°19'08"	1,82 ± 0,1m a.s.l.	6-3-2002

Lithology



Depth	*Grain size*	*Sedimentary characteristics*		*Proposed environment*
		0-2.5m	Redish brown, silty clay, with depth gradually changing to sand	Deltaic
		2.5-3.5m	Medium sand	
		3.5-7.8m	Lost sample	
		7.8-8.3m	Redish brown, silty clay and plant remains	
		8.3-14.0m	Lost sample	
		14.0-19.0m	Brown clayey silt with plant humus, with depth becoming lighter in colour. Locally mixed with fine sand (at 16 -16,5m, there was organic gas)	
		19.0-33.0m	Reddish brown to greyey green silt clay, silt intermixed with thin layers of sand, forming couplets	
		Sand-silt-clay couplets. Silty clay and clayey silt with plant humus, of varying colour. With shells and a sandy lens		Marine
		Brown silty clay mixed with fine sand and greenish grey clay containing plant humus and shell. Some peat in the lower part		Estuary
		Brown silty clay (rich in peat) mixed with greenish grey clay layers with plant remains and laterite		Tidal flat
				Marsh
		Coarse sand with thin shells mixed with thin layers of clayey silt		Pleistocene sediment
		Greenish grey clay		

Fig. 2. Sedimentary and environmental characteristics of NP core (referenced from Grothe St [35]).

4. The pollen diagram

All together, 175 species and genera belonging to 90 families were identified and categorized into eco-stratigraphical groups (Table 2).

The Namphu core can be subdivided into 8 pollenzones (fig. 3).

Zone NP1 (69.35m-64.25m, spectra 1-4) is characterized by high percentages of PINUS. QUERCUS and CASTANOPSIS TYPE in the upper part of this zone (fig. 3). Besides, values of CYPERACEAE, GRAMINEAE, and SALIX are very high (fig. 4). Mangrove types and pollen types restricted to the lowlands and midlands such as TRIANTHENUM, DODONEA, BOEHMERIA, CASUARINA, PSIDIUM, and VITEX are absent in this zone (fig. 4).

Zone NP2 (64.25m-60.25m, spectra 5-9) is characterized by the presence and often dominance of PTEROCARYA. ULMUS also shows high values (fig. 4). ALNUS (fig. 3) just appears in this zone and shows, just like CARPINUS, high values in the upper part of this zone. The percentages of PINUS, QUERCUS, CASTANOPSIS TYPE, and SALIX are (much) lower than in zone NP1. CYCAS (fig. 3) also shows high values in this zone. GRAMINEAE and CYPERACEAE (fig. 4) show lower values than in NP1. Spore types are very dominant, especially POLYPODIACEAE (fig. 4) that reaches its highest values in this zone.

Zone NP3 (60.25m- 56.6m, spectra 10-13) is characterized by the dominance of back mangrove pollen types including SCYPHIPHORA HYDROPHYLLACEAE and PHOENIX (fig. 4). Some mangrove forest types are also sporadically found in this zone. HELWINGIA and ACER display high frequencies, whereas QUERCUS is also very well-represented in this zone (fig. 3). Values of PINUS are slightly higher than in NP2, whereas CASTANOPSIS TYPE and CARPINUS are not much different. Lowland types including GYMNOSPORIA and TRIANTHENUM also show higher values than in zone NP2. The values of GRAMINEAE are higher than previously (fig. 3).

Zone NP4 (56.6m-47.0m, spectra 14-21) is characterized by the absence of SCYPHIPHORA HYDROPHYLLACEAE and PHOENIX (fig. 3). Mangrove pollen types also are absent in this zone. The percentage of PINUS continues to rise. PODOCARPUS and ALNUS are only prevailing in the lowest part and are rarely found in the rest of the zone (fig. 3). TRIANTHENUM (fig. 3), HELWINGIA, and ACER (fig. 3) are less frequent. CASTANOPSIS TYPE, QUERCUS, and CARPINUS do not change much compared to NP3 (fig. 3).

Zone NP5 (47.0-40.5m, spectra 21-28) is characterized by a reoccurrence of mangrove pollen types including ACANTHUS, BRUGUIERA, CERIOPS TAGAL, and RHIZOPHORA, and also of back mangrove pollen types including EXOECARIA and ACROSTICHUM although with low values (fig. 4). PINUS shows much lower values, QUERCUS a gradual decrease. ILEX, ALNUS, MACARANGA, and MALLOTUS show higher values than in the previous zone (fig. 3). GRAMINEAE gradually decreases (fig. 4). The number of pollen types is much higher than in other zones (fig. 3).

Zone NP6 (40.5m-28.0m, spectra 28-46) is characterized by the presence of many mangrove forest types like BRUGUIERA, SONNERATIA, and RHIZOPHORA, and also of back mangrove types like EXEOCARIA and ACROSTICHUM, and of CHENOPODIACEAE. Only BRUGUIERA shows a high and stable presence, other mangrove types are rarely found. The back mangrove types show higher values than the mangrove types (fig. 4). PINUS and ALNUS show higher, QUERCUS and CASTANOPSIS TYPE lower values than in NP5. CARPINUS remains approximately the same (fig. 3). GRAMINEAE shows a gradual increase (fig. 4).

Zone NP7 (28.0m-16.7m, spectra 47-54) is characterized by the virtual absence of mangrove forest types. They are only rarely found in the lower part of the zone. ACROSTICHUM shows a much lower value than in NP6 (fig. 4). QUERCUS and CASTANOPSIS TYPE (fig. 3) and PTEROCARYA and ULMUS (fig. 4) show generally higher values than in zone

NP6. Also CYPERACEAE and GRAMINEAE are found with higher values than before.

Zone NP8 (16.7m-3.3m, spectra 55-57) is characterized by a relatively high value of BRUGUIERA in the upper part of the zone (fig. 3). PINUS shows high values, as do, ACER, CARPINUS, and TAXUS (fig. 3). The pollen type diversity in this zone is lower than in the other zones. Many types are no longer present and the pollen concentration is very low. Spore types are more common, especially CYATHEA, MICROLEPIA, and ATHYRIACEAE.

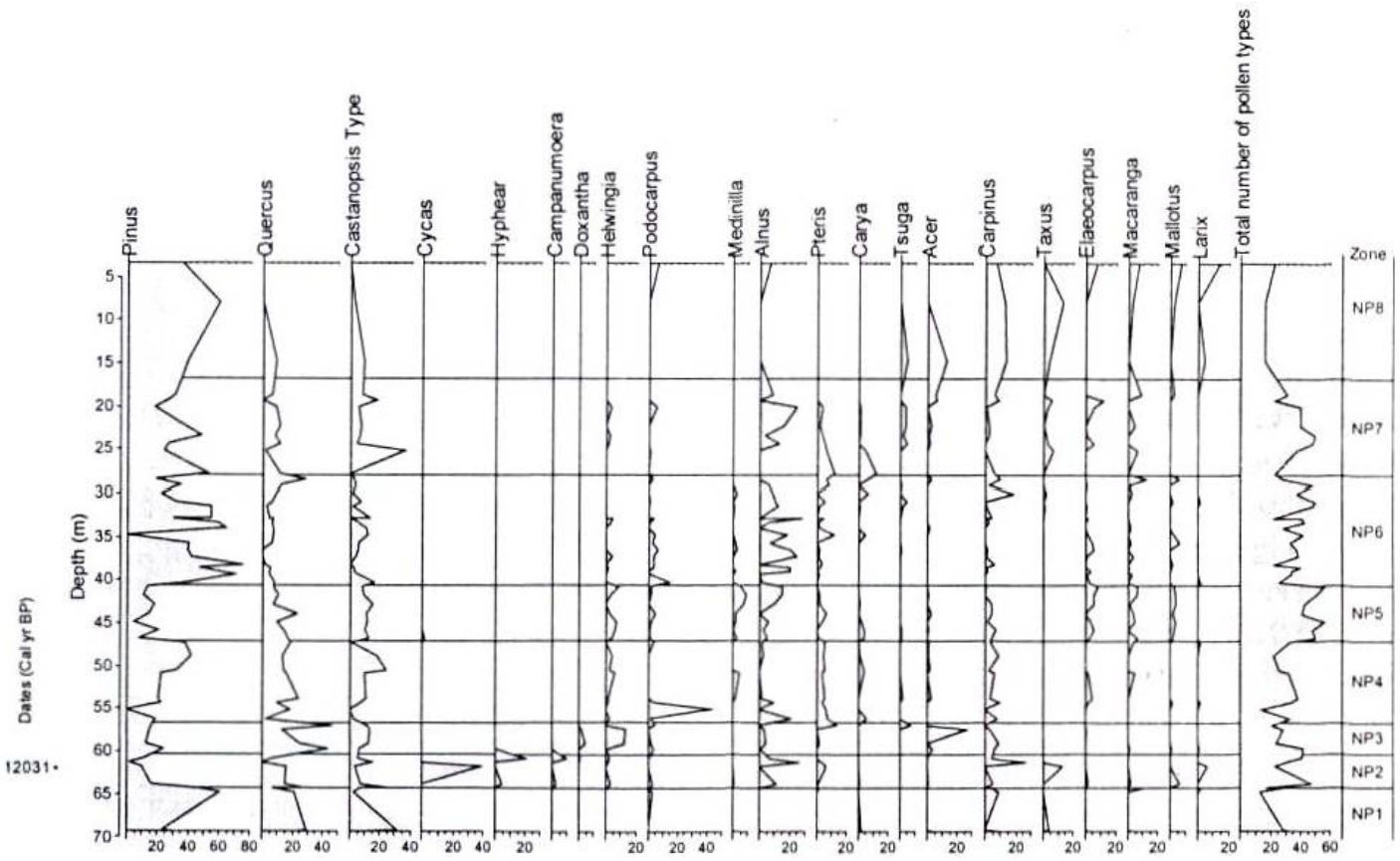


Fig. 3. Relative pollen diagram of pollensum types (Sellectecd curves only).

5. Discussion

The high percentages of PINUS, CASTANOPSIS TYPE, and QUERCUS (all present-day mountainous types), SALIX, POACEAE, and CYPERACEAE, the absence of mangrove types and the low numbers of pollen types in **zone NP1** show that the environment must have been terrestrial. Lowland pollen types are absent from this zone, indicating that the climate was colder than today and temperate vegetation prevailed in the area. The high percentages of POACEAE and CYPERACEAE in the assemblages and the absence of pollen of plants of standing water indicate a freshwater marsh environment [36].

PTEROCARYA is the dominant pollen type in **zone NP2**. *Pterocarya* is a native species to northern Vietnam, where it is widely distributed from 50 to 1000m a.s.l., especially on alluvial sediments along rivers and streams. Also ULMUS shows high values in this zone. Also *Ulmus* often grows along stream and river banks or in valleys in limestone mountain ranges [29]. The high values of both types indicate that these species were growing close to sampling site and that the sampling site at that time may have been a river floodplain. The

very low value of SCYPHIPHORA HYDROPHYLLACEAE in this zone suggests that the area was very rarely influenced by tide.

The higher diversity of pollen types shows a warmer climate, a conclusion supported by the presence of many pollen types that are attributable to tropical and subtropical taxa, including BIFARIA, HYPHEAR, CAMPANUMOERA, SPATHODEA, ZIZYPHUS, HEDERA, JASMINUM LANCELARIUM, FAGOPYRUM, and CALYSTEGIA. Also the high values of spore types, especially POLYPODIACEAE, in the sediment point at a higher temperature [37].

Zone NP3 is characterized by the dominance of SCYPHIPHORA HYDROPHYLLACEAE. *Scyphiphora hydrophyllaceae* is a back mangrove species that is currently common in the landward zones of the mangrove that are infrequently flooded by tide [32]. We will call this type of environment a "high tidal flat".

Also *Phoenix* (cf. PHOENIX pollen in this zone) is a back mangrove type that is present on the high tidal flat. The rare occurrence of BRUGUIERA and RHIZOPHORA in this zone shows that *Bruguiera* and *Rhizophora* were no components of the mangrove forest. Their pollen was probably washed in by the tides from mangrove forests closer to the sea. Gramineae seem to be a component of the local vegetation also here, as the high values of GRAMINEAE illustrate. Values of pollen types attributable to taxa of non-marine environments, including QUERCUS, HELWINGIA, and ARTEMISIA are quite high in this zone, which means that the influence of river water was still large. We may conclude that the sampling site belonged to the high tidal flat environment with back mangrove forest dominated by *Scyphiphora hydrophyllaceae* and *Phoenix*.

The development of back mangrove forest and the presence of some pollen types of tropical taxa, such as DOXANTHA and GYMNOSPORIA in this zone indicate an increased development of tropical vegetation in the area.

SCYPHIPHORA HYDROPHYLLACEAE and mangrove pollen types are absent in **zone NP4** suggesting a complete change of environmental conditions. The absence of mangrove pollen may be due to either a change to terrestrial or a change to marine conditions. In the first case, the sea level must drop strongly and rapidly leading to a complete change in vegetation. The pollen signal, however, does not support such scenario. With a regression, the deposition of lowland pollen types must increase in the pollen assemblages. In fact, the lowland pollen type TRIANTHENUM shows a strong decrease, whereas another lowland pollen type DODONEA is absent in this zone. The second case, implying a rapid rise of the sea level, would prevent mangrove development in the coastal zone area when the sampling area was rapidly covered by salt water and the tidal action took place further inland, affecting a large part of the lowland. This may be the reason for the much lower values of lowland pollen types. In addition, the values of mountain forest types, including PINUS, QUERCUS, and CASTANOPSIS TYPE are higher than in the previous zone.

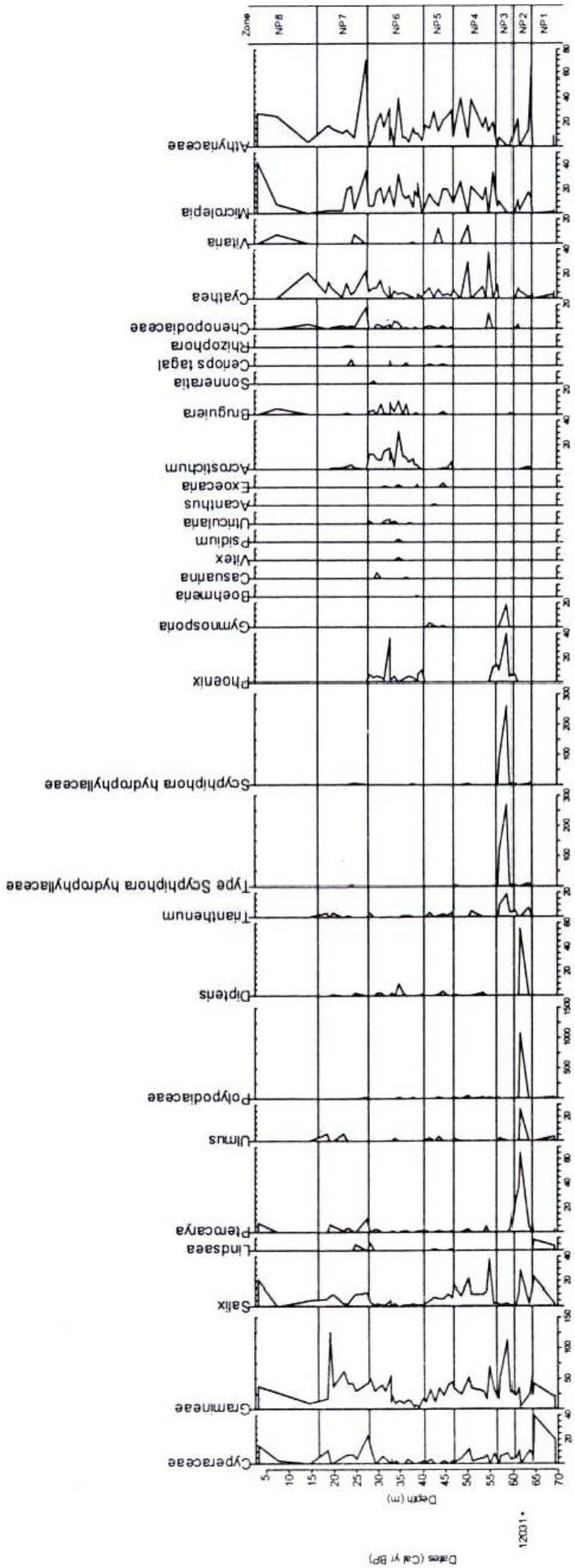


Fig. 4. Relative pollen diagram of none pollensum types (Sellectecd curves only).

Mangrove pollen types start to be found in **zone NP5** suggesting an initiation of delta development, which happens when the sea level rises more slowly [38] leading to the stronger and more extensive development of mangrove forest. The low percentage of mangrove forest types show that the environment was not optimal for pollen deposition.

With the decrease of temperate elements, tropical midland and lowland pollen types (TRISTANIA, DRYPETES, MACARANGA, MALLOTUS and ELAEOCARPUS) are more common in zone 5. Although their percentages are low they show an expansion of the tropical flora in the regional vegetation

The rather high values of the mangrove type BRUGUIERA and the back mangrove types (ACROSTICHUM) in **zone NP6** show that the mangrove forest developed strongly at the coastal zone area in the condition of a high stand of the sea, as this is the most suitable time for mangrove development. The increased values of these types probably point at more erosion from the coastal lowland as a result of the coastline migrating seaward. This shows a change in sedimentary condition from estuarine to delta. The fine-grained sediments are characteristic for a prodelta environment [39]. The appearance of prodelta sediment marks the beginning of a regression.The increase of magrove types at the depth of 35m suggests the environment changing from more seaward to more landward and a change from a prodelta to a delta front environment.

The low presence of back mangrove types and the higher values of fresh water and riverine types indicate a stronger influence of the river in **zone NP7**. This also may be caused by a rapid decrease in sea level that led to a continuous change of the coastline and provided insufficient time for an extensive development of mangrove forest. The presence of ACROSTICHUM, a back mangrove type, shows an environment affected by the sea. The silt mixed with fine sand sediment of zone NP7 and the prodelta environment of zone NP6 suggests a delta front slope environment for zone NP7.

The low pollen concentration and diversity show a rapid clastic sedimentation in **zone NP8**, which is characteristic for the prevailing sandy sediments (that were largely lost during sampling). The presence of BRUGUIERA in the upper part of the zone indicates the development of mangrove forest around the sampling site and that the site in this period belonged to the coastal zone. Possibly the sampling site was part of a sandy bar in the delta front platform area. The high values of pollen types ascribed to temperate taxa including CARPINUS, ACER, TAXODIACEAE, and also PINUS, suggests a slightly cooler climate.

6. Conclusion

The study of pollen and spores from the NP core in the coastal zone area of the Red River Delta, provides a record of vegetation and climate change covering ca. 12,000 years B.P. (Before Present). Based on this study results, vegetation development history, environment and sea level change was reconstructed.

Before 12.000 B.P (at about 14.000 B.P), sedimentary environment of the study area was belong to fresh water marsh condition with the strong development of fresh water plant like Graminae, Cyperaceae and *Salix* in a colder climate condition than today. At about 12.000 B.P, the environment was transformed to riverine conditions rarely influenced by tide with the dominant of riverine taxa like *Pterocarya, Ulmus, Salix* in a wamer climate

than the time before. Because of the sea level rise, the studying area was changed to high tidal flat condition with the dominant of a brackish water species *Scyphiphora hydrophyllaceae*. At the depth of 40.5m, the pollen data shows a change from estuary environment to deltaic environment.

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