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Mangrove vegetation changes since mid-Holocene in a coastal swamp of northern Hainan Island, China

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Abstract

This paper presents mangrove vegetation changes since mid-Holocene based on pollen analysis in a coastal mangrove swamp of northern Hainan Island, south China.

To examine the surface mangrove pollen deposits and dispersal in an intertidal-littoral area, particularly within the intertidal zone, four transects (1, 2, 3, 4) were observed to determine the local mangrove zonal pattern along an intertidal mangrove environment in Dongzhai mangrove swamp. As an initial step, in order to reconstruct mangrove vegetation changes geohistorically, surface samples were collected along two transects (1, 3) for pollen analysis, to reveal the relationship between pollen deposits and parent plants of mangroves, littoral vegetation, and terrestrial vegetation. Pollen spectra from surface sediments show close linkage between pollen and local source vegetation. Mangrove pollen are roughly arranged in a zonal pattern along an intertidal flat. Notably, *Rhizophora*, *Ceriops*, *Bruguiera* and *Avicennia*, are well present and localized. Nevertheless, some other common mangroves are poorly represented by their pollen in sediments, including *Excoecaria*, *Kandelia*, *Aegiceras* and *Xylocarpus*. The exotic components in certain proportions are also present. However, the dominant pollen taxa are from the local source of mangroves, so mangrove pollen deposition is revealed to be of limited distribution and strongly localized.

Pollen analysis of a sediment core (DZ01) has been undertaken to reconstruct mangrove vegetation changes since mid-Holocene in the same mangrove swamp. Chronology of core DZ01 is determined, based on four radiocarbon ages, by conventional radiocarbon dating. Mangrove fossil pollen recorded in core DZ01 are rich since mid-Holocene. Nevertheless, pollen evidence also shows that allochthonous components account for a considerable amount, largely due to water or/and wind transportation. The results of pollen analysis from core DZ01 suggest that mangroves have developed since mid-Holocene, markedly around 6,650-5,000 yr BP and 3,100-2,000 yr BP, during which the mangrove environment probably was favored by high sea-level stands and adequate sediments input. However, mangrove vegetation changes are inferred around 5,000-3,100 yr BP and 2,000 yr BP- present, probably resulting from coastal environment changes around 5,000-3,100 yr BP, such as sea level changes, and the influence of human activities since 2,000 yr BP, particularly in recent centuries. The limitation of this study is also discussed.

Key-words : mid-Holocene, pollen analysis, mangrove, sea-level, Hainan Island, south China

1. Introduction

"Mangrove" is an ecological term referring to a taxonomically diverse assemblage of trees and shrubs that form the dominant plant communities in tidal and saline wetlands along sheltered tropical, subtropical coasts (Blasco et al., 1996). Mangrove species are rarely found outside the intertidal area, and mostly occur between mean sea level (MSL) and the level of mean high water (MHW) spring tides. Mangrove species can grow opportunistically for a generation on any tropical shoreline, but their permanent establishment over extensive areas is limited to locations of optimal environmental conditions of calm water, a gently sloping sedimentary intertidal area and a relatively stable sea-level. Extensive mangrove ecosystems occur in such areas as the west coast of Florida, the Ganges and Brahmaputra deltas in India and Bangladesh, the coasts of Sumatra, Borneo and Papua New Guinea, the deltas and estuaries of Queensland and the Northern Territory in Australia, and similar locations in east and west Africa, north further to the south Japan favored by ocean warm current (Chapman, 1970, 1975; Walsh, 1974).

Mangroves are also the rainforests by the sea, which are one of the most productive and biodiversity wetlands on earth, thriving on intertidal mudflats, and they form a linkage between terrestrial and marine environments. Therefore, mangroves provide many ecological and economic benefits to mankind; foremost amongst these are the support and enhancement of coastal fisheries. Moreover, the mangrove forest is a natural barrier that protects the coastline from erosion. It acts as a windbreak, prevents salinization of soils and filters pollutants. The majority of the subtropical and tropical coastlines are dominated by mangroves, and it is believed that today mangrove forests comprise 15.8 million hectares, or 0.6% of all inland forests in the world. This is roughly less than half of the original mangrove forest cover, and it is fast declining further at an assumed rate of 2 to 8 % per year, as a result of a variety of human activities, such as over harvesting, freshwater diversion and conversion to other uses (Peter et al., 1985). Consequently, future natural and/or human related changes of the mangrove ecosystem might substantially have an impact on the economy and society of the coastal regions.

Regardless of the overall environmental setting (river, cay, shore, etc.), an interesting feature found in most of the mangrove forests throughout the world is zonation. This zonation is evidenced by the growth of different mangrove species which occur in bands that grow roughly parallel the shore. Generally, the seaward zone is dominated by pioneer genus *Sonneratia*, *Avicennia* and *Rhizophora*, then followed by *Bruguiera*, *Lumnitzera* and *Ceriops* landward. The transition zone is usually dominated by salt-tolerant vegetation, e.g., plants like *Pandanus*, *Pongamia* and *Hibiscus*. The supralittoral zone is often vegetated by rainforest or is unforested, which can be variable due to local individual climate zones, topography and geomorphology. Nonetheless, overall and complete zonation occurs ONLY in areas with: considerable inter-tidal range, high rainfall in all seasons, and available silt in suspension, which ensures deposition of mud on soil surface so that it is always raising the soil level enabling mangrove to penetrate further seaward (Tomlinson, 1986).

Mangroves have been receiving increasing attention in both ecology and their related studies like geography, biogeography, global changes, sea-level changes, and coast and island geomorphology in the subtropics and tropics (Islam and Tooley, 1991; Woordroffe and John, 1991; Pieter, 1995; Li and Lee, 1996; Azmi and Kamaludin, 1997; Lin, 1999; Behling and Marcondes, 2001a; Behling et al., 2001b, 2002; Velez et al., 2001). In view of the unique ecologic characteristics of mangroves, relict mangrove sediments and fossil mangroves, particularly their pollen, have been used extensively in the interpretation of palaeogeography and stratigraphy. Mangrove pollen are particularly good markers because their presence in the sediments indicates a warm climate and a nearby shoreline at the time the pollen were deposited (Blasco et al., 1996; Paolo, 1996).

Pioneered by Muller (1959), the fundamental studies on modern and fossil pollen morphology of mangroves have been extensively performed by many researchers (Muller, 1969, 1978; Muller and Caratini, 1977; Wang et al., 1975, 1997, 1998; Liu and Tang, 1989; Zhang et al., 1997). Mangrove pollen records have been classically used to reconstruct mangrove vegetation changes, and to indicate the relationship to definite sea-level changes since the past several decades, particularly in the coastlines of Central American and northern Australia (John, 1985, 1988; Joanna, 1989, 1996; Behling et al., 2001b). It has been documented that mangrove pollen were found in the sediment cores from the South China Sea (Sun and Li, 1999a; Sun et al., 1999b, 2000). However, it's rarely reported in southern China about mangrove development history geologically, especially in Hainan Island, where mangroves are well developed presently with abundant mangrove species in wide areas. Several state mangrove nature reserves to preserve mangrove ecosystems have been established successively since 1980s.

In this study pollen analysis of core DZ01 from the coastal mangrove swamp of northern Hainan Island in south China provides unprecedented insight into mangrove vegetation changes since mid-Holocene. The principal aim of this paper is to present the results of pollen analysis, and reconstruct mangrove vegetation changes, then to discuss the potential factors which probably trigger mangrove environment changes at the site, such as coastal environmental changes, sea level changes, and influences of human activities on the coastal region of northern Hainan Island in south China.

2. Study Area

2.1 Location

The regional area of Hainan Island is located on the northern margin of the South China Sea. The study area lies within a mangrove nature reserve (110°32′-110°37′E, 19°51′-20°01′N), and it trans-bounds the tropical and sub-tropical zones of southern China and has a correspondingly diverse transitional fauna and flora with the southern sub-tropical species dominant (Fig. 1). The transitional climatic and hydrological conditions, specific topographic features (estuarine ecosystems) and its rich biodiversity ensure its global significance as a wetland of international importance. Its relatively large area of mangrove forest and wide intertidal sand- and mudflats provide migratory water birds and fish with rich feeding grounds and breeding habitats. We selected Dongzhai mangrove swamp within the mangrove nature reserve as present study area considering the well preserved mangrove diversities, and it being the largest area of mangroves in China. It is also a part of the tropical wetland in China, and is listed in the Wetlands International Inventory since the late 1980s concerning its international ecosystem importance.

2.2 Geology and Hydrology

The bed rock of the Dongzhai estuary has formed over a long geological period and is therefore quite rigid. The estuary has a dense network of tidal canals and a deep soil layer. The soils under the mangroves are mainly saline marsh soils (Hainan Geology Institute, 1992).

The Dongzhai estuary has an irregular rectangular shape with a south-north orientation. It is the largest bay in Hainan Island, with a total area of nearly 100 square kilometers. The estuary forms a nearly closed

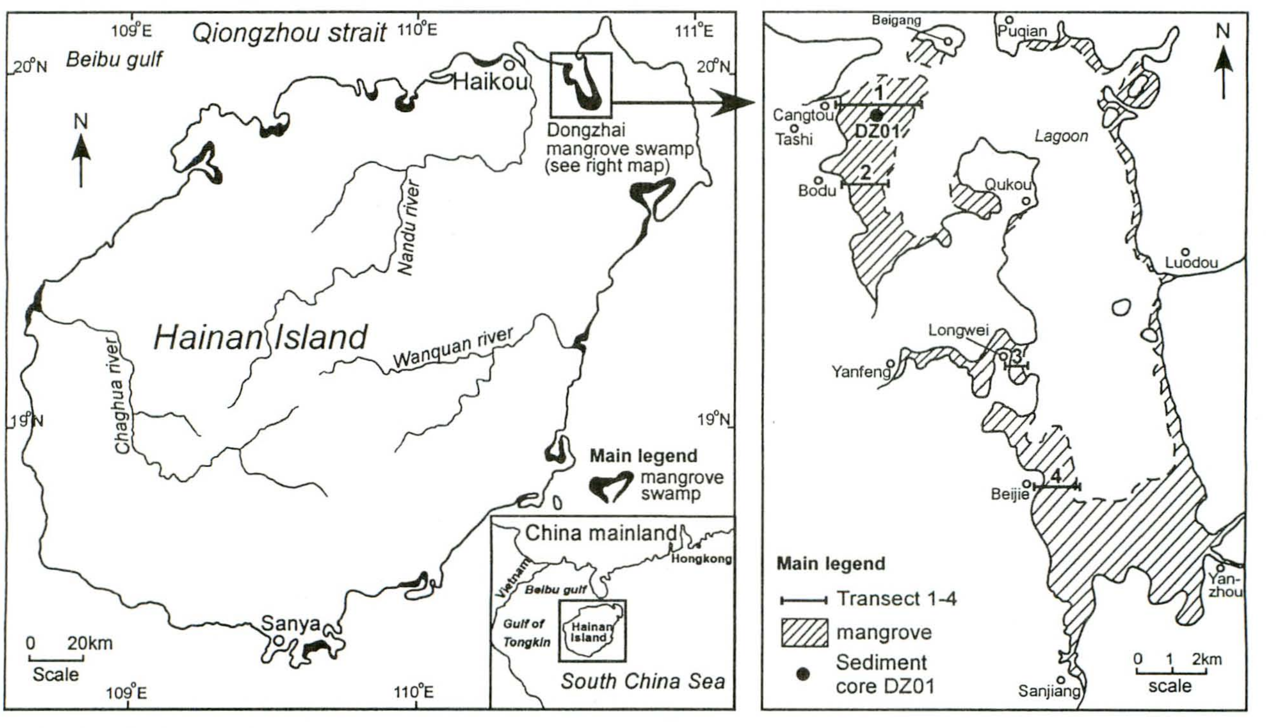

Fig. 1 Left map shows the location of study area and key mangrove swamps in Hainan Island; right map shows sampling location of transects and sediment core from Dongzhai mangrove swamp of northern Hainan Island, China.

lagoon having only two narrow channels connecting it to the South China Sea in the north. Beigang Island, situated at the mouth between the two channels, is large enough to block the effects of strong storms from the South China Sea, which, in turn, favors mangrove development by buffering high energy of wave and storm (Fig. 1). The eastern side of the estuary consists of an alluvial plain and the western side is bordered by low hills. Four small rivers pour into the Dongzhai estuary. During the rainy season, the four rivers carry large amount of silt which are largely deposited within the bay to create the extensive inter-tidal mudflats, providing a favorable environment for mangrove growth in this area.

The seawater temperature is high due to the low latitude and warm winter currents that affect the area. Within the Dongzhai estuary, the annual mean temperature of the sea water is 25.4℃, while the highest mean water temperature from the May to July is 31.5℃, and the lowest in January is 17.7℃. Salinity within the estuary ranges from 9.31‰ to 34.4‰ in different parts of the estuary and at different states of the tide. The salinities in the dry season are higher than those in the rainy season. Mangroves are known to tolerate a wide range of water salinities and can grow in coastal areas and along rivers with salinities between 2.17-34.5‰ (Annul report of Dongzhai Mangrove Nature Reserve, Hainan Island, 1994).

The Dongzhai estuary has irregular semi-diurnal tides with an average high tide elevation of 2.09 m and low tide elevation of 1.19 m. The maximum tidal range is 1.8 m while the average tidal range is 0.89 m (Geography Association of China, 1996).

2.3 Climate

Climate in study area is a tropical monsoon marine climate, with an average annual rainfall of 1670-1840 mm and a mean annual temperature of 23.3-23.8℃. The rainy season starts in early May and ends in late October. Offshore wind prevails during winter months, while landward wind prevails during summer months (Hainan Geology Institute, 1992).

3. Regional Vegetation and Coastal Mangrove

3.1 Regional Vegetation

Vegetation in Hainan Island shows tropic biodiversities in response to humid and warm climate, complicated geomorphologic units, various soil features and climate differentiation throughout the island. Regional vegetation is generally partitioned into lowland and sub-montane rain forest, mid-upper montane forest and coastal forest. Tropical rain forest mainly occurs in humid valleys and billabongs in southeastern Hainan Island, which is dominated by evergreen trees, consisting generally of *Vatica astrotricha*, *Tarrietia parvifolia*, *Diospyros hainanensis*, Leguminosae, Meliaceae, Moraceae, Melastomataceae, Araliaceae, Dipterocarpaceae, Sterculiaceae, Ebenaceae, Sapotaceae. The understory of shrub layers are composed of Palmae, Rubiaceae and Myrsinaceae. The tropical monsoon rain forest is largely distributed in the northern and western area of Hainan. The year-round 5-month drier period of less rainfall in the northern and western Hainan Island results in the vegetation being consequently composed mainly of tropical monsoon rain forest, with a majority of arboreal evergreen trees. The representative species are *Kleinhovia hospita*, *Spondias pinnata*, *Hainania triochosperma*, Apocynaceae, Anacardiaceae, Tiliaceae, Myrtaceae, Altingiaceae, Meliaceae and Euphorbiaceaem, and lower layers of shrub and herbs give way to Moraceae, Rubiaceae and Verbanaceae. The tropical bosks (small wooded areas) are distributed in the western and northwestern Hainan Island, where a drier period with less rainfall lasts around 8 months year-round. The vegetation in the tropical bosks (small wooded areas) consists mainly of *Flacourtia*, *Pandanus*, *Phoenix* and Cactaceae. In the central region of Hainan Island, topography is mountainous and hilly. More than six mountains are over 1,500m, among which the highest mountain is Wuzhishan (1879m). Thus various montane/upland forests are densely vegetated in the central mountainous area. Vertically, vegetation varies with elevation levels in the mountains, namely with tropical rain forest and monsoon rain forest below 500m, and between 500m and 1,000m with subtropical montane evergreen broad-leaved forests, beside some tropical species, mainly presented by *Castanopsis*, *Pentaphylax*, Lauraceae, Theaceae, and with subtropical coniferous components like *Dacrydium*, *Podocarpus*. Above 1,000 m evergreen coniferous-broadleaf trees and evergreen dwarf show dominance, mainly represented by *Pinus*, Fagaceae, Lauraceae, Theaceae and Ericaceae (Guangdong Institute of Botany, 1976).

3.2 Coastal Mangrove and Associates

Mangrove swamps are believed to play an important role in the ecology of coastal waters in southern tropical China. They cover a significant fraction of the coastline, help to stabilize the banks of tidal rivers and creeks, help maintain a deep tidal channel, are believed to be nursery areas for some species of fish from the adjoining continental shelf, provide a habitat for shrimp and other fishes (Fan and Liang, 1995). Mangroves naturally occur along the southeast Chinese coasts and traverse the provinces of Hainan Island, Guangdong, Guangxi, Fujian and Taiwan, intermittently extending from 18-27°N. Thirty seven mangrove tree species, representing 20 families and 25 genera, were documented, with thermophilic eurytopic species being the dominant components (Lin, 2001). A remarkable decrease of species richness is evident from Hainan Island (18-22°N) to Fujian (23.5-27°N) (35vs. 9 species).

The major vegetation community in this area is mangrove and its associated salt-tolerant species termed 'mangrove associates'. The major mangrove communities include (1) *Bruguiera gymnorrhiza* community, mainly distributed in the upper reaches of Sanjiang river and lower reaches of Yanfeng river; (2) *Bruquiera sexangula* community, mainly distributed in front of Yanfeng harbor village, Longwei village and Qukou village; (3) *Ceriops tagal* community, large areas of this community being situated to the south of the core area at Tashi and at the river mouth of Yanfeng river; (4) *Avicennia marina* community, which is the main pioneer species found predominantly along the accreting front edge of the mangrove and beside tidal channels (Fig. 2C-D), which is a highly adaptable species and the crown can be partly or totally submerged during high tides; (5) *Kandelia candel* community, which is a pioneer species which grows along the front edge of the forest in the accretion zone; (6) *Rhizophora stylosa* community, which is a pioneer species and usually grows along the accreting front edge of the mangroves at the interface with the mudflats (Fig. 2A); (7) *Nypa fruticans* community, which normally grows in the high tidal zone landward, this community being easily identified as it consists of dwarf green palm forest (Fig. 2F); (8) *Acrostichum aureum* community, a fern that normally grows in the drier landward margins of the mangrove forest; (9) *Aegiceras corniculatum* community, another pioneer mangrove species, sprouts easily and usually grows along the banks of the estuary and on the seaward edge of the mangrove forest, especially in previously cleared mangrove areas; (10) *Lumnitzera racemosa* community, which grows only in areas reached by the spring tides; (11) *Rhizophora stylosa*+*Ceriops tagal* community, which occurs in the mid- to high tidal mudflat; (12) *Ceriops tagal*+*Aegiceras corniculatum* community, which is restricted to the solid sand clay areas; (13) *Sonneratia caseolaris*+*Kandelia candel* community (Lin, 1999).

The mangrove-associated communities include (1) *Pandanus tectorius* community, a distinctive palm-like plant growing in relatively high areas reached only by the Spring tides, the plants being 3-6 meter high with a DBH (diameter at breast height) of 10-15 cm; (2) *Pongamia pinnata* community. *P. pinnata* forms a deciduous broadleaf forest and grows along the inside edge of the mangrove forest neighboring the mainland. The trees are 2-6 meter high with a base diameter of 10-25 cm. Dense mangroves along intertidal flats along lagoon fringing, riverine diverse mangrove, and selected representative species from Dongzhai mangrove swamp in northern Hainan Island are demonstrated by photos in Fig. 2A-F.

Historically, Dongzhai estuary was more forested than it is today. In the early 1950s, 3,414 ha of mangrove forest was recorded. However, this was reduced to 1,773 ha by the 1960s and 1970s due to intensive agricultural reclamation and mangrove forestry operations. Through an annual replanting program and the cessation of logging the area of mangrove forest, today the area expands to 2,006 ha (General Report of Mangrove Forests in Dongzhai Mangrove Natural Reserve, 1985).

Totally, the Dongzhai mangrove forest holds 26 "true" mangrove species from 12 families, and 40 semi-mangrove and mangrove-associated species belonging to 22 families. The rarer species include *Nypa fruticans*, *Lumnitzera littorea*, *Sonneratia hainanensis*, *S. ovata*, *S. paracaseolaris*, *Xylocarpus granatum*, *Rhizophora apiculata* and *Acrostichum speciosum*, of which *S. hainanensis* is believed to be an endemic species restricted to Hainan Island. In addition, *N. fruticans*, *L. littorea*, *S. hainanensis*, *S. paracaseolaris* and *X. granatum* have been listed in the endangered species (Chinese Academy of Sciences, 1995).

4. Material and Methods

4.1. Field Methods

The mangrove vegetation survey was performed using field observations of accurate plant collections, as well as referring to available photographs from existing documents (Lin, 1999, 2001; Tomlinson, 1986). No significant mangrove taxon was ignored. The location of transects for the mangrove survey is shown in Fig. 1. The mangrove zonal pattern from four transects is briefly illustrated by Fig. 3. Considering naturally well preserved mangrove habitats from transects 1 and 3, and comparing them to transects 2 and 4 in Dongzhai mangrove swamp, transects 1 and 3 within or immediately

Fig. 2 (A) Dense *Rhizophora* community with large area in the north part of Dongzhai mangrove swamp; (B) Riverine mangroves with abundant species largely due to frequent fresh water containing high nutrient sediments in the south part of Dongzhai mangrove swamp; (C) Lagoon fringing *Avicennia* consists of pioneering species in the north part of Dongzhai mangrove swamp; (D) Dense *Avicennia* community with large area in the west part of Dongzhai mangrove swamp; (E) Pioneering species *Sonneratia* with bamboo-like pneumatophore; (F) High *Nypa* in the higher tidal flat of Dongzhai mangrove swamp.

adjacent to mangrove swamps are sampled for pollen analysis (Fig. 3). Surface samples were taken along transects unevenly, which consist of superficial sediments beneath the mangroves. We collected these samples by taking 4 random pinches of the top 1~2cm of soil/sediment over an area of ~4-8m^2.

The sediment core DZ01, 780 cm long and 5 cm in diameter, was taken from the northern part of Dongzhai mangrove swamp (Fig. 1). A modified Livingstone piston sampler was used from a wooden platform, which was fixed on mangrove tidal flat. After stratigraphic description, and sub-sampling for pollen analysis and radiocarbon dates, core sections were stored in the refrigerator. Stratigraphy of the core is given in Table 1.

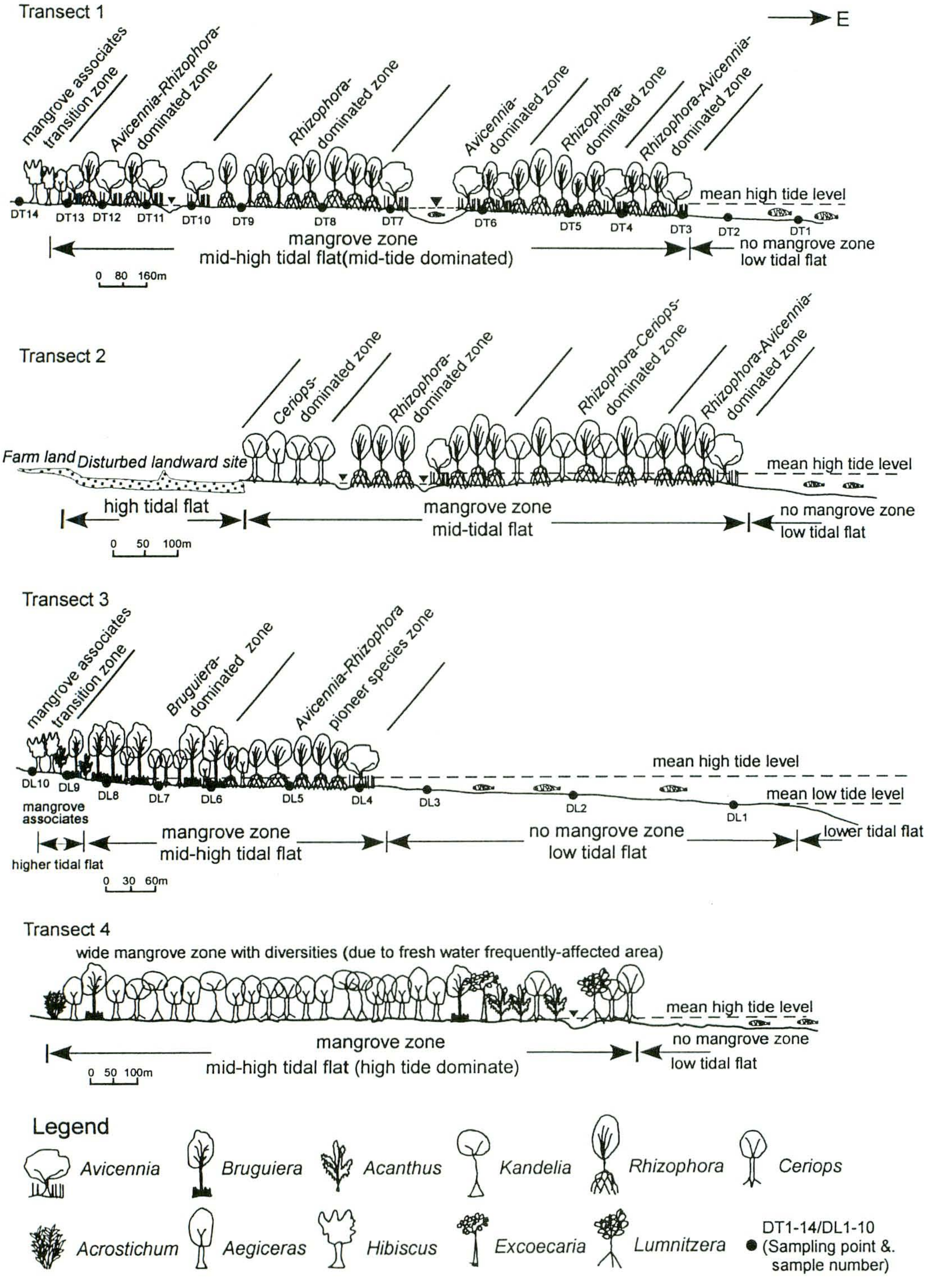

Fig. 3 Transect 1-4 (unscaled vertically) show mangrove zonation over intertidal zone in Dongzhai mangrove swamp; sample DT1-14, DL1-10 collected from seaward to landward for pollen analysis.

4.2. Laboratorial Work

For pollen analysis, we took 24 surface samples from two transects and 52 subsamples at 15-cm interval from core DZ01. All samples were processed following standard pollen analytical techniques and acetolysis (Faegri and Iversen, 1989). To determine the pollen concentration, one tablet containing exotic spores of *Lycopodium* was added to each sample. For sand-silt samples, and potentially containing rich pollen and spores, we used 20 gram dry sediments for pollen analysis and concentration calculating. At least 300 pollen grains in each sample are counted for drawing pollen diagram. The total pollen sum includes herb, shrub, and tree taxa. Mangrove pollen identification was performed by comparison with both the reference collection of the Department of Biology at Sun Yet-sen University (Liu and Tang, 1989), the Department of Marine Geology at Tongji University (Wang et. al, 1975, 1997, 1998; Zhang et. al, 1997) and personal collections.

Table 1 Stratigraphy of core DZ01 (for stratigraphic column see Fig. 5c)

Depth (cm)	Description
0-42	Dark-colored humic loamy mud, very soft, rich in organic matter
42-63	Dark gray mud, somewhat fine sandy, very compact, strongly decomposed, a few plant remains
63-70	Dark-colored fine mud, somewhat fine sandy, compact, less decomposed, some plant remains
70-118	Brown-black fine mud, more compact
118-153	Dark-colored mud with debris, compact, strongly decomposed, 118-127 cm: more compact, 127-153: less decomposed
153-320	Dark-colored and organic-rich mud, with plant remains, roots
320-415	Peat (mangrove peat)
415-476	Light gray mud, with rich organic material, less compact
476-544	Dark-colored organic-rich mud, with plant remains
544-557	Fine mud, with black organic material, compact, 552-557: wood fragment
557-563	Gray fine sand, with many roots
563-596	Light gray fine sand, with black organic material
596-740	Dark-colored organic-rich mud, compact
740-780	Light-colored mud, with plant debris

To establish a chronology for core DZ01, four samples were dated by conventional ^{14}C dating in Guangzhou Institute of Geography, China, and linear interpolation was also used based on four radiocarbon ages. Calibrated dates are from the calibration computer program CALIB 4.3 based on INTCAL98 dataset (Stuiver et al., 1998) and refer to one sigma age ranges (maximum and minimum) based on the intercepts method. Materials dated and results are presented in Table 2.

5. Results

5.1. Modern Mangrove Zonal Pattern

As introduced in the previous text, mangroves occur in diffuse zones in response to local environmental variables, especially tidal flooding or inundation frequency and salinity gradient, and are normally aligned perpendicular to the coastline or river, regardless of the overall environmental setting (river, cay, shore, etc.). According to extensive field investigation of mangrove vegetation, and comparing previous studies in terms of mangrove zonal pattern, mangroves are generally characterized by successional communities in study area. *Sonneratia* and *Avicennia* tend to be pioneer genera which establish initially on intertidal mudflats. As the sediment becomes stabilised, other genera such as *Rhizophora* and *Bruguiera* eventually succeed the pioneer species. *Lumnitzera* and *Xylocarpus* are found in areas that are subject to only a few tidal washes each month. The transition zone is dominated by *Pandanus*, *Pongamia*, and *Hibiscus*. Mangrove zonation over the intertidal zone are illustrated by four transects (1-4) in Fig. 3.

5.2. Description of Surface Pollen Spectra

Mangrove pollen are very abundant in surface sam-

Table 2 Radiocarbon dates of samples from core DZ01

Depth(cm)	Age (^{14}C yr BP)[a]	Calibrated Age (Solution range) (cal yr BP±1σ)[b]	$\delta^{13}C$(‰)	Material dated	Lab number[c]
158-160	1,530±90	1410 (1312-1525)	-29.9	Organic-rich mud	GIGRL-1102
338-340	3400±110	3673 (3475-3827)	-29.4	Mangrove peat	GIGRL-1103
488-490	5,040±130	5830 (5613-5924)	-30.0	Organic-rich mud	GIGRL-1104
758-760	6,650±140	7534 (7427-7658)	-29.5	Plant debris	GIGRL-1105

a. Conventional radiocarbon age.
b. Calibrated according to calibration program CALIB 4.3 based on INTCAL98 dataset (Stuiver et al., 1998).
c. GIGRL: Guangzhou Institute of Geography Radiocarbon Laboratory.

ples collected beneath the mangrove zones. Over 45 main pollen types were recognized. To demonstrate pollen spectra clearly and directly, we grouped pollen into mangroves and associated taxa, montane/submontane taxa, other lowland taxa, fern spores, herbs, aquatics and indeterminate and unidentified forms. Fungal spores are also counted. Mangrove pollen are identified mostly at genera level, some even at species level, like *Avicennia marina*, *Sonneratia hainan islandensis* and several mangrove associates. Nevertheless, Rhizophoraceae pollen are extremely similar in both morphology and size, particularly among *Kandelia*, *Bruguiera*, and *Ceriops*. So Rhizophoraceae pollen were identified based on intensively referring to those published collections (Wang et. al, 1975, 1997, 1998; Liu and Tang, 1989; Zhang et. al, 1997) and a personal collection. Figure 4 illustrates the percentages of the selected mangroves, other frequent pollen and spores in the two sampled transects. Counts for pollen types are expressed as percentages of the total pollen, excluding fern spores, aquatics and indeterminates; counts for fern spores are expressed as percentages of total pollen and spores. Pollen diagrams show continuous and intermediate high in concentration of 3,000-6,000 grains/g of dry sediments. A brief description of pollen spectra from surface sediments for each transect is given below.

Transect 1

This transect spans about 2 km from seaward to landward, but with a slight slope the pollen diagram shows distinct variation along the transect. Rhizophoraceae and *Avicennia* show higher percentages in pollen assemblages in zone DT-2, whereas the other pollen taxa show relative high percentages in zone DT-1 and zone DT-3.

Zone DT-1 shows high pollen percentages (62-67%) in mangrove and associates in low tidal flats, where regional pollen deposits also occur in relative large amounts. The frequent mangrove pollen are *Avicennia* and *Rhizophora*. Regional components Fagaceae and other trees provide rich pollen deposits, probably transported by water or tidal current. Aquatics and herbs provide higher percentages than in zone DT-2.

Zone DT-2 is apparently distinctive as compared to zone DT-1 and zone DT-, being characterized by high percentages of *Rhizophora* and *Avicennia*, up to 60-65% of total pollen sum, and sum pollen of mangrove and associates account for 73-84% of total pollen. *Ceriops* also occurs in a relatively high percentage in the *Ceriops*-dominated site. The marked increase and decrease in the pollen diagram is due to the *Avicennia* pollen percentage, which can be clearly explained by sampling sites along tide channels, as *Avicennia* is apt to grow in the places with high frequency of tide inundation. Fewer aquatics and herbs are present in the pollen diagram in this zone.

Zone DT-3 is characterized by a slightly lower mangrove pollen percentage (64-69%) than the previous zone, and shows nearly equal amounts to zone DT-1. Landward species take the place of mangrove species, and pollen from terrestrial hinterlands are also present in a relative high percentage, including regional airborne and water-transported pollen. Aquatics and herbs show a slightly higher percentage than zone DT-2.

Transect 3

This transect extends about 1km from seaward to landward. The pollen diagram shows a simple and marked zonation along the transect. Pollen assemblages from surface samples across the transect show that pollen deposits reflect the source plants effectively (Fig. 4)

Zone DL-1 shows the lowest zone seaward consisting of abundant pollen generated from local and regional vegetation. Around 60-65% mangrove and associates pollen are present in pollen assemblages, whereas regional components are represented in high percentage as compared with DL-2 zone in mid-high tidal flat. Aquatics and herbs provide slightly higher percentages than in zone DL-2, and are similar to zone DL-3.

Zone DL-2 is strongly dominated by Rhizophoraeae (maximum 63%) in the mid-tidal flat, where *Rhizophora* is dominant among mangrove communities. This zone shows an increase of mangrove and associates pollen percentages (75-82%), mainly from *Rhizophora*, *Bruguiera*, *Ceriops* and *Avicennia*. Very few aquatics, herbs and ferns are present in this zone.

Zone DL-3 provides a lower percentage (60-62%) of mangrove and associate pollen compared to the previous zone. Mangrove associates show higher percentages. The other tree taxa, shrubs and herbs show 30-35% of total pollen, which are probably generated from landward and regional vegetation, such as Palmae, Fagaceae, Euphorbiaceae, *Pandanus*, *Casuarina* and Poaceae. Aquatics and herbs show slightly higher percentages than those in zone DL-2, and are similar to zone DL-1.

5.4. Description of Fossil Pollen Assemblages of

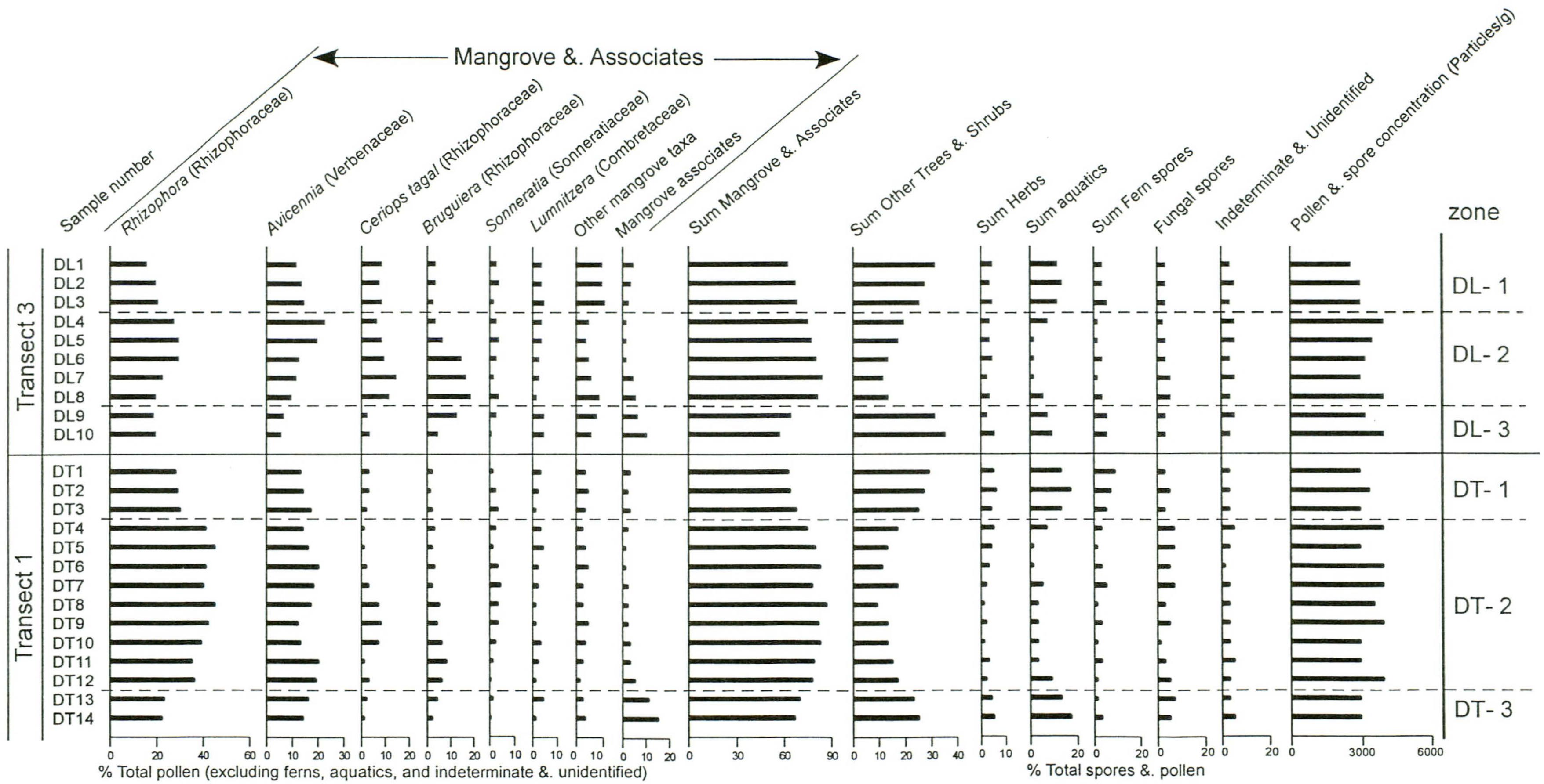

Fig. 4 Percentage summary pollen diagram for transects 1 and 3, showing vegetation groups, percentages of the most frequent mangrove pollen taxa, and pollen concentration (horizontal solid lines separate transects (see column to left); dash lines separate pollen zone)

Sediment Core DZ01

A pollen percentage diagram is illustrated in Fig. 5, grouped by mangroves and associates, montane/submontane taxa, other lowland taxa, fern spores, herbs, aquatics, and indeterminate and unidentified forms. Based on pollen assemblages and abundance, four pollen zones (D-1, D-2, D-3, D-4) are recognized, of which D-4 is subdivided into two sub-zones (D-4a, D-4b). High pollen concentration (3000-6000 particles/g) is presented successively in core DZ01.

Zone D-1(10-205cm) is characterized by rich pollen of mangrove taxa (48-59%), represented by *Rhizophora*, *Avicennia*, *Bruguiera* and *Ceriops*, with *Rhizophora* pollen (8-10%) dominant, then followed by *Avicennia*. Lesser types include the other mangrove taxa, like *Lumnitzera*, *Aegiceras*, *Excoecaria* and *Nypa fruticans*. Other shrub and tree pollen (29-41%) originate mostly from montane/submontane taxa like *Quercus*, *Castanopsis*, *Ericaceae*, *Pinus*, and other lowland taxa, like *Ilex*, *Magnolia*, *Meliaceae*, *Elaeocarpus*, *Mallotus* and *Casuarina*. Percentages of fern spores are higher than in the other zones. Abundant aquatics and herbs are also well present in this zone.

Zone D-2 (220-295cm) is marked by an increase of mangrove and associates (72-81%) and a decrease of herbs (less than 5% in average), ferns (less than 5% in average) and aquatics (2-8% in average). The frequent pollen of mangrove and associates are from *Rhizophora* (21-38%) and *Avicennia* (10-15%), then followed by *Ceriops* and *Bruguiera*, and lesser types including *Lumnitzer* and *Aegiceras*. Pollen of other trees and shrubs generate mostly from *Quercus*, *Castonopsis*, *Mavaceae* and *Mallotus*, but with lower percentages in pollen assemblages.

Zone D-3 (310-475cm) is characterized by a remarkable decrease in total pollen of mangrove and associates (minimum 45%), whereas pollen of other trees and shrubs show a marked increase (maximum 43%). This zone is also marked by a sharp increase in herbs, ferns and aquatics. Herbs are represented primarily by Poaceae, *Merremia*, Cyperaceae, Chenopodiaceae and *Crucifera*.

Zone D-4 (490-775cm) is characterized by low values of herbs (less than 5% in average), ferns (around 7% in average), and aquatics (less than 10% in average). Pollen taxa of mangrove and associates dominate this zone, then followed by other trees and shrubs (15-38%). Mangrove pollen taxa are mainly from Rhizophora (21-42% in average) and *Avicennia* (4-24%), while other trees and shrubs are from Fagaceae and montane/submontane taxa.

D-4a (475-745cm) is dominated by mangrove and associates taxa, primarily at the beginning and end of the zone (maximum 84%). While in the midway of the zone, pollen of other trees and shrubs show higher percentage of 25%. Herbs, ferns and aquatics provide poor contents throughout this sub-zone.

D-4b (760-775cm) shows a slightly decrease in pollen percentages of mangrove and associates, whereas other trees and shrubs provide an increase in pollen percentage (maximum 38%). Herbs, ferns and aquatics are still very poorly presented, but show a slight increase compared with D-4a.

6. Mangrove Vegetation and Environment Reconstruction

Palynology is one technique that allows one to look at past replacement of mangrove zones through time. A transgressive succession (i.e., replacement of zones with progressively more seaward zones) has been demonstrated using pollen in southwest Florida (Speckman et al., 1969). A regressive succession of mangrove zones on a progradational chenier plain in northern Australia has been demonstrated (John, 1985).

In the present study, based on pollen analysis of surface samples from transects 1 and 3, mangrove pollen generally disperse within a very limited distribution area, with abundant mangrove and associates pollen, which provides reliable evidence of mangrove vegetation development history, although potential water dynamics and pollen pollination by wind result in the pollen redistribution (Muller, 1959; Tomlinson, 1986). Many previous studies on modern pollen rain and surface pollen analysis have already shown high pollen productivities (particularly Rhizophoraceae pollen) in mangrove vegetated areas, and mangrove pollen proved to be strongly localized within limited dispersal (John, 1985, 1988; Joanna, 1989, 1996). The present study also shows the consistent results with those previous studies, so it is reliable to reconstruct mangrove vegetation changes according to fossil pollen assemblage changes, based on surface pollen analysis.

The stable presence of diverse mangroves and monsoonal evergreen forest (mainly *Quercus* and *Castanopsis*) implied a warm climate since the mid-Holocene. Generally, pollen assemblages from core DZ01 indicate that the vegetation has mainly dominated by mangrove and associates in the study area, although other trees and shrubs, including montane/submontane trees and other lowland tress and shrubs, are also relatively common.

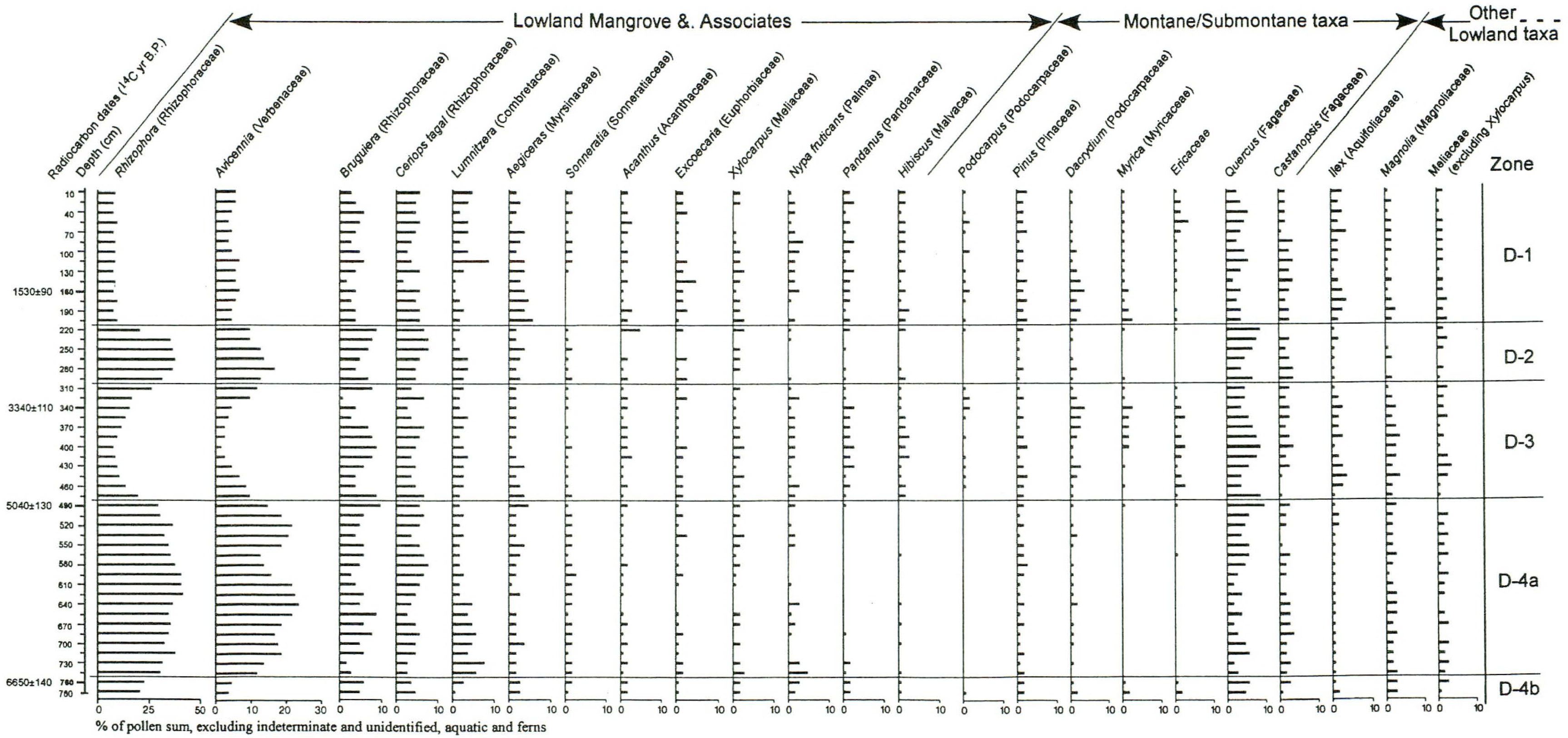

Fig. 5(a). Percentage pollen diagram of core DZ01, also showing vegetation group by Mangrove &. Associates, Montane/Submontane taxa, Other Lowland taxa, pollen zones and radiocarbon dates

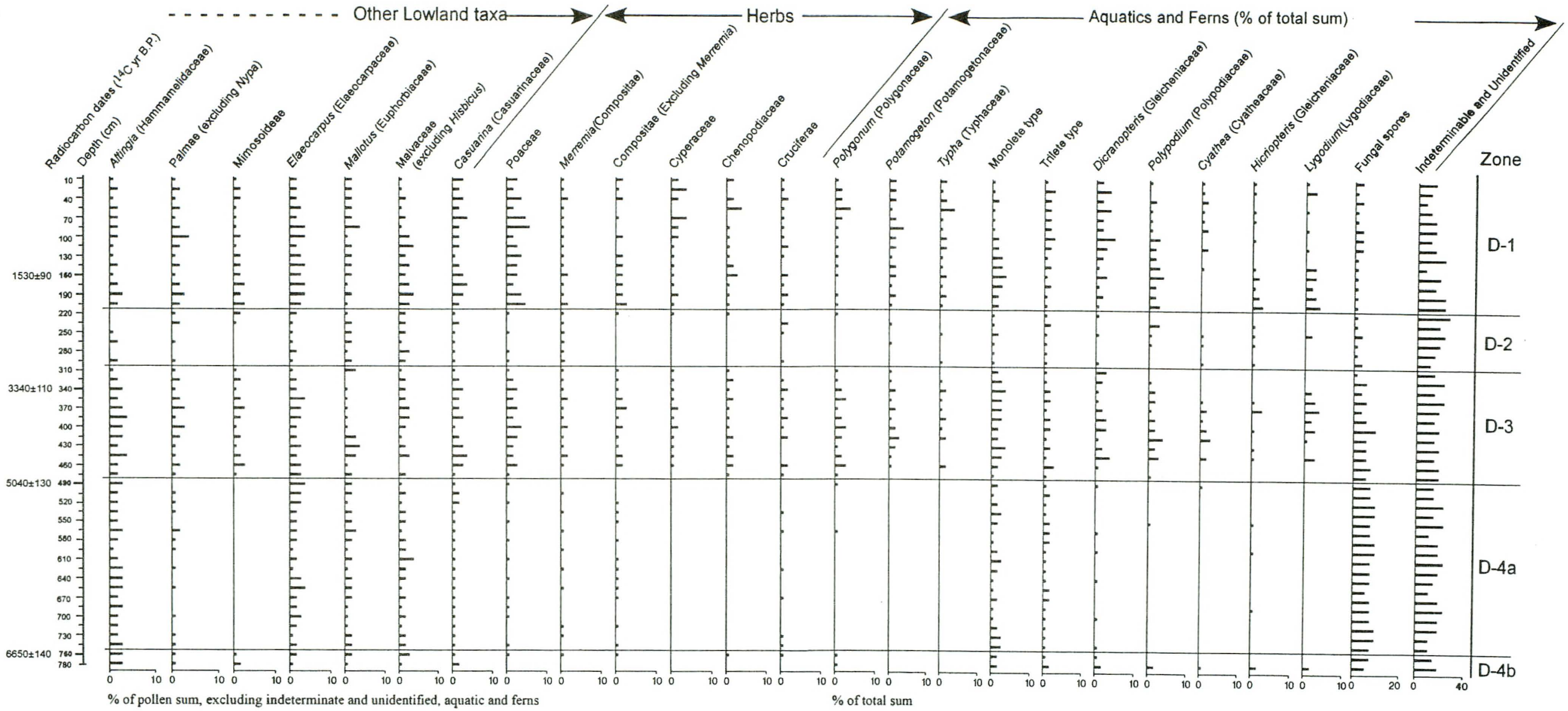

Fig. 5 (continued) (b). Percentage pollen diagram of core DZ01, also showing vegetation groups by Montane/Submontane taxa, Other Lowland taxa, Aquatic and Ferns; and pollen zones, radiocarbon dates

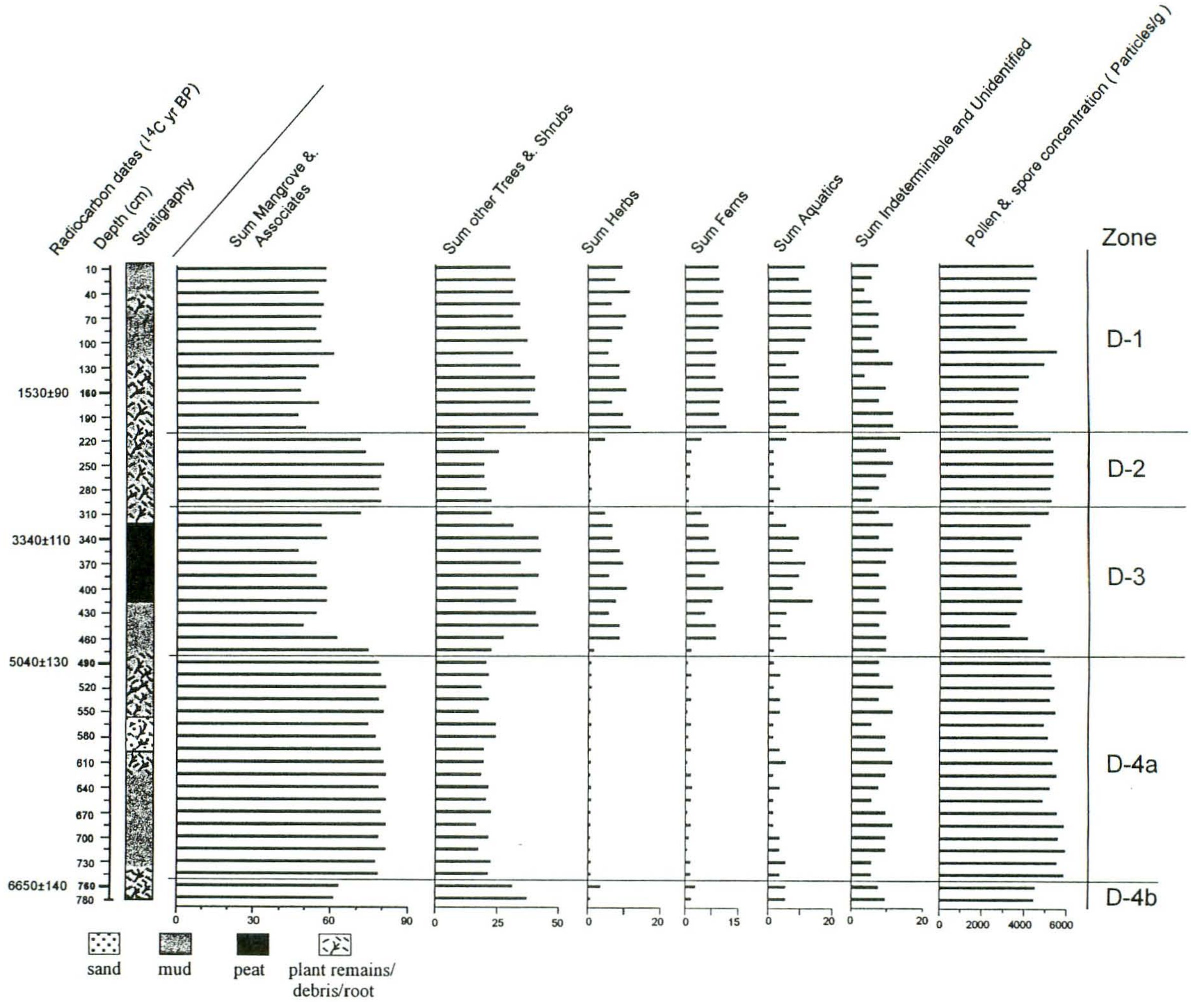

Fig. 5 (continued) (c). Percentage summary pollen diagram for core DZ01, showing vegetation groups by Mangrove &. Associates, Other Trees and Shrubs, Herbs, Aquatics and ferns; also showing pollen concentration, pollen zones, stratigraphy and radiocarbon dates

The relatively fine silt deposits of the DZ01 core bottom suggest that the study site was probably a former intertidal sedimentary environment, instead of an erosion environment. Mangrove pollen deposits and preservation should start prior to the bottom of core DZ01. Here we focus only since 6,650 ^{14}C yr BP to reconstruct and interpret mangrove vegetation changes based on pollen analysis, so future detailed study should be carried out to investigate the mangrove development history prior to mid Holocene or Pleistocene, and even pre-Quaternary.

The chronology for core DZ01 is established with linear interpolation based on four radiocarbon ages. Approximately, 2000, 3100, and 5000 yr BP are roughly defined within the boundaries of four pollen zones.

Zone D-4 (around 6,650—D5,000 yr BP)

Mangrove vegetation have developed well at the study area, as inferred from pollen evidence since mid-Holocene, though other lowland vegetation and montane monsoon rain forest are also well presented, particularly in the beginning of this zone, mainly represented by Magnoliaceae, Meliaceae, Hammamelidaceae, *Elaeocarpus*, *Mallotus*, Valvaceae, *Casuarina*, and evergreen *Quercus* and *Castanopsis*. At present, montane rain forest is distributed far from the study area, while lowland vegetation mainly consists of secondary forests. From surface pollen analysis, these taxa are also recorded in pollen deposits, which are probably allochthonous. Mangrove environments seem to have extended, as inferred from higher values of mangrove pollen through pollen zone 4a. Interestingly, during this period, highstands of Holocene sea-level have been documented in the coasts of southern China (Huang et al., 1986; Zhang and Zhao, 1990). And it is newly reported in the southwest of Leizhou Peninsular (for location see Fig. 1) that using the coral reef and its biological-geological zones as the high sea level indicators, combined with TIMS U-series, four episodes of sea-level high-stands can be recognized throughout Holocene (7.2-6.7~ 5.8, 5.0-4.2, 2.8-2.0, and ~ 1.5 Cal. ka BP), generally matching those indicated by coral reefs from the west coast of the South China Sea (Vietnam) and the Taiwan Strait (Yu et al., 2002; Zhao and Yu, 2002).

Zone D-3 (around 5,000—D 3,100 yr BP)

Percentage values of total mangrove pollen are relatively decreased, but no less than other trees and shrubs, which suggest that mangrove vegetation still grew well at the study site. Surface pollen from the transition zone in transects 1 and 3 show about 45-60% of the total pollen sum (Fig. 4). Moreover, in this zone, mangrove associates show an obvious increase in pollen assemblages (Fig. 5), represented by *Hibscus* and *Pandanus*, i.e., more landward zone domination. So it can be inferred that mangrove vegetation probably grew in the similar higher tidal zone to the present, adjacent to landward, not in the favorable environment dominated by the pioneering genera *Rhizophora* and *Avicennia*. From well-presented other trees and shrubs, and increased herbs, ferns and aquatics, the mangrove environment experienced significant changes. Increased herbs, fern and aquatics can be explained by increasing local fresh water influence, while in this zone, both other lowland taxa and montane/submontane taxa show higher percentages in pollen assemblages. These pollen, probably transported by water, appear to become stronger than ever since, which is consistent with increase in freshwater herbs, aquatics and ferns in pollen records. Pollen evidence of mangrove vegetation changes may suggest a slight sea-level fluctuation, more regression than transgression during the earlier period of 5,000 -3,100 yr ^{14}C BP. According to Zhang and Zhao (1990), sea-level in the southern China during 16,000-6,000 yr BP rose from -42.1m to +4.5m, with the rising rate up to 12.25mm/yr; from +4.5m to -2.7m during 6,000-4,000 yr BP, with the falling rate up to 6.84 mm/yr; since 4,000 yr BP, with general rising trend among fluctuation in sea-level changes, at least two stages of fluctuation are recognized. The results, however, also show discrepancies in some stages, as LGM in sea-level changes while comparable with those reported in the Vietnam offshore or Philippine coasts, which probably can be attributed to local tectonic activities, as reported, the offshore Vietnam site could be subject to some subsidence from the sediment load forming the Mekon Delta (Lambeck et al., 2002).

Zone D-2 (3,100—D2,000 yr BP)

Mangrove and associates taxa dominate pollen assemblages, similar to zone D-4, which again clearly indicates mangrove highly developed in the study site. The pioneer genus of *Rhizophora* and *Avicennia* appear to have developed in the core site, and those species, thriving only in higher tidal flat, and mangrove associates primarily occurring in transition zone appear to decrease in pollen records. This suggests that the sampling site was located in the mid-low tidal flat, nearer to the water level. Consequently sea-level seems to rebound, inferred from mangrove zonation replacement by more seaward species domination in the sampling site. Pollen taxa of other lowland and montane/submotane still occurs in a considerable amount in this zone, on the contrary, herbs, aquatics, and ferns show a sharp decrease in pollen assemblages. Coastal environment for mangrove growth in the study site seems to have been sensitively affected by sea-level fluctuation, which can be correlated to horizontal profiles of sea-level changes (Huang et al., 1986; Zhang and Zhao, 1990; Yu et al., 2002; Zhao and Yu, 2002).

Zone D-1 (2,000 yr BP—D present)

The lower representation of mangrove pollen since 2,000 yr BP can be inferred from pollen assemblages, which probably indicates that mangrove were more distant to the core site than before, and suggests a lower sea-level. Nevertheless, an abrupt rise of *Dicranopteris* spores, a fern growing mainly on deforested areas, indicates increasing influences from freshwater and/or active human interference with the vegetation over 2,000 yr BP. Moreover, mangrove pollen sum also shows a decrease when compared with earlier stages. Meanwhile the sum of herbs in the pollen diagram, represented by Poaceae pollen increase, shows an increase in abundance, and thus all these results preferably indicate more interference from human activity than from freshwater during this period, and probably suggests that the mangrove vegetation development has ever influenced by human activities since 2,000 yr BP.

7. General Discussion and Conclusions

Mangrove forests are best developed where there is an extensive suitable intertidal zone (as found on low-gradient or macrotidal coasts), and an abundant supply of fine-grained sediment. They are more luxuriant in areas of high rainfall or abundant fresh-water supply through run-off or river discharge. They may also grow, however, on sand, peat or coral substrates (Steve et al., 1997; Woodroffe, 1981, Woodroffe et al., 1985). In present study area, the genera *Rhizophora* (Fig. 2A) and *Avicennia* (Fig. 2C-D) are most common, though there are many others. Mangroves show high diversity, particularly along Indo-Pacific coasts. The impacts of sea-level changes on mangroves have been reviewed and discussed in several studies (Bird, 1972, 1993; Joanna, 1989; Woodroffe and John, 1991; Ellison and Stoddart, 1991; Woodroffe, 1981, 1988, 1990, 1995) and there is a general agreement that fossil mangrove deposits, especially above present high-tide level, can be used to indicate former sea levels, although the interpretation, whether indicative of positive or negative sea-level changes is still pen to debate. Mangrove peat layers are useful in stratigraphical reconstructions of sea-level histories.

It is widely accepted that over the Holocene (the last 10,000 years) there has not been a single global sea-level pattern. Instead the interaction of changes in the volume and distribution of ice and seawater have led to regional- and local-scale isostatic adjustments, and sea-level history has varied from place to place. Nevertheless, response to global pattern in the later Quaternary, sea-level changes of two phases are clearly recognized in the study area: 1) an early-Holocene phase of rapid sea-level rise, the postglacial marine transgression; and 2) a mid- to late-Holocene phase of sea-level stability, but with fluctuations. There are two types of sea-level indicators which have been used to determine most of the sea-level reconstructions for the tropics: these are fossil corals and fossil mangroves (Woodroff, 1990). Fossil corals extend back a long way in the geological record but are generally poor indicators of past sea levels. Few (except intertidal microatolls) can be used to actually pinpoint the past sea surface; that is, most corals are relational (directional) and merely indicate that the sea was above a particular level at a particular time. More exact are reconstructions based on fixed (indicative) sea-level indicators, which do relate to a particular palaeosea level (Woodroffe, 1981, 1988, 1990). Mangroves generally grow intertidally; furthermore, individual species are often restricted to a narrow range within the tidal range (Tomlinson, 1986), and thus, if occupation of a particular level can be demonstrated by a mangrove species in the past, this provides a firm indication of where that former sea level was. The majority of mangrove sediments, whether mangrove-derived peats typical of sediment-starved areas or terrestrial clays with occasional woody remains in them, are deposited in situ, beneath a mangrove forest, Rise of mean sea-level (MLS) has an immediate and direct effect on ecosystems of the intertidal zone, with decline in influence of terrestrial processes at all locations, and increase in influence of marine processes. It has been envisaged that species with specific tolerances within the tidal spectrum will migrate landward as their former habitats become increasingly marine (Ellison and Stoddart, 1991).

It is clear that mangrove forests have persisted through the Quaternary despite substantial fluctuations of sea level. Although these must have caused repeated total disruptions to mangrove shorelines, sea-level rise of up to rates of 10-15mm/yr are unlikely to endanger the overall existence of mangrove forest ecosystems (Woodroff, 1990). However, it is equally clear that sedimentation beneath mangrove forests does not keep pace with the most rapid rates of sea-level rise that have been experienced during the postglacial marine transgression. If that had occurred then mangrove forests would still occupy the location they occupied 18,000 years ago, underlain by up to 100 m of mangrove sediment (Woodroffe, 1981, 1988, 1990). The stratigraphy and chronology of Holocene deposits on those mangrove shorelines where sedimentation has been occurring allow reconstruction of the way that mangrove forests have responded to past sea—level rise. As documented by Zhang and Zhao (1990), sea-level in the southern China during 16,000-6,000 yr BP rise from -42.1m to +4.5m, with the rising rate up to 12.25mm/yr; from +4.5m to -2.7m during 6,000-4,000 yr BP, with the falling rate up to 6.84 mm/yr. So the existence of mangrove vegetation was not possibly endangered by sea-level fluctuation in the study area in later Quaternary, if tectonically stable.

From Pleistocene to early Holocene, volcanic activity frequently took place in north Hainan Island, which contributed the basal rock for the coastal area (Hainan Geology Institute, 1992). Around 16,000 to 6,000 yr BP, rapid marine transgression on a large scale in Hainan Island changed the sedimentation model from an erosion-dominated to deposition- dominated environment, and the rapid transgression made relative sea-level rise around 50 m. Hence, the sedimentary construction of lagoon and tide-dominated barrier coastlines was formed on the basis of paleogeomorphology of late Pleistocene and earlier Holocene, which, in turn, provided the paleogeographical background for

Holocene brackish peat development. With the poor supply of inorganic detritus, the large amount of accumulation of plant fragments, the water medium condition of acid and the well-developed and stable mangrove tidal flats, the organic matter content of the deposits increased rapidly and the mangrove peats accumulated in a wide range in the mangrove tidal flats, those tidal flats occurring in the tropical and subtropical zones are suggested as being "peat flats" (Liu et al., 1997; Sang et al., 1993). Studies of sea level changes in south China, including the provinces of Fujian, Gangtong and Hainan Island (19°N~26°N; 110°E~120°E), have shown that sea levels were relatively higher at about 5.8 ka and 2.2 ka BP (uncalibrated ^{14}C ages). Those authors rechecked the 126 available dates and their occurrences within the dating material, evaluating the quality of former shoreline representation. They also considered the tectonic factor by offsetting local uplift or subsidence to estimate regional sea-level changes. A relatively consistent curve was estimated for the coastal areas in south China. The three peaks of high sea levels were at about ^{14}C ages 5.8, 2.2 and 1.4 ka BP. The shoreline was 4.5 m higher at about 5.8 ka, 1.5 m higher at 2.2 ka and 0.6 m higher than present level at 1.4 ka in the Pearl River Delta. The first two fluctuations were more widely recognized (Huang et al., 1986). Nevertheless, our hypothesis closely matches newly reported highstands of mid-late Holocene sea-level, inferred from U-series dating and is locally coincident, but is also premature and required further refinement. Moreover, the discrepancy to the sea-level changes in the vicinities of Vietnam Red River during 4,000-5,000 yr BP (Hori et al., 2002), can probably be explained by local tectonics activities.

Mangrove organic horizons provide convincing sea level indicators as the mangroves themselves maintain a close relationship to regularly recurring levels of tidal inundation. Mangrove pollen have been used as a directional indicator of past sea-levels by several researchers (John, 1985, 1988; Joanna, 1989, 1996; Islam and Tooley, 1991; Woordroffe, 1990; Woordroffe and John, 1991; Behling et al., 2001b). The genus *Rhizophora* provides the most abundant evidence, being an anemophilous species producing prolific amounts of pollen (John, 1985, 1988). Early studies of pollen in surface samples within the mangrove ecosystem showed that there is a high *Rhizophora* proportion in and immediately adjacent to the *Rhizophora* zone (Muller, 1959), and this was utilized as a sea-level indicator. Mangrove peat formation results from vegetative detritus accumulating beneath the trees, growing between MSL and MHW, and peat also contains allochthonous inorganic and organic matter brought in by the tides. Its formation within the upper half of the tidal range renders it a useful sea-level indicator (John, 1988).

Rising sea-level may account for raising of the local water table, resulting in the formation of organic deposits. Sang et al. (1993) and Liu et al. (1997) reported that mangrove peat was found in the east coastal Hainan Island, where mangrove developed well geologically, and mangrove peat occurs in two layers, separated by intertidal deposits composed mainly of fine silt and clay layers. This indicates depositional environmental changes, hence mangrove habitats experienced environmental changes. The leading factor to trigger environmental changes may come from sea-level changes or/and local tectonics such as differential movement vertically. Only when sediment accretion rate keeps pace with sea-level rising, can a mangrove environment survive and still grow in good form. However, mangrove sediments are controlled by sediment supply through run-off and river discharge. In the east Hainan Island, sediment accumulate rate is less than that in the north Hainan Island (Sang et al., 1993). Mangrove peat found in core DZ01 (95cm thick, the upper part of peat layer is dated back to 3,400 ^{14}C yr BP) provides an important indicator of an environmental change, which probably formed during the stable environment settings. Mangrove peat in core DZ01 can be correlated with the lower peat layer found in the coast mangrove swamp of east Hainan Island (Liu et al., 1997). According to Liu et al. (1997), mangrove peat was formed in the relatively stable transition of transgression and regression. Pollen evidence in this study shows abundant mangrove pollen in the peat layer, which suggests well developed mangrove vegetation.

Obviously, we do not understand enough about the interactions of environmental factors and sedimentation patterns within mangrove forests. To a large extent mangroves appear to opportunistically colonize areas that are favorable for them. These complex ecosystems play a very valuable role in estuarine and nearshore food webs, and yet they have evidently been through a very changeable history throughout the Quaternary as sea level has fluctuated. As an ecosystem, mangrove systems must be well adapted to change; human influence on those ecosystems, particularly through reclamation and landward development, may, however, represent the ultimate disruption to many large areas of mangroves forests. Other impacts resulting from possible greenhouse-related climate change, i.e., changes in the frequency of storms and changes in the incidence of precipitation are less clear, and their impact is harder to predict. These are beyond the scope of this study. In brief, different mangrove shorelines will behave in different ways. It becomes increasingly clear how little we really do know about the factors which have controlled the development of many of these systems, and a more detailed understanding can only come from many more studies.

Clearly, using pollen analysis to reconstruct mangrove vegetation changes is an effective method. Nevertheless, when we discuss mangrove environment changes, particularly sea-level changes, if merely depending on palynological evidence and mangrove peat which are formed during regressive phases of sea-level movement, the results may not be perfectly conclusive, so the limitation of this paper is unavoidable. Future studies with multiproxy methods, such as diatom, micro- and macro- littoral fossil analysis, are extremely important to support and supplement our results. Additionally, in order to improve understandings about mangrove development history, more accurate, higher resolution of chronological data should be further obtained to establish mangrove stratigraphy, and parallel cores in the study area and the other coastal mangrove swamps in the whole Hainan Island should be used to correlate pollen records in the Holocene or earlier stages. Moreover, the large mangrove species assemblage of Hainan Island gives complicated zones. The assemblages include genera between which pollen is difficult to distinguish at the light microscopical level, such as *Bruguiera*, *Ceriops* and *Kandelia*. Further studies to evaluate mangrove pollen records in the stratigraphy of coastal mangrove swamps from Hainan Island are necessary.

Pollen analysis of core DZ01 from the coastal mangrove swamp of northern Hainan Island in south China provides unprecedented insight into mangrove vegetation changes since mid-Holocene. Mangrove vegetation changes are recognized from pollen evidence. The potential factors which probably trigger mangrove environment changes at the site are mainly from sea level changes, which resulted in coastal sedimentary environment changes, and then mangrove vegetation changed in response to coastal environment changes. As to tectonic activities, since mid-Holocene, the regional neotectonic activities tended to be stable, although vertical differential movements occurred in the southern Hainan coasts (Hainan Geology Institute, 1992). Pollen records since 2,000 yr BP seem to be overshadowed by the influence of human activities inferred from the marked increases of herbs, aquatics and ferns. Hence human impacts during past centuries in the study area are worthy of notice. However the archeological records are less available to support our hypothesis in terms of human impacts. It is well documented that mangrove forests worldwide were damaged dramatically in past decades, as a result of a variety of human activities. The existing mangrove area in China is approximately 17,800 ha, accounting for slightly more than 0.1% of the world's total. Nearly two-thirds of China's mangroves have been lost during the past 40 years, largely due to conversion for rice-farming, embankment for aquaculture ponds and, recently, increasing reclamation for urban development (Li and Lee, 1996).

The results of pollen analysis document the predominance of mangrove vegetation during the mid-Holocene in the study area in the northern Hainan Island. The presence of mangrove species throughout core DZ01 suggests either a low rate of sea-level fall or a high rate of subsidence. Surface pollen analysis show that abundant mangrove pollen are roughly arranged in a zonal pattern along an intertidal flat. Notably, *Rhizophora*, *Ceriops*, *Bruguiera* and *Avicennia*, are well present, although some other common mangroves are poorly represented by their pollen, including genus of *Excoecaria*, *Kandelia*, *Aegiceras* and *Xylocarpus*. Exotic components are also present, but the dominant pollen taxa are from local sources of mangroves. Thus mangrove pollen deposition in the study area is revealed to be of limited distribution and strongly localized. Pollen evidence from the sediment core DZ01 suggests that mangrove vegetation was well developed since mid-Holocene. However, mangrove vegetation experienced slight degradational changes around 5,000-3,100 yr BP and since 2,000 yr BP, probably resulting from coastal environment changes induced by sea level changes; impacts from human activities on mangroves during the past several centuries have overshadowed mangrove pollen records to some extent. During 6,650-5,000 yr BP and 3,10-2,000 yr BP mangroves have developed highly in the widest area and with good form since mid Holocene, which probably benefited from the warm and humid climate and appropriate coastal environment with increased salinity, and abundant silt-mud deposits discharged from terrestrials nearby. Moreover, organic accumulation also benefits from sea-level rise when the rising rate is consistent. According to previous studies, local relative sea-level reaches its highstands for several times, and abundant mangrove pollen evidence in Dongzhai mangrove swamp seems to be consistent with local relative high sea levels.

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