Southeast Asian Studies, Vol.36, No.3, December 1998

Sediments of the Lower Barito Basin in South Kalimantan: Fossil Pollen Composition

Basuki SUMAWINATA *

Abstract

During the present century, Holocene sediments of the lower Barito basin have been reclaimed for agricultural purposes. On Martapura river sediments, stable agricultural plots have been established which are not affected by severe acid toxicity problems; but on Barito river sediments, many plots have been abandoned because of such problems.

To clarify the characteristics of the sediments of the lower Barito basin, boring observations were made along two transects on the Barito and Martapura river sediments. The fossil pollen composition, layering patterns, and the presence of sulfidic materials were used to identify the depositional environments of the sediments.

This paper presents details of the succession of depositional environments on the Martapura river sediments and Barito river sediments, and demonstrates that the stable agricultural plots belong to a riverine environment, while the unstable agricultural plots belong to a brackish environment.

I Introduction

Southern Kalimantan has extensive swampy areas stretching from around Banjarmasin and Aluh-aluh in the south to around Amuntai in the north (Fig. 1). The sediments in these swampy areas constitute a part of what Kemmerling [1915] called Barito river basin sediments. The Barito river basin sediments were deposited by the Barito river and smaller rivers in the surrounding area during the Holocene period.

Naturally, the sediments were covered by the dense swamp forest that grows on thick peat soils. According to Van Wijk [1951], nearly all the swampy areas around Banjarmasin to Pulau Petak were covered by peat varying in depth from one to three meters. Around 1920, however, many parts of these swampy areas started to be opened for agriculture. With the subsequent expansion of agriculture and other human activities, the natural peat swamp forest has been destroyed and is now hard to find in this area.

From the viewpoint of stability, the agricultural land in this swampy area can be classified into two categories. One comprises stable agricultural plots which are not affected by toxic

* Department of Soil Sciences, Bogor Agricultural University, Jalan Raya Pajajaran Bogor, Indonesia (Guest Scholar, Graduate School of Asian and African Area Studies, Kyoto University from May 1998 to November 1998)

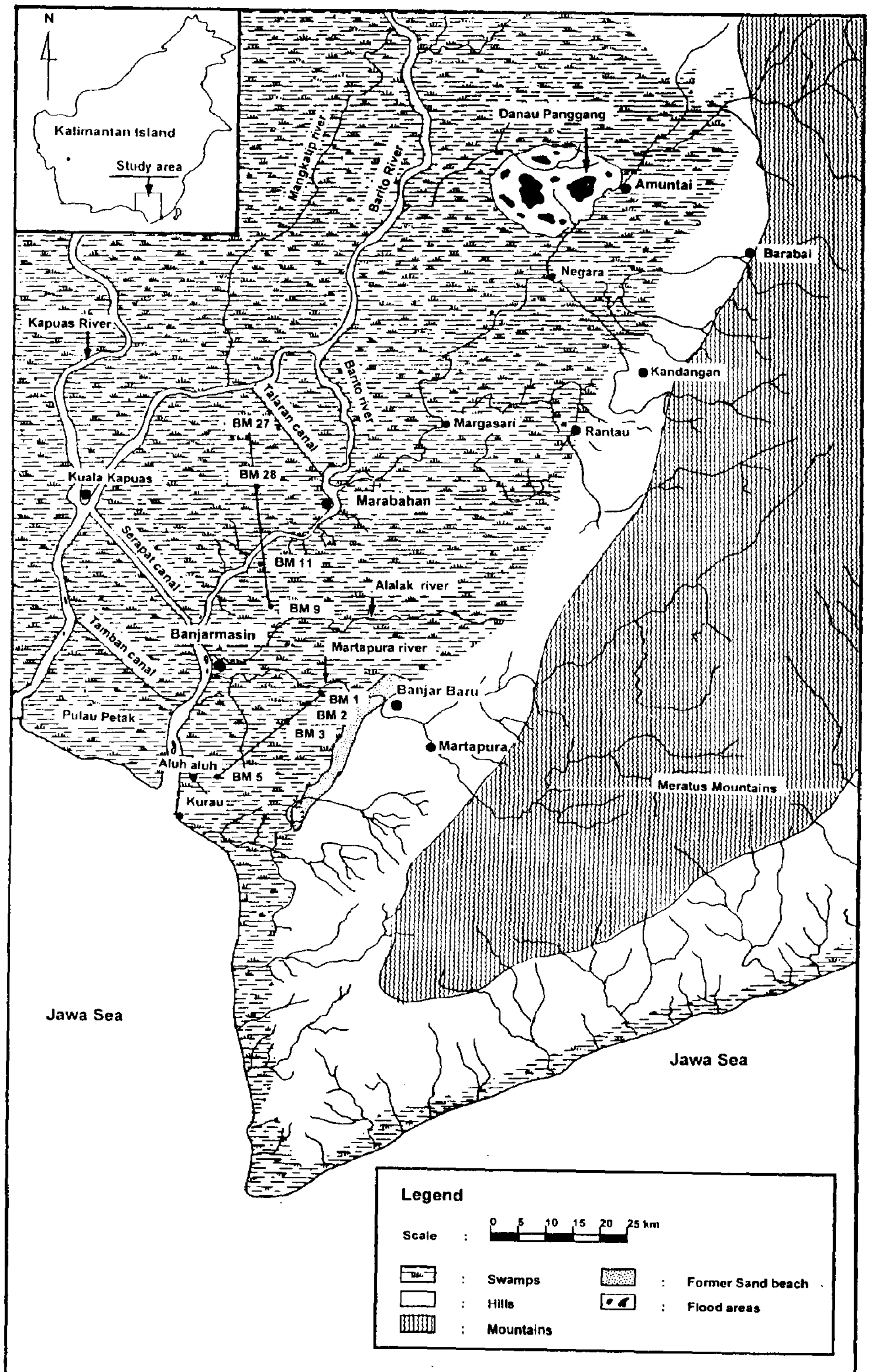


Fig. 1 Location of the Study Area

acidity; the second, unstable agricultural plots which are so affected. People follow a unique land-use cycle to cultivate rice on these lands [Sumawinata 1992]. The stable agricultural plots are found around the southern part of the Martapura river, while the unstable agricultural plots are found more extensively around the northern part of the Alalak river and in the Pulau Petak area.

How the areas of stable and unstable agricultural land developed remains unclear. One possible explanation is that their depositional environments differed. Another is that the stable and unstable agricultural lands developed by different pedogenic processes in the same depositional environment. Intensive pedogenic processes involve intensive leaching of toxic materials from the sediments, which would result in the stable agricultural plots. Since severe toxic acidity is formed by oxidation of pyrite minerals, and the accumulation of pyrite minerals is related closely with brackish environments, it is important to study the depositional environment of the sediments in order to predict the stability of the reclaimed land.

The composition of fossil pollens embedded in deposits can be used to trace the depositional environments. Palynological studies of tropical peat swamp began with Polak [1933], who studied peat in swampy areas of Rawa Lakbok and confirmed that it contained abundant and well-preserved pollens. Muller [1965] and Anderson and Muller [1975] studied the pollen from Sarawak peat swamps and demonstrated that the concentric series of vegetation zones observed on many Sarawak peat swamps does indeed represent a temporal succession. The aim of this study is to reconstruct the succession of the environments of the swampy areas of the Barito and Martapura rivers in order to characterize the sediments of the Barito river basin.

A. *Geographical Setting of the Barito and Martapura Rivers*

The Barito river, 900 kilometers in length, is the longest river in southern Kalimantan. Rising in the Muller mountain range, where the highest peak is 2,240 meters, it flows southward into the Jawa Sea. Debouching from the foothills, the river enters a nearly flat, swampy area with many small lakes. During the rainy season, river flooding causes the small lakes to join together, to form an extensive area of flooding to the west of Amuntai and Negara (Fig. 1). The swampy lower reach of the Barito is nearly flat, with an elevation of 3-5 meters, and the tidal influences can reach up to Marabahan, 60-70 kilometers from the river mouth.

The Martapura river, a tributary of Barito has a course of less than 200 kilometers. It rises in the Meratus mountain range, where the highest peak is 1,800 meters, then crosses a swampy area before joining the Barito river near Banjarmasin. Unlike the Barito river, the Martapura river has no natural lakes.

II Methods

To study the depositional environments of the sediments, soil observation were made along two transects (Fig. 1). The first (Transect I) was drawn in order to study the depositional environments of the Martapura sediments, where most of the stable plots are located. The second (Transect II) was drawn in order to study the depositional environments of the Barito river sediments, where unstable agricultural plots occur extensively. Transect I runs from the Martapura river to Bunipah village. Transect II runs from around Sei Pantai to around Karya Tani village, close to the Talaran canal in the northern part of the Pulau Petak area. Four borings were made on each transect. The maximum depth of boring was five meters.

To detect the presence of sulfidic materials in these deposits, the pH and pH after treatment with hydrogen peroxide (pHox) of samples were measured. The total sulfur content of the soils was assayed by the Begheijn method [1980: 25-40].

To make pollen diagrams of the deposits, boring samples were analyzed for pollen at 10 cm intervals. Pollen was separated from the sediment matrix by the method of Faegri and Iversen [1975]. The cleaned pollen grains were dropped quantitatively onto a glass slide and mounted with glycerin jelly. Slides were examined under 200 or 400 times magnification. The pollen grains were counted by line methods through the slide with the maximum count of 1,000 grains per slide.

An attempt was made to identify pollen grains to the level of genus. The characteristics of pollens were compared with descriptions and figures reported by earlier palynologists or with the herbarium pollen standards prepared by Dr. Sabiham from specimens of the Herbarium Bogoriensis (personal communication). For those which could not be classified into a specific genus because their characteristics were not clearly identifiable, an attempt was made to classify them into an undifferentiated family ("undiff." in pollen diagrams). Some unclassified spores of ferns were grouped into spore type only, for example, monolette spores and trilette spores. The term "unknown" is used for pollens or spores which could not be identified because they were incomplete, broken, or deformed.

III Results

A. *Present Land Use at the Boring Sites*

The present land use at each boring site is presented on Table 1. The paddy fields in the BM

Table 1 Land Use at the Boring Sites

No	Location	Land Use	Note
1	BM 1	Paddy fields	
2	BM 2	Paddy fields	
3	BM 3	Secondary forest	*Gelam* (*Melaleuca leucadendron*)
4	BM 5	Paddy fields	
5	BM 9	Secondary forest	*Gelam* (*Melaleuca leucadendron*)
6	BM 11	Abandoned paddy fields occupied by *Eleocharis* sp.	affected by severe acidity
7	BM 28	Abandoned paddy fields occupied by *Eleocharis* sp.	affected by severe acidity
8	BM 27	Secondary forest	*Gelam* (*Melaleuca leucadendron*)

1, BM 2, and BM 5 areas on Transect I are good paddy fields, showing no acid toxicity problems. The paddy fields at BM 11 and BM 28 on Transect II, however, have been affected by severe toxic acidity. The primary peat swamp forest in the study areas has disappeared. Frequent forest fires in the past and the abandonment of cultivation have resulted in the growth of secondary *gelam* forests (see Table 1).

B. *Stratigraphy*

The physical and chemical properties of the sediments along Transects I and II were used to interpret their depositional environments. These properties include: sediment texture, content of plant fragments or plant debris, layering pattern, presence of sulfidic materials, and total sulfur content. Five different depositional environments were identified along Transect I, and six along Transect II. The stratigraphy of sediments along Transects I and II is presented in Figs. 2 and 3, respectively.

B1. *Stratigraphy of Sediments along Transect I*

a. *Sand Beach*

Layer 3 of site BM 1 (BM 1/3) and BM 3/2 are white quartz sand layers containing few plant fragments. They contain admixtures of rounded gravel or pebbles. These sediments do not contain sulfidic materials (Fig. 2).

The presence of white quartz sand mixed with rounded gravel or pebbles which is free from plant fragments indicates that the deposits were transported long distances, sorted and

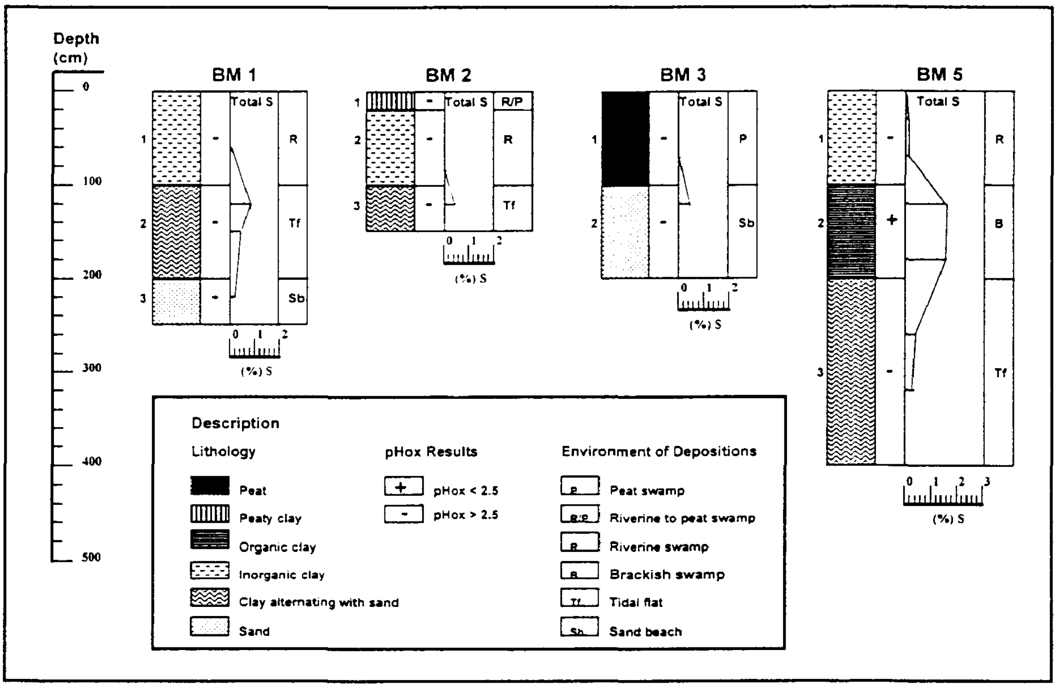


Fig. 2 Characteristics and Stratigraphy of Sediments along Transect I

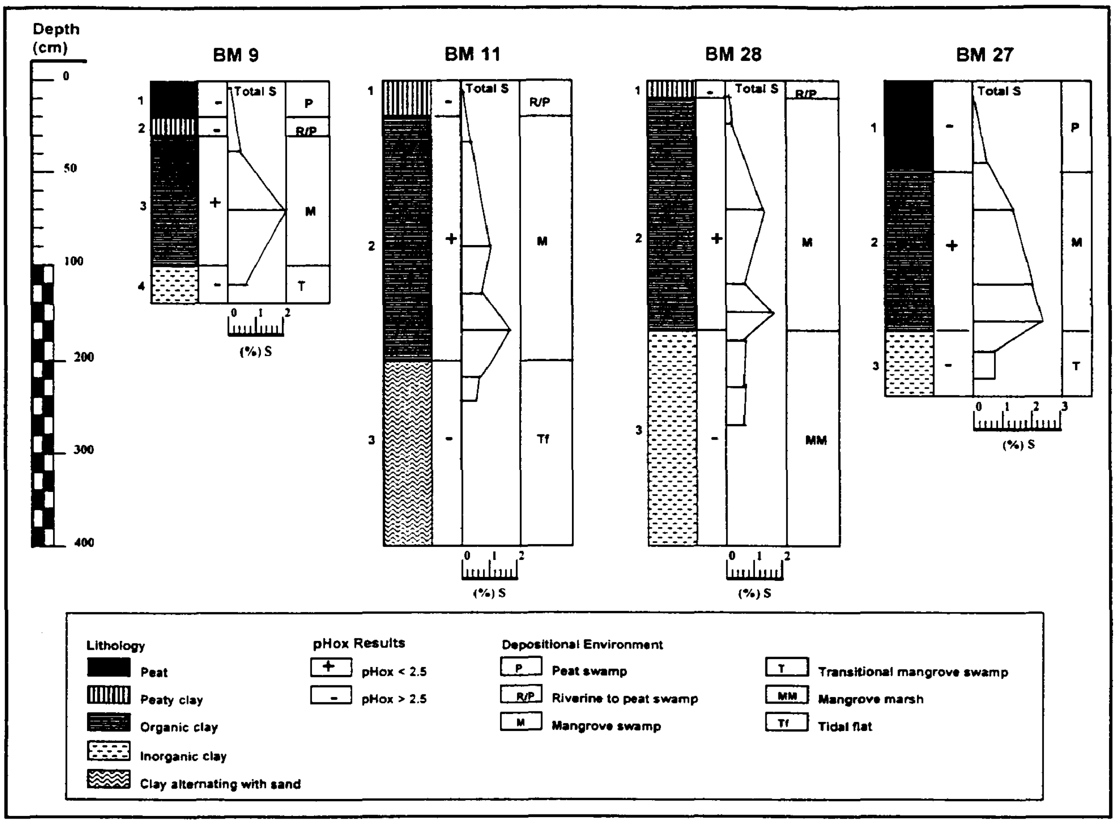


Fig. 3 Characteristics and Stratigraphy of Sediments along Transect II

deposited through the interaction of river sediments with sea waves and currents. These layers are therefore considered to represent former sand beach environments. The white sand deposits were found over an extensive area as a long strip in the margin between the hilly areas and the swampy areas from around Banjar Baru to Banjarmasin (Fig. 1).

b. *Tidal Flat*

Over the sand beach deposit lies a layer (BM 1/2) of clay and fine sand in alternating laminae. Similar deposits are also found in layers BM 2/3 and BM 5/3. The clay laminae are generally thicker, about 0.5-1 cm, while the fine sand laminae rarely exceed 0.5 cm. Sometimes very thin laminae of 1-2 mm of plant debris are found on the clay laminae. These deposits contain few sulfidic materials, and their sulfur content is below 0.7% (see Fig. 2).

Based on these characteristics, the deposits of clay alternating with fine sand laminae are considered to have been formed in a tidal flat environment. Interaction of sediments, waves, and tidal currents on unconsolidated deposits at a river mouth mix, transport, and sort the deposits at high tides, and these deposits dry out and become stabilized during low tides. The few plant fragments present in the deposits also confirm that each lamina had occupied the exposed surface of a tidal flat.

c. *Brackish Swamp*

The tidal flat deposits are covered by two types of clay layer, which represent different depositional environments. One is an organic clay that is discolored with many coarse plant fragments or plant debris. This is found in the layer BM 5/2. This so-called organic clay is dark greenish gray which fresh but rapidly becomes darker in color upon exposure to air. It has a high content of sulfidic materials, as indicated by very low values of pHox, ranging from 1.9 to 2.2 (Fig. 2). The sulfur content of the deposits is also high, ranging from 1.6 to 1.9%.

The organic clay with a high content of sulfidic materials is thought to have been deposited in a brackish swamp environment, which favors the accumulation of sulfidic material. The mangrove which usually flourishes in this environment supplies a huge amount of plant debris, and its decomposition give rise to strongly reduced conditions. Under these conditions, sulfate ions in the sea water react with ferrous ions, and pyrite is accumulated. The mangrove pollen in these deposits will be shown later.

d. *Riverine Swamp*

The second type of clay is inorganic clay, which contains few plant fragments and no sulfidic materials and has a pHox of over 2.5. This is considered to be a riverine swamp deposit. Such deposits are overlaid on tidal flat deposits in BM 1/1 and BM 2/2, and on brackish swamp deposits in BM 5/1 (Fig. 2).

The inorganic clay deposits is thought to have been deposited under freshwater swamp conditions with inundation by river flooding. The depositional environments are considered to be riverine swamps. This interpretation will be validated if most the pollens contained in these deposits belong to freshwater swamp vegetation.

e. *Peat Swamp*

Peat deposits are found overlying the riverine swamp deposits in layer BM 2/1 and overlying the sand beach deposits in layer BM 3/1 (Fig. 2). They are mainly woody peat, showing a very wide range of decomposition. The degree of decomposition of the peat surface (0-10 cm) is mainly sapric, while in the deeper part it varies from fibric to hemic.

Peat is considered to have been formed in peat swamp environments. These environments develop in continuously waterlogged swamps which are affected by river flooding. The further these are located from the river, the less clastic materials are added from the sediment load of the river. The decomposition rate of plant debris is depressed under waterlogged conditions. The continuous accumulation of slowly decomposing organic matter from dense swamp forests results in a tropical peat deposit.

B2. *Stratigraphy of the Sediments along Transect II*

a. *Tidal Flat*

Evidence of a tidal flat environment is found in layer BM 11/3 (Fig. 3). The tidal flat deposits, which are often interlayered with very thin lamina of plant fragments, show low accumulation of sulfidic materials (pHox >2.5). The total sulfur content of these deposits is below 0.5%.

b. *Brackish Swamp*

Along Transect II, brackish swamp deposits are found in layers BM 9/3-4, BM 11/2, BM

28/2-3, and BM 27/2-3. These are organic clay layers with a high content of sulfidic materials as indicated by the low pHox values (Fig. 3). The brackish swamps in the former Barito delta seem to have accumulated rather high amounts of pyrite. The sulfur content of brackish swamp deposits of Transect II varies widely from 0.45 to 2.96%. However, compared with the riverine deposits on Transect I, the lowest sulfur content in the brackish swamp deposits is still very high. In the riverine deposits the sulfur content is below 0.15% (layer BM 5/1, Fig. 2), but the lowest sulfur content in brackish swamp deposits is 0.69% (layer BM 28/3, Fig. 3).

The depositional environment of the high sulfur deposits should differ from that of the low sulfur deposits. Based on the contents of plant fragments, sulfur, and sulfidic materials, the brackish swamp deposits of Transect II can be grouped into three different depositional sub-environments: (1) mangrove marsh, (2) mangrove swamp, and (3) transitional environment from mangrove marsh to mangrove swamp (transitional mangrove swamp). The positions of sub-environments of the brackish swamp along Transect II are given in Fig. 4.

The mangrove marsh (1) is considered to be a depressional area surrounded by mangrove swamp. It is not as deep as an interdistributary bay, being shallow enough for mangrove vegetation to grow, but the vegetation density is much lower than that in mangrove swamp environments. At the same time, the accumulation rate of clastic materials from river flooding is higher than in the other sub-environments. The high accumulation rate of clay and low accumulation rate of plant fragments result in mangrove marsh deposits that are characterized as inorganic clay, low in sulfidic materials, and low in sulfur content (< 0.7%). Mangrove marsh deposits are found in layer BM 28/3 (Fig. 3).

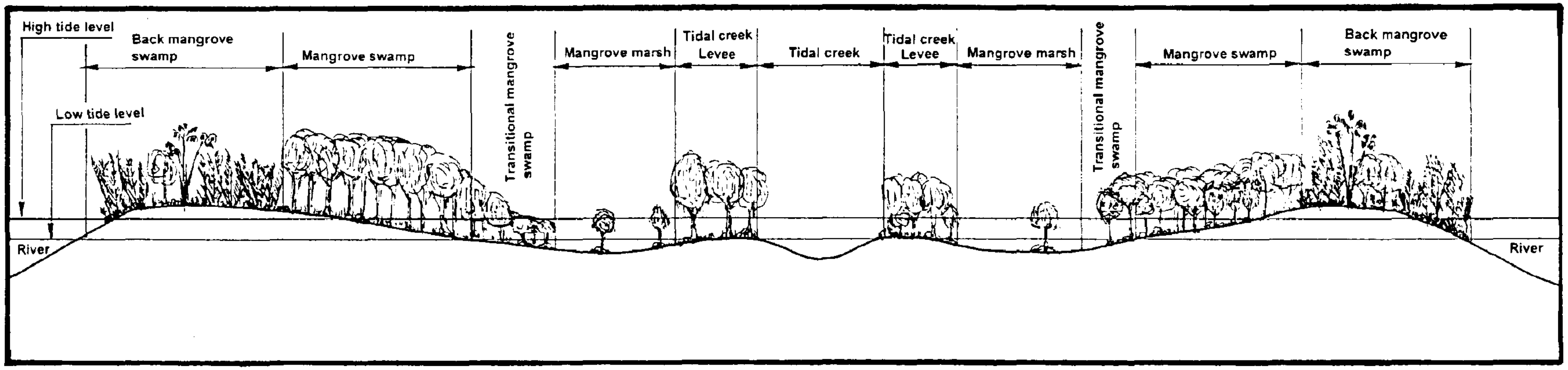
The mangrove swamp environment (2) favors the accumulation of sulfide and pyrite minerals. It is occupied by dense mangrove swamp forests, so the organic supply is high; and it receives clay materials from the river sediments, and is inundated by seawater, especially during spring or equinoctial tides. The deposits are characterized as organic clay with high sulfur content. The sulfur content varies from 1.0 to 2.9%.

Mangrove swamp deposits were found at all boring sites on Transect II. They appear as a wide pyritic clay blanket spreading over the other deposits. They are found in layers BM 9/3, BM 11/2, BM 28/2, and BM 27/2 (Fig. 3).

Between the mangrove marsh and the mangrove swamp, there is a transitional mangrove swamp environment. The transitional mangrove swamp deposits (3) are inorganic clay deposits with a high content of sulfidic materials. However, the sulfur content of these deposits is only 0.70-1.0%.

c. *Peat Swamp*

Peat deposits are found in layers BM 27/1 and BM 9/1, overlying the mangrove swamp deposits (Fig. 3). They consist of woody peat with a lower content of sulfidic materials. At the margins between the peat swamp deposits and mangrove swamp deposits is a transitional environment which produces peaty clay layer such as BM 9/2, BM 11/1, and BM 28/1 (Fig. 3). The peaty clay layer BM 9/2 does not contain sulfidic materials, having been deposited in a transitional environment from riverine to peat swamp. Its sulfur content is low. Some peaty



Ecology	Tidal creek	Mangrove marsh	Transitional mangrove swamp	Mangrove swamp	Back mangrove swamp
Main vegetation	Sonneratia sp. *Rhizophora mucronata* *Avicennia alba*	Sonneratia sp. *Rhizophora mucronata* *Avicennia alba*	Sonneratia sp. *Rhizophora mucronata* Rhizophora sp.	Rhizophora sp. Sonneratia sp. *Bruguiera gymnorrhiza* *Ceriops tagal*	*Nypa fructicans* *Xylocarpus granatum* *Excoecaria agallocha* Oncosperma sp. *Sonneratia caseolaris*

Fig. 4 Positions of Mangrove Marsh, Transitional Mangrove Swamp, Mangrove Swamp, and Back Mangrove Swamp in the Brackish Swamp Environment

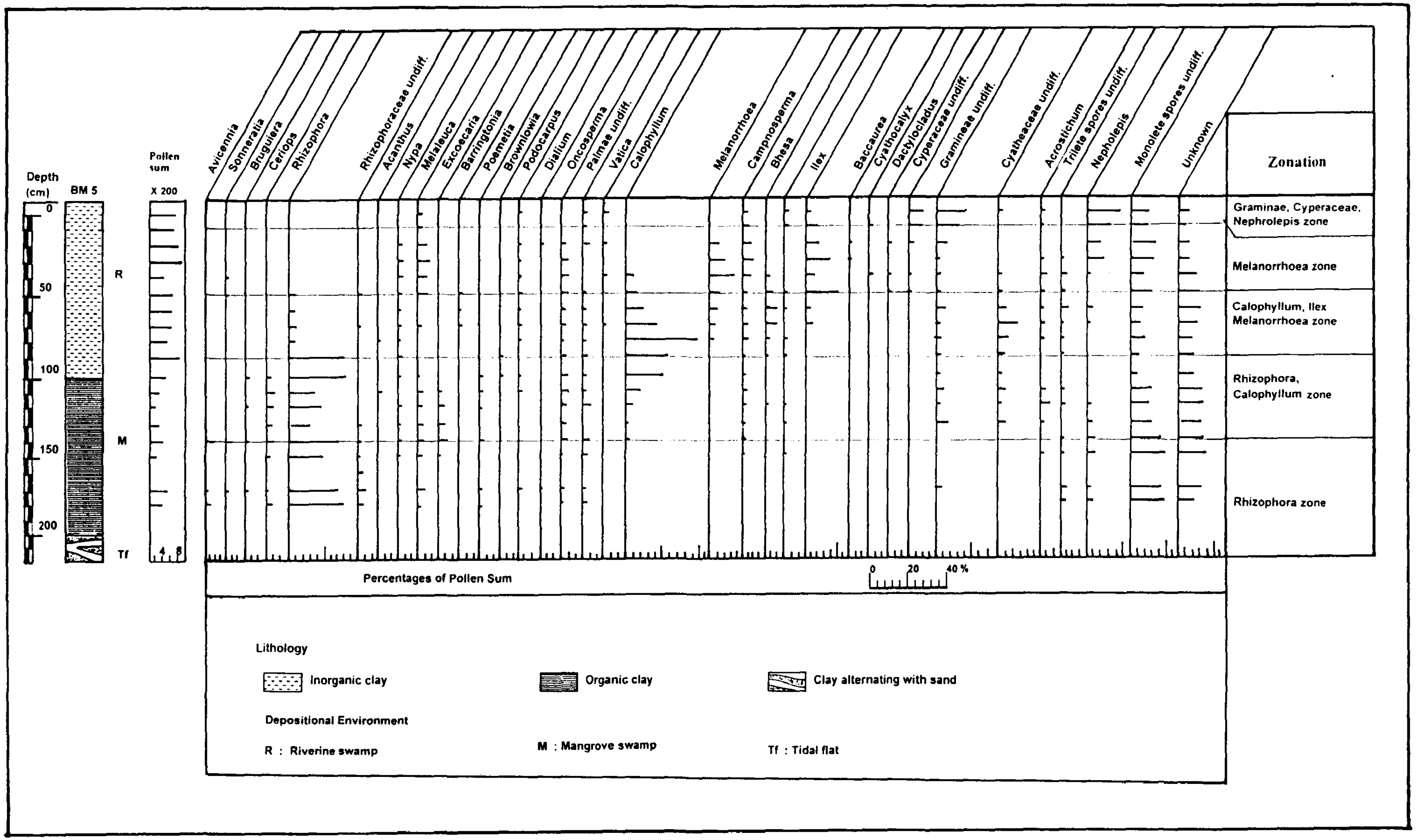


Fig. 5 Pollen Diagram of Selected Taxa of Boring BM 5

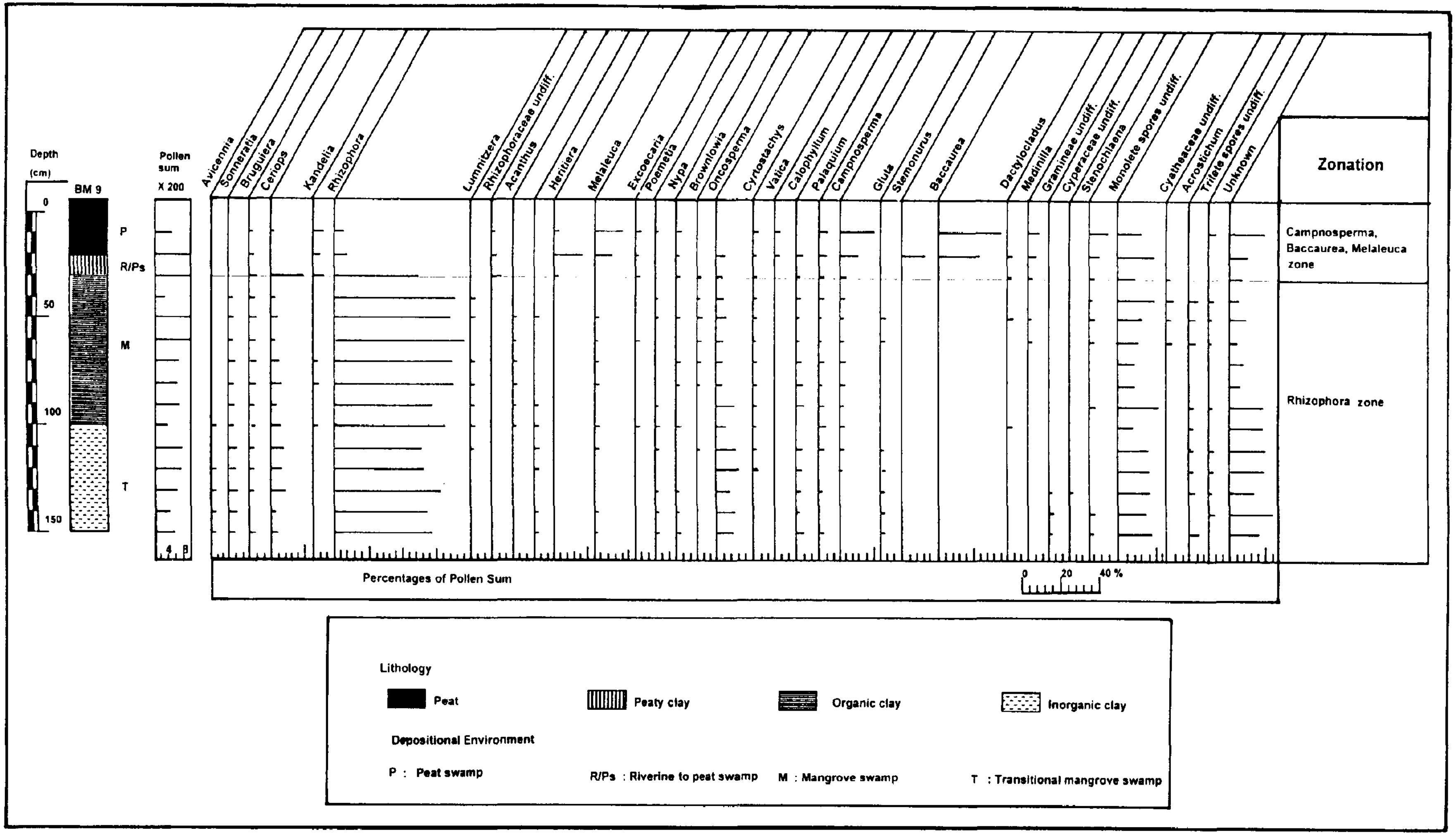


Fig. 6 Pollen Diagram of Selected Taxa of Boring BM 9

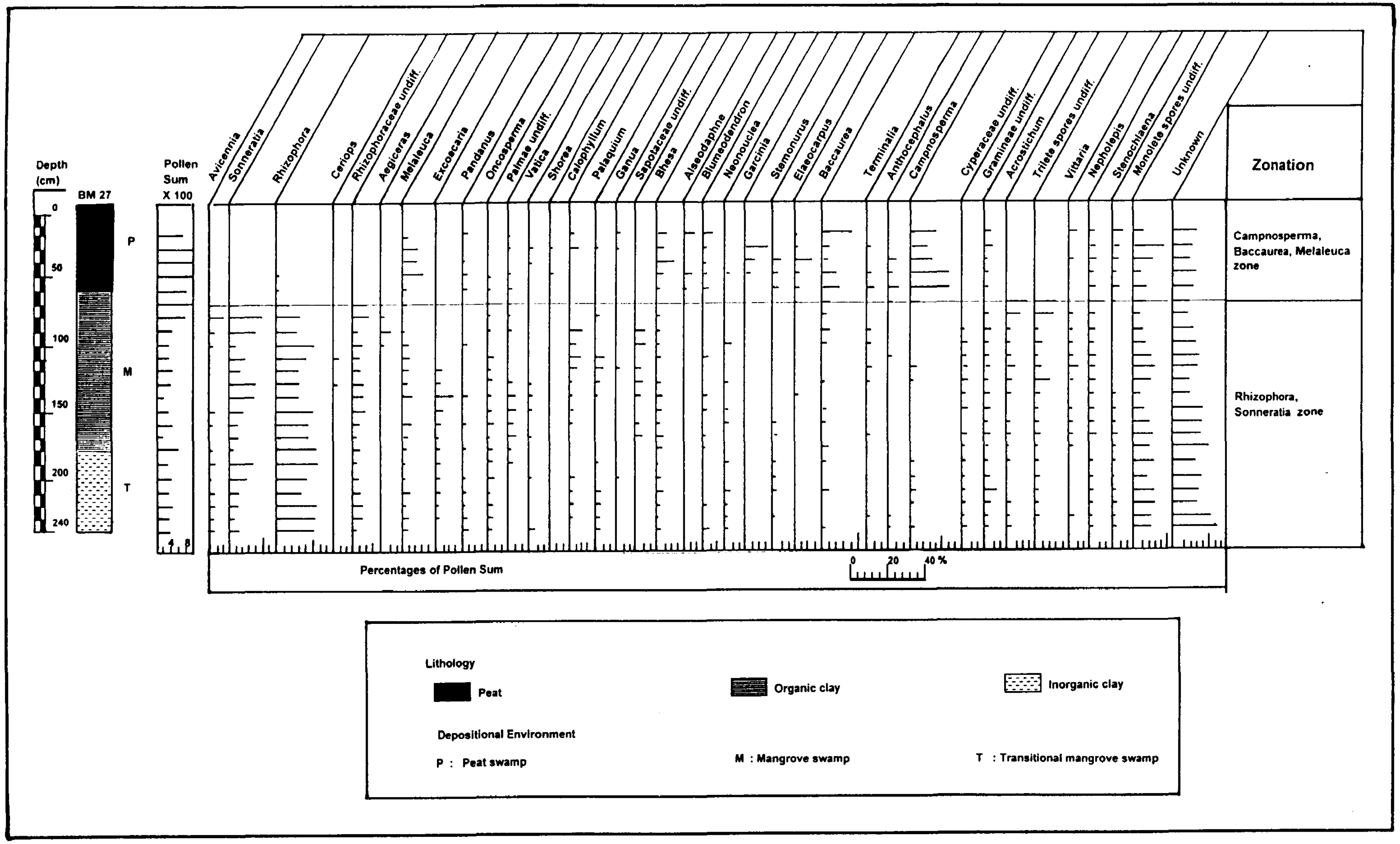


Fig. 7 Pollen Diagram of Selected Taxa of Boring BM 27

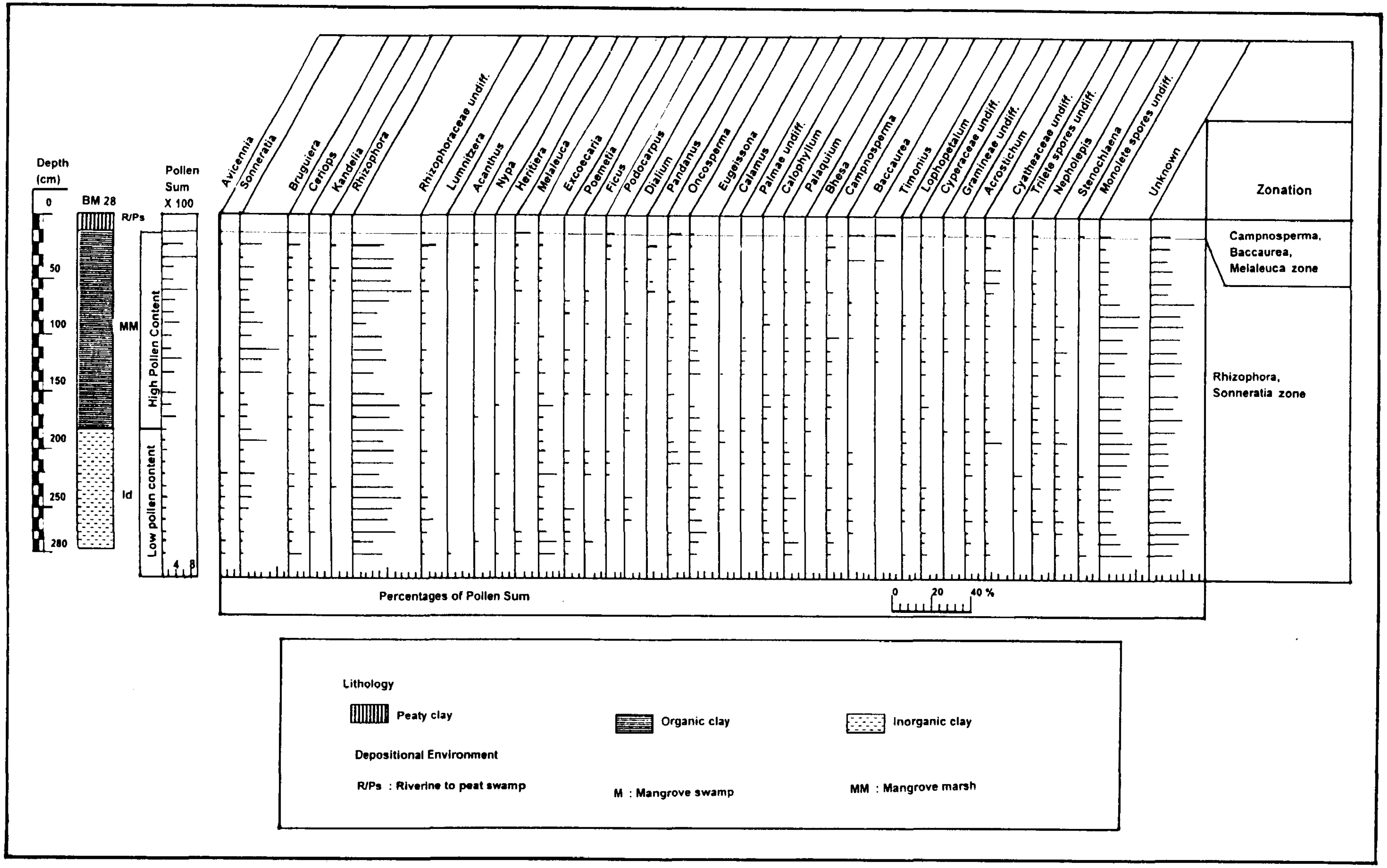


Fig. 8 Pollen Diagram of Selected Taxa of Boring BM 28

clay layers are quite thin, such as BM 11/1 and BM 28/1, the thickness varying from 10 to 20 cm.

C. *Pollen Diagram of Swamp Deposits*

Pollen spectra from each boring site are presented on conventional pollen diagrams. Pollen diagram of selected samples are presented in Fig. 5 for Transect I and Figs. 6, 7, and 8 for Transect II.

C1. *Pollen Diagram along Transect I*

Samples of boring BM 5 were chosen for palynological studies along Transect I. BM 5 is located on stable agricultural land, which is not affected by severe toxic acidity (Table 1). Based on the stratigraphy data in the previous section, the deposits in the second layer of BM 5 (BM 5/2) contain sulfidic materials and a high percentage of sulfur.

The pollen diagram in Fig. 5 shows the alteration in the environment during the deposition processes of BM 5 samples (0-180 cm). Five different forest association zones are found through the boring samples, which are described below.

a. *Rhizophora Zone (180-140 cm)*

This zone is characterized by the dominance of *Rhizophora* pollen, which reaches frequencies of up to 36% of the pollen sum. Pollens of *Sonneratia*, *Avicennia*, and other Rhizophoraceae like *Ceriops* are also present in these deposits, but their frequencies do not exceed 5%. These findings indicate the deposit developed under a *Rhizophora* mangrove environment.

Mangrove species grow in very specific environments. One of the most important factors controlling the distribution of mangrove species is tidal influence. Watson [1928] defined five tidal inundation classes in terms of the combination of frequency and height of tidal inundation and found a close correlation between these classes and the distribution of mangrove species in the Malay Peninsula (Table 2). These inundation classes are adopted here in an attempt to explain the succession of the depositional environments of mangrove deposits.

Table 2 shows that *Rhizophora mucronata* and *Rhizophora conjugata* belong to inundation classes 2 and 3, and classes 3 and 4, respectively. Depending on the species, *Sonneratia*, *Avicennia*, and *Ceriops* vegetation is found in inundation classes 2, 3, 4, and 5. Since the back mangrove vegetation, like *Nypa fructicans* and *Oncosperma filamentosa*, and *Excoecaria agallocha*, which belong to classes 3, 4 and 5, are present in very low frequencies, the environment of these deposits is considered to be a mangrove swamp area. Mangrove swamps are inundated during medium high tides (class 2) or normal high tides (class 3).

b. *Rhizophora, Calophyllum Zone (140-90 cm)*

This zone is still dominated by *Rhizophora* pollen, which is found in frequency up to 36%, but the back mangrove vegetation like *Oncosperma*, *Excoecaria*, *Nypa*, and *Ceriops* and the spores of Cyatheaceae are present in frequencies of up to 5%. The environment of this zone is considered to differ from the previous zone, since this zone contains abundant pollen of *Calophyllum*, present in frequencies of up to 30%.

Table 2 Inundation Class of Selected Vegetation in Mangrove Forest

No	Name	Inundation Class
1	*Acanthus ebracteatus*	4, 5
2	*Acanthus iliciofolius*	4, 5
3	*Acrostichum aureum*	3, 4, 5
4	*Aegiceras majus*	3, 4
5	*Avicennia alba*	2
6	*Avicennia intermedia*	2, 3
7	*Avicennia lanata*	2, 3
8	*Avicennia officinalis*	3, 4
9	*Bruguiera caryophyloides*	4
10	*Bruguiera eriopetata*	3, 4
11	*Bruguiera gymnorrhiza*	3, 4, 5
12	*Bruguiera parviflora*	3, 4
13	*Ceriops candolleana*	3, 4
14	*Excoecaria agallocha*	4, 5
15	*Kandelia rheedii*	4
16	*Lumnitzera coccinea*	4, 5
17	*Lumnitzera racemosa*	4, 5
18	*Nypa fructicans*	3, 4, 5
19	*Oncosperma filamentosa*	5
20	*Rhizophora conjugata*	3, 4
21	*Rhizophora mucronata*	2, 3
22	*Sonneratia alba*	3, 4
23	*Sonneratia acida*	4, 5
24	*Sonneratia griffithii*	2, 3

Source: [Watson 1928]

Note:

	Height above datum (feet)	Times flooded per month
Class 1. Inundated by all high tides	(0-8)	(56-62)
Class 2. Inundated by medium high tides	(8-11)	(45-59)
Class 3. Inundated by normal high tides	(11-13)	(20-45)
Class 4. Inundated by spring tides	(13-15)	(2-20)
Class 5. Inundated by exceptional or equinoctial tides	(15- -)	(- - 2)

According to Table 2, *Oncosperma filamentosa* belongs to class 5, *Nypa fructicans* to classes 3, 4, and 5, *Excoecaria agallocha* to the classes 4 and 5, and *Ceriops candolleana* to classes 3 and 4. *Calophyllum*, which is present in abundant pollen frequencies, is not mangrove vegetation. According to Anderson [1963], who studied the ecology of tropical swamp forest in Sarawak and Brunei, *Calophyllum* and ferns of Cyatheaceae are usually found in the mixed swamp forest at the perimeter of mangrove forest. Thus, it is considered that the depositional environment of this zone is a mixed swamp forest. This zone is inundated by seawater during spring tides (class 4) or during equinoctial tides (class 5) at the upper margin.

c. *Calophyllum, Ilex, Melanorrhoea Zone (90-50 cm)*

Rhizophora pollen, the dominant pollen in the lower zones, is present in frequencies of up to only

5% in this zone. Here, *Calophyllum* is the dominant pollen, with frequencies of up to 40% of the pollen sum. Pollens of *Ilex*, *Bhesa*, and *Melanorrhoea* are present in frequencies of 10-20% of the pollen sum. Spores of Cyatheaceae are also present in frequencies of up to 16%. *Oncosperma* and *Nypa* are still present in this zone, but only in frequencies of less than 5% of the pollen sum.

According to Anderson [*ibid.*], *Calophyllum*, *Ilex*, and *Melanorrhoea* are found mainly in mixed swamp forest or Phase Community I (PC I). The environment of this zone is considered to be one in which the inundation effects of seawater are significantly decreased, so that mangrove vegetation is only temporary. This zone is occupied by freshwater swamp forest: namely, the deposits developed in a riverine swamp environment.

d. *Melanorrhoea, Ilex Zone (50-20 cm)*

Pollens of mangrove vegetation like *Avicennia*, *Sonneratia*, and *Rhizophora* are not present in the pollen diagram. *Calophyllum* pollen also decreases sharply, being found only at the depth of 40-50 cm in frequencies of up to 10%. *Melanorrhoea* pollen reaches the peak accumulation, being found in frequencies of up to 18%, and *Ilex* pollen is still present in frequencies of 15-20%.

According to Anderson [*ibid.*], *Ilex hypogluca* is found in mixed swamp forest to Alan Bunga forest (PC I-III). *Ilex sclerophylloides* is found in Padang Alan forest to Padang Keruntum forest (PC IV-V). *Melanorrhoea beccarii* is found in mixed swamp forest to Alan forest (PC I-II). The absence of *Rhizophora*, *Sonneratia*, *Avicennia* indicates that the environment of this zone has become a true riverine swamp.

e. *Graminae, Cyperaceae, Nephrolepis Zone (20-0 cm)*

Arboreal pollen is present in relatively small amount in this zone, while the pollens of secondary vegetation like Graminae, and Cyperaceae, and the spores of *Nephrolepis* are found in frequencies of up to 25, 12, and 20% respectively. This means that the forest has been converted to agricultural lands and grasslands with shrubs. The Cyperaceae and ferns of *Nephrolepis* are common vegetation of the agricultural plots in this area.

C2. *Pollen Diagram along Transect II*

Borings BM 9, BM 27, and BM 28 were chosen for palynological study along Transect II. Based on the stratigraphy, texture, and pH data presented in Fig. 3, the swamp deposits of BM 9 and BM 27 are considered to have been formed in a transitional mangrove swamp, then a mangrove swamp, and finally a peat swamp. The succession of swamp deposits of BM 28 is considered to comprise mangrove marsh, mangrove swamp, and finally peat swamp. The pollen diagrams of borings BM 9, BM 27, and BM 28 are presented in Figs. 6, 7, and 8, respectively.

C.2.1. *Pollen Diagram of Boring BM 9*

Based on the pollen diagram in Fig. 6, BM 9 can be divided into the following two zones.

a. *Rhizophora Zone (150-30 cm)*

This zone is characterized by presence of abundant pollen of *Rhizophora*, which reaches frequencies of up to 75% of the total pollen. Pollens of *Avicennia*, *Sonneratia*, *Bruguiera*, and *Ceriops* are present in minor frequencies of only about 5% each. Pollen of *Oncosperma* is found in considerable frequencies of up to 16%. Pollen of *Calophyllum* is also found in frequencies of up to 5%.

Based on this pollen composition, it is clear that this zone is dominated by *Rhizophora*, which grows mainly in zones of inundation classes 2-4 (Table 2). The fact that this *Rhizophora* forest is associated with other mangrove vegetation like *Avicennia*, *Sonneratia*, *Bruguiera*, and *Ceriops* vegetation is confirmed by the presence of those pollens (Fig. 6).

The pollens of *Oncosperma filamentosa*, which belongs to back mangrove and mixed swamp forest vegetation, and *Calophyllum*, which belongs to mixed swamp forest vegetation, that are found in this zone are considered to come from a transitional location between the distributary levees and the mangrove swamp.

The results of stratigraphy shown in Fig. 3 suggest that this zone comprises two depositional sub-environments: mangrove swamp and transitional mangrove swamp. The pollen diagram, however, does not show such sub-environments in this *Rhizophora* zone. Although this fact appears contradictory, it also clearly illustrates the succession of landform building. The transitional mangrove swamp shows that pioneering *Rhizophora* colonies establish themselves in the brackish water, and in a "natural poldering" process, they stabilize the sediments which would otherwise be swept away by along-shore currents. Once the colonies are stabilized, they accelerate the sedimentation under the mangrove swamp, which supports the flourishing mangrove vegetation and also receives abundant plant debris.

The differences between the mangrove swamp zone and the transitional zone are based on the sulfur content and the organic matter content of the deposits. Both of the depositional environments are considered to be developed under brackish swamp forest, which is confirmed by the abundant presence of *Rhizophora* pollen. However, the transitional mangrove swamp environment occurs in an area with higher sedimentation rate than the mangrove swamp environment. Therefore the transitional mangrove swamp environment is characterized by lower organic matter and sulfur contents, while the mangrove swamp zone is characterized by higher organic matter and sulfur contents.

b. *Campnosperma, Baccaurea, Melaleuca Zone (30-0 cm)*

Rhizophora pollen, which is dominant in lower zones, diminishes to the frequencies of up to 10% in this zone. This zone is dominated by non-mangrove vegetation like *Baccaurea*, *Melaleuca*, and *Campnosperma*, which are present in frequencies of up to 35, 20, and 20% respectively. According to Anderson [1963], *Baccaurea*, *Melaleuca*, and *Campnosperma* belong to vegetation of Phase Community I. They are found at the perimeter of coastal swamps gradating to peat swamps.

C.2.2. *Pollen Diagram of Boring BM 27*

The pollen diagram of boring BM 27, which is presented in Fig. 7, indicates that the depositional environment can be divided into two zones.

a. *Rhizophora, Sonneratia Zone (240-60 cm)*

The pollen diagram in this zone is dominated by mangrove pollens of *Rhizophora*, *Sonneratia*, and undifferentiated Rhizophoraceae, which are present in the frequencies of up to 24, 20, and 10%, respectively. The pollen of *Avicennia* is present in the frequencies of up to 8%. *Avicennia, Rhizophora*, and *Sonneratia* are commonly found between the areas inundated during medium to high tides and those inundated during spring tides (Table 2). The pollen diagram, however, also suggests the presence of back mangrove and mixed swamp forest vegetation. The back mangrove pollens found in this zone are *Oncosperma*, *Excoecaria*, and *Pandanus*, present in the frequencies of up to 5, 10, and 10%, respectively. The mixed swamp forest pollens represent the more inland vegetation and include *Calophyllum*, *Melaleuca*, and Palmae, which are found in frequencies up to 10, 4, and 6%, respectively.

The mangrove species other than *Avicennia* produce abundant pollen which is deposited locally [Muller 1964]. The high percentage of mangrove vegetation pollen in this zone indicates that the zone represents a mangrove environment. The back mangrove and mixed swamp forest pollens may suggest the change of micro-topography and subsequent vegetation successions.

Like the *Rhizophora* zone BM 9, the brackish swamp comprises two sub-environments: a mangrove swamp environment at depths of 200-60 cm, and a transitional mangrove swamp environment at depths of 240-200 cm.

b. *Campnosperma, Baccaurea, Melaleuca Zone (60-20 cm)*

The mangrove genera *Avicennia*, *Rhizophora*, and *Sonneratia* that represent the dominant pollen frequencies in the previous zone are no longer found. Pollens from mixed swamp forest, such as *Campnosperma*, *Baccaurea*, *Melaleuca*, and *Bhesa*, dominate in this zone, being found in frequencies of up to 28, 20, 16, and 16% respectively.

According to Anderson [1963] *Campnosperma coriacea* is frequently found in shallow coastal peat; *Baccaurea bracteata* is frequently found in mixed swamp forest and Alan forest; *Melaleuca leucadendron* is found in coastal to shallow peat swamp forest; and the *Bhesa paniculata* is frequently found in mixed swamp forest. It is clear that this zone developed under mixed swamp forest resulting in the formation of shallow peat.

C.2.3. *Pollen Diagram of Boring BM 28*

Based on the pollen diagram presented in Fig. 8, BM 28 samples can be divided into two zones of depositional environment.

a. *Rhizophora, Sonneratia Zone (290-10 cm)*

The pollen diagram in this zone is dominated by mangrove pollen, *Rhizophora*, *Sonneratia*, and other undifferentiated Rhizophoraceae, which are present in pollen frequencies up of to 36, 20, and 12% respectively. The pollen of *Avicennia* is present in frequencies of up to 8%. *Bruguiera* and *Ceriops* are found in minor frequencies of up to 8%. This zone also contains pollens from back mangrove and mixed swamp forest vegetation like *Oncosperma* and *Melaleuca*, which are present in frequencies of up to 4 and 12% respectively. The pollen composition of this zone closely resembles that of the *Rhizophora*, *Sonneratia* zone of BM 27.

Based on the pollen data (Fig. 8), this zone can be divided into two parts, one with high pollen content at depths of 200-10 cm and one with low pollen content at depths of 290-200 cm. Superimposing the stratigraphy and the pollen diagram shows that the low pollen content deposits was formed in the mangrove marsh environment, and the high pollen content deposits in mangrove swamp environment.

b. *Campnosperma, Baccaurea, Melaleuca Zone (10-0 cm)*

While *Avicennia, Rhizophora*, and *Sonneratia* are dominant in the previous zone, here these mangrove genera are found in frequencies of up to only 3%. Pollens from mixed swamp forest vegetation become dominant: *Campnosperma, Baccaurea, Melaleuca, Pandanus*, and *Bhesa* are found in frequencies of up to 12, 12, 8, 8, and 7%, respectively. In its pollen composition, this zone resembles the *Campnosperma, Baccaurea, Melaleuca* zone of boring BM 27, and it is likewise to belong to a mixed swamp forest with shallow peat environment.

V Discussion

A. *Succession of Depositional Environments on Transect I*

Based on the stratigraphy and pollen diagram data, an attempt was made to reconstruct the succession of depositional environments of the sediments of the Martapura river, a short tributary river, that traverses rather mountainous terrain, and has a high sediment supply.

Sand Beach, Tidal Flat, and Bay

When the sea level reached its maximal stage in the post-glacial period, the Martapura river presumably emptied into a shallow sea or bay that was located near the western flank of the Martapura hills. The river sediments developed subaqueous levees, subaqueous delta plains, and tidal flats on the river mouth. At the coastal margin there were sand beach deposits (Fig. 9A), and the tidal flats flanked the sand beaches. The small estuary of the Martapura river is considered to have been protected by several lagoons and bays which were partially occluded by sand beaches.

The Martapura river brought a continuous sediment load to the estuary, and the river deposits contributed to the development of the channel levees, subaqueous levees, and tidal flats (Fig. 9B).

Levee and Tidal Flat

In the early stages of development, subaqueous levees and the tidal flats were still inundated by sea water. Since the sedimentation processes were continuous, the levees and tidal flat continued to develop until they were inundated only during the medium high tides. Under these conditions, pioneer species of mangrove like *Avicennia, Sonneratia*, and *Rhizophora* took root on temporarily exposed sites (Fig. 9C). The growth of mangrove accelerated the deposition processes, since the aerial roots of mangrove act to trap sediments and protect them from waves and currents. The presence of mangrove swamp environments in this area is shown by the presence of *Rhizophora* zone in the pollen diagram BM 5 (Fig. 5).

The sedimentation and land accretion processes continued seaward. The sedimentation under the mangrove proceeded to such level that sea water could no longer freely inundate the

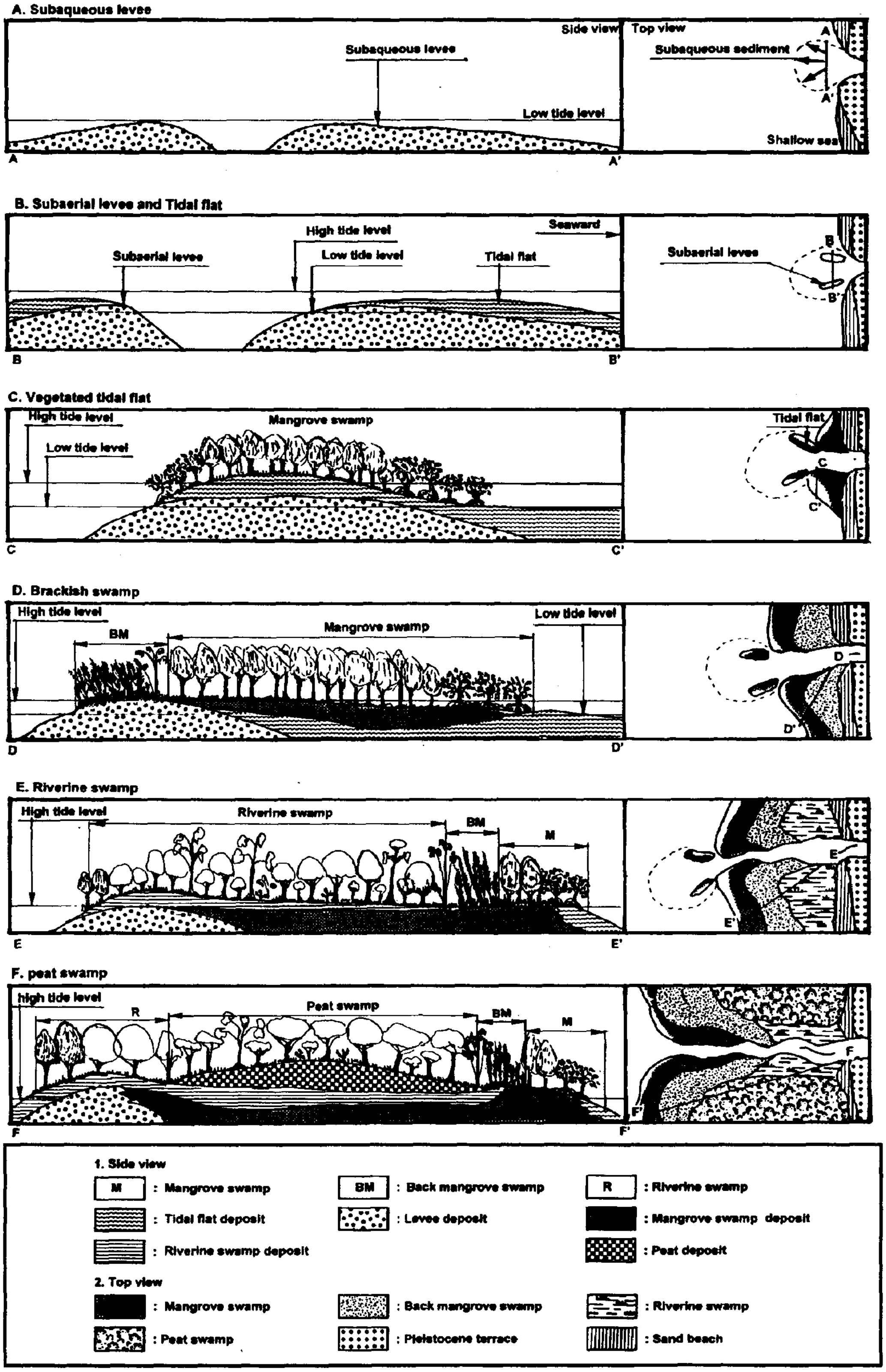


Fig. 9 Succession of Depositional Environments of the Martapura River Sediments from Subaqueous Levees to a Peat Swamp Environment

mangrove swamps. The swamps were inundated by sea water only during the exceptional tides or equinoctial tides. Under these conditions, the brackish swamp environment (Fig. 9D) was established.

Brackish to Riverine Swamp

As the land progradation advanced seaward, following the regressing sea level, the brackish swamps ceased to be inundated by sea water. The environment then became a freshwater swamp (Fig. 9E). The freshwater swamp was affected by the river flooding, especially during the rainy seasons, and additional river sediments were laid down at these times. The presence of riverine swamp deposits is confirmed by pollen diagram of boring BM 5 (Fig. 5). The absence of *Rhizophora* pollen and the presence of freshwater swamp vegetation pollen in the *Calophyllum*, *Ilex*, *Melanorrhoea* zone (90-50 cm) and the *Melanorrhoea*, *Ilex* zone (50-20 cm) confirm that these zones belong to the riverine swamp.

Riverine Swamp to Peat Swamp

Freshwater swamps support flourishing rain forest which supplies huge amounts of plant debris. Under the water-saturated conditions, peat started to build up because the decomposition of plant debris was retarded (Fig. 9F). Nevertheless decomposition rates differed different parts of the peat plain: the periphery had higher microbial activities because of the eutrophic conditions due to the nutrient addition from the flooding river water, while the central plain had a lower decomposition rate because of the mesotrophic conditions. This difference in decomposition rate caused the peat layer to develop faster in the central plain than the periphery, and resulting in the peat-dome landform.

Most of the peat deposits on the swampy areas of the Barito and Martapura rivers have disappeared due to human activities, and the remaining shallow peat deposits appear sporadically such as in the surface layer of BM 3.

B. *Succession of Depositional Environments on Transect II*

The succession of depositional environments of lower Barito estuary is depicted in Fig. 10. The Barito river has a long main stream, with lake areas in the middle reach, resulting in a low sediment supply.

Tidal Flat and Shallow Sea

In the early stage of development, the Barito river carried a heavy sediment load as result of erosion in the mountainous and hilly area and debouched into a shallow sea or bay, which presumably engulfed the present Barito basin. In the course of the riverine sedimentation processes, the coarser grains were deposited directly at or near the river mouth and along the channel, while the finer grains settled farther away. These sedimentation processes resulted in subaqueous levees and subaqueous delta plains (Fig. 10A). The sedimentation processes continued until the subaqueous levees and delta plain emerged from the sea to become subaerial

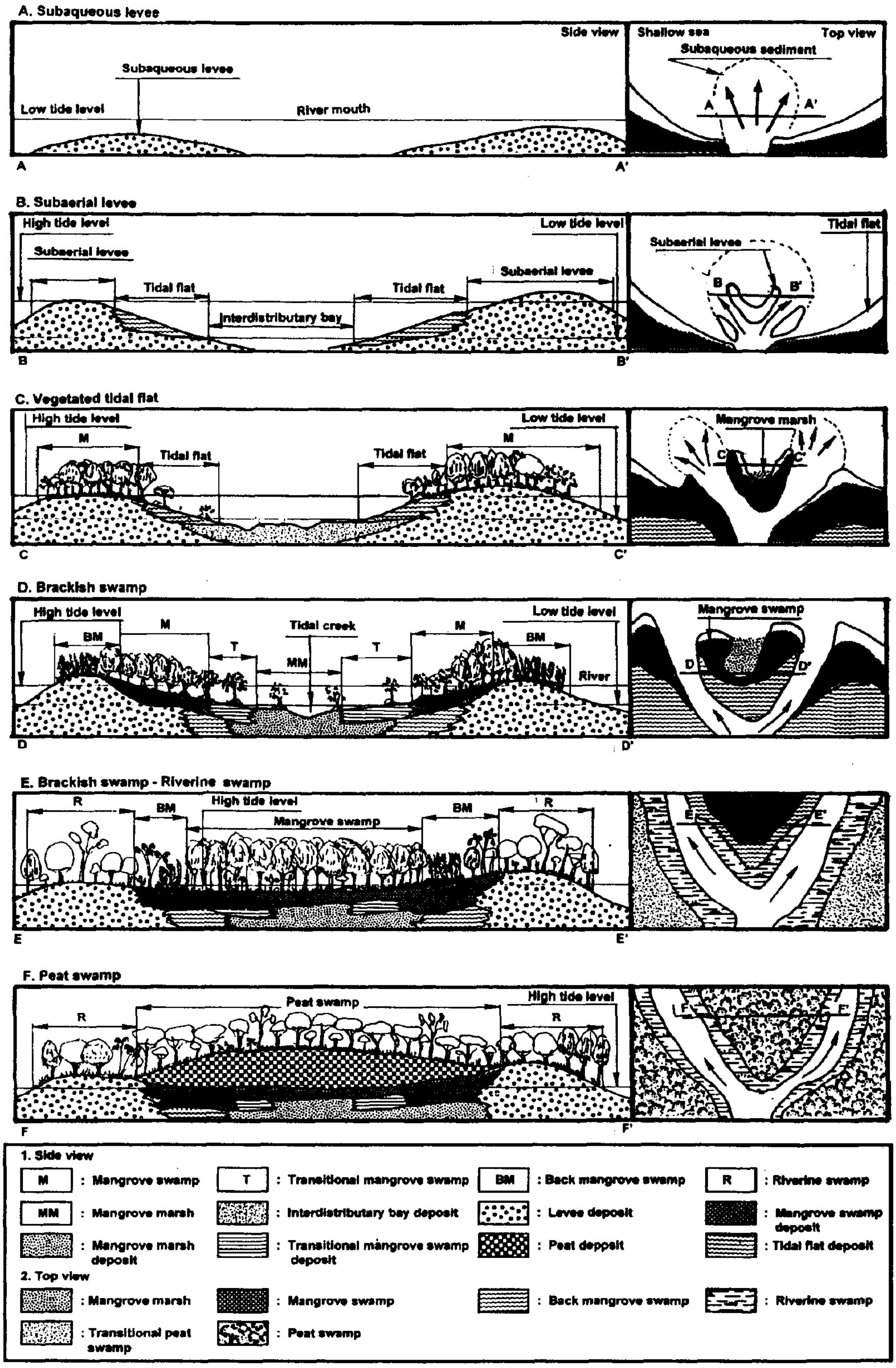


Fig. 10 Succession of Depositional Environments of the Barito River Sediments from Subaqueous Levees to a Peat Swamp Environment

levees and a tidal flat (Fig. 10B). The sedimentation processes at the river mouth continued and caused remarkable development of the distributary mouth bar (Fig. 10C). Because of this distributary mouth bar, the channel velocity of the Barito river was remarkably decreased at the river mouth, and this caused the development of braided channels there. This characteristic, combined with tidal actions on newly deposited sediments, favored the formation of extensive tidal flats. The tidal flat environment is found in BM 11/3 (Fig. 3). As the sedimentation processes continued, the land prograded seaward. The tidal flat and subaerial levees gradually become high enough to be settled by mangrove vegetation (Fig. 10C). The mangrove vegetation produced dense aerial roots, which protected the deposits from wave and current actions and trapped sediments. With the growth of mangrove vegetation on the tidal flat and subaerial levees, the environment began to change into a brackish swamp (Fig. 10D).

Brackish Swamp

The former distributary mouth bar developed into a river delta (Fig. 10D). At the first stage of delta-building, the vegetated levees received much higher addition of river sediments than the central parts. These differences in sedimentation rates in the delta plain gave rise to differences in micro-topography on the delta. The highest parts were the river levees on the delta margin, while the lowest was the tidal flat.

As land progradation continued toward the sea and also toward the delta plain, the river levees and interdistributary bay developed further. The influence of sea water on the river levees decreased, and the mangrove vegetation that formerly dominated the river levees gradually gave way to back mangrove vegetation, which developed into back mangrove swamp forest such as *Nypa fructicans* on the river levees. When the interdistributary bay filled with reworked river sediments, mangrove could grow on it. This environment is called a mangrove marsh environment. The mangrove marsh zones were the lowest places on the delta plain and they were inundated by sea water for longer time and to greater depth than the mangrove swamp. The mangrove marsh environment deposits are characterized by low contents of sulfur, organic matter, and pollen. They are found on Transect II in BM 28 at the depth of 200 to 290 cm.

Variations in micro-topography and distance of sedimentation sites from the sediment-bearing rivers caused differences in depositional environments. Microtopography is closely related with the degree of sea water inundation, and the distance of the sedimentation sites from the rivers is closely related with the rate of sedimentation. Based on differences in the organic matter and sulfur contents of the brackish swamp deposits (Fig. 3), the brackish swamp in the area between the river levees and the mangrove marsh environments along Transect II is thought to consist of mangrove swamp and transitional mangrove swamp environments. The mangrove swamp deposits are characterized by high sulfur, organic matter (Fig. 3), and pollen contents (Figs. 6 and 7). They are found at the places that still received sediments from the rivers, were inundated by sea water, and occupied by dense brackish swamp vegetation. The transitional mangrove swamp deposits, however, are characterized by low sulfur, and organic matter (Fig. 3), and moderate pollen contents (Figs. 6 and 7). They are found on the transitional swamp between the mangrove swamp and the mangrove marsh.

As the land progradation advanced following the regressing sea water, the delta plain gradually built up until it was no longer affected by sea water. The river levees were still affected by river flooding, so the addition of clastic materials to the delta plain continued. Under such conditions, the river levees were covered by riverine swamp vegetation (Fig. 10E). The addition of clastic sediments to the central parts of the delta plain changed the transitional swamp and the mangrove marsh to mangrove swamp. The presence of the mangrove swamp environments along Transect II is shown on the pollen diagrams of BM 9, BM 27, and BM 28 (Figs. 6, 7, and 8).

Peat Swamp

When the river flooding ceased to influence the delta plain, the supply of clastic materials ended, and water on the swamp derived only from rainfall. Plant remains or plant debris accumulated under water-logged conditions, and the mixed swamp forest vegetation then changed to peat swamp forest (Fig. 10F). The peat deposits are dominated by pollens from mixed swamp to shallow peat swamp forest vegetation, like *Campnosperma*, *Baccaurea*, *Melaleuca* (Figs. 6 and 7).

The peat plain developed peat-dome topography. However, peat-dome in Pulau Petak area has been destroyed or disturbed by forest fire or agricultural development.

References

Anderson, J.A.R. 1963. The Flora of the Peat Swamp Forest of Sarawak and Brunei, Including a Catalogue of All Recorded Species of Flowering Plants, Ferns and Ferns Allies. *Garden Bull.* 20: 131-228.

Anderson, J.A.R.; and Muller, J. 1975. Palynological Study of a Holocene Peat and a Miocene Coal Deposit from NW Borneo. *Rev. Palobot. and Palynology* 19: 291-351.

Begheijn, L., Th. 1980. *Methods of Chemical Analyses for Soils and Waters*. Wageningen, The Netherlands: Dept. of Soil Science and Geology. Agric. Univ.

Faegri, K.; and Iversen, J. 1975. *Textbook of Pollen Analysis*, 3rd edition. Copenhagen: Munssgaard.

Kemmerling, G.L.L. 1915. Geographishe en geologische beschrijving van het Baritobekken. *Tijdschirft van het Aardrijkskundig Genootschap* 32: 575-717.

Muller, J. 1964. A Palynological Contribution to the History of the Mangrove Vegetation. In *Ancient Pacific Floras: The Pollen Story*, edited by L.M. Cranwell, pp. 33-43. Hawaii.

――――. 1965. Palynological Study of Holocene Peat in Sarawak. In *Symposium on Ecological Research in Humid Tropics Vegetations*, pp. 147-156. Kuching, Sarawak: UNESCO.

Polak, E. 1933. Ueber torf und moor in Neiderlandisch Indien. *Kon. Akad. wet., Verhandelingen (tweede Sectie)* 30(3): 1-85.

Sumawinata, B. 1992. Adaptive Agricultural Practices and Land Use Cycles on Pyritic Sediments in South Kalimantan. *Tonan Ajia Kenkyu* [Southeast Asian Studies] 30(1): 93-104.

Van Wijk, C.L. 1951. Soil Survey of the Tidal Swamp of South Borneo in Connection with the Agricultural Possibilities. *Con. Gen. Agr. Res. Stat. Bogor, Ind.* 123: 5-49.

Watson, J.G. 1928. Mangrove Forest of the Malay Peninsula. *Malayan Forest Records* No. 6. Singapore: Fraser and Neave, Ltd.