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A Late Pleistocene palynoflora from the coastal area of Songkhla Lake, southern Thailand

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ABSTRACT: A sediment sample dating from the Late Pleistocene from Ban Bo So, Singha Nakhon district, Songkhla province, in the Sathingpra Peninsula of southern Thailand was extracted for palynological study. The predominance of mangrove palynomorphs, which are from various families including Rhizophoraceae, Sonneratiaceae, and Avicenniaceae, infers a marine deposit in a tidal environment. Other pollen is representative of tropical plants in back mangrove forest, beach forest, swamp, and lowland-montane forest. The presence of a mangrove community is indicative of a high sea level whereas inland pollen types suggest a tropical vegetation.

KEYWORDS: palynology, Late Pleistocene, mangrove community, Songkhla Lake, Southern Thailand

INTRODUCTION

There is very little information about vegetation and climatic changes during the Pleistocene epoch in Thailand. This epoch has long been known as the "Ice Age," a time sensitive to climatic and sea level changes[1]. It is believed that for much of the Pleistocene, Thailand was drier and cooler than at the present day and the sea level during the glacial phases was considerably lower than at present, causing the Gulf of Thailand to be exposed to the atmosphere[1]. There are some pollen studies from areas in southeast Asia confirming expansion of dry land, especially during the last Pleistocene glacial maximum (18,000 BP)[2,3], but most of the studies are restricted to the Holocene or to the time of the Pleistocene / Holocene boundary[4–9]. Evidence prior to that time is needed to arrive at a long-term picture of vegetational change in Thailand.

This study focuses on the vegetation in the coastal area of southern Thailand, because this vegetation type plays an important role in demonstrating the prehistoric fluctuation of sea level. The main objective is to highlight a pollen assemblage as evidence of plant communities, environments, and sea level prior to the glacial maximum of the Late Pleistocene.

AREA AND METHODS

The sediment core no. 2–1 was retrieved in 1998 by the geological mapping section of the Khlong Siam Project at Ban Bo So, Singha Nakorn district, Songkhla province. The drilling site is located at lat. 7° 16′ N, long. 100º 30′ E, or grid reference 666300806400, altitude 8 m above mean sea level, where the surface sediment is beach sand on the tip of the Sathingpra Peninsula, approximately 2 km to the west of the present shoreline of the Gulf of Thailand and about 8 km from the east shore of Songkhla Lake[10] (Fig. 1). Land use around the site consists of villages surrounded by paddy fields and orchards, with scattered patches of beach vegetation. Songkhla Lake basin near the site is also mostly occupied by villages, rubber plantations, shrimp farms, and patches of mangrove and beach forest.

The 40 m long sediment core has been studied for geological and lithological information. A sample at 31 m depth was dated to 30,950 ± 620 yr BP[10], which is in the Late Pleistocene. However, an overlying sample at a depth of 24.5 m gave an age of 33,870 ± 280 yr BP when the sediment was dated by AMS (laboratory number: Beta-228197; material: organic

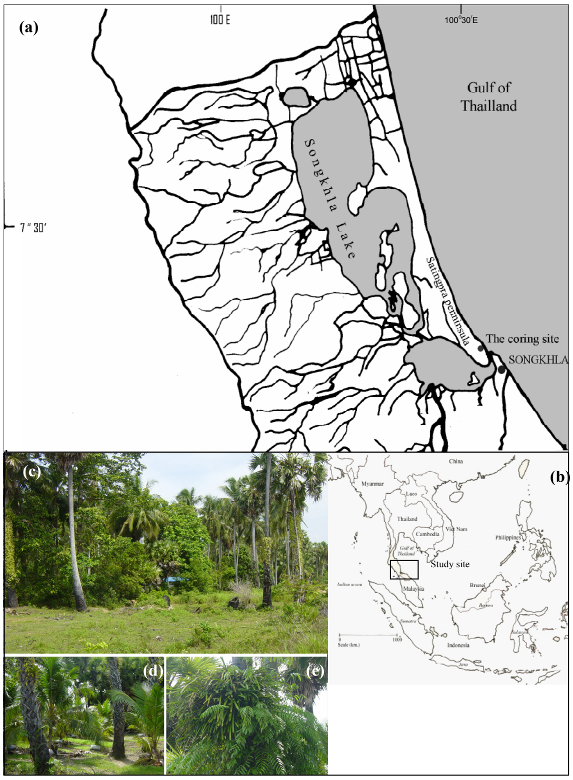

Fig. 1 Maps and photographs of the coring site (a) map showing the coring site in Songkhla Lake basin; (b) map showing the coring site in southeast Asian; (c) an abandoned paddy field at the coring site; (d) an orchard with coconuts, palms, and vegetables planted around the coring site; (e) *Stenochaena palustris* growing on palm trunk, common around the site.

sediment; pretreatment: acid washes). It is not clear whether this older date is correct or was caused by an influx of old carbon. Therefore the age of the sample at 31 m depth could be older than 33,870 ± 280 yr BP. Unfortunately financial constraints prevented additional datings from being made.

A sample at the same depth of 31 m was investigated palynologically. It was treated by various chemicals, mainly HCl for $CaCO_3$ removal, HF for removal of siliceous matter, and acetolysis mixture for cellulose removal. The heavy liquid ($ZnBr_2$) separation method was conducted because a high amount of inorganic matter was left after chemical treatment[11–14]. The pollen grains became yellow upon treatment, so additional staining was not needed. The palynomorphs were identified, counted, and photographed under a light microscope at a magnification of 400x. A scanning electron microscope (JEOL 6400) was also used at 10 kV for detailed morphological observation. After taking a photograph of a selected pollen grain under the light microscope, the same grain of pollen was moved from the glycerine slide by using a nose-hair needle and placed on the SEM stub. Then, it was coated with gold, investigated, and photographed with the scanning electron microscope[13,14]. The identifications were made using modern reference slides and by comparison with illustrations in the literature[15–18]. The pollen percentage calculations are based on the counting of 493 pollen grains and spores.

RESULTS AND DISCUSSION

Recent flora

Remaining natural plant communities are rare around the study site. The area is mostly covered by disturbed beach or coastal vegetation, which is dominated by *Casuarina equisetifolia* J.R. & G. Forst., *Thespesia populnea* (L.) Soland. ex Corr., *Ipomoea pes-caprae* (L.) R. Br., *Cocos nucifera* L., and *Pandanus* sp. Inland from the coring site, there is a paddy field with *Borassus flabellifer* L. along the field dykes. The pervasive anthropological influences on the vegetation preclude the use of surface samples to interpret Pleistocene-aged pollen assemblages.

Westwards toward the Songkhla Lake basin, there are some mangrove communities which are mostly disturbed by human settlement. The patches of these communities comprise *Rhizophora* spp confronting the tide, followed by other dominant species, such as *Excoecaria agallocha* L. and *Xylocarpus* spp. There is a mixture of additional species such as *Ceriops* spp., *Bruguiera* spp., *Avicennia* spp., *Lumnitzera* spp., *Sonneratia* spp., and *Acanthus ebracteatus* Vahl. The species growing landward are *Phoenix paludosa* Roxb. mixed with *Heritiera littoralis* Dryand. Inland behind the mangrove zone is a *Melaleuca leucodendra* L. dominated zone, which is mixed with some coastal and mangrove species, namely *Hibiscus tiliaceus* L., *Lumnitzera* spp., *Excoecaria agallocha* L., and the fern *Acrostichum aureum* L. *Nypa fruticans* Wurmb. is distributed along the canals or creeks in the tidal zone.

Late Pleistocene palynoflora

The fossil palynomorphs in this study are mostly identified to the genus or family level. The percentages of pollen types found in the sample are shown in Fig. 3, whereas photographs of some selected pollen grains and spores are presented in Figs. 5 and 6. Characteristics of parent plants are discussed below.

Pollen of Rhizophoraceae is the most abundant group in the sample comprising 25.76% of the total

Table 1. Inundation classes of some plants in tidal zone (after Santisuk)[27]

Species	Inundation classes					Adjacent and inland vegetation[a]
	1	2	3	4	5	
Rhizophora apiculata		xxxxxx	xxxxxx	xxx		
R. mucronata	xxx	xxxxxx	xxxxxx			
Bruguiera cylindrica			xxxxxx	xxxxxx		
B. gymnorrhiza			xxxxxx	xxxxxx	xxxxxx	
B. hainesii			xxxxxx	xxxxxx	xx	
B. parviflora			xxxxxx	xxxxxx	xxx	
B. sexangula				xxxxxx	xxxxxx	
Ceriops decandra				xxxxxx	xxxxxx	
C. tagal			xxxxxx	xxxxxx		
Avicennia alba	xxx	xxxxxx	xxxxxx			
A. marina	xxx	xxxxxx	xxxxxx			
A. officinalis			xxxxxx	xxxxxx	xxxxxx	
Sonneratia alba	xxxxx	xxxxxx	xx			
S. caseolaris			xx	xxxxxx	xxxxxx	
S. griffithii			xxxxx	xxxxxx	xxxxxx	
S. ovata			xxxxx	xxxxxx	xxxx	
Xylocarpus gangeticus					xxxxxx	xx
X. granatum			xxxxx	xxxxxx	xxxxxx	
X. moluccensis				xxxxxx	xxxxxx	
Lumnitzera littorea				xxxxxx	xxxxxx	
L. racemosa				xxxxxx	xxxxxx	
Excoecaria agallocha				xxxxxx	xxxxxx	
Acanthus ebracteatus				xxxxxx	xxxxxx	
A. ilicifolius				xxxxxx	xxxxxx	
Oncosperma tigillaria					xxxxxx	xxxxx
Barringtonia asiatica					xxxxxx	xxxxxxxxxxx
B. racemosa					xxxxxx	xxxxxxxxxxx

1 = Flooded 56–62 times/ month; 2 = flooded 45 – 56 times/ month; 3 = flooded 20 – 45 times/ month; 4 = flooded 2 – 20 times/ month; 5 = flooded up to twice a month; [a] = beach, fresh water, peat swamp vegetation or salt flat.

palynomorps. The parent plants are trees which have stilts and knee-like roots for breathing and supporting the tree. They prefer growing in wet, muddy, and silty sediments in the tidal zone. They can survive inundation by salt water twice a day. *Rhizophora* flowers are mainly wind pollinated, while those of other genera are insect and possibly bird pollinated[19]. Today, this family in Thailand has members mostly growing in mangrove areas, namely *Rhizophora apiculata* Bl., *R. mucronata* Poir., *Ceriops tagal* (Perr.) C.B. Rob., *C. decandra* (Griff.) Ding Hou, *Bruguiera cylindrica* Bl., *B. gymnorrhiza* (L.) Savingny, *B. parviflora* (Roxb.) Wight and Arn. ex Griff., and *B. sexangula* (Lour.) Poir[20].

Avicennia (Avicenniaceae) pollen composed 3.85% of the total grains. The trees are tolerant of a wide salinity range. They prefer low sloping areas, allowing them to be found in wide areas along the seaside and in stands of mangrove. In mangrove areas of eastern Thailand, they are usually found landward of the Rhizophoraceae group. The pencil-like pneumatophores protect them from suffocation when growing in poorly oxygenated mud. Their flower are small and insect pollinated, with low pollen productivity[21]. In Thailand today, four species of *Avicennia*, i.e., *A. alba* Bl., *A. marina* Forssk., *A. tomentosa* Jacq., and *A. officinalis* L. occur.

Sonneratia (Sonneratiaceae) was represented by 2.23% of the total palynomorphs. The trees have cone-shaped pneumatophores adapted for growing in the tidal zone. *Sonneratia alba* J. Sm. is highly tolerant of salinity, so it is often found growing associated with taxa of Rhizophoraceae and *Avicennia* spp. on the seaward side of the mangrove zone. Other members, such as *S. ovata* Backer, *S. griffithii* Kurz, and especially *S. caseolaris* (L.) Engl., prefer growing in environments with more freshwater input, such as areas near tidal rivers or channels. The flowers are ephemeral (one-night blooming) and pollinated by bats[22].

Acanthus pollen comprised 1.01%. The parent plant is a shrub growing on mud near the high tide mark. It can be found growing under trees and also in open areas of the disturbed mangrove forest. It prefers areas with more fresh water input, such as along river banks. *Acanthus ebracteatus* Vahl and *A. ilicifolius* L. are found in mangrove areas of Thailand today[23]. Their flowers are pollinated by insects or possibly sunbirds in the case of *A. ilicifolius*[19].

Lumnitzera (Combretaceae) pollen had a very small presence with 0.61%. The parent plants are back mangrove trees. Flowers of *L. racemosa* are pollinated by insects, whereas those of *L. littorea* are mainly pollinated by birds[19].

Xylocarpus (Meliaceae) pollen occurred at 0.81%. The parent plants are often found in the inner areas of the mangrove stands where the forest floor is higher and salinity is lower[23]. The flowers are pollinated by insects[19].

Excoecaria agallocha (Euphorbiaceae) was also represented by 0.81% of the palynomorphs. The parent plant is a tree with wind or insect pollinated

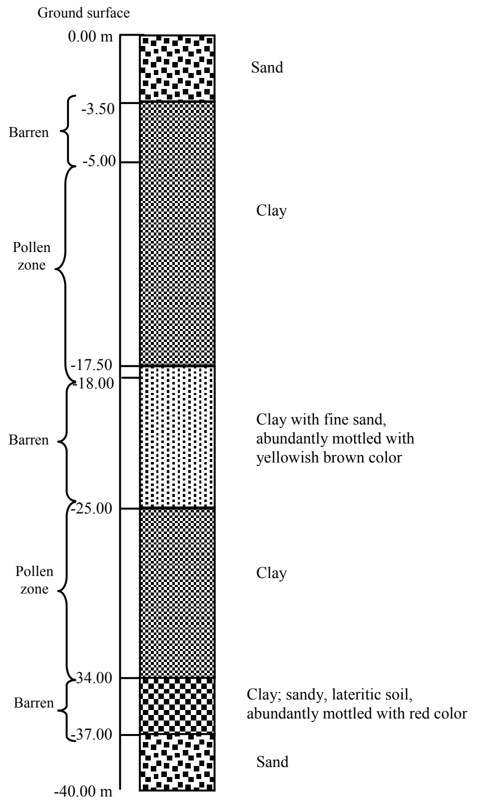

Fig. 2 The lithological column (modified after Tiyapairach[10]) along with the pollen occurrence column; the studied sample is from the 31 m-depth layer.

flowers associated with mangrove forests. It usually grows in land preferably on either stony or muddy ground at the high tide mark as a marginal mangrove[19,21].

Oncosperma (Arecaceae) pollen constituted 0.61%. The parent plant is a palm tree and has both brackish and freshwater wetland representatives.

Barringtonia (Lecythidaceae) was represented by 1.01% of the palynomorphs. The parent plant can be found situated inland in the swamp and lowland forest. Pollinators of its flowers are bats or insects, mainly moths.

There was 0.61% *Casuarina* pollen present in the sample. The native species in Thailand today is the wind pollinated *Casuarina equisetifolia* (Casuarinaceae). It occurs in open, coastal strands, on sandy beach, sand dune, sand bar, and rocky coast environments. Because of its nitrogen-fixing root nodules, it can colonize nutrient-poor soil or disturbed areas but cannot grow well in sites that are flooded for a prolonged length of time[24]. *Casuarina* is commonly found today near the coring site.

The pollen of Myrtaceae (2.43%), Fagaceae (1.42%), Menispermaceae (1.22%), *Calamus* (Arecaceae) (1.01%), *Ilex* (Aquifoliaceae) (0.61%), *Podocarpus* (Podocarpaceae) (0.41%), *Lagerstroemia* (Lythraceae) (0.41%), and *Dipterocarpus* (Dipterocarpaceae) (0.20%) are commonly found in swamps, peatland, and lowland forest vegetation[1,25].

Various types of fern spores were common in the sample including the interesting spores of *Acrostichum* spp., ferns in the family Pteridaceae. These ferns can tolerate saline soil but cannot tolerate flooding. They occur in the back mangrove brackish environment. In addition, they grow in freshwater swamps and in freshwater swamps and marshes. There are two species commonly found in Thailand, *A. aureum* L. and *A. speciosum* Willd.[23] Another interesting fern spore is that of *Stenochlaena palustris* (Burm. f.) Bedd., a climbing fern, belonging to the family Blechnaceae. It grows in the open habitat of swamps or lake margins[26]. This fern is still common at the study site today. In addition, the sediment the sediment contains algae and various types of fungal spores.

Late Pleistocene ecosystems

Pollen present in the sediment can be grouped into 4 vegetation types based on the ecology of the parent plants, *i.e.*, (i) mangrove, (ii) back mangrove, (iii) beach, and (iv) lowland-montane vegetation. Palynomorphs of (v) grasses, (vi) ferns, and (vii) unknown components are classified as separate groups because they are open to various interpretations. The proportion of each group in the sample is shown in Fig. 4.

(i) Mangrove vegetation is the main group of pollen present in this layer with 34% of total palynomorphs. This component is clearly dominated by the taxa of Rhizophoraceae, along with *Avicennia, Sonneratia*, and *Acanthus*, whereas taxa of *Excoecaria, Lumnitzera, Xylocarpus*, and *Oncosperma* are present in much lower relative percentages (less than 1% each).

The presence of mangrove pollen types suggests marine or mangrove deposition in this area at that time. The assumption that this area used to be a marine flooded area is supported by the data of inundation frequencies of mangrove plant species in Table 1[27]. Moreover, a study of pollen distribution in Indonesian marine sediment suggested that mangrove pollen grains are not exported widely from their source area[28]. This agrees with the study of modern pollen deposition in mangrove sediments of Eastern Thailand which shows that pollen of mangrove plants is likely to be deposited close to the parent plants. A high percentage of mangrove pollen was found in sediment of the *Avicennia alba* zone, mangrove community zone, and nipa association zone, whereas a low percentage of mangrove pollen (<30%) was found in the landward area of transitional swamp zone and marine offshore[17]. The present habitat of these mangrove plants is mud flats, whose sediments were supplied by inland freshwater runoff.

Although Rhizophoraceae seemed to be the dominant element of the flora, it might or might not have been the most abundant of the parent plants at the site because studies of mangrove forest and recent marine sediments found that the pollen percentages always show an over-representation of Rhizophoraceae but under-representation of *Avicennia, Acanthus, Excoecaria*, and *Lumnitzera* compared to the real floristic composition[16,17]. One of the reasons could be the higher pollen productivity of Rhizophoraceae plants. Moreover, study of pollen sedimentation on the mangrove and marine surface found that the smaller size of their pollen grains allowed them to be disseminated and deposited over wider areas[17].

(ii) Pollen in the group comprising back mangrove vegetation is characterized by a very low percentage (1.62%) of *Barringtonia* and *Oncosperma* pollen. The parent plants usually occur inland in brackish environments. Their presence suggests that there were freshwater sources in the surrounding areas forming the brackish environment. Pollen from this area was then transported by wind or water to be deposited in the study site.

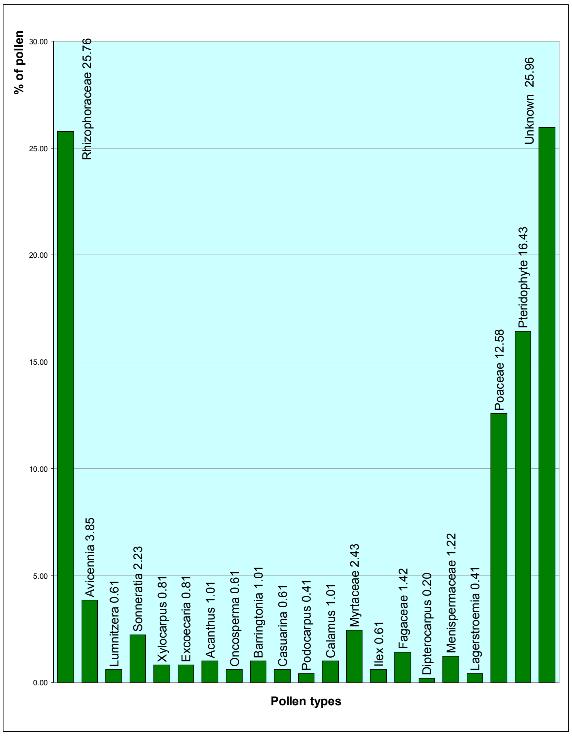

Fig. 3 Percentages of pollen types associated in the pollen assemblage.

(iii) Beach forest vegetation, which is also less common, was represented by only 0.61% of *Casuarina* pollen. *Casuarina* wind-pollinated pollen is normally produced in large numbers and distributed over wide areas. The parent plants are usually found in sand ridge or sand bar environments. The presence of only a few grains of *Casuarina* pollen suggests that there were no *Casuarina* plants growing in the study site, but there might have been a sand ridge or sand bar environment with *Casuarina* at some distance from the site.

(iv) Lowland-montane forest vegetation was represented by 8% of the pollen. It comprised many pollen types, but each of them was represented by only a very few grains from the following taxa: Myrtaceae, Fagaceae, Menispermaceae, *Calamus* (Arecaceae), *Ilex* (Aquifoliaceae), *Podocarpus* (Podocarpaceae), *Lagerstroemia* (Lythraceae), and *Dipterocarpus* (Dipterocarpaceae). Except for *Podocarpus* and some Fagaceae, most of the plants have animal-pollinated flowers. Due to their lower productivity and short distance of distribution, one pollen grain of animal-pollinated plants suggests more parent plants than one pollen grain of wind-pollinated plants.

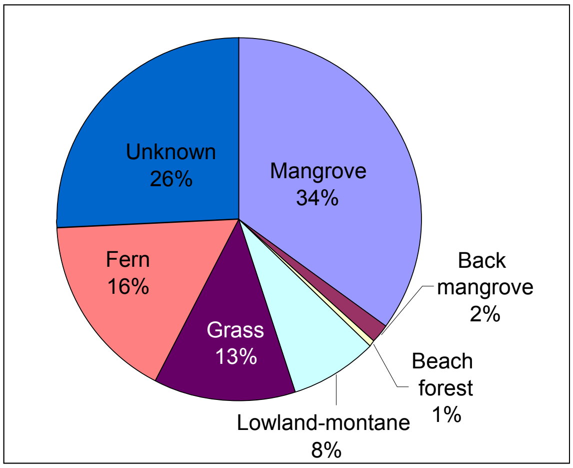

Fig. 4 Percentages of pollen vegetation components.

Podocarpus has been frequently interpreted as a genus of high elevations. However, in Thailand two of the six species of *Podocarpus* s.l., namely *P. motleyi* (Parl.) Dummer and *P. polystachyus* R. Br. ex Endl., can be found at low altitudes[29]. They usually grow in the lowland tropical evergreen forests or in swamp forests. More particularly, *P. polystachyus* is frequently found in evergreen forest at about 800 m above mean sea level (msl), but it often occurs at lower elevations along the seashores or along rivers and even in the mangrove swamps. So in this study the *Podocarpus* pollen type was classified as a representative of the lowland forest.

Fagaceae has been found growing widely in the temperate-subtropical zone and also at high altitudes in the tropics. In Thailand today, it can be found in both evergreen and deciduous forest. Members of the Fagaceae family are dominant plants in montane forest (>800 m msl). However, some species are present at low altitude (0–800 m msl), such as *Castanopsis argyrophylla*, *C. indica, Lithocarpus fenestratus, L. garrettianus, L. echinops, L. lindleyanus, L. poly-stachya, L. sootepensis, Quercus aliena, Q. brandisiana, Q. kerrii, Q. kingiana,* and *Q. mespilifolia*[30].

This is similar to *Ilex* spp. (Aquifoliaceae), which are also found growing in the lowlands of Thailand, for example, *Ilex umbellulata, I. godajam*, and *I. englishii*[30]. *Ilex cymosa* even grows in the swamp forest.

The above taxa are representatives of swamp, peat, lowland-montane forest. This shows that inland forests were established around the core site during the Late Pleistocene, and the above pollen was transported by wind and water into the marine deposit. Another possible explanation is that these groups of pollen might have been transported from the mainland on the west side of Songkhla Lake, which today supports some lowland montane communities. In either case, this group of forest plants suggests the presence of tropical evergreen vegetation.

(v) Grass (Poaceae) is quite common in the area at 13% of the pollen. It normally occupies open areas and grows well in a dry climate such as in grass-land and savanna. In Thailand today, grasses normally grow on the floor of open deciduous dipterocarp forest in Northeastern, North, and Central Thailand[25]. In addition, a study in Tonga mentioned the presence of grasses in the coastal wetland near the shore[31].

(vi) Ferns are also common, constituting 16% of the sporomorphs. In general, this plant group prefers high humidity habitats. The ferns often found in mangrove forests are *Acrostichum* species. *Stenochlaena palustris* is also associated with mangroves as a climbing fern on the trees. This fern is also a representative of the humid lowland environment. Today, it is common in the study site, even though there is no longer a mangrove environment.

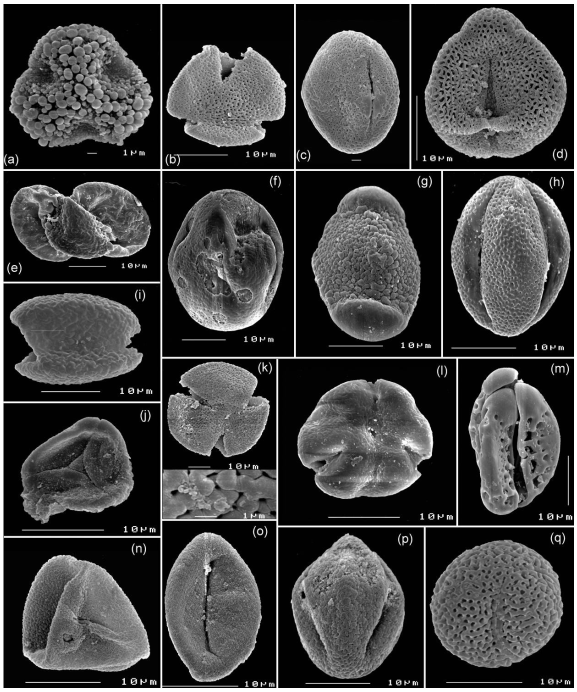

Fig. 5 Pollen types present in the sediment sample: (a) *Ilex* sp.; (b, c) *Rhizophoraceae;* (d) *Avicennia* sp.; (e) *Podocarpus* sp.; (f) *Xylocarpus* sp.; (g) *Sonneratia* sp; (h) *Excoecaria agallocha*; (i) *Calamus* sp.; (j) *Myrtacaea*; (k) *Diptero-carpus* sp.; (l) *Lumnitzera* sp.; (m) *Barringtonia* sp.; (n) Poaceae; (o) Fagaceae; (p) *Lagerstroemia* sp; and (q) Menispermaceae.

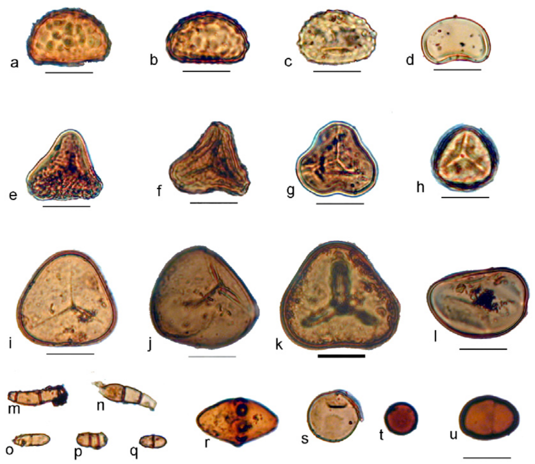

Fig. 6 Other palynomorphs present in the sediment: Pteridophyta (a-l) including Polypodiaceae (a, b), *Stenochlaena palustris* (c), *Pteris* spp. (d-f), Cyatheaceae (g), *Lycopodium cernuum* (h), *Acrostichum* sp. (i), unidentified fern spores (j-l), fungal spores (m-u). Scale bar = 10 micron.

(vii) The unknown pollen group, comprising many types of pollen, was quite highly represented at 26%. From modern pollen comparison, their pollen morphology is not close to that of modern mangrove pollen present in Thailand today. They were probably inland pollen transported to the site. This information infers a high diversity of the flora at that time.

These vegetation groups show community diversity at the study site. The Sathingpra Peninsula at that time was occupied by many types of vegetation belonging to mangrove, back mangrove, and beach forest communities mixed with fern species, whereas landward areas were covered by swamp, lowland-montane, and grass communities.

These ecosystems are still present in many areas of southern Thailand today. That means that during the Late Pleistocene southern Thailand had a similar environment to that of the present day. However, the study site, being 2 km from the present coast, no longer has any mangrove or back mangrove and is not subject to marine inundation anymore. The remnants of the natural vegetation represent lowland forest, which is being replaced by orchards and paddy fields. The Late Pleistocene ecosystems were more similar to the plant communities growing around Songkhla Lake, especially at the mouth of the lake where it debouches into the ocean to form brackish and marine environments.

The Late Pleistocene sea level

The Pleistocene is known as a dry and cold epoch and is commonly referred to as the "Ice Age." There has been much discussion about the dry/cold and wet/warm climatic fluctuation and how much it affected the equatorial zone, which is tropical today[1,4,9,32]. The sea level has also fluctuated and was located mostly below the present mean sea level. During the glacial phases, regression caused the Gulf of Thailand to become dry land, while during the interglacials the area became flooded again.

In this study, it was found that at 30,950 ± 620 yrBP during the Late Pleistocene the sediment was a marine deposit likely in the tidal zone and supported a mangrove community. This indicates that it was deposited during a transgressive episode. The sediment sample comes from a depth of 31 m below ground level, which is 23 m below present sea level. Without considering local tectonic effects and sediment compaction effects, it could be estimated that the sea level at that time was about 23 m below present sea level.

However, the position of the sea level at about 30,000 yr BP is still disputed. Studies by Woldstedt in Europe and Dreimannis and Goldthwait in North America mentioned sea levels varying from above present sea level to ~50 m below[33]. At Huon Peninsula, New Guinea, a study of coral reefs suggested a level 40–42 m[33] while another study suggested a level 64–84 m[34] below present sea level. A study at Northwestern Australia sugested a level ~ 60–70 m below present sea level[35]. The sea level proposed in the present account is a preliminary estimate, which needs to be tested by future research.

Our sample would appear to date from the beginning of a transgression phase because the sediment is underlain by clay with silty, sandy, and lateritic soil, which was presumably formed during the prior low, regressional phase. This date is confirmed by the large numbers of mangrove pollen found in the overlying sediments. At this time (33–28 Ka), Europe experienced relatively mild climatic conditions (Denekamp Interstadial)[32,36].

This marine transgression was followed by a large drop in sea level in the Pacific and Indian Oceans to about 100 to 150 m below present sea level[37–45], which turned the Gulf of Thailand into emergent land during the Last Glacial Maximum. This scenario agrees with the pollen observations in many sediment layers in the upper part of the section. Between 24.5–17.5 m depth, there is little or no pollen present[46]. The sediments are silty, fine-grained sand, abundantly mottled with a yellowish brown colour indicative of oxidizing conditions, suggesting that the area was exposed to the atmosphere at that time.

CONCLUSIONS

The palynomorph assemblage from the Late Pleistocene sediment sample indicates that the Sathingpra Peninsula was an intertidal environment occupied by a mangrove community. This suggests a period of interstadial marine transgression prior to the subsequent drop in sea level during the Last Glacial Maximum. The inland vegetation close to the site was tropical swamp and lowland forest.

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