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Studies on Peat in the Coastal Plains of Sumatra and Borneo

Part IV: A Study of the Floral Composition of Peat in Coastal Plain of Brunei, Borneo

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Abstract

The coastal plain of the Baram-Belait river basin, Brunei can be divided into two stratified sequences; peat and mineral deposits. The mineral deposits consist of sand terrace, mangrove deposits and tidal flat deposits. Peat deposits derived from many kinds of the former vegetation cover started to accumulate on these mineral deposits during the Holocene period. Tidal flat and mangrove deposits are characterized by the abundant fossil pollen of mangrove vegetation, while fossil pollen in sand terrace are mostly derived from the former freshwater-swamp forest.

Two kinds of peat deposits were found in the Baram-Belait river basin; (1) freshwater peat swamp, and (2) brackish-water peat swamp. Brackish-water peat swamp is mostly deposited in the bottom layer, and characterized by the dominance of mangrove pollen, except for peat deposits taken from Profile BRNI 86-28. All peat layers of this profile are mostly dominated by pollen derived from freshwater-swamp forest.

Freshwater peat swamp taken from Profiles BRNI 86-14 and BRNI 86-18 is characterized by the former mixed dipterocarp forest. Between the upper and bottom layers, the mixed swamp forest occur, and they are characterized by the dominance of many kinds of fossil pollen types.

Introduction

Peat deposits in Brunei, Borneo were discovered in vast coastal plain of the lower Baram-Belait river basin. Generally believed to be from the Holocene age, the most important feature of these peat deposits is that they develop in a stratified sequence of former vegetation. This opened up the possibility of stratigraphic analysis, provided that adequate data were available on the former vegetation identified. Therefore, I examined the pollen composition of peats in order to describe the vegetational change from the basal clay to the present-day forest.

Pollen grains and spores buried by further deposits of organic matter can be used for determination of former vegetation, as well as for identification of the former state of the environment. It should not be overlooked that pollen grains buried in peat deposits may be typical of vegetation types derived from different environments, because pollen transportation by air or river into the coastal plain of Brunei is also possible. However, I am convinced that the analysis of fossil pollen buried by organic matter deposits will allow reconstruc-

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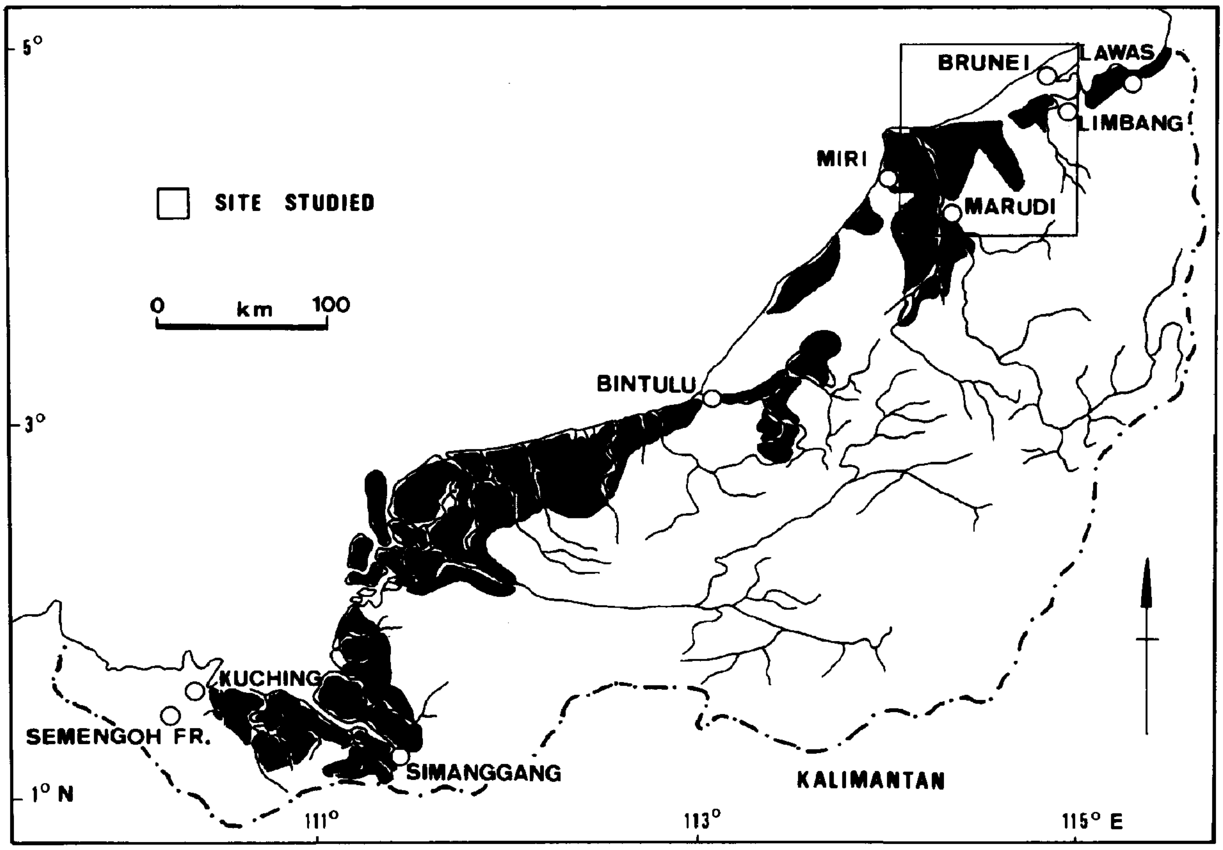
tion of the past succession of plant communities.

In this study, pollen diagrams were prepared for three sections of peat deposits. Each section was taken from a different locality. Stratigraphy and geomorphology of this coastal plain are also presented here in order to distinguish the peat accumulations.

Soil Sampling and Methods of Investigation

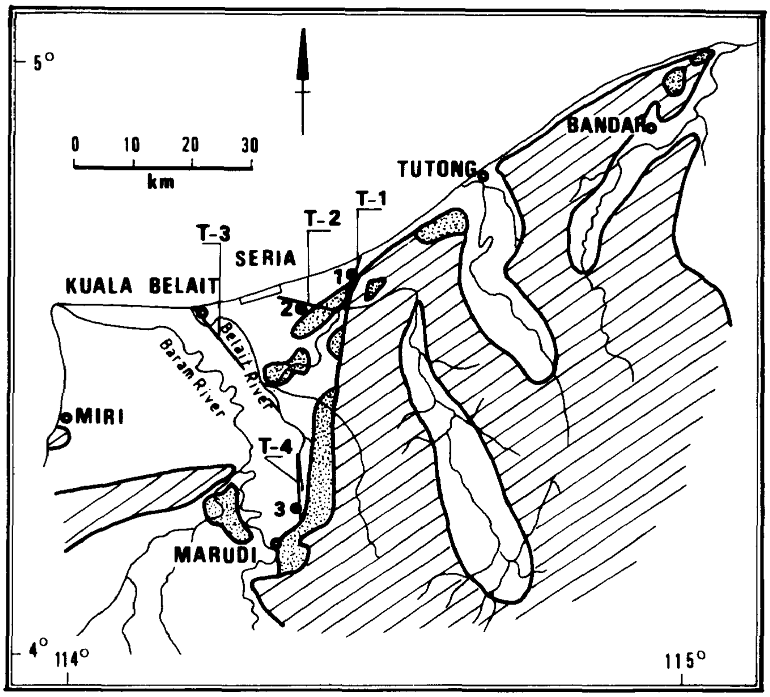
A borehole survey was done by H. Furukawa in the period 2–29 September 1986, using gouge augers and peat augers up to the depth of about 10 m. During this survey, he collected core samples in half-cut plastic pipes or bamboo pipes. For this study, he made four transects: (1) along the Lumut water pipeline, from Lumut to Badas (T–1); (2) along the Seria water pipeline, from Seria to Badas (T–2); (3) in the lower Belait river (T–3); and (4) in the Damit river area (T–4). The location of the study area is presented in Fig. 1.

To study the fossil pollen in connection with the history of plant communities, I collected samples from layers at three observation points of Profiles BRNI 86–14, BRNI 86–18 and BRNI 86–28 (see Fig. 2) using the sub-sampling method. Two-centimeter-thick samples were taken from each soil sample in a plastic or bamboo pipe at 10-centimeter intervals in vertical sequence. The fossil pollen grains and spores in soil samples were investi-



■: Peat Deposits in the Coastal Plains of Sarawak and Brunei (After Brunig [1974])

Fig. 1 Location of the Study Area



: TERTIARY HILL
: PLEISTOCENE TERRACE
: ALLUVIAL LOWLAND AND TROUGH

1, BRNI 86-14; 2, BRNI 86-18; 3, BRNI 86-28;

T-1, Transect along the Lumut water pipeline, from Lumut to Badas;
T-2, Transect along the Seria water pipeline, from Seria to Badas;
T-3, Transect in the lower Belait river;
T-4, Transect in the Damit river area.

Fig. 2 Simplified Landform Map of Baram-Belait River Basin (After Furukawa [1988]) and Soil Sampling Site

gated by pollen analysis in order to reconstruct the floral composition. The Erdtman method [Brown 1960] was used for extraction of fossil pollen from soil samples. For reference, I used pollen and spore types described by Anderson and Muller [1975], Huang [1972], and Kremp and Kawasaki [1972]. Modern pollen samples collected from the Herbarium Bogoriense were extracted by the Jimbo method [Brown 1960], and the results were also used for reference.

Results and Discussion

Stratigraphy and Geomorphology

Furukawa [1988] divided the landform of Brunei into two categories: lowlands and hills. The lowlands consist of the Baram-Belait river basin, Belait trough, Tutong trough and Brunei river trough. The hills are composed of Plio-Pleistocene formation and Miocene formation, and are surrounded at the periphery by a low terrace of beach origin and a higher terrace on a flat-topped crest, which were apparently formed in the middle Pleistocene (Fig. 2). The peat deposits were found in the lowlands, sometimes exceeding 8 m in depth, and the basement on which peat developed comprises sand deposits, mangrove deposits, and tidal flat deposits.

Furthermore, Furukawa reported the stratigraphic layers of this plain along each transect (see Fig. 2), as follows.

1. Along the transect from Lumut to Badas (T-1), peat deposition took place on a valley floor which had been cut on a low terrace surface before the Holocene sea rise started. When sea level was much lower than it is at present, the ground surface depicted by the sand cover represents the former landform at the end of the last glaciation. During the sea level rise in the Holocene period, the valley floor changed into a swampy plain, and this caused peat deposition to be initiated. Peat formation continued in pace with the gradual sea rise, and finally filled up the former valley, resulting in a smooth and level topography. Today, these peat deposits have been covered by dense forest which is dominated by *alan batu* (*Shorea albida* Sym.).

2. Along the transect from Seria to Badas (T-2), peat deposits overlie mangrove deposits and marine clay. Intrusions of marine and brackish sediments are supposed to have taken place during the Holocene sea rise. Today, these peat deposits are covered by dense forest which is dominated by *alan* trees (*Shorea albida* Sym.) with many *rengas* (*Gluta*) and *kerkup* (*Millettia* spp.).

3. A later formation of peat was found in an area along the transect in the lower Belait river (T-3). In this site, shallow peat started to accumulate on the tidal flat that emerged after the final regression of the sea. This means that peat formation here is much younger than in the Badas transect. Thus, the duration of peat formation is thought to be much longer in the Badas area than in the lower Belait area.

4. In the Damit river area, borings were done along the logging line of Lutong sawmill (T-4). From field observations, peats appear to have developed on mangrove deposits. Bluish gray sand was found below the mangrove deposits. This sand is rather different from the sand which underlies the peats in the Badas area.

Floral Composition in Mineral and Peat Deposits

In the transgressive period of the Holocene, which is believed to have started about 11,000 years BP [Tjia 1987], most of the coastal plain of Brunei was submerged by the sea. This caused several off-shore sand bars to rise above the sea during the transgression [Furukawa 1988]. The high portions close to these sand bars were converted into freshwater swamps, and peat formation was initiated. In addition, peat formation developed in the lower plains. The bottom layer of these plains was covered by tidal flats and mangrove deposits. When the sea level dropped, these mangrove deposits emerged. The environment was converted into freshwater swamp, in which organic matter deposition started to form a thick peat dome. Today, the swampy area of the Baram-Belait river basin of Brunei is mostly covered by peat deposits.

During the peat accumulation, the vegetation type has changed gradually in composition. To

Table 1 Distribution of Arboreal and Non-arboreal Pollen Types in Sub-samples of Profiles BRNI 86–14, BRNI 86–18 and BRNI 86–28

Depth (cm)	Total Grains	Pollen Types (%)		Un-known (%)
		Arboreal Pollen	Non-arboreal Pollen*	
		Profile BRNI 86–14		
0– 50	1448	76	19	5
50–100	—**	—	—	—
100–150	1322	78	18	4
150–200	1980	72	22	6
200–500	—	—	—	—
500–600	6705	43	53	4
600–700	6208	37	58	5
		Profile BRNI 86–18		
0–100	5190	58	38	4
100–200	—	—	—	—
200–300	5124	61	35	4
300–600	—	—	—	—
600–650	1873	63	29	8
650–700	1483	62	35	3
700–750	1395	62	34	4
750–800	1552	72	23	5
800–900	—	—	—	—
		Profile BRNI 86–28		
0– 50	2075	53	45	2
50–100	—	—	—	—
100–270	7898	58	39	3
270–300	—	—	—	—
300–330	2384	48	47	5
330–350	1349	35	61	4
350–400	—	—	—	—
400–450	1494	37	56	7
450–700	—	—	—	—
700–740	1022	44	49	7
740–750	341	43	51	6

* Consists of shrubs, grasses and spores.
** No sample.

study the floral composition of these peat deposits, fossil-pollen observations were made, and the results are presented in Table 1 and Figs. 3, 4 and 5.

In the following discussion, I try to describe the former floral composition in each layer of each profile using the fossil-pollen diagrams. The most important fossil-pollen types found in the peat and mineral soil deposits are presented in Plates 1, 2, 3, 4 and 5.

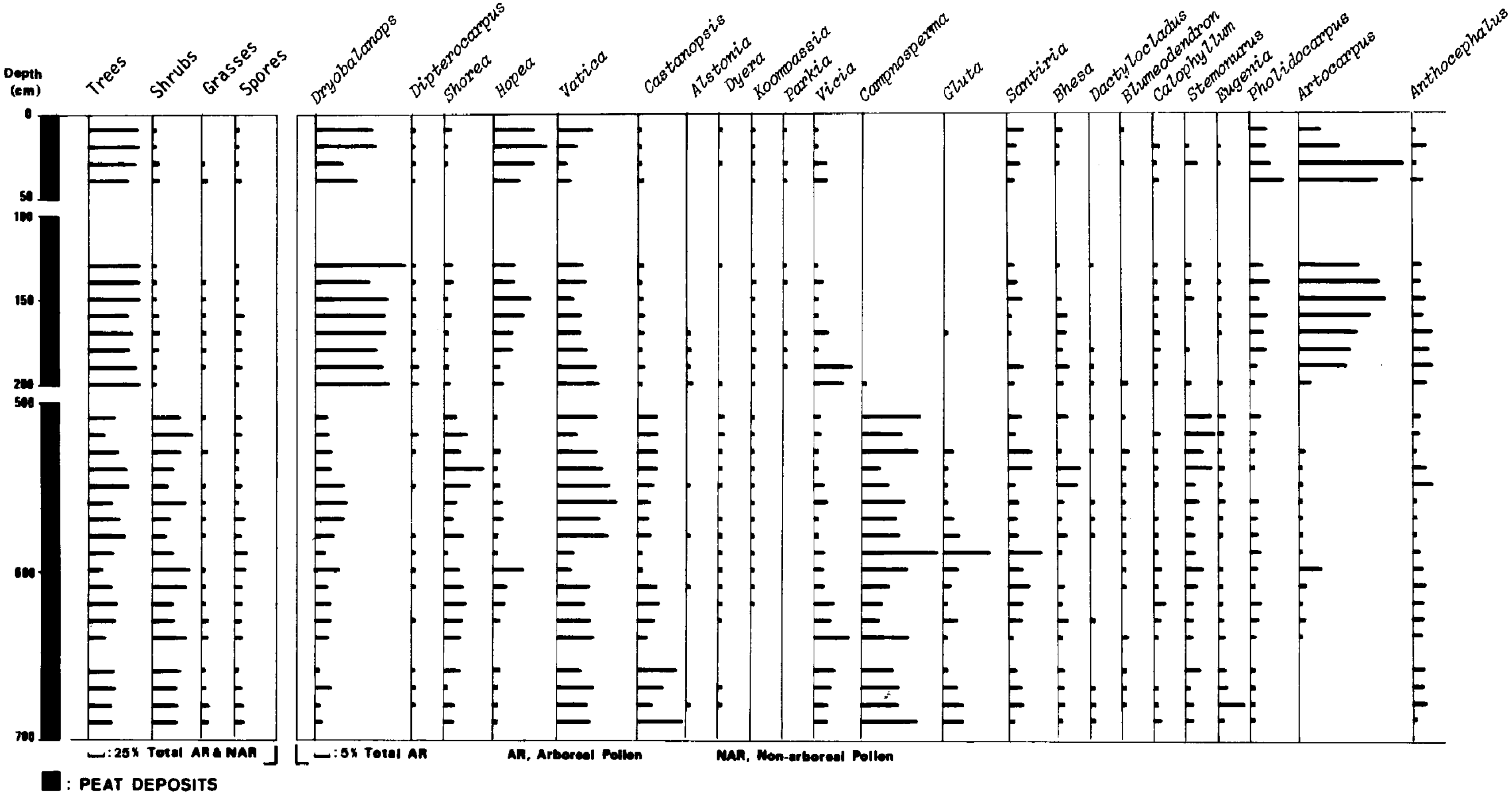


Fig. 3 Pollen Diagram of Deep Peat Taken from Profile BRNI 86–14 near Lumut, Brunei

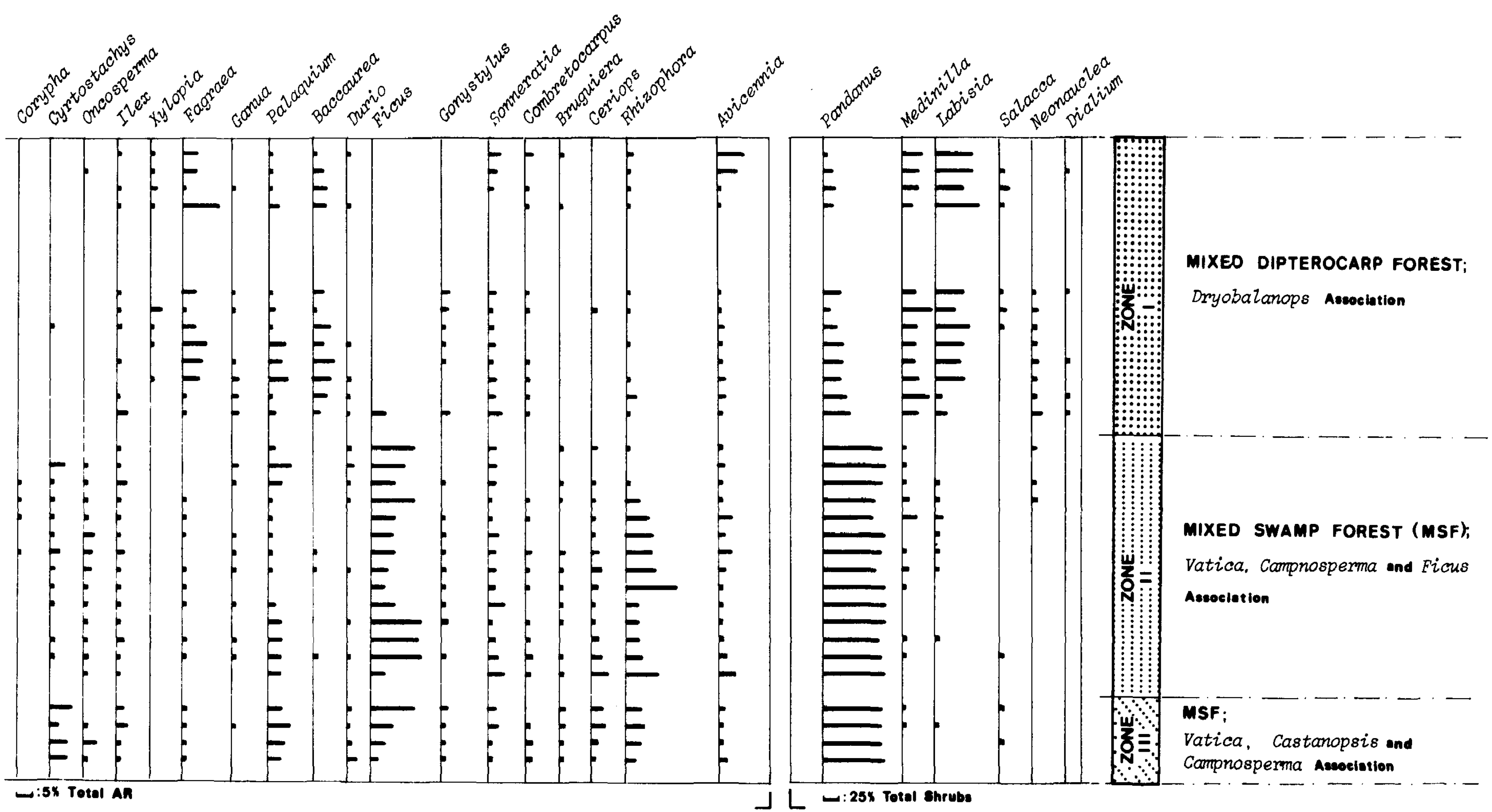
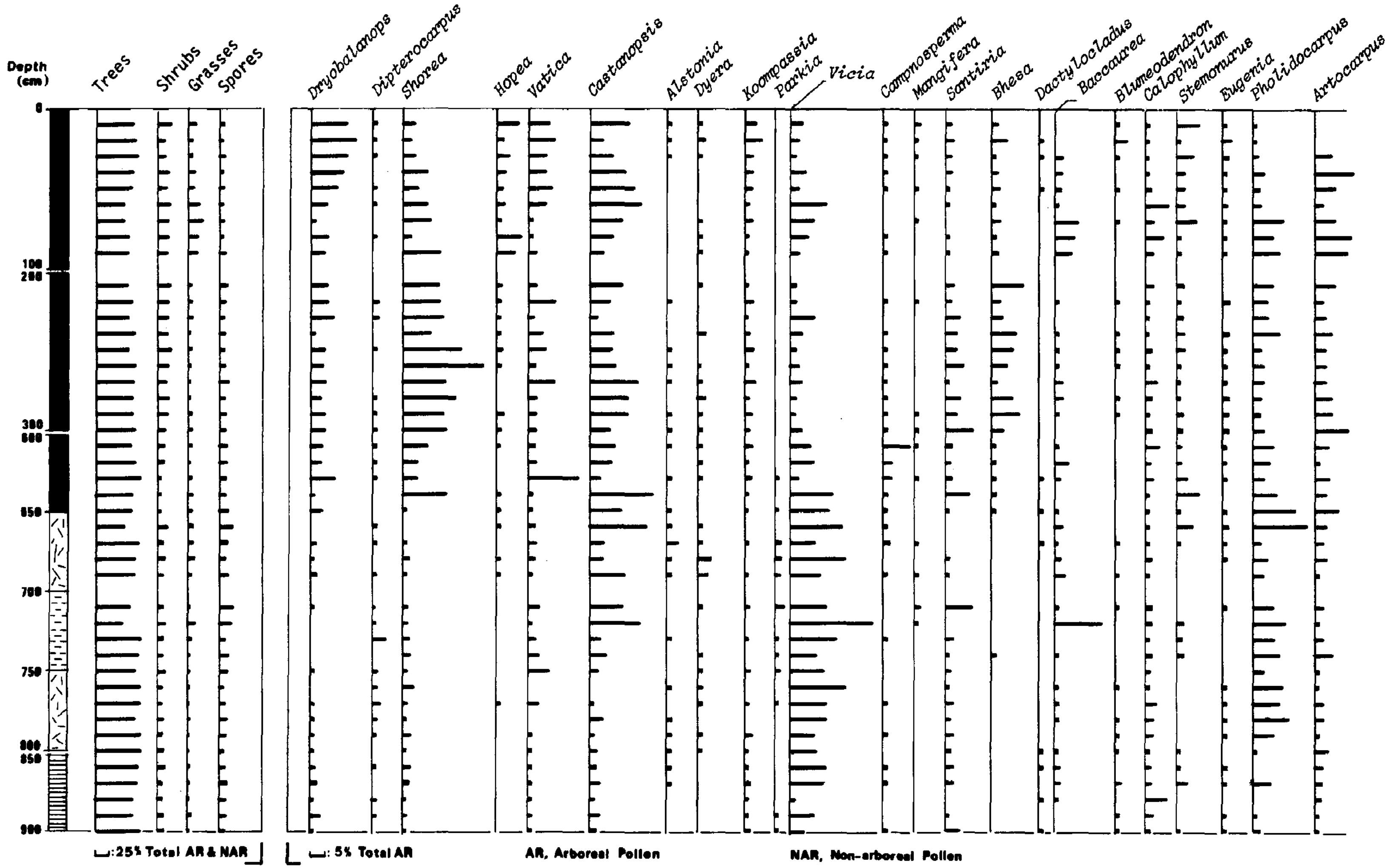


Fig. 3-Continued



■: PEAT DEPOSITS; ▤: PEATY CLAY; ▧: MANGROVE DEPOSITS; ▤: MARINE CLAY

Fig. 4 Pollen Diagram of Peat Deposits Taken from Profile BRNI 86–18 near Badas, Brunei

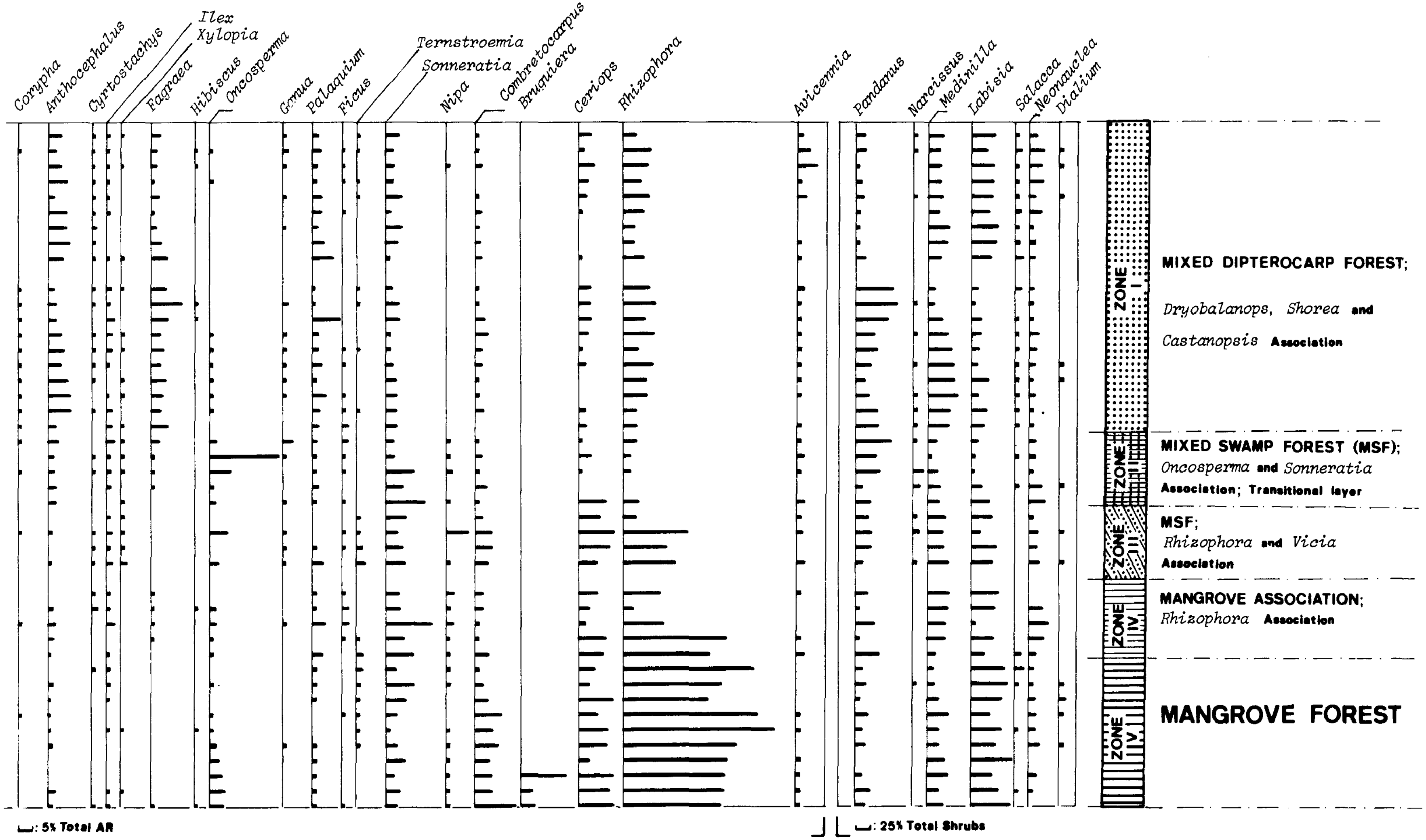


Fig. 4–Continued

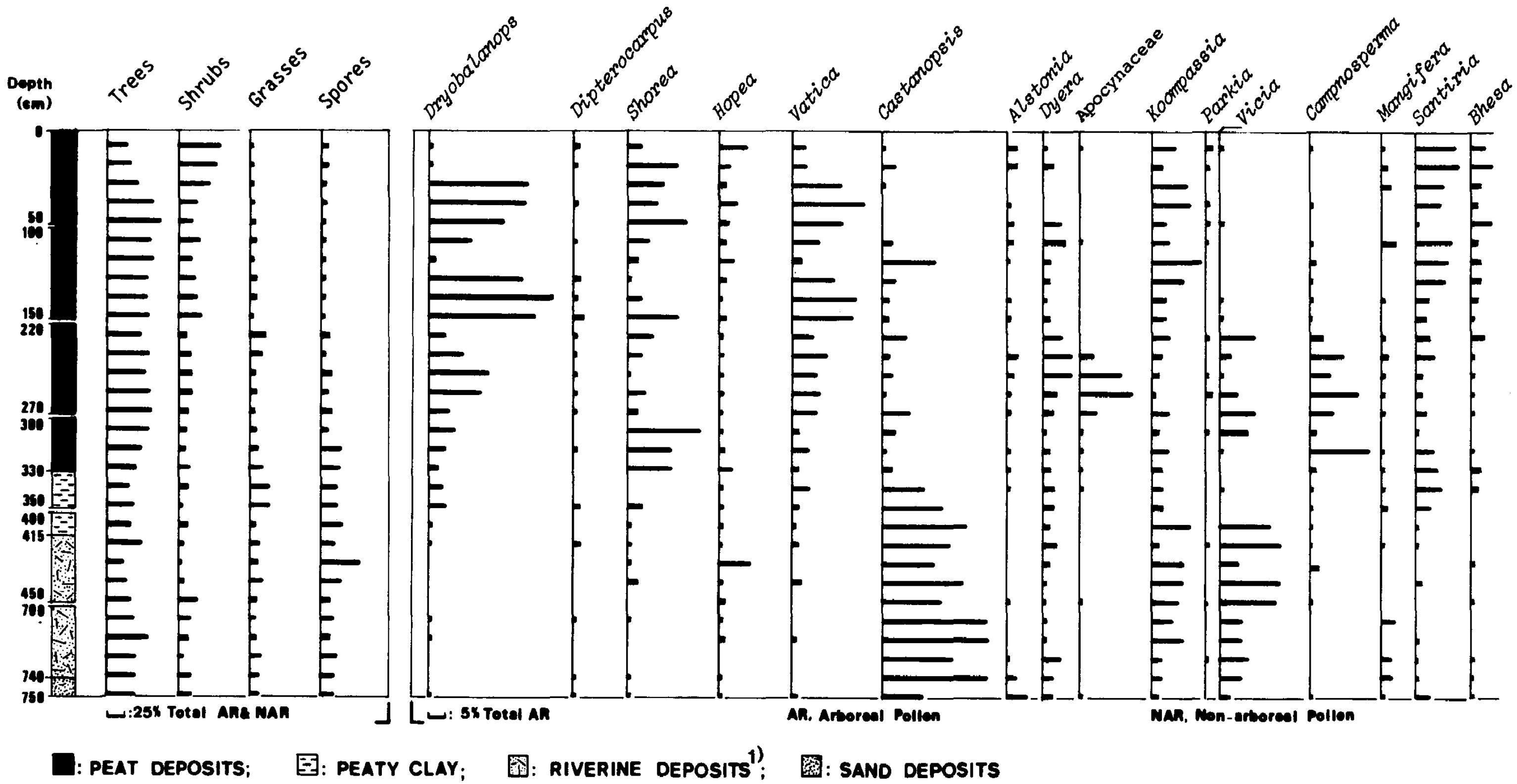


Fig. 5 Pollen Diagram of Peat Deposits Taken from profile BRNI 86-28 near Lutong, Brunei

1) From field observations, this layer was categorized as mangrove deposits

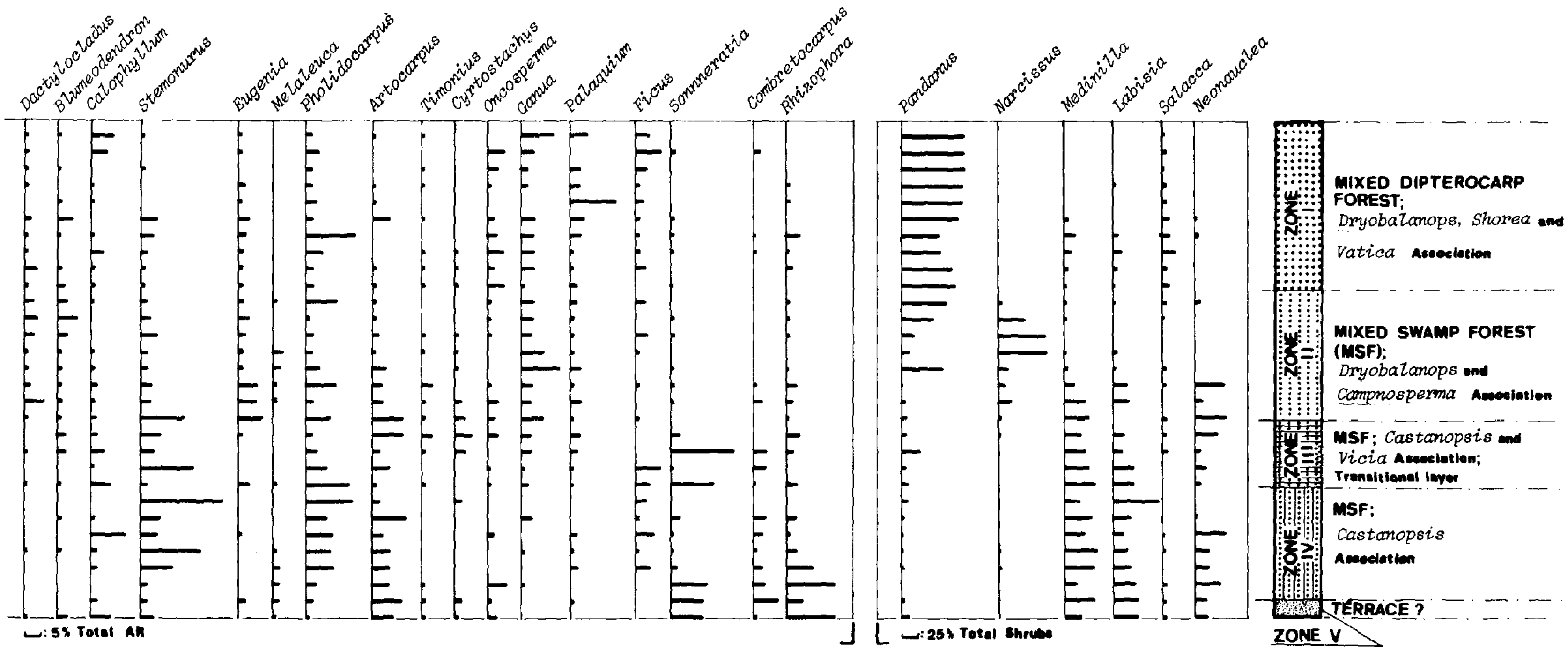


Fig. 5-Continued

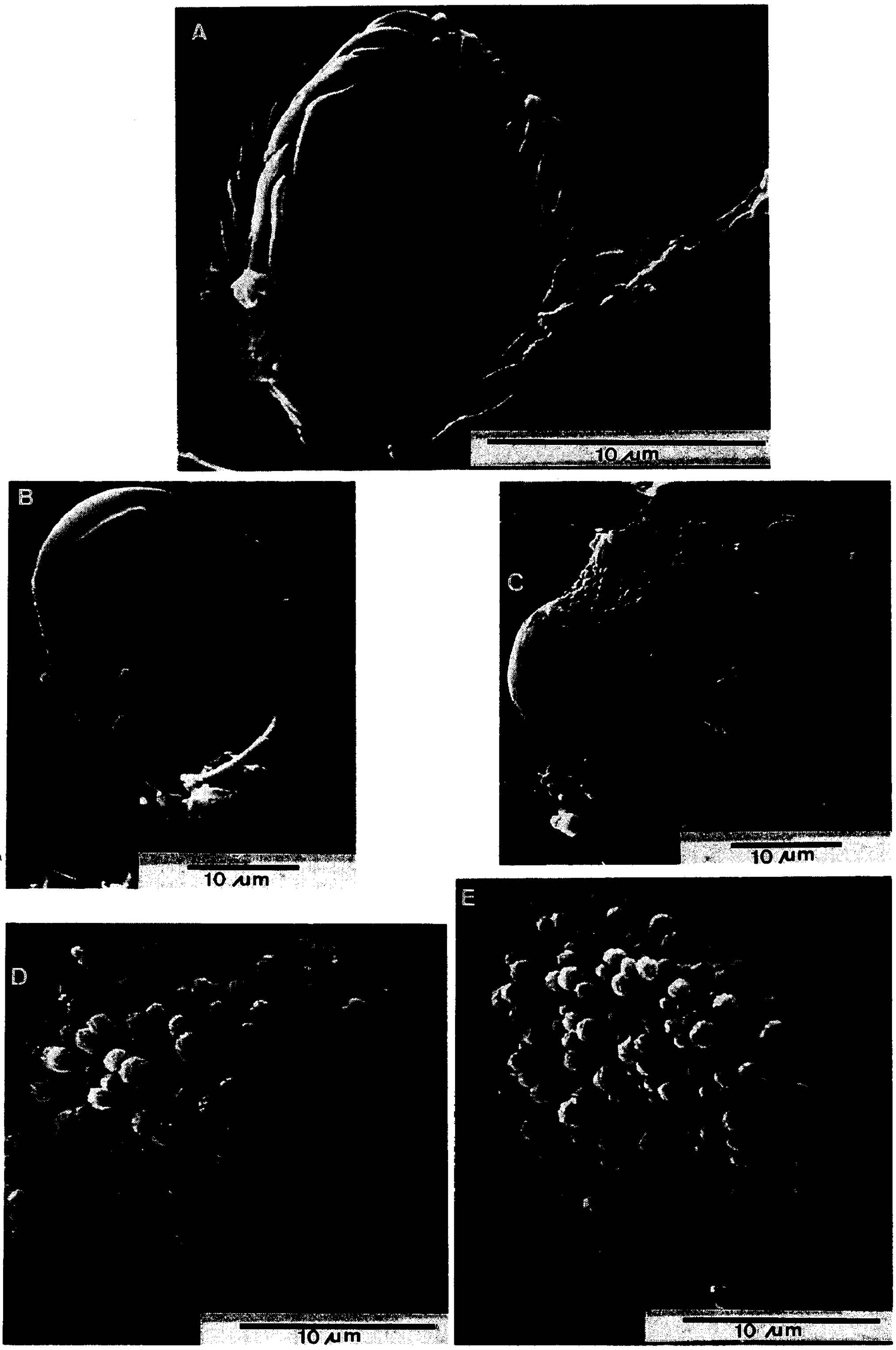


Plate 1 The Scanning Electron Micrograph of Arboreal Fossil-pollen Types of *Campnosperma* (A), *Vicia* (B, C) and *Oncosperma* (D, E)

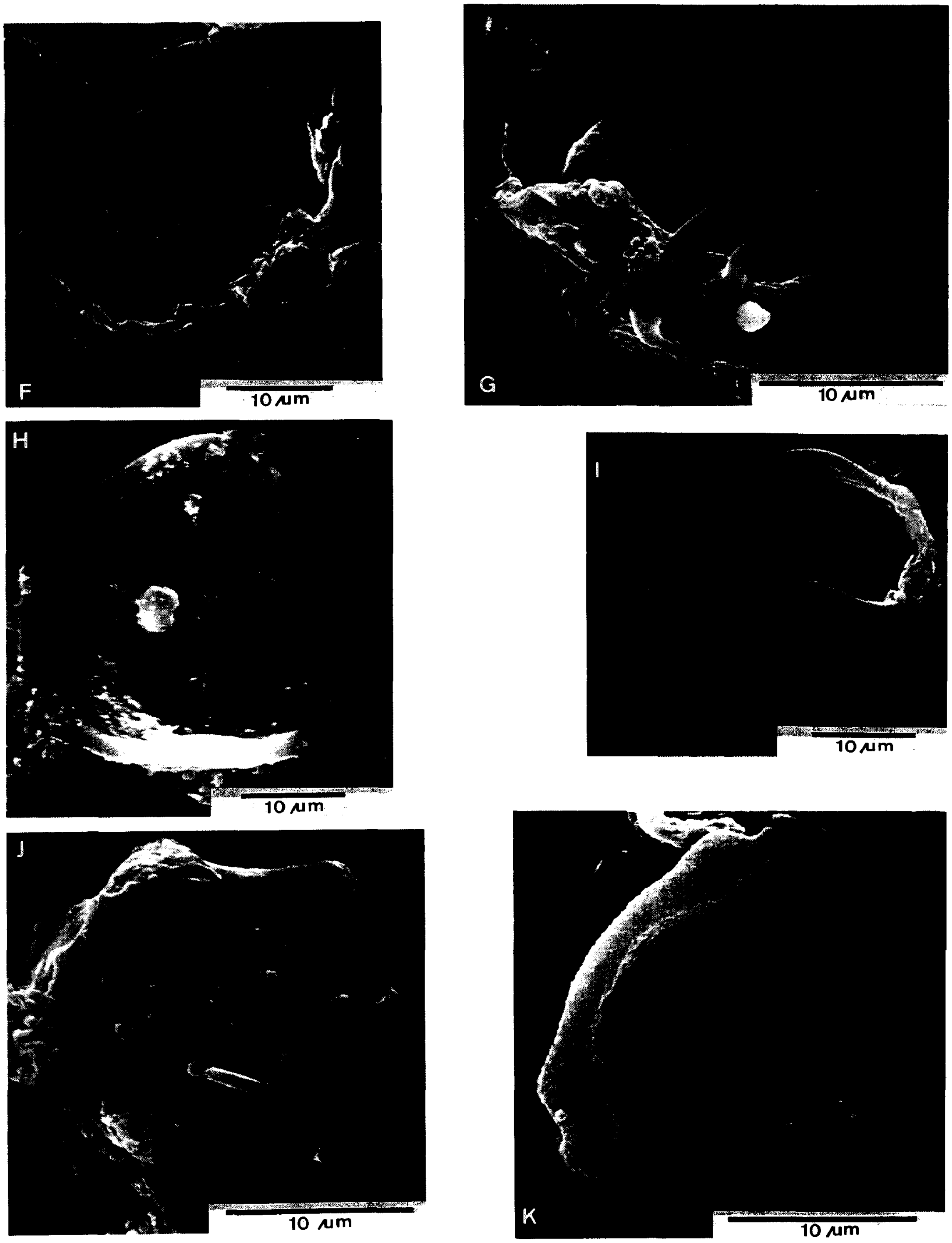


Plate 2 The Scanning Electron Micrograph of Arboreal Fossil-pollen Types of *Dactylocladus* (F) and *Hibiscus* (G), and Non-arboreal Fossil-pollen Types of *Acrostichum* (H, I), *Asplenium* (J) and *Alsophylla* (K)

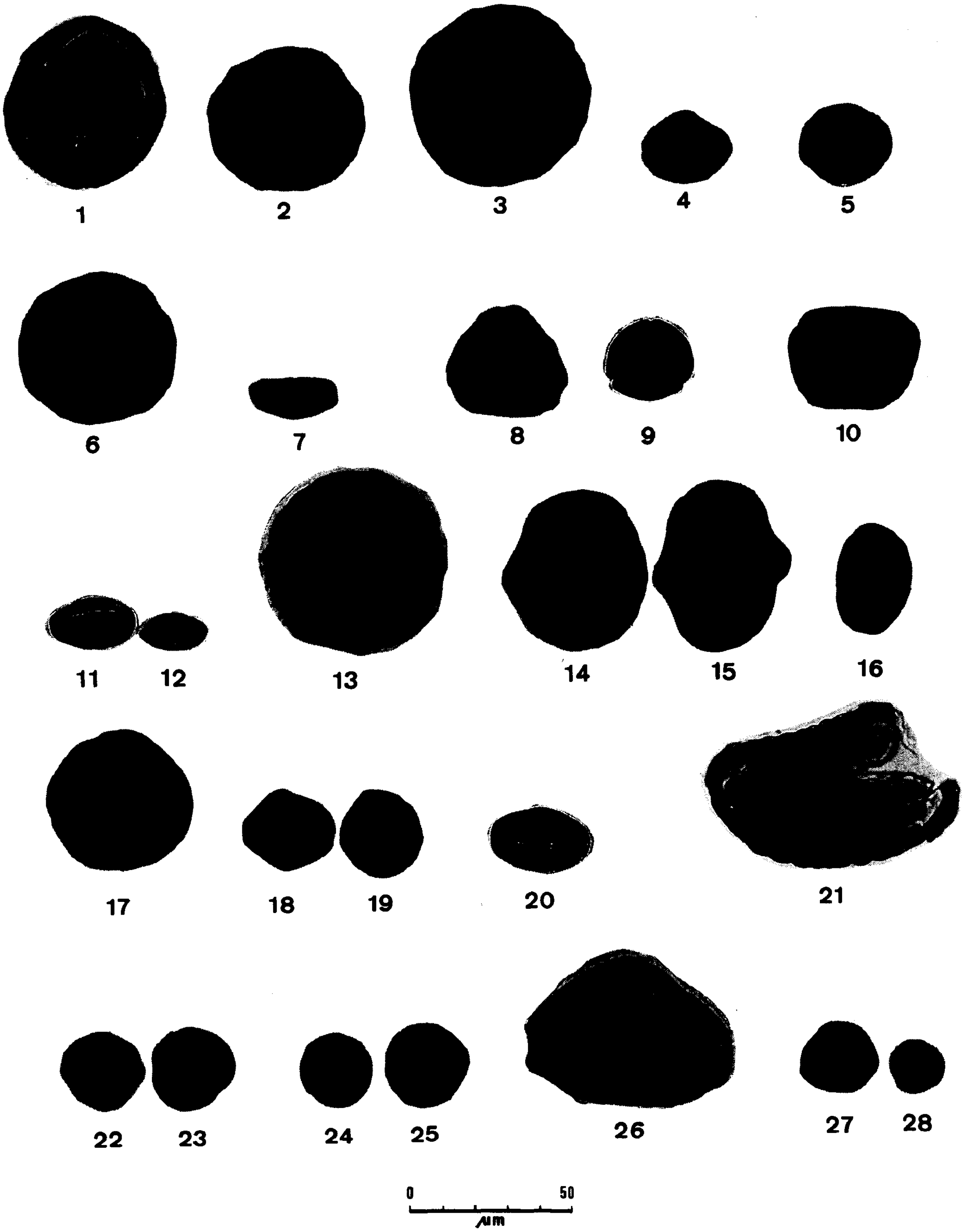


Plate 3 The Microphotograph of Arboreal Fossil-pollen Types of *Dryobalanops* (1, 2), *Dipterocarpus* (3), *Shorea* (4), *Hopea* (5), *Vatica* (6), *Castanopsis* (7), *Alstonia* (8, 9), *Dyera* (10), *Koompassia* (11, 12), *Parkia* (13), *Vicia* (14, 15), *Campnosperma* (16), *Mangifera* (17), *Santiria* (18, 19), *Bhesa* (20), *Dactylocladus* (21), *Baccaurea* (22, 23), *Blumeodendron* (24, 25), *Calophyllum* (26) and *Stemonurus* (27, 28)

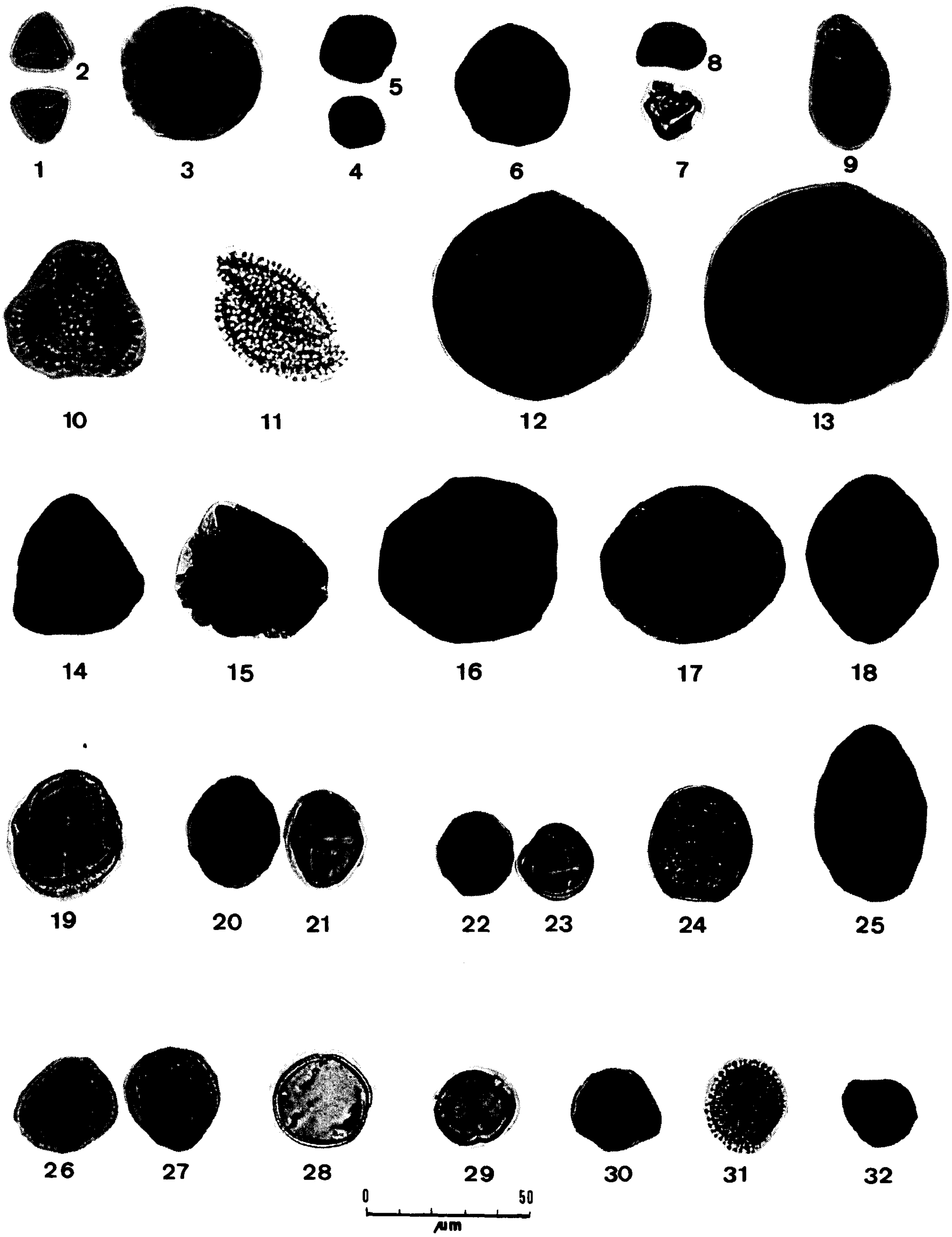


Plate 4 The Microphotograph of Arboreal Fossil-pollen Types of *Eugenia* (1, 2), *Pholidocarpus* (3), *Artocarpus* (4, 5), *Corypha* (6), *Anthocephalus* (7, 8), *Cyrtostachys* (9), *Ilex* (10), *Oncosperma* (11), *Ganua* (12, 13), *Palaquium* (14), *Ficus* (15), *Ternstroemia* (16), *Sonneratia* (17, 18), *Combretocarpus* (19), *Bruguiera* (20, 21), *Ceriops* (22, 23), *Rhizophora* (24) and *Avicennia* (25), and Non-arboreal Fossil-pollen Types of *Pandanus* (26, 27), *Neonauclea* (28), *Medinilla* (29), *Labisia* (30), *Salacca* (31) and *Dialium* (32)

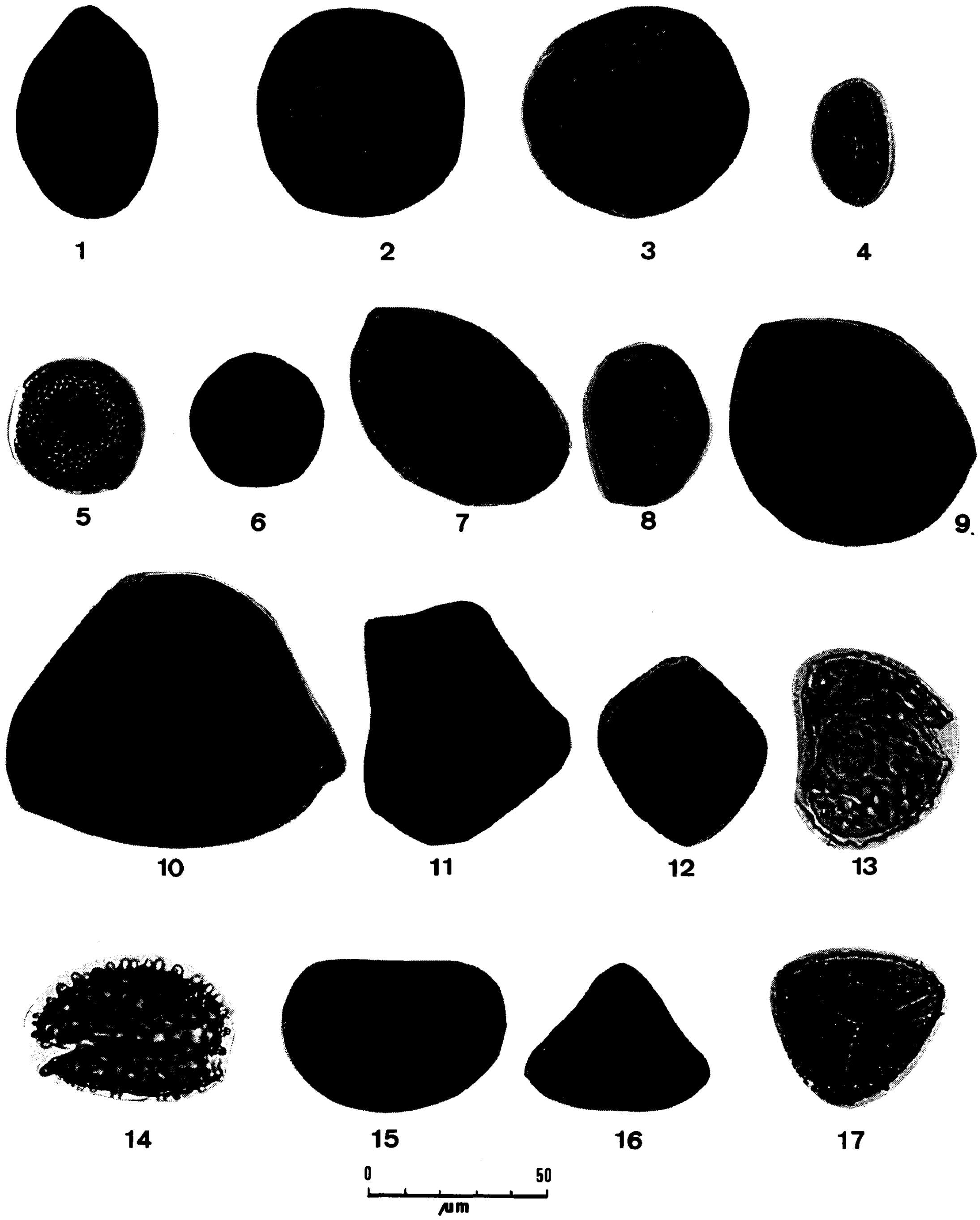


Plate 5 The Microphotograph of Arboreal Fossil-pollen Types of *Nipa* (1), *Gonystylus* (2, 3), *Gluta* (4), *Fagraea* (5) and *Xylopia* (6), and Non-arboreal Fossil-pollen Types of *Narcissus* (7), *Cyperus* (8), *Gramineae* (9), *Acrostichum* (10), *Lindsaea* (11), *Alsophylla* (12), *Nephrolepis* (13), *Asplenium* (14), *Stenochlaena* (15), *Schizaea* (16) and *Lycopodium* (17)

Diagram I. This diagram (see Fig. 3) shows the floral composition of deep peats taken from profile BRNI 86–14 near Lumut. All layers of this profile are categorized as peat deposits.

The profile description is as follows [Furukawa 1988]:

1. 0– 50 cm Dark reddish brown (5YR 3/2) pseudo-fibric peat; many roots.
2. 50–150 cm Dark reddish brown (5YR 3/2) sapric peat; many roots.
3. 150–200 cm Brownish black (5YR 2/2) pseudo-fibric peat.
4. 200–500 cm Peat (falls from auger).
5. 500–600 cm Brownish black (7.5YR 3/1) sapric peat.
6. 600–700 cm Brownish black (7.5YR 3/1) pseudo-fibric peat.
7. 700–800 cm Peat (falls); many fresh wood blocks.

In places sand terrace appeared beneath these deposits. This sand is probably the former sand beach of the early Holocene.

Samples from the layer at the depth of 600 to 700 cm indicate that the pollen grains of *Vatica, Campnosperma, Castanopsis* and *Ficus* are dominant in the arboreal pollen, whereas *Shorea* and *Dryobalanops* are very few. In the non-arboreal pollen, *Pandanus* is characteristic of this layer, while *Nephrolepis* and *Alsophylla* type are dominant. The presence of *Pandanus* clearly demonstrates the former vegetation to have been swamp forest [Anderson and Muller 1975]. Nevertheless, very few pollen grains of mangrove vegetation, which are often associated with fine-grained sediments, were found in this layer. I believe that the pollen grains of mangrove vegetation accumulated here may have been carried in by sea water during the rise of sea level in the past.

Between 500 and 600 cm, there is a major change in the pollen diagram. In the arboreal pollen, *Dryobalanops, Shorea* and *Vatica* show a marked increase while *Ficus* and *Castanopsis* rather decrease. Likewise, spores of *Lycopodium* and *Nephrolepis* show a marked increase in the non-arboreal pollen. *Campnosperma* and the non-arboreal pollen of *Pandanus* do not show such a marked change, while *Stemonurus* increases. This indicates that this layer was previously located in a swamp. *Stemonurus secundiflorus* Bl. Bijdr reported by Ridley [1922] grows mostly on river-banks and in low swampy woods. Also, starting at 580 cm, this layer shows a dominant increase of Dipterocarpaceae genera. This indicates that the vegetational succession gradually gave rise to a uniform vegetation type dominated by *Vatica*. The layer from 530 to 580 cm shows a drastic decrease of *Rhizophora* pollen type, indicating a regression. The few mangrove elements found here are considered to be contaminants carried in by the air.

Between 150 and 200 cm another major change occurs in the pollen diagram. In the arboreal pollen, *Campnosperma* and *Ficus* virtually disappear. Likewise, *Vatica, Shorea* and the non-arboreal pollen of *Pandanus* decrease, whereas the arboreal pollens of *Dryobalanops, Hopea* and *Artocarpus* show a marked increase. Anderson [1980] recorded six species of the genus *Dryobalanops,* 38 species of *Hopea* and 21 species of *Artocarpus* in Sarawak, and he reported that these tree species grow well in mixed dipterocarp forest. The species *Dryobalanops rappa* Becc. (*Kapur paya*), *Hopea pentanervia* Sym. (*Chengal paya*), and *Artocarpus glaucus* Bl. (*Pudau puteh*) and *A. rigidus* Bl. (*Pudau paya*) are occasional, and locally frequent, in mixed swamp forest. This clearly demonstrates a succession from mixed swamp forest to mixed dipterocarp forest, which probably started approximately 2,000 years BP. Anderson and Muller [1975] dated the peats near Marudi at the depth of about 4 m to about 2,200 years BP. I believe this mixed dipterocarp forest developed under swampy conditions. This is substantiated by the increase of *Pholidocarpus* pollen type, species of which Ridley [1925] reported to inhabit mostly swampy areas in the Malay Peninsula. In this layer, *Medinilla* and *Labisia* pollen types were also found, which species usually occupy the undergrowth of mixed dipterocarp forest.

The layer from 50 to 150 cm was classified in the field as a sapric peat. It showed no marked change in the vegetation types, which were apparently dominated by Dipterocarpaceae.

The surface 50 cm shows a continued minor change. The fossil pollens of *Artocarpus* and *Dryobalanops* decrease, while *Hopea, Pholidocarpus* and *Fagraea* increase. Anderson [1980] recorded three species of the genus *Fagraea* (*F. blumei* G., *F. elliptica* Roxb. and *F. racemosa* Jack ex Wall.) in Sarawak, which grow well in mixed dipterocarp forest. The presence of *Pholidocarpus* in this layer shows that it is a swamp formation. This clearly indicates that the vegetation was still dominated by Dipterocarpaceae genera, which grow well in swampy conditions, although *Pandanus* was almost absent. The *Avicennia* and *Rhizophora* found in this layer may be extraneous, having been carried in by air.

From these fossil-pollen observations, peat deposits of profile BRNI 86-14 can be divided into three zones (see Fig. 3). *First*: Zone I is peat swamp derived from mixed dipterocarp forest which is dominated by *Dryobalanops*. *Second*: Zone II is peat swamp derived from mixed swamp forest containing mostly *Vatica, Campnosperma* and *Ficus*. *Third*: Zone III is peat swamp derived from mixed swamp forest containing mostly *Vatica, Campnosperma* and *Castanopsis* in the arboreal pollen types and *Pandanus* in the non-arboreal pollen types.

Diagram II. This diagram (see Fig. 4) shows the floral composition of peats taken from profile BRNI 86-18 near Badas.

The profile description is as follows [Furukawa 1988]:

1. 0-100 cm Dark reddish brown (5YR 3/2) sapric peat.
2. 100-200 cm Peat (falls).
3. 200-300 cm Dark reddish brown (5YR 3/2) sapric peat.
4. 300-600 cm Peat (falls).
5. 600-650 cm Dark reddish brown (5YR 3/2) fibric peat.
6. 650-700 cm Gley clay; dirty faced with many plant remains; mangrove deposits.
7. 700-750 cm Peaty clay.
8. 750-800 cm Dark olive gray (2.5GY 4/1) dirty-faced clay; mangrove deposits.
9. 800-900 cm Gray (5Y 4/1) clean clay; marine clay.

Remark: This site is close to the sand terrace and Plio-Pleistocene outcrop used as earth cut.

Peat deposits to the depth of 650 cm started to accumulate during the high sea level of the Holocene. Alternating peaty soils and mangrove deposits from 650 to 800 cm may be interpreted as indicating the regression and transgression phases of the deposits in the early Holocene.

The layer at the depth of 800 to 900 cm comprises sediments of marine clay. These sediments were probably deposited on the sand deposits during the early Holocene period. This is supported by the fact that the site of this profile is very close to the sand terrace (see Fig. 2).

The layer from 800 to 900 has been categorized as a marine clay. This is supported by my finding that the samples from 850 to 900 cm contain pollen grains dominated by *Rhizophora, Ceriops, Bruguiera,* and *Combretocarpus* in the arboreal pollen sum, and by *Acrostichum* in the non-arboreal pollen sum. *Sonneratia* and *Oncosperma* are also present, which clearly demonstrates the presence of mangrove vegetation in the earlier period. The non-mangrove pollen types, particularly *Medinilla* and *Labisia,* in this layer may be extraneous, having been carried in by tidal action. The presence of *Calophyllum, Vicia* (Leguminosae) and *Castanopsis* indicates that this site was probably very close to an area of sandy soil. *Castanopsis motleyana* King and *Calophyllum lanigerum* Miq., which were recorded by Anderson [1980] in Sarawak, can grow well in mixed dipterocarp forest on sandy soil.

Between 750 and 800 cm only small changes are apparent. *Rhizophora* and *Sonneratia* in this layer increase, while *Oncosperma* decreases and *Bruguiera* virtually disappears. *Ceriops* and *Combretocarpus,* in contrast, do not show a marked change. This clearly demonstrates that this layer was also formerly dominated by mangrove vegetation. However, non-mangrove pollen types, particularly *Pholidocarpus* and *Vicia,* also increase. Presumably, the vegetation of freshwater swamp gradually started to invade the mangrove vegetation here. Thus, I believe that this layer was previously influenced by brackish water. This is also supported by the dominance of such spore grains as *Acrostichum* and *Alsophylla* in the non-arboreal pollen sum.

The layer from 700 to 750 cm is peaty soil. The pollen grains of *Vatica* and *Castanopsis* increase, while those of *Vicia* and *Pholidocarpus* are relatively constant in percentages. In the mangrove pollen types, *Sonneratia* increases, while *Rhizophora, Ceriops* and *Combretocarpus* decrease. This clearly represents the first stage in the formation of the former mixed-swamp forest. Support for this interpretation comes from the presence of *Baccaurea* pollen in this layer, because several *Baccaurea* spp. can grow well in mixed dipterocarp forest and coastal peat-swamp forest. Species of *Pandanus, Neonauclea, Labisia, Medinilla* and the fern *Alsophylla* might occur in the undergrowth of this mixed swamp forest.

The layer from 650 to 700 cm covering the peats indicates a transgressive phase. This caused major changes in the composition of vegetation, both in arboreal and non-arboreal pollen types. *Ceriops* pollen shows a slight increase, while *Rhizophora, Combretocarpus* and *Sonneratia* decrease. *Pholidocarpus, Castanopsis* and *Vicia,* in contrast, do not show a marked change. However, *Oncosperma, Artocarpus, Stemonurus* and the non-arboreal pollen of *Pandanus* increase. This clearly demonstrates a succession from mangrove association to a swampy forest, which probably started approximately 4,000 years ago. Anderson and Muller [1975] report that the humiferous clay near Marudi at the depth of about 12 m was dated about 4,200 years BP. Thus, the succession is believed to be related to the sea level rise. This caused a rise of river levels inland, so that river water spilled over into the backswamp. The rise of the sea level at that time was also reported by Tjia *et al.* [1983/1984].

The layer from 600 to 650 cm shows a major change in floral composition, coinciding with a change in the environment which is characterized by peat deposits. The mangrove pollen types, particularly *Rhizophora* and *Ceriops*, decrease sharply. *Sonneratia* and *Oncosperma* show a marked increase, which indicate a decreased saline influence on the environment. This is interpreted as indicating that the coastline gradually advanced seaward, and the environment was gradually converted into freshwater swamp. This is substantiated by the increase of non-mangrove pollen types, particularly *Vatica, Shorea* and *Dryobalanops*, which represent the first stage of succession in the formation of the mixed dipterocarp forest. In the non-arboreal pollen sum, *Pandanus* also shows a marked increase, which also supports the change to freshwater swamp vegetation.

Samples from 200 to 300 cm show that the pollen grains of *Shorea* to be dominant in the arboreal pollen sum. *Dryobalanops* and *Vicia* show a slight increase. This clearly indicates that former vegetation was dominated by Dipterocarpaceae genera. However, *Castanopsis, Pholidocarpus, Santiria, Bhesa, Artocarpus* and *Fragraea* are also prominent in this layer. In the non-arboreal pollen sum, *Pandanus* shows a marked increase. The vegetation type suggested by the data is a climax mixed-dipterocarp forest. It is supposed that this layer was sometimes inundated during high water level.

The layer from the surface to 100 cm is also characterized by the abundance of *Dryobalanops*. The pollen types of *Shorea, Hopea* and *Vatica* are also prominent. Thus, the vegetation types recovered for 0 to 600 cm are dominated by Dipterocarpaceae genera. The presence of non-Dipterocarpaceae pollen types indicates mixed-dipterocarp forest in nearby sites. The increase of *Stemonurus* may imply that the habitat was continuously a swamp [Ridley 1922].

Based on this fossil-pollen observation, profile BRNI 86–18 can be divided into five zones in order of increasing depth (see Fig. 4). The inferred habitat is as follows, respectively. *First*: Zone I is peat swamp derived from mixed dipterocarp forest. *Second*: Zone II is peat swamp, and is categorized as a transition layer in which *Oncosperma* and *Sonneratia* are more prominent in the mangrove pollen types. *Third*: Zone III is intruding mangrove deposits on the first stage of peat formation; the floral composition of this layer shows the last stage of the mangrove vegetation. *Fourth*: Zone IV is peat swamp; *Rhizophora* is dominant in the arboreal pollen types. *Fifth*: Zone V is the mangrove deposits; mangrove elements are dominant in the arboreal pollen types.

Diagram III. This diagram (see Fig. 5) shows the floral composition of peat deposits taken from profile BRNI 86–28 near Lutong sawmill.

The profile description is as follows [Furukawa 1988]:

1. 0– 50 cm Brownish black (5YR 2/2) sapric peat.
2. 50–100 cm Peat (falls).
3. 100–270 cm Dark reddish brown (2.5YR 3/2) fibric peat; many wood branches.
4. 270–330 cm Black (7.5YR 1.7/1) pseudo-fibric peat, many wood branches.
5. 330–415 cm Dark bluish gray (10BG 4/1) peaty

clay.

6. 415–740 cm Gray (10Y 4/1) heavy clay; dirty-faced mangrove deposits.
7. 740–750 cm Bluish gray loamy sand.

Remark: This site is covered by a pure forest of *alan bunga* (*Shorea albida* Sym.). The tree height is quite homogenous and reaches about 55 m. *Pandanus* grows well in the undergrowth.

The peaty soil from 330 to 415 cm probably represents the first stage of peat deposition. I believe that these peat deposits started to accumulate in the middle Holocene and are probably of the same age as the peats near Marudi which were found by Anderson and Muller [1975].

The layer at the depth of 415 to 740 cm is a clay deposit. Although this was categorized in the field as a mangrove deposit, fossil-pollen analysis indicates it to be a riverine deposit, as will be discussed hereafter. I believe that it was deposited during the transgression period; and it is probably of the same age as the riverine deposits overlying the Pleistocene terrace in the Tanjung area of Jambi. The riverine deposits in the Tanjung area, represented by the woody peat of sample GaK–11893, were deposited approximately 6,800 years BP [Supiandi and Furukawa 1986].

The layer from 740 to 750 cm is characterized by sandy deposits with small amounts of plant remains. In this layer, *Castanopsis* clearly dominates the fossil grains. Spores of *Alsophylla* are prominent in the non-arboreal pollen types. The abundant *Castanopsis* pollen and the presence of *Oncosperma* may indicate that this site lay inland, where saline influence was less strong. Although mangrove pollen types, like *Rhizophora, Sonneratia* and *Combretocarpus*, are prominent in the arboreal pollen sum, it is difficult to ascertain whether this layer was derived from mangrove vegetation, because non-mangrove pollen types, particularly *Alstonia, Koompassia, Santiria, Calophyllum* and *Anthocephalus*, are also prominent, and these mostly grow well in mixed dipterocarp forest. This seems to imply that mangrove pollen types in this layer may be extraneous, having been carried in as the result of a sea level rise in the past.

A major change in the pollen diagram is apparent in the middle and lower layers. *Rhizophora* and *Combretocarpus*, which are significantly present in the layer from 700 to 740 cm, decrease markedly in the layer from 415 to 450 cm, where non-mangrove pollen types, particularly *Koompassia, Vicia, Stemonurus* and *Pholidocarpus*, show a marked increase. *Castanopsis* dominates the fossil grains in both these layers. This clearly indicates the presence of mixed-swamp forest. The existence of mangrove vegetation is not proved satisfactorily. Although *Sonneratia* shows a marked increase in the peat sample at the depth of 420 cm, this pollen may be extraneous. Thus, I believe that the sediments in these two layers can be categorized as riverine deposits. This is supported by the presence of *Ficus* pollen type, as *Ficus* trees are common constituents of riparian vegetation in the coastal plain. For example, the *Ficus androchaete* Corner recorded by Anderson [1980] in Sarawak was mainly found on alluvial soil and riverine deposits. This clearly indicates that before the transgression period, the vegetation types from 415 to 740 cm were probably dominated by *Castanopsis* spp. with many *Ficus* trees. However, after the riverine deposits here had been transformed into swampy soil in the transgression period, the tree-species of *Stemonurus* spp., *Vicia* spp. and *Pholidocarpus* spp. increased.

Between 330 and 415 cm another major change is apparent in the pollen diagram. From the depth of 330 to 350 cm, *Castanopsis* and *Vicia* show a marked decrease in the arboreal pollen sum, while *Dryobalanops, Shorea* and *Vatica* increase. The spores of *Nephrolepis* and *Alsophylla* dominate the non-arboreal pollen grains. This clearly represents the succession from mixed swamp forest to mixed dipterocarp forest. *Ganua* and *Santiria* also show a marked increase in this layer. Thus, it can be concluded that this peat layer is a transition layer between the basal clay and peat deposits, and is characterized by the increase of Dipterocarpaceae genera.

The layer from 270 to 330 cm is a peat deposit. Although the samples from 270 to 300 cm were lost during boring in the field, the samples from 300 to 330 cm show a marked increase in the arboreal pollen types of *Shorea, Campnosperma, Eugenia* and *Dactylocladus*. On the other hand, *Dryobalanops* and *Vatica* do not show a marked change. The spores of *Stenochlaena* and *Nephrolepis* dominate the non-arboreal pollen grains. The existence of *Campnosperma, Dactylocladus* and *Eugenia* clearly indicates that this peat deposit was a swampy area. *Dactylocladus* trees are an endemic member of peat swamp forest in Sarawak [Anderson 1980].

The layer from 100 to 270 cm is also peat. Samples from 100 to 150 cm and from 220 to 270 cm show a marked change in the arboreal and non-arboreal pollen sums. *Dryobalanops* and *Vatica* increase drastically, while *Shorea* decreases. Other pollen types like *Ganua, Koompassia* and *Santiria* are also prominent in the arboreal pollen sum. In the non-arboreal pollen sum, *Pandanus* starts to increase rapidly. These data clearly demonstrate that Dipterocarpaceae genera developed on a freshwater peat swamp and eventually formed a mixed dipterocarp forest.

This mixed dipterocarp forest formation continues up to the present day. This is substantiated by the dominance of Dipterocarpaceae pollen types at the depth from 0 to 50 cm. These are accompanied by many pollen grains derived from other tree species, such as *Koompassia, Santiria* and *Ganua*. At this depth also, *Pandanus* dominates the non-arboreal pollen sum.

From the results of fossil-pollen observation, peat deposits of profile BRNI 86–28 can be divided into five zones (see Fig. 5). *First*: Zone I is peat swamp derived from mixed dipterocarp forest. *Second*: Zone II is peat swamp derived from mixed swamp forest; in this layer Dipterocarpaceae genera start to appear together with *Campnosperma*. *Third*: Zone III is peat swamp, and is categorized as a transitional layer containing many kinds of arboreal pollen types; *Castanopsis* and *Vicia* are prominent in the arboreal pollen sum. *Fourth*: Zone IV consists of riverine deposits, characterized by gray matrix color; *Castanopsis* and *Vicia* dominate the fossil grains. *Fifth*; Zone V is sandy deposits; *Castanopsis* dominates the fossil grains.

Conclusion

As just discussed, significant stratification of mineral and peat deposits of different periods was found in the Baram-Belait river basin and it is suggested that these swampy sediments are linked to the last eustatic rise and fall of the sea level.

In the early Holocene period, the maximum sea level caused development of extensive beach and lagoon systems which encroached onto the sand terrace. When the sea level fell some of these terraces were covered by mangrove deposits. These mangrove deposits, which are characterized by the dominance of such mangrove pollen types as *Rhizophora, Ceriops, Bruguiera* and *Combretocarpus*, were found in Profile BRNI 86–18 near Badas at the depth of 750 to 900 cm.

When the sea level again rose, in coastal areas, it was characterized by brackish-water conditions, due to the extensive encroachment of the sea into the mangrove vegetation. This is substantiated by the presence of mangrove deposits overlying organic matter deposits, as represented by Profile BRNI 86–18. These mangrove deposits (Profile BRNI 86–18 at the depth of 650 to 700 cm) are characterized by the former presence of *Rhizophora* association. In contrast, the deposition process in the area around Lutong sawmill, Brunei (Profile BRNI 86–28 at the depth of 415 to 740 cm) is characterized by the presence of riverine deposits overlying sand deposits. This is because the discharge of the Baram river was obstructed by the sea during the rise of the sea level, so a large volume of river water might have spilled over into this area. When the sea level fell the stagnant water also decreased, causing riverine deposits to be formed on Plio-Pleistocene sand deposits. These sand and riverine deposits are characterized by the abundance of *Castanopsis* pollen grains.

Further succession, when the sea level again rose, is characterized by changes in the composition of the vegetation inland. The rise of the sea level caused peat swamps to develop in the area near the Lutong sawmill (Profile BRNI 86–28 at the depth 330 to 415 cm). The dominance of *Castanopsis* is inferred from the pollen types. I interpret this as indicating that freshwater swamp was involved in peat formation in the area near Lutong sawmill, because the discharge of the Baram river would have been obstructed by the sea level rise, causing the river water to spill over into the area. Peat swamps in the area near Badas, Brunei (Profile BRNI 86–18 at depth of 600 to 650 cm) are characterized by *Oncosperma* and *Sonneratia* association, which indicates a decreased saline influence. In contrast, the area near Lumut (Profile BRNI 86–14 at the depth of 650 to 700 cm) was characterized by freshwater peat-swamp formation with mixed swamp forest. Probably, the different topography of the Lumut and Badas areas caused the different deposition processes.

The last succession is characterized by a major change in the composition of the vegetation covering peat deposits. In the area near Lutong sawmill, the peat swamp at the depth of 220 to 330 cm, which was significantly derived from mixed swamp forest, changed abruptly into mixed dipterocarp forest at 0 to 220 cm. Also, in the peat swamps of Profile BRNI 86–14 in the area near Lumut, the vegetation changed into mixed dipterocarp forest from the depth of 650 cm. The succession into mixed dipterocarp forest is substantiated by the dominant fossil pollen of Dipterocarpaceae genera. The question, why *Shorea albida* pollen is not so abundant while the present vegetation cover is pure stand of *Shorea albida* in the site of profiles BRNI 86–18, BRNI 86–14 and BRNI 86–28, is an interesting one. To explain the presence of this question, the flowering cycle of *Shorea albida* should be studied in more detail.

The floral composition in this peat swamp differs from that in the coastal plain of Jambi reported by Supiandi and Furukawa [1986]. The difference in the floral composition in Jambi and Brunei is probably due to the differences in bio-geographical conditions.

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