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Distribution, Classification, Petrological and Related Gochemical (SRA) Characteristics of a Tropical Lowland Peat Dome in the Kota Samarahan-Asajaya area, West Sarawak, Malaysia

Research Article

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Abstract: Petrographic studies indicate that lateral variations in the decomposition levels of peat are associated with the predominantly occurring peat macerals. Source Rock Analyzer (SRA) results indicate lateral variation in peat organic matter types from type II to III and back again to type II, occurring laterally within the top 0-m to 0.5-m layer at the basin margin to the midsection and further towards the near-center areas of the peat dome. This variation is most likely caused by a combination of factors: (a) Horizontal zonation and lateral variation of the dominant species of plant assemblages (b) Fibric (marginal) peats and hemic to sapric peats associated with type II organic matter (kerogen). Sample organic matter (coal-equivalent kerogen) typing indicates that the relative abundance of phytoclasts and palynomorphs generally supports the organic matter classification obtained by the SRA method. Lateral variations in the peat organic matter types may support the lateral vegetation variation concept. The classification of peat organic matter types (interpreted from visual analyses of palynological slides) occurring from the basin periphery to the mid-section and further towards the basin center yields organic matter of type II to type III and mixed types II to III (coal kerogen-equivalent), respectively.

Keywords: tropical lowland peats • organic matter type (coal-equivalent kerogen) • palynofacies • phasic community zonation • phytoclasts

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1. Introduction

Understanding the formation of peat swamps requires proper insight into the mode of formation of the deposits and the conditions that led to their development. The formation or genesis of organic materials is caused by biochemical processes, whereas the process of organic material accumulation is primarily a function of the environmental conditions or the climate and ecosystems (peat swamps, bogs or mires) in which the peat is formed. Organic materials only accumulate to form peat under certain conditions, and it is essential that the production of biomass (organic materials) be greater than the amount of chemical breakdown in the formation of peat [1].

Peats are generally considered to consist of partly decomposed biomass (vegetation), and they display varying degrees of decomposition. Kurbatov [2] (in Andriesse [1]) briefly summarizes the formation of peat as follows: "The formation of peat is a relatively short biochemical process carried on under the influence of aerobic micro-organisms in the surface layers of the deposits during periods of low subsoil water. As the peat which is formed in the peat-producing layer becomes subjected to anaerobic conditions in the deeper layers of the deposit, it is preserved and shows comparatively little change with time". According to this theory, the presence of either aerobic or anaerobic conditions determines whether any biomass will accumulate and in what form.

Anaerobic and swampy conditions, which inhibit the microbiological activity required for the chemical breakdown of organic materials, are generally assumed to be largely responsible for the accumulation of partly decomposed biomass/organic matter in the form of peat. These anaerobic conditions are created by a specific hydrotopography in the form of marsh, swamp, bog or mire. The properties of such hydrotopographic units depend on many environmental factors, including climate, landform, local geology and hydrology [1].

The definition of peat also refers to the net accumulation of pure 100% organic matter and the difference between the soil and organic or vegetative accumulation, which varies [3], most likely due to varying definitions from the different academic fields associated with the practical study of peat and its properties (e.g., agriculture, botany, geology and engineering). 'Peats' have been alternately referred to as 'organic soils' and histosols. Peat is referred to as organic soil based on its mass composition [3, 4], i.e., soils that contain at least 65% organic matter or, conversely, less than 35% mineral content. The Soil Division of Sarawak (Malaysia) has adopted a definition for organic soil based on profile partitioning, i.e., for soils with 50 cm or more organic soil matter within 100 cm or more than twice the amount of mineral soil materials overlying bedrock within 50 cm [3]. In contrast, the United States Department of Agriculture (USDA) has defined soil types as organic soils (or histosols) if more than half of the upper 80 cm of the soil is organic or if organic soil material of any thickness rests on rock or on fragmental material exhibiting interstices filled with organic materials [3, 5].

As we now know, peats are formed by the limited decomposition and hence the accumulation of organic soil materials, and these organic materials can further consist of undecomposed, partially decomposed and highly decomposed plant remains. Tropical lowland peats usually contain undecomposed and partly decomposed branches, logs or twigs, form a fragile ecosystem because of their domed shape and are almost purely organic in composition [6].

1.1. Origin and Characteristics of Peat Deposits

The paludal deposits of Sarawak occur in large basin swamps and in small interior valleys that have developed primarily near coastal areas in relatively recent times [3]. Data from C14 dating from Baram in northern Sarawak indicate that the sea was located at the inland margin of the peat swamp approximately 5400 years ago [3, 7]. Peat basin swamps are often dome-shaped with thick 'ombrogenous peat' occupying the central portion of the peat dome [3, 6, 8–15]. 'Ombrogenous peat' or ombrogenic peats [6] are primarily composed of broken tree trunks, branches, leaves, roots and fruits [12, 16, 17] and are relatively mineral- or ash-free. However, the marginal peats surrounding the base and along the fringes or margins of the peat dome and the lower bank of streams draining the peat swamps are dominated by 'topogenous' or 'topogenic' peat, which consists of slightly to moderately decomposed plant matter and fine clastic mineral sediments (moderate to high ash content). According to Paramananthan [6], tropical lowland peats have a soil temperature regime that is isohyperthermic or warmer with a mean annual soil temperature greater than 22°C (with a monthly variation of < 5°C) and a common elevation of $\leq$750 m or 2,500 feet.

1.2. Location and Accessibility

The study region covers an area of approximately 25 square kilometers located between longitudes 01°26'30"N and 01°29'46"N (north and south of Sungai Tuang) and latitudes 110°27'44"E and 110°30'58"E (east and west of Batang Samarahan). This area is located approximately 30 km from Kuching City and is easily accessible via a sealed road. Within the study area (Figure 1), accessibility is possible by means of gravel, bund or sealed roads.

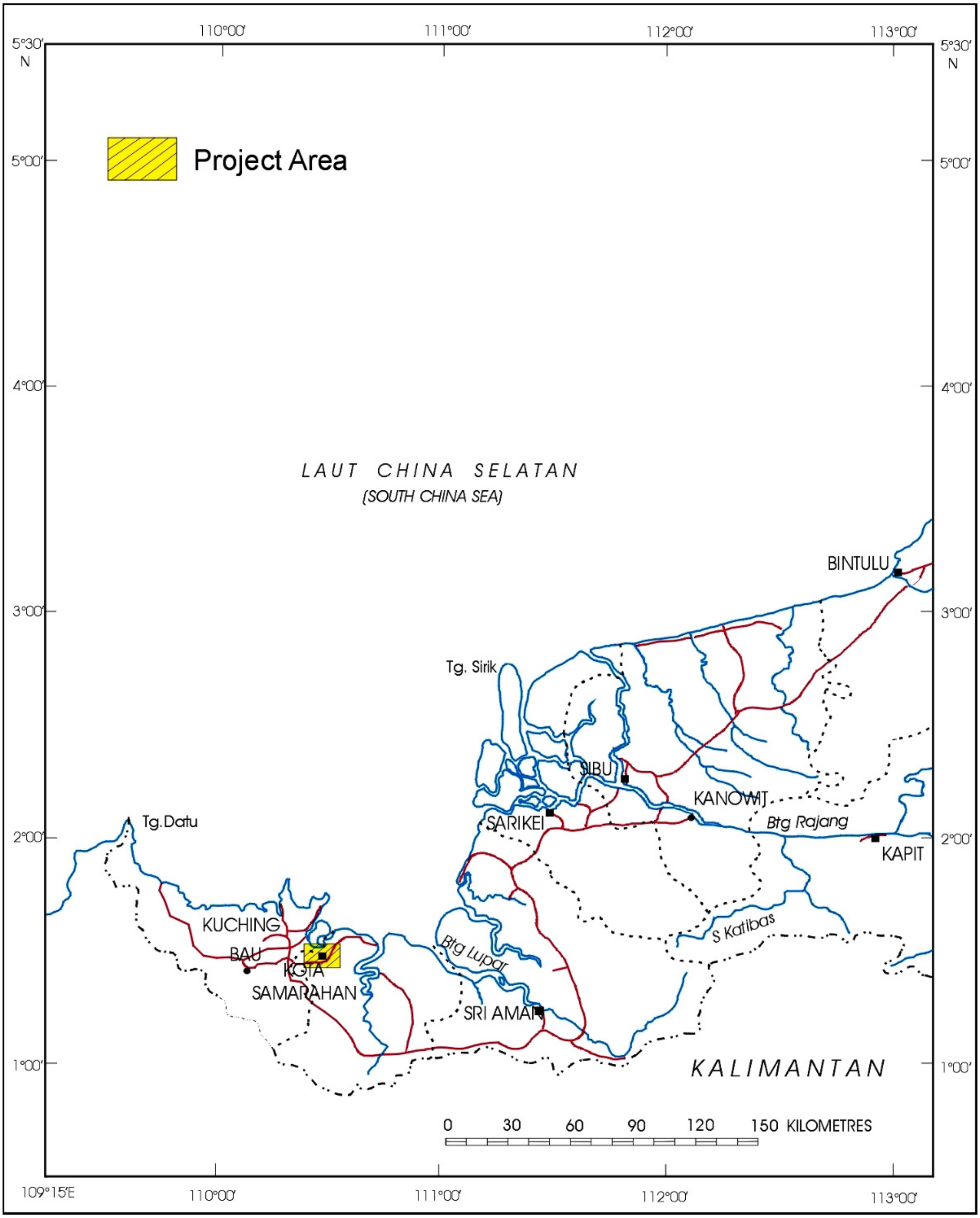


Figure 1. Location map of the study area.

1.3. Physiography - Topography, Drainage, Climate and Vegetation

The topography of the Kota Samarahan area is generally flat and low-lying with isolated hills rising out of the floodplains of the Batang Samarahan and Sungai Tuang rivers. The general elevation of the floodbasin is generally low and seldom higher than 5 m a.m.s.l. The majority of these areas are prone to high-tide flooding with the exception of a few localities on the natural levees along rivers and in the central area of the peat dome/basin and man-made bunds.

The major rivers that drain the study area into the South China Sea are the Batang Samarahan and its tributary, the Sungai Tuang. The meandering Batang Samarahan flows in a generally northerly direction, and the Sungai Tuang flows eastward to join the Batang Samarahan.

The area experiences an equatorial climate characterized by hot and humid conditions with a drier period occurring during the middle of the year. The annual rainfall at Kota Samarahan (Kuching area) reaches a maximum during the months of November and December.

The majority of the study area is covered by paddy fields, fruit orchards (cocoa, pineapple, coconut, tapioca, vegetables, etc.) and abandoned old rubber trees. Swamp forests cover a small portion in the western part of the area. Small mangrove swamp forests ('nipah/apong') occur in the south and southeast corner of the study area along the Batang Samarahan and Sungai Tuang rivers and their tributaries.

The initial objective of this study was to identify the peat deposits and to classify and map the distribution and natural occurrence of peat in the Kota Samarahan-Asajaya study area. A further objective was to determine the depth and thickness of peat in the project area and to study the tropical lowland peats in terms of their related petrological, palynological and organic geochemical characteristics (SRA) using samples collected from auger holes

2. Method of Investigation

2.1. Field Method

Quaternary peat and soft soil field mapping was conducted on foot in swampy jungle areas deemed inaccessible by motor vehicle. Augering was performed using hand augers (Figure 2). A peat or Russian-type sampler was primarily used for peat sampling. Samples collected using the peat sampler are not disturbed (Figure 2) compared with those collected with a gouge auger (Guts auger) because the samples remain enclosed within the sampling chamber throughout the sampling process. The auger holes and sampling points were located using a Garmin GPS device (models GPS 76 and GPSmap 76CSx).

Figure 2. Logging carried out in the field by the author and field assistants.

Hand-auger core samples were extracted, photographed and logged in the field (Figure 2). Peat sample classification was carried out in the field using the von Post and modified von Post description method described in the 'Guideline for Engineering Geological Investigation in Peat and Soft Soils' [18].

2.2. Field description

2.2.1. Peat and organic soil

Description of the peat in the field was attempted using the von Post description method, as described in Chapter 8.1.1-'Guideline for Engineering Geological Investigation in Peat and Soft Soils' [18] and as shown in Table 1.

2.2.2. Soft soil classification and description

In the field, the cores were logged and described based on textural and visual observations (Figure 2). The samples were described according to the Malaysian Soil Classification System for Engineering Purposes and Field Identification [17–19] which includes the factors of organic content and degree of humification for the classification of peat. Soils with organic content ranging from 3% to 20% are referred to as slightly organic soils, soils with organic content in the range of 20% to 75% are classified as organic soils, and finally, soils greater than 75% organic content are classified as peats. Fibric or fibrous peats (Ptf) have a humification range of H1 to H3, whereas hemic or moderately decomposed peats (Pth) have a range

Table 1. The von Post classification system and von Post degree of humification (H1 to H10) for peat (adapted from Andriesse [1]).

Symbol	Description
H1	Completely undecomposed peat that, when squeezed, releases almost clear water. Plant remains easily identifiable. No amorphous material present.
H2	Almost entirely undecomposed peat that, when squeezed, releases clear or yellowish water. Plant remains easily identifiable. No amorphous material present.
H3	Very slightly decomposed peat that, when squeezed, releases muddy brown water, but from which no peat passes between the fingers. Plant remains identifiable. No amorphous material present.
H4	H5 Moderately decomposed peat that, when squeezed, releases muddy water with a very small amount of amorphous granular peat escaping between the fingers. The structure of the plant remains is indistinct, although it is still possible to recognize certain features. The residue is very pasty. H6 Moderately highly decomposed peat with an indistinct plant structure. When squeezed, approximately one-third of the peat escapes between the fingers. The residue is very pasty but the plant structure is more distinct than before squeezing. H7 Highly decomposed peat. Contains a significant amount of amorphous material with faintly recognizable plant structure. When squeezed, approximately one-half of the peat escapes between the fingers. The water, if any is released, is very dark and almost pasty. H8 Very highly decomposed peat with a large quantity of amorphous material and indistinct plant structure. When squeezed, approximately two-thirds of the peat escapes between the fingers. A small quantity of pasty water may be released. The plant material remaining in the hand consists of residues such as roots and fibers that resist decomposition. H9 Almost fully decomposed peat in which there is hardly any recognizable plant structure. When squeezed, it is a fairly uniform paste. H10 Completely decomposed peat with no discernible plant structure. When squeezed, all of the wet peat escapes between the fingers.
H6	Moderately highly decomposed peat with an indistinct plant structure. When squeezed, approximately one-third of the peat escapes between the fingers. The residue is very pasty but the plant structure is more distinct than before squeezing.
H7	Highly decomposed peat. Contains a significant amount of amorphous material with faintly recognizable plant structure. When squeezed, approximately one-half of the peat escapes between the fingers. The water, if any is released, is very dark and almost pasty.
H8	Very highly decomposed peat with a large quantity of amorphous material and indistinct plant structure. When squeezed, approximately two-thirds of the peat escapes between the fingers. A small quantity of pasty water may be released. The plant material remaining in the hand consists of residues such as roots and fibers that resist decomposition.
H9	Almost fully decomposed peat in which there is hardly any recognizable plant structure. When squeezed, it is a fairly uniform paste.
H10	Completely decomposed peat with no discernible plant structure. When squeezed, all of the wet peat escapes between the fingers.

of H4 to H6. Sapric or amorphous peats range from H7 to H10 on the humification scale [19].

3. General Geology

The study area is underlain by soft Quaternary sediments. Two sedimentary facies exposed in the study area represent the peat (paludal) deposits and the floodplain deposits. In the augering and logging observations, these two facies were observed as deposited over estuarine/deltaic sediments.

3.1. Peat (Paludal) Deposits

The term paludal deposit has been introduced to define a Holocene unit consisting primarily of peat. According to the Malaysian Soil Classification System, soils with greater than 75% organic content are described as peat. Peats are organic deposits consisting of partially decomposed plant matter with or without clastic sediment. Paludal deposits are formed in swampy basins by the rapid accumulation of plant remains. In this environment, the decomposition of plant debris occurs at a much slower rate, thus enabling a net accumulation for the formation of peat.

Peat covers a small portion of the western part of the study area (referred to in this work as the 'Plaie area'). The thickness of the peat in the western (Plaie) area ranges from 0.2 m to 2.0 m. The types of peat mapped and encountered in the study area are as follows:

(a) Topogenous peat: Also known as clayey peat, this type is composed of plant remains and clastic sediments (with relatively higher ash content) and is formed in topographic depressions by plants that extracted nutrients from the mineral subsoil. Topogenous peat is influenced by floodwaters, which supply the mineral components (mainly clay and silt).

(b) Ombrogenous peat: This type consists of plant remains formed by plants growing solely from nutrients cycled through vegetation and peat (little or no mineral subsoil or ash content) and fed by rain water only. The produced peat is composed of plant remains without any clastic sediment from the mineral subsoil and is usually formed above flood levels and away from mineral deposition by flooding rivers.

Topogenous peat is composed of slightly to moderately decomposed plant matter. Topogenous peats with a humification range of H3 to H8 on the von Post humification scale were augered, logged and classified in the Plaie peat forest located in the western portion of the Kota Samarahan-Asajaya study area (Figure 9 and Table 1). Ombrogenous peat is formed above the tidal flood levels and is characterized by a high water content, an extremely low bulk density, a relatively higher decomposition rate and a relatively lower pH; this type is primarily composed of loose trunks, branches, roots, fruits and leaves [6]. The ombrogenous peat encountered in the study area was moderately to highly decomposed and ranged from H5 (hemic) to H7 (sapric) on the von Post scale of humification (Table 1). The Munsell color value was 7.5YR 2.5/2 (very dark brown) based on the Munsell Soil Color Chart, depending on the degree of humification.

3.2. Peat in the Western Peat Forest (Plaie) of the Study Area

The peat in the Plaie area is composed of slightly to moderately decomposed plant material ranging from H3 to H8 on the von Post degree of humification scale (Table 1). The encountered peat can be classified as fibric, hemic, hemic to sapric and sapric peat. The thickness of the peat layers ranges from 0.2 m to 2.3 m, with the thickness increasing in the westward direction. This peat has a brown to very dark brown color ranging from 10YR 3/3 (dark brown), 10YR 3/4 (dark yellowish brown), 10YR 5/2 (grayish brown), 10YR 5/ (gray), 10YR 4/1 (dark gray) to 7.5 YR 3/2, 7.5 YR 3/3, 7.5 YR 3/4 (dark brown) to 7.5 YR 2.5/2-2.5/3 (very dark brown) according to the Munsell Soil Color Chart. The groundwater levels in the western portion of the Kota Samarahan (Plaie) peat area lie approximately 0.3 m below the ground surface at auger locations KS.TP.02, KS.TP.07, KS.TP.08, KS.TP.09 and KS.TP.1 (Figures 3, 4, 5, 6, 7, 8 and 9).

3.3. Floodplain Deposits

The exposed floodplain deposits cover the northern, eastern and southern parts of the Kota Samarahan area, including the cross-river Asajaya area. In the western Plaie area and in a portion of the Kg Sui area, the deposits are overlain by peat deposits (Figure 3 and Figure 9).

Floodplain deposits, also known as riverine deposits, were formed by the deposition of river sediments during floods in the flood basins (backswamp deposits) or on levees along the river banks (levee deposits). These floodplain deposits are confined to the river valleys upstream of the estuarine/deltaic system and away from tidal marine or estuarine influences. The levee floodplain deposits form narrow belts along the banks of the rivers and streams and consist mainly of silt and fine sand, rare gravel and minor to abundant plant remains. The backswamp floodplain deposits, which are located behind the levees, are predominantly underlain by clays and silts with minor to abundant plant remains [20].

3.3.1. Lithology

The lithology of the Quaternary floodplain (backswamp) deposits observed to occur in the area consists mainly of clay, silt and fine sand with minor to abundant plant matter (wooden fragments 0.5 cm to 4 cm thick). Plant matter is observed to occur as wood fragments ranging from less than 5% to 50%.

These deposits are usually pale brown in color and, at times, greenish gray to dark bluish gray or bluish gray in color with Munsell color values of 10YR 3/3 to 10YR 6/3, GLEY 2 6/1, GLEY 2 5/1, GLEY 2 4/1 and 10YR 4/2. Typical auger log sections of the floodplain deposits are shown in Figures 4, 5, 6, 7 and 8.

3.4. Estuarine/Deltaic Deposits

Estuarine/deltaic deposits underlie the floodplain and peat deposits in the study area. These deposits are located at depths ranging from 0.5 to 2.5 m and deeper (at auger locations KS.TP.02 to KS.TP.10) in the western Plaie peat forest area, and conclusions are drawn from pollen analysis studies (manuscript in preparation); these deposits are generally believed to be marine in origin [20].

3.4.1. Lithology

The underlying estuarine/deltaic deposits are primarily composed of soft to very soft marine clayey silts and silt, clay and infrequent thin layers of fine sand accompanied by shell debris/fragments, as observed in auger holes KS.TS.05 and KS.TS.06. These deposits are greenish gray to dark bluish gray or bluish gray in color with Munsell color values of GLEY 2 6/1, GLEY 2 5/1, GLEY 2 4/1 and 10YR 4/2.

The estuarine and deltaic deposits are most likely marine in origin, and these deposits can be differentiated from the overlying floodplain deposits because the former have

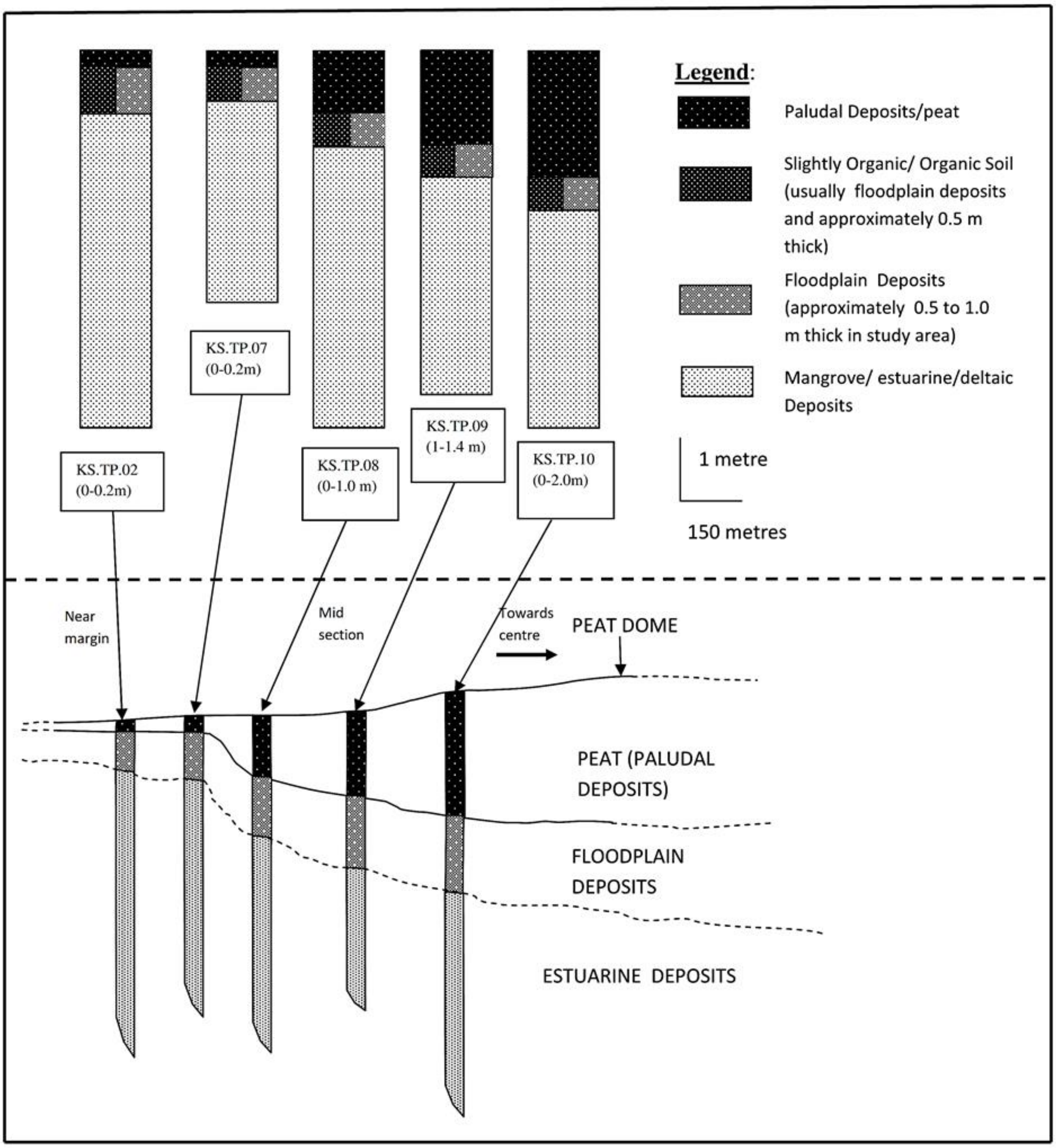


Figure 3. Location of peat cores KS.TP.02, KS.TP.07, KS.TP.08, KS.TP.09 and KS.TP.10 within the peat basin/dome/deposit (Plaie peat forest) and the depth or thickness of the peat (lithological depth concluded from field observations and pollen analyses).

a rather soft consistency and a gritty feel when rubbed between the fingers, are greenish gray to dark bluish gray or bluish gray in color, are saturated or very wet in appearance and are sometimes accompanied by marine shell fragments. In the field, these deposits are observed to contain few or no wooden fragments compared with the overlying floodplain deposits. They are usually sulfidic (acidic) and are observed in the field to produce yellow-colored minerals known as jarosite when exposed to and oxidized by the atmosphere [21].

KS.TP.02	AUGER LOG FOR PEAT OCCURRENCE STUDY(PhD PROJECT) IN THE KOTA SAMARAHAN AREA, WEST SARAWAK.		
PROJECT	THE GEOLOGICAL OCCURRENCE OF PEAT IN THE KOTA SAMARAHAN-ASAJAYA AREA		
LOCATION	N 01^0 28' 24.6" E 110^0 28' 13.6"		
AUGERHOLE NO.	KS.TP.02	**22/10/2011**	10.30 am
GROUND WATER LEVEL	0.3m	**TOP OF AUGERHOLE [(Above m.s.l)]**	7.9
RECORD BY	MOHAMAD TARMIZI BIN MOHAMAD ZULKIFLEY	**CHECKED BY**	MOHAMAD TARMIZI BIN MOHAMAD ZULKIFLEY

CLASSIFICATION SYMBOL: SYMBOL	CLASSIFICATION SYMBOL: GRAPHIC LOG	DEPTH (M)	SOIL DESCRIPTION	REMARKS
(Ptf)		0 **(Pt 0.2m)**	Dark brown FIBRIC PEAT. Wet. Wood fragments 20-30%, 3-4cm. Fine rootlets 40-50%, 4-5cm long, 1-2mm thick.	10 YR 3/3 H3B4F3W3,
Mo		0.2	Pale brown, banded, soft SLIGHTLY ORGANIC CLAYEY SILT. Wood fragments 5-10%,2-3cm. Very wet. Shell fragments 5-10%	10 YR 6/3
Mo		0.5	Banded, gray to light brownish gray to light yellowish brown, soft SLIGHTLY ORGANIC CLAYEY SILT. Wood fragments10-20%,2-3cm.Very wet. Sandy, 'gritty feel'	10 YR 6/1 to 10 YR 6/2 to 10 YR 6/4
M		1	Gray, soft SILT. Wood fragments 20-30%,1-2cm. Wet. Plastic.	10 YR 6/1
M		1.5	Gray, very soft SILT. Wood fragments <5%,1-2cm. Wet. Plastic. White and black shell fragments 5-10%, 1-2cm	10 YR 6/1
M		2	Gray, very soft SILT. Wood fragments 5-10%,1-2cm. Wet. Plastic. White and black shell fragments 5-10%, 1-2cm	10 YR 5/1
M		2.5	Gray, soft SILT. Wood fragments <5%,1-2cm. Wet. Plastic. White and black shell fragments <5%, 1-2cm	10 YR 5/1
M		3	Gray, soft to firm SILT. Wood fragments <5%, 1-2cm. Moist to wet. Plastic.	10 YR 5/1
M		3.5	Gray, soft to firm SILT. Wood fragments 5-10%, 1-2cm. Moist to wet. Plastic.	10 YR 5/1
M		4	Gray, soft to firm SILT. Wood fragments 5-10%, 1-2cm. Moist to wet. Plastic.	10 YR 5/1

LEGEND:

Paludal Deposits/Peat

Slightly Organic Soil

Floodplain Deposits

Estuarine/Deltaic Deposits

Figure 4. Log section of auger hole KS.TP.02.

KS.TP.07	AUGER LOG FOR PEAT OCCURRENCE STUDY(PhD PROJECT) IN THE KOTA SAMARAHAN AREA, WEST SARAWAK.		
PROJECT	THE GEOLOGICAL OCCURRENCE OF PEAT IN THE KOTA SAMARAHAN-ASAJAYA AREA		
LOCATION	N 01^0 28' 26.2" E 110^0 28' 07.4"		
AUGERHOLE NO.	KS.TP.07	28/10/2011	9.47 am
GROUND WATER LEVEL	0.3m	**TOP OF AUGERHOLE [(Above m.s.l)]**	6.0 TO 7.0
RECORD BY	MOHAMAD TARMIZI BIN MOHAMAD ZULKIFLEY	**CHECKED BY**	MOHAMAD TARMIZI BIN MOHAMAD ZULKIFLEY

CLASSIFICATION SYMBOL: SYMBOL	CLASSIFICATION SYMBOL: GRAPHIC LOG	DEPTH (M)	SOIL DESCRIPTION	REMARKS
(Ptf)		0 (0.2m peat)	Dark brown FIBRIC TO HEMIC PEAT.Brown,muddy water extruded. Slightly amorphous material present.Plant struct still identifiable. Wood fragments 20 to 30%, 3 to 4cm. Very wet. Slightly pasty.	7.5 YR 3/4 H3B4F2W1 to H4B4F2W1
Mo(poor sorted silt)			Light gray- gray (banding),very soft SLIGHTLY ORGANIC SILT. Wood frag.10- 20%. Rootlets 2-4 cm,1-2 mm thick.Wet .Sticky,plastic.	10 YR 7/2 to 10 YR 6/1
M (vy.poorly sorted silt)		0.5	Grey ,soft SILT. Wood fragments 10 to 20%.	10 YR 6/1
(M)		1	Gray, soft to firm SILT.Wood fragments 10 %.Shell fragments present (black,flat,1 to 2cm long,1 to 2 cm wide)	10 YR 6/1
M (poorly sorted silt)		1.5	Gray ,soft SILT.Wood fragments 10%.	10 YR 5/1
(M)		2	.... Gray ,very soft SILT.Wood fragments <5%	10 YR 5/1
(M)		2.5	Gray ,soft SILT.Wood fragments <5%	10 YR 5/1
(M)		2.9	Gray ,soft SILT.Gritty feel	10 YR 4/1
M (poorly sorted silt)		3	Dark gray , soft SILT.Wood fragments 10 to 20 %.	10 YR 4/1
(M)		3.5	Dark gray , soft SILT.Wood fragments 10 to 20%.Gritty feel.	10 YR 4/1
(M)		4	Dark gray soft SILT.Wood fragments 10 to 20%.Gritty feel (Augering stopped at 4.0 m due to consistant soil type return)	10 YR 4/1

LEGEND:

Paludal Deposits/Peat

Slightly Organic Soil

Floodplain Deposits

Estuarine/Deltaic Deposits(marin

M-silt
'vy' -very
'frag'-fragment

Figure 5. Log section of auger hole KS.TP.07.

KS.TP.08	AUGER LOG FOR PEAT OCCURRENCE STUDY(PhD PROJECT) IN THE KOTA SAMARAHAN AREA, WEST SARAWAK.		
PROJECT	THE GEOLOGICAL OCCURRENCE OF PEAT IN THE KOTA SAMARAHAN-ASAJAYA AREA		
LOCATION	N 01^{0} 28' 26.4" E 110^{0} 28' 04.1"		
AUGERHOLE NO.	KS.TP.08	28/10/2011	9.47 am
GROUND WATER LEVEL	0.3m	**TOP OF AUGERHOLE [(Above m.s.l)]**	7
RECORD BY	Mohamad Tarmizi M.Z.	**CHECKED BY**	MOHAMAD TARMIZI MOHAMAD ZULKIFLEY

CLASSIFICATION SYMBOL: SYMBOL	CLASSIFICATION SYMBOL: GRAPHIC LOG	DEPTH (M)	SOIL DESCRIPTION	REMARKS
(M)		4.5	Grey soft SILT. Wood fragments 10% Intermediate plasticity	10 YR 5/1
(M)		5	Grey soft SILT. Wood fragments 5 to10% Intermediate plasticity	10 YR 5/1
M (poorly sorted silt)		5.5	Grey soft SILT. Wood fragments 5 to10% Intermediate plasticity	10 YR 5/1
		6	(Augering stopped at 6.0m due to consistent soil type return)	

LEGEND:

Paludal Deposits/Peat			Slightly Organic Soil
Floodplain Deposits		M-silt (L.P.S.A.) 'vy' -very 'frag'-fragment	
Estuarine/Deltaic Deposits			

Figure 6. Log section of auger hole KS.TP.08.

KS.TP.09	**AUGER LOG FOR PEAT OCCURRENCE STUDY(PhD PROJECT) IN THE KOTA SAMARAHAN-ASAJAYA AREA, WEST SARAWAK.**		
PROJECT	THE GEOLOGICAL OCCURRENCE OF PEAT IN THE KOTA SAMARAHAN-ASAJAYA AREA		
LOCATION	N01^0 28' 26.4" E110^0 28' 01.8"		
AUGERHOLE NO.	KS.TP.09	**29/10/2011**	11.40 a.m.
GROUND WATER LEVEL	0.3m	**TOP OF AUGERHOLE [(Above m.s.l)]**	9.2m
RECORD BY	MOHAMAD TARMIZI MOHAMAD ZULKIFLEY	**CHECKED BY**	MOHAMAD TARMIZI BIN MOHAMAD ZULKIFLEY

CLASSIFICATION SYMBOL		**DEPTH (M)**	**SOIL DESCRIPTION**	**REMARKS**
SYMBOL	**GRAPHIC LOG**			
(Pta)		0	Dark brown SAPRIC PEAT. Dark brown muddy water extruded. Wet. 1/3 to 1/2 residue left. Pasty.Plant structure indistinct. Amorphous material content considerable.Decomposition strong. Rootlets and fibers 20%.Rootlets 1 to 2 cm long,1 to 2 mm thick. Wood fragments 20 to 30 %, 2 to 20cm long.	7.5YR , 3/3 H7B3 F2 W2 to H8B3 F2 W2 Sapric Pt
(Pth-Pta)		0.5	Dark brown HEMIC to SAPRIC PEAT. Brown muddy water extruded. Wet. 1/3 to 1/2 residue left. Pasty. Plant structure indistinct. Amorphous material content considerable. Wet Decomposition strong. Rootlets and fibers 20%, 1 to 2 cm long, 1 to 2 mm thick. Wood frag.20 to 30%, 2 to 20cm long.	7.5YR , 3/2 H6 B3 F1 W2 H7 B3 F1 W2 hemic-sapric peat
(Pth-Pta)		1	Dk. brown HEMIC to SAPRIC PEAT. Brown muddy water extrud. 2/3 or more residue left. Wet. Pasty. Plant structure indistinct. Amorph. material content considerable. Decomp. moderate. Rootlets and fibers 20 %, Rootlets 1 to 2 cm in length. Wood frag.20 to 30%, 2 to 15 cm long. Wet	7.5YR ,3/2 H5B4F2W2 H6B4F2W2 hemic-sapric peat
(M)		1.5	Banded, dark yellowish brown to yellowish brown ,very soft SLIGHTLY ORGANIC SILT. Wet. Plastic Light gray, very soft SILT. Wet. Plastic	10 YR , 4/6 to 10 YR , 5/4 10 YR, 7/2
M		2	Dark gray, very soft SILT. Very wet. Plastic.	10 YR , 4/1
M		2.5	Dark gray, very soft SILT. Very wet. Plastic.	10 YR , 4/1
M		3	Dark gray, soft to firm SILT. Plastic Wood fragments 10 to 20%	10YR ,4/1
M		3.5	Dark gray,soft to firm SILT. Plastic Wood fragments 20 to 30%	10YR ,4/1
M (Vy.poorly sorted silt)		4	Dark gray,soft SILT. Plastic Wood fragments 10 to 20%	10YR ,4/1

LEGEND:	Paludal Deposits/Peat			Slightly Organic Soil
	Floodplain Deposits	M-silt (L.P.S.A.) 'vy' -very 'frag'-fragment		'Dk.'-Dark 'Extrud'-extruded
	Estuarine/Deltaic Deposits			

KS.TP.09	AUGER LOG FOR PEAT OCCURRENCE STUDY(PhD PROJECT) IN THE KOTA SAMARAHAN-ASAJAYA AREA, WEST SARAWAK.			
PROJECT	THE GEOLOGICAL OCCURRENCE OF PEAT IN THE KOTA SAMARAHAN-ASAJAYA AREA			
LOCATION	N01^{0} 28' 26.4" E110^{0} 28' 01.8"			
AUGERHOLE NO.	KS.TP.09	29/10/2008	11.40 a.m.	
GROUND WATER LEVEL	0.3m	TOP OF AUGERHOLE [(Above m.s.l)]	9.2m	
RECORD BY	MOHAMAD TARMIZI BIN MOHAMAD ZULKIFLEY	CHECKED BY	MOHAMAD TARMIZI BIN MOHAMAD ZULKIFLEY	

CLASSIFICATION SYMBOL: SYMBOL	CLASSIFICATION SYMBOL: GRAPHIC LOG	DEPTH (M)	SOIL DESCRIPTION	REMARKS
M (poorly sorted silt)		4.5	Dark gray,soft SILT.Intermediate plasticity. Wood fragments 10 to 20%	10YR ,4/1
(M)		5	Dark gray,soft SILT. Intermediate plasticity. Wood fragments 10 to 20%	10YR ,4/1
		5.5	(Augering stopped at 5.5 metres due to consistant soil type return)	

LEGEND:

Paludal Deposits/Peat

Slightly Organic Soil

Floodplain Deposits

M-silt (L.P.S.A.)
'vy' -very
'frag'-fragment

'Dk.'-Dark
'Extrud'-extruded

/Deltaic Deposits

Figure 7. Log section of auger hole KS.TP.09.

KS.TP.10	AUGER LOG FOR PEAT OCCURRENCE STUDY(PhD PROJECT) IN THE KOTA SAMARAHAN-ASAJAYA AREA, WEST SARAWAK.		
PROJECT	THE GEOLOGICAL OCCURRENCE OF PEAT IN THE KOTA SAMARAHAN -ASAJAYA AREA		
LOCATION	N01° 28' 25.7" E110° 27' 57.5"		
AUGERHOLE NO.	KS.TP.10	**29/10/2011**	10.05 am
GROUND WATER LEVEL	0.5m	TOP OF AUGERHOLE **[(Above m.s.l)]**	9.2m
RECORD BY	Mohamad Tarmizi M.Z.	**CHECKED BY**	Mohd Tarmizi M.Z.

CLASSIFICATION SYMBOL: SYMBOL	CLASSIFICATION SYMBOL: GRAPHIC LOG	DEPTH (M)	SOIL DESCRIPTION	REMARKS
(Pth-Pta)		0	Vy. Dk. Brown HEMIC to SAPRIC PEAT. Muddy water and peat extrud. 1/2 to 1/3 residue left. Strongly pasty. Plant struct. faintly recognizable. Amorphous material content high.Decomposition strong. Wood fragments 40%, 2 to 20 cm long. Wet. Rootlets 2 to 3 cm long,1 to 3 mm thick.	7.5YR , 2.5/2 H6-H7 B3 F2 W2 hemic to sapric Pt
(Pth)		0.5	Very dark brown HEMIC PEAT. Muddy water and some peat.extrud., less than 1/2 residue left. Pasty. Plant struct.recog.but vague to indistinct. Amorphous material content considerable. Decomposition moderately strong. Wood fragments 20 to 30%, 2 to 20cm long. Wet.	7.5YR , 2.5/2 H5-H6 B4 F1 W1 hemic peat
(Pth)		1	Very dark brown HEMIC PEAT. Brown muddy water extruded,1/2 to 2/3 residue left. Somewhat pasty. Plant structure indistinct. Some amorph. material present. Decomp.slight to moderate. Wood fragments 50 to 60%, 10 to 20 cm in length. Wet	7.5YR ,2.5/2 H4-H6 B4F2W2 hemic peat
(Ptf-Pth)		1.5	Vy.dk brown FIBRIC to HEMIC PEAT. Brown,muddy water extruded, not pasty, less than 1/2 to 2/3 residue left. Plant structure indistinct. Some amorph. material present. Decomposition slight to moderate. Wood fragments 50 to 70%, 5 to 10 cm in length. Wet	7.5YR, 2.5/2 H3-H5 B4F2W2 fibric to hemic Pt
(M)		2	Brown to gray(banding) ,very soft SLIGHTLY ORGANIC SILT. Plastic Wood fragments 30 to 40%. Wet	10 YR ,5/3 to 10 YR ,5/1
M		2.5	Dark gray, very soft SILT. Plastic Wood fragments 30 to 40%. Wet	10YR ,4/1
M		3	Dark gray, soft SILT. Plastic Wood fragments 10 to 20%. Wet.	10YR ,4/1
M		3.5	Dark gray, soft to firm SILT. Plastic Wood fragments 5 to 10%. Moist to wet.	10YR ,4/1
M		4	Dark gray, soft to firm SILT. Plastic Wood fragments 10 to 20%. Moist to wet.	10YR ,4/1

LEGEND:

- Paludal Deposits/Peat
- Floodplain Deposits
- Estuarine/Deltaic Deposits
- Slightly Organic Soil

M-silt (L.P.S.A.)
'vy' -very
'frag'-fragment
Pt.-peat
'Dk.'-Dark
'Extrud'-extruded

Figure 8. Log section of auger hole KS.TP.10.

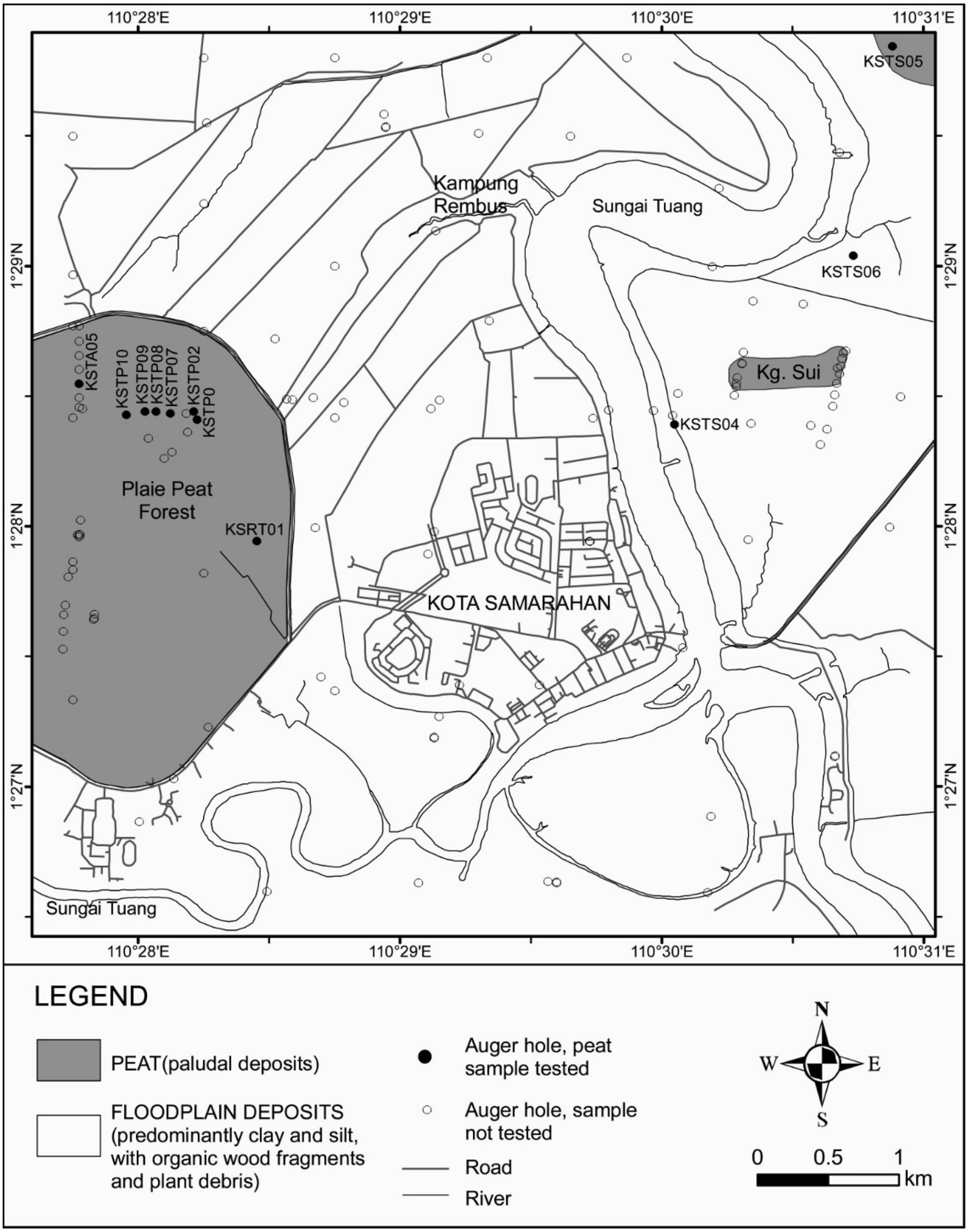


Figure 9. Geological map of the Kota Samarahan-Asajaya study area in West Sarawak indicating the sample locations in the western Plaie peat forest area. The enlarged inverted section (top left-hand corner) denotes the locations of the major peat cores selected for this study.

3.5. Peat Characterization

Table 2 displays the characterization of peat as described in the field based on a von Post classification of logged auger holes KS.TP.02, KS.TP.07, KS.TP.08, KS.TP.09 and KS.TP.10 at locations near the peat basin boundary or margin near the center of the peat dome in the western peat forest of the Kota Samarahan-Asajaya study area. Most of the peat profiles show varying and generally decreasing humification levels with vertical depth. In addition, lateral variation of the peat humification levels occurs from the margin to the near-center of the peat dome. Field identification and classifications (von Post) indicate a lateral variation of the peat decomposition levels in the form of predominantly occurring fibric, fibric to hemic, sapric and hemic to sapric peat, occurring progressively from the margin towards the near-center area of the peat dome or basin (Table 2).

4. Petrographic Method and Sample Preparation

A total of five auger samples were collected from the top 0–0.5 m of the peat layer in the peat dome from the margin towards the near-center at the locations labeled KS.TP.02, KS.TP.07, KS.TP.08, KS.TP.09 and KS.TP.10 (Figure 3 and Figure 9).

The samples were oven dried at 400°C for three days before being crushed into fine powder and analyzed using a source rock analyzer (SRA Weatherford), which is equivalent to the conventional Rock-Eval instrument used for evaluating source rock quality in petroleum exploration. Details of the SRA and pollen analysis results and related discussions are included in articles currently under preparation (manuscript in preparation). The current paper discusses the distribution, classification and petrographic characteristics of the above-mentioned tropical lowland peat swamp organic palynofacies.

4.1. Petrographic Study

For petrographic maceral identification, dried peat samples (oven dried at 400°C for three days) were prepared by mounting crushed auger peat sample fragments in slow-setting polyester (serifix) together with a resin hardener and allowing them to set. The samples were subsequently ground flat on a diamond lap and polished using silicon carbide paper of different grades (P800, P2400 and P4000) with water as a lubricant. Using finer alumina suspensions (sizes of 1 micron, 0.3 micron and 0.05 microns), the polished block sample surfaces were finally polished to achieve a highly reflective surface, and the polished sections were deemed suitable for petrographic analysis. Petrographic examination was carried out under oil immersion with plane-polarized reflected light using a LEICA DM6000M microscope and a LEICA CTR6000 photometry system equipped with fluorescence illuminators. A combination of BP 340-380 excitation filters, a RKP 400 dichromatic mirror and a LTP 425 suppression filter was used for the filter system. Peat maceral identification was carried out under both normal reflected 'white' light and UV (ultra-violet) light for all five peat samples, and the results correlated with the identified von Post field classification and humification (H1 to H10) levels and ranges (see Table 1). Petrographic maceral studies of the peat samples were performed to identify the diagenetic stages involved in the peatification or humification process and were based on peat diagenetic studies by Stout and Spackman [22] and Jaafar [23]. Visual peat organic matter (coal kerogen-equivalent) studies and pollen analyses were carried out by microscopic examination of palynological slides under transmitted light.

4.2. Source Rock Analysis (SRA)

The SRA instrument is a non-isothermal open-system source rock analyzer (comparable to Rock-Eval) used to measure parameters such as S1, S2, S3, TOC and Tmax values. The peat parameters were measured by the SRA (TPH/TOC mode) for peat samples located from the margin of the peat dome towards the center at locations KS.TP.02, KS.TP.07, KS.TP.08, KS.TP.09 and KS.TP.10 (in preparation) from a depth of 0 m to 0.5 m.

4.2.1. SRA Results (HI values)

The hydrogen index (HI) (given in mg HC per gram TOC) represents the normalized hydrogen content of a rock sample. Kerogen typing is derived from this value whereby type I kerogens are hydrogen rich, type III kerogens are hydrogen poor and type II kerogens are intermediate between type I and III (Table 3). The HI values decrease with sample maturity. The HI value may decrease due to weathering or mineral matrix interactions that cause a reduction in the S2 value [24].

5. Results

5.1. Petrographic Study Results

Photomicrographs of polished sections of the peat macerals are shown in Figure 10 (a to p). The peat maceral (premaceral) types are observed to vary with

Table 2. Description of sampled peats occurring from the peat basin margin (near location KS.TP.02) towards the near-center areas of the peat dome (near location KS.TP.10) in the western peat forest of the Kota Samarahan-Asajaya study area.

Auger hole/sample no.	KS.TP.02	KS.TP.07	KS.TP.08	KS.TP.09	KS.TP.10
Thickness of peat	0.2 m	0.2 m	1.0 m	1.4 m	2.0 m
Classification of peat type with depth (von Post classification)	0 to 0.2 m: H3	0 to 0.2 m H3-H4	0 to 0.5 m H7 to H8 0.5 to 1.0 m: H6 to H7	0 to 0.5 m H7 to H8 0.5 to 1.0 m: H6 to H7 1.0 to 1.4 m: H5 to H6	0 to 0.5 m: H6 to H7 0.5 to 1.0 m: H5 to H6 1.0 to 1.5 m: H4 to H6 1.5 to 2.0 m: H3 to H6
Classification/ Type of peat with depth	0 to 0.2 m: Fibric	0 to 0.2 m: Fibric to hemic	0 to 0.5 m: Sapric (amorphous) 0.5 to 1.0 m: Hemic to Sapric) (amorphous	0 to 0.5 m: Sapric (amorphous) 0.5 to 1.0 m: Hemic to Sapric (amorphous) 1.0 to 4.0 m: Hemic	0 to 0.5 m: Hemic to sapric 0.5 to 1.0 m: Hemic 1.0 to 1.5 m: Hemic 1.5 to 2.0 m: Fibric to Hemic
Groundwater level (distance from surface in meters)	0.3 m (below surface)	0.3 m (below surface)	0.3 m (below surface)	0.3 m (below surface)	0.5 m (below surface)
Color of peat (Munsell color code)	0 to 0.2 m: 10YR 3/3	0 to 0.2 m: 7.5YR 3/4	0 to 0.5 m: 7.5YR 2.5/2 0.5 to 1.0 m: 3.5YR 2.5/2	0 to 0.5 m: 7.5 YR 3/3 0.5 to 1.0 m: 7.5YR 3/2 1.0 to 1.4 m: 7.5YR 3/2	0 to 0.5 m: 7.5YR 2.5/2 0.5 to 1.0 m: 7.5YR 2.5/2 1.0 to 1.5 m: 7.5YR 2.5/2 1.5 to 2.0 m: 7.5YR 2.5/2
Elevation (a.m.s.l.) (Garmin GPS)	7.9	6	7	9.2	9.2

Table 3. Relationship between HI values and kerogen type (adapted from Espitalie *et al.* [24]).

HI	Kerogen Type
<150	Type IV (gas prone)
150-300	Type III (gas/oil prone)
300-600	Type II (oil prone)
>600	Type I (oil prone)

humification levels together with their peat diagenetic stages from the basin margin towards the near-center of the peat dome. Descriptions of the dominant maceral types and dominant peat diagenesis stages (after Stout and Spackman [22]) are listed in Table 4.

The dominant coal-equivalent peat palynomaceral (or phytoclasts and palynomorphs) and related peat organic matter (kerogen) type classifications occurring from the tropical lowland peat basin margin to the midsection and further towards the near-center areas of the peat dome are presented in Table 5. The coal organic facies and palynofacies nomenclature and classification are primarily based on the work of Ercegovac and Kostić [25]. Comparisons of the dominant peat organic matter (coal-equivalent kerogen) types and classification as concluded from both the palynological study of slides (transmitted light) and SRA analysis of the tropical lowland peats are presented in Table 6. The related tropical lowland peat (coal-equivalent) organic facies and palynofacies terminology and classification of the peat basin/dome in the study area are proposed as shown in Table 7. The organic facies and palynofacies nomenclature and classification for coals were proposed by Ercegovac and Kostić [25].

5.2. SRA Results

The marginal peats at KS.TP.02 have a HI value of 337 HC/g TOC (type II; oil prone). The HI value increases from the margin of the peat basin towards the center, i.e., from

Table 4. Description of the dominant maceral types and dominant peat diagenesis stages (after Stout and Spackman [22]) observed in sampled peats deposited from the peat basin margin (near location KS.TP.02) towards the approximate center of the peat dome (at location KS.TP.10) in the western peat forest (Plaie) of the Kota Samarahan-Asajaya study area.

Auger hole/sample no.	**KS.TP.02**	**KS.TP.07**	**KS.TP.08**	**KS.TP.09**	**KS.TP.10**
Thickness of peat	0.2 m	0.2 m	1.0 m	1.4 m	2.0 m
Color of peat (Munsell color code)	0 to 0.2 m: 10YR 3/3	0 to 0.2 m: 7.5YR 3/4	0 to 0.5 m: 7.5YR 2.5/2	0 to 0.5 m: 7.5 YR 3/3	0 to 0.5 m: 7.5YR 2.5/2
Major macerals occurring with depth of peat (0-0.5 m)	Fresh yellow to orange cells and red textinite	Fresh yellow to orange cells, red textinite with dark humodetrinite and humocollinite	Red textinite with humodetrinite and humocollinite	Humodetrinite and humocollinite	Humodetrinite and humocollinite
Diagenetic phases observed in the peatification/ decomposition process and approximate percentage of peat macerals undergoing diagenetic phase	I, II, post-phase V. -Fresh cells-yellow to whitish yellow: 0-10%	I, II, post-phase V. -Fresh cells-yellow to whitish yellow: 10-25%	I, II, post-phase V. -Wood fragments-fresh cells-yellow to orange: 5-10%,	II, III, IV, V or post-phase V. -Red textinite (II): 5-10%	II, V and post-phase V. -Cell fragments /humodetrinite and humic colloidal material /humocollinite (post V): 60-70%
I, II, III, IV or V or post-phase V, color of cells or maceral types	-Red textinite (II): 40-50% -Humodetrinite and humocollinite (post-phase V): 10-20% -Clastic fragments/mineral soil: 30-50%	-Red textinite (II) :30-40% -Humodetrinite and humocollinite (post-phase V): 30-40% -Clastic fragments: 5-15%	-Red textinite (II 30-40% -Humodetrinite and humocollinite (post-phase V): 60-70%	-Gray textinite (III): 5-10% – texto-ulminite (phase IV): 5-10% -Eu-ulminite (phase V): 5-10% -Cell fragments /humodetrinite and humic colloidal material / humocollinite (post-phase V): 70-80%	-Red textinite (II): 30-40%, -Eu-ulminite (phase V): 5-10%
Dominant stage/phase of peat diagenesis (phase I-V or post-phase V/fragment or colloidal cell stage) at 0- to 0.5-m depth.	Dominant phase: phase II (von Post field classification: FIBRIC)	Dominant phase: phase II and post-phase V (II=V, equivalent% -(von Post field classification: FIBRIC-HEMIC)	-Wood fragments-fresh cells-yellow to orange: 5-10%, -Red textinite (II): 30-40% -Humodetrinite and humocollinite (post-phase V): 60-70% Dominant phase: post-phase V followed by phase II (V>II, von Post field classification: SAPRIC)	Dominant phase: post-phase V (von Post field classification: SAPRIC)	Dominant phase: post-phase V, followed by phase II (von Post field classification: HEMIC to SAPRIC)
Organic matter (kerogen) type (from SRA data)	II	III	III	II	II
Dominant plants growing presently (and PC)	Waxy plants, leaves, shrubs (PC I)	*S. albida* wood fragments, (mixed PC I-II) (?)	*S. albida* wood fragments (PC II)	Waxy plants, ferns (mixed PC II-III-IV?)	Waxy plants, ferns (mixed PC II-III-IV?)
Peat premaceral photos	Figures 10 a, b, c and d.	Figures 10 e, f, g and h.	Figures 10 m and n.	Figures 10 o and p	Figures 10 i, j, k and l
Peat depth	0.2 m, very shallow	0.2 m, shallow	1.0 m, intermediate	1.4 m, intermediate	2.0 m, intermediate to deep
Peat type (Paramananthan [6])	Topogenous peat	Topogenous peat	Topogenous peat	Topogenous peat	Ombrogenous peat

Table 5. Dominant coal-equivalent palynomaceral (or phytoclasts and palynomorphs) and related organic matter (kerogen) type classification occurring from the tropical lowland peat basin margin to the midsection and further towards the near-center areas of the peat dome (organic facies and palynofacies nomenclature and classification primarily based on work by Ercegovac and Kostić [25]).

Sample location	Dominant palynomaceral (phytoclasts and palynomorphs) present (approximate overall percentage)	Dominant coal-equivalent maceral group	Dominant coal-equivalent maceral type	Dominant ot organic matter (coal equivalent-kerogen) type (visual classification from palynological slides)	Other minor palynomacerals present
KS.TP.02 (0-0.5 m)	Cuticles, spores and pollen (60%)	Liptinite	Cutinite, sporinite and pollinite	II	30% woody tissue: biostructured woody tissue with cellular structure still visible and degraded black wood with brown edges. Low percentages of black opaque highly oxidized woody/plant tissue, amorphous organic matter and some fungal debris (hyphae and spores).
KS.TP.07 (0-0.5 m)	Brown-translucent woody tissue, degraded dark brown plant tissue, biostructured woody tissue and black woody tissue (with brown edge) (70%)	Vitrinite	Telinite; telocolinite	III	Low percentages of fungal debris, black opaque highly oxidized plant tissue, pollen and spore grains and cuticles and rare occurrences of amorphous organic matter.
KS.TP.08 (0-0.5 m)	Mostly degraded yellow plant tissue with original cellular structure still preserved, biostructured woody tissue, brown-translucent woody tissue, black wood (with brown edges) (80%)	Vitrinite	Subrinite/telinite, telinite, telocolinite	III	Moderate percentages of pollen, spores and black opaque highly oxidized plant tissue. Minor amorphous organic matter and fungal debris are present in low percentages.
KS.TP.09 (0-0.5 m)	Cuticles, spores and pollen grains (70%)	Liptinite	Cutinite, sporinite and pollinite	II	Moderate to low percentage of biostructured woody tissue, black woody tissue with brown edges, brown-translucent woody tissue and some degraded yellow plant tissue with original structure still visible. Rare occurrences of fungal debris and black opaque highly oxidized plant tissue.
KS.TP.10 (0-0.5 m)	Cuticles, spores and pollen grains (30 to 40%). Degraded yellow plant tissue (cellular structure still visible), brown- translucent woody tissue and biostructured woody tissue (30 to 40%).	Equal amounts of liptinine and vitrinite/huminite groups.	Cutinite, subrinite, telinite, telocolinite	mixed II-III	Low percentages of fungal debris, amorphous organic matter and black opaque highly oxidized plant tissue.

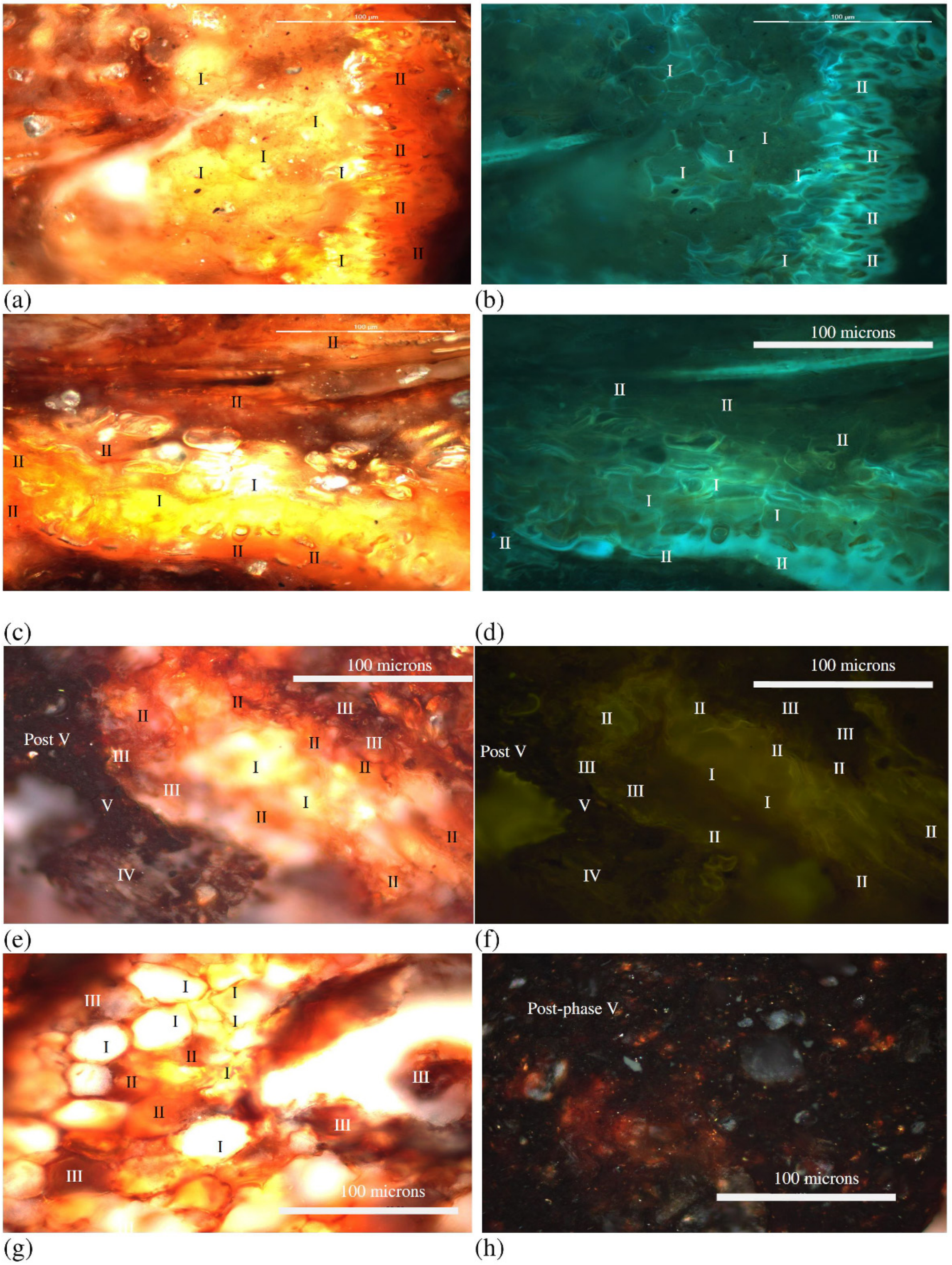
Table 6. Comparison of dominant peat organic matter (coal-equivalent kerogen) type classification as concluded from palynological studies and SRA analyses for the peats occurring from the basin margin to the midsection and further towards the near-center areas of the dome.

Sample location	Dominant palynomaceral (phytoclasts and palynomorphs) present (approximate overall percentage)	Dominant coal-equivalent maceral group	Dominant coal-equivalent maceral type	Dominant organic matter (coal-equivalent kerogen) type (from analysis of palynological slides)	Dominant organic matter (kerogen) type by SRA analyses (based on HI index values) (Espitalie *et al.* [24])
KS.TP.02 (0-0.5 m)	Cuticles, spores and pollen (60%)	Liptinite	Cutinite, sporinite and pollinite	II	II
KS.TP.07 (0-0.5 m)	Brown-translucent woody tissue, degraded dark brown plant tissue, biostructured woody tissue and black woody tissue (with brown edges) (70%)	Vitrinite	Telinite; telocolinite	III	III
KS.TP.08 (0-0.5 m)	Mostly degraded yellow plant tissue with original cellular structure still preserved, biostructured woody tissue, brown-translucent woody tissue, black wood (with brown edges) (80%)	Vitrinite	Subrinite/telinite, telinite, telocolinite	III	III
KS.TP.09 (0-0.5 m)	Cuticles, spores and pollen grains (70%).	Liptinite	Cutinite, sporinite and pollinite	II	II
KS.TP.10 (0-0.5 m)	Cuticles, spores and pollen grains (30 to 40%). Degraded yellow plant tissue (cellular structure still visible), brown- translucent woody tissue and biostructured woody tissue (30 to 40%).	Approximately equal amounts of liptinine and vitrinite/huminite groups.	Cutinite, subrinite, telinite, telocolinite	Mixed types II and III	II

Table 7. Proposed tropical lowland peat (coal-equivalent) organic facies and palynofacies nomenclature and classification (based on Ercegovac and Kostić [25]) of the peat basin/dome in the study area.

Category of structured (SOM) /structureless (amorphous) organic matter (AOM)	Constituent/source	Peat (coal-equivalent) maceral group	Peat (coal-equivalent) maceral	Peat coal-equivalent organic matter type (kerogen) classification
Phytoclast (SOM)	Cuticle (leaf-epidermal tissue)	Liptinite	Cutinite	II
Phytoclast (SOM)	Cortex tissues of stem or root	Huminite/vitrinite	Subrinite/telinite	III
Phytoclast (SOM)	Woody tissues (secondary xylem)	Huminite/vitrinite	Telinite, telocolinite	III
Phytoclast (SOM)	Charcoal, biochemically oxidized wood	Inertinite	Pyrofusinite, degradofusinite	IV
Phytoclast (SOM)	Fungal debris: hyphae, spores	Inertinite	Secretinite	IV
Palynomorphs (SOM)	Spores and pollen grains	Liptinite	Sporinite, pollinite	II

207 HC/g TOC (type III; gas/oil prone) at KS.TP.07 to 407 HC/g TOC (type II; oil prone) at KS.TP.10. The organic matter types vary from type II (oil prone) at the margin to type III (gas/oil prone) in the mid-section area to type II (oil prone) again towards the basin center (Table 9). In general, a mixture of organic matter types II and III (kerogen) occurs horizontally on the tropical lowland peat basin within a depth interval of 0 m to 0.5 m.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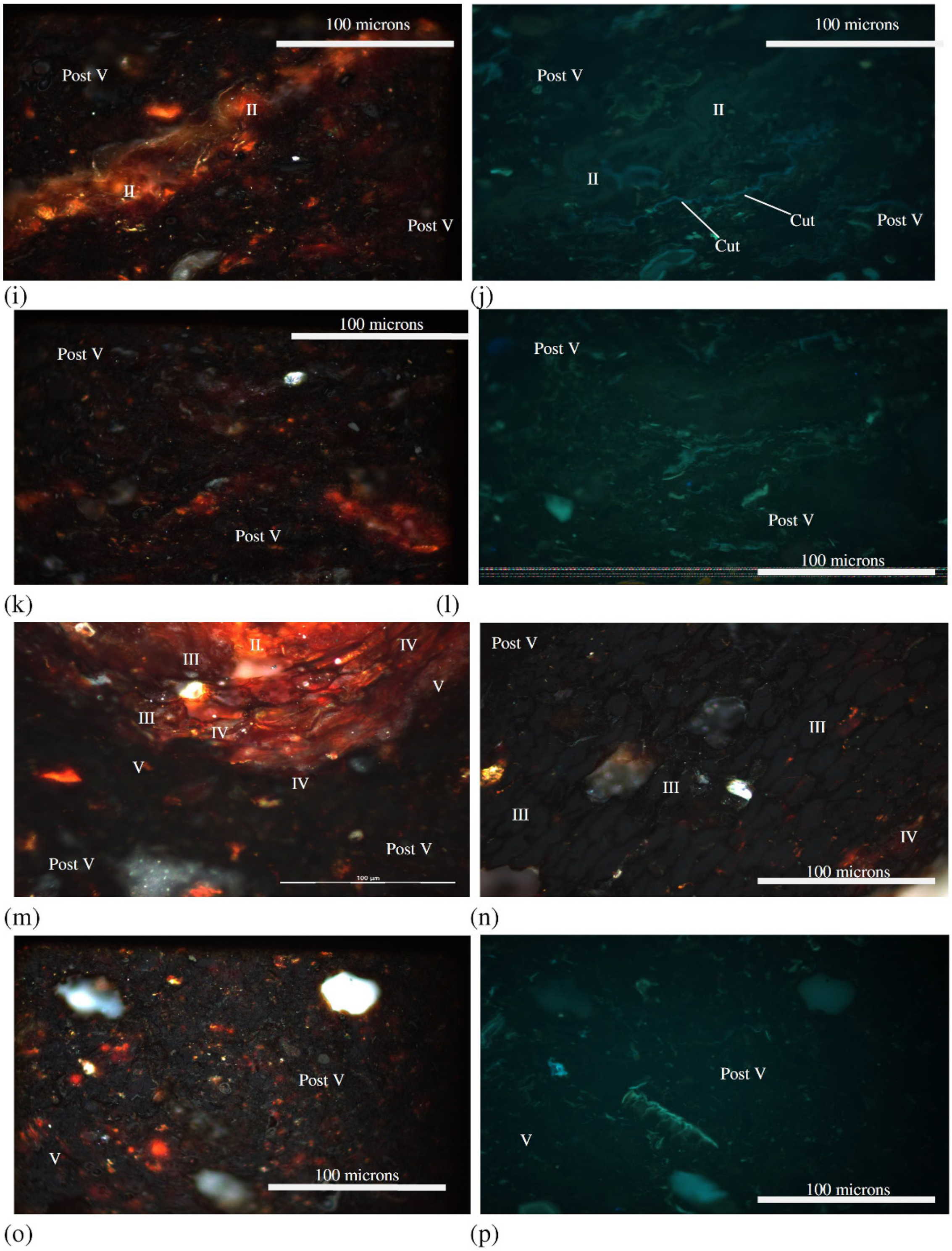
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(p)

Figure 10. (a) Yellow, distinct cell with lumen intact (phase I) changing to red textinite (phase II). Dominant diagenetic phase: phase II. Von Post field classification: fibric. Reflected 'white' light, 50x magnification, oil immersion. Sampling location: KS.TP.02 (0-0.5 m), Kota Samarahan-Asajaya area; (b) Same view as (a) but under UV light excitation; (c) White to yellow distinct cells with lumen (phase I) changing to red textinite (phase II) with intact cell structure. Dominant diagenetic phase: phase II. Von Post field classification: fibric. Reflected 'white' light, 50x magnification, oil immersion. Sampling location: KS.TP.02 (0-0.5 m), Kota Samarahan-Asajaya area; (d) Same view as (c) but under UV light excitation; (e) White to yellow fresh cells (phase I), cell structure and lumen quite distinct (demonstrating why the plant structure observed is clearly visible or still 'fibric'). Yellow cells (phase I) changing or altering to red textinite (phase II), red cells altered with a distinct cell wall structure and intact lumen. Red textinite (phase II) changing or degrading to gray textinite (phase III). Gray textinite undergoing phase IV (cell structure changed due to humification and partial gelification) to phase V (cell wall structure humified and gelified and cell structure destroyed with no lumen (demonstrating why a portion of the peat is highly decomposed and pasty or 'hemic' due to humification and gelification). Dominant diagenetic phase: phase II and post-phase V. Overall range of von Post classification: fibric to hemic plant structure/rootlets visible ('fibric') but with paste present ('hemic' due to gelification) when squeezed. Reflected 'white' light, 50x magnification, oil immersion. Sampling location: KS.TP.07 (0-0.5 m), Kota Samarahan-Asajaya area); (f) Same view as (e) but under UV light excitation; (g) White to yellow fresh cells (phase I), cell structure and lumen distinct (demonstrating why the von Post classification is 'fibric'). Yellow cells (phase I) changing to red textinite (phase II), red cells altered with distinct cell wall structure and lumen intact. Red textinite (phase II) degrading to gray textinite (phase III). Dominant diagenetic phase: phase II and post-phase V. Overall range of von Post field classification: 'fibric to hemic' (plant structure/rootlets visible but paste present when squeezed). Reflected 'white' light, 50x magnification, oil immersion. Sampling location: KS.TP.07 (0-0.5 m), Kota Samarahan-Asajaya area; (h) Matrix of humodetrinite and humocollinite with no intact cell structure with lumen observed. Diagenetic phase: post-phase V (humodetrinite and humocollinite) (demonstrating why the von Post classification is also 'hemic' due to gelification). Clastic fragments present. Dominant diagenetic phase: phase II and post-phase V. Overall range of von Post field classification: 'fibric to hemic' (plant structure/rootlets visible but paste present when squeezed). Reflected 'white' light, 50x magnification, oil immersion. Sampling location: KS.TP.07 (0-0.5 m), Kota Samarahan-Asajaya area; (i) Red textinite (Phase II) with cutinite (Cut), in matrix humodetrinite or humocollinite (Post phase V). Dominant diagenetic phase: Post phase V. Overall range of field Von Post Classification: Sapric. Reflected â€Ÿwhiteâ€Ź light, 50x magnification, oil immersion. Sampling location: KS.TP.08 (0-0.5m), Kota samarahan-Asajaya area; (j) Same view as in (i) but under UV light excitation. Observe red textinite (Phase II) with cutinite, in matrix humodetrinite or humocollinite (Post phase V); (k) Matrix humodetrinite or humocollinite (Post phase V). Dominant diagenetic phase: Post phase V. Overall range of Von Post field Classification: Sapric. Reflected 'white' light, 50x magnification, oil immersion. Sampling location: KS.TP.08 (0-0.5m), Kota Samarahan-Asajaya area; (l) Same view as in (k) but under UV light excitation; (m) Progressive change from red textinite (Phase II) degrading to grey textinite (Phase III-cell and lumen shape is still distinct and is grey or partially grey in colour), to texto-ulminite (Phase IV-cell and lumen shape 'flattens' and begins to deform) and to eu-ulminite (Phase V- cell and lumen shape usually 'flattened' or is largely indistinct or deformed), in matrix humodetrinite or humocollinite (Post phase V). Dominant diagenetic phase: Post-phase V. Overall Von Post field Classification: Sapric. Reflected 'white' light, 50x magnification, oil immersion. Sampling location: KS.TP.09 (0-0.5m), Kota Samarahan-Asajaya area; (n) Grey textinite (diagenetic phase III-cell and lumen shape is still distinct and is grey or partially grey in colour) changing to texto-ulminite (diagenetic phase IV-cell and lumen shape 'flattens' and begins to deform), in matrix humodetrinite or humocollinite (Post phase V). Dominant diagenetic phase: Post phase V. Von Post field Classification: Sapric. Reflected 'white' light, 50x magnification, oil immersion. Sampling location: KS.TP.09 (0-0.5m), Kota Samarahan-Asajaya area; (o) Eu-ulminite (diagenetic phase V) in matrix Humodetrinite or humocollinite (diagenetic phase: post phase V). Dominant diagenetic phase: Post phase V. Von Post field Classification: Sapric. Reflected 'white' light, 50x magnification, oil immersion. Sampling location: KS.TP.10 (0-0.5m), Kota Samarahan-Asajaya area; (p) Same view as in (o) but under UV light excitation.

6. Discussion

The hydrocarbon generation potential of coals has been widely discussed in the literature [26–30]. Conventional coal petrographic studies are usually conducted to evaluate the evolutionary history of the analyzed coals whereby the macerals, microlithotypes and lithotypes provide evidence regarding the nature and type of plant community, the duration and intensity of decomposition in the peatification process and the related depositional setting. The interpreted coal evolutionary history provides the basis for further investigation of the related paleogeography and paleoclimate of the peat-coal precursor basin [30–32]. Hence, this study attempts to investigate the relationship or association between the present-day tropical lowland peat depositional environments and premaceral types together with their peat organic matter (coal-equivalent kerogen) types (from SRA data and palynological slides) based on organic petrological and geochemical methods (in preparation).

Based on the petrographic and SRA analyses, an association appears to exist between the organic matter (kerogen) type and the related premaceral types (at different levels of decomposition and diagenesis) for the peat samples as a function of distance from the periphery towards the near-center of the peat basin. This observation further relates to or supports the concept of horizontal variation as proposed by Anderson [8, 9, 11] and Anderson and Muller [12]. This concept of horizontal variation and zonation may explain why a mixture or combination of organic matter (kerogen) types occurs together within a 'raised' or domed peat basin. Furthermore, this concept may also explain why, how and where there is more leafy or waxy material and palynomorph input into certain zones within the basin that may give rise to the formation of predominantly type II organic matter (kerogen) or higher HI values in the peats, as previously mentioned. Similarly, this study attempts to improve our understanding of how woody plant material, which may give rise to predominantly type III organic matter (kerogen), can occur primarily in certain vegetation zones located concentrically within a tropical lowland peat basin. In addition, this work attempts to explain the dominant plant type or assemblage of trees, shrubs or plant species that may contribute to either the additional input of waxy leafy shrubs or additional woody material to the peat along the horizontal or near-surface layer of the peat basin moving concentrically from its margin towards the center of the tropical lowland peat dome (Table 8 and Table 9). If these or similar types of tropical lowland peats succeed as coal precursors and eventually become coal that is productive as either gas- or oil-prone hydrocarbon source material upon sufficient burial and thermal maturity, then the results of this study may contribute towards our understanding of the paleo-depositional environment of coal in relation to its associated organic matter (or kerogen) types.

6.1. Horizontal or Lateral Zonation in Tropical Lowland Peat Domes

Anderson [8, 9, 11], Anderson and Muller [12], Dehmer [14] and Esterle and Ferm [15] studied the dome topography of tropical peat deposits and the relationship between the concentric zonation of the surface vegetation and increasing peat thickness, acidity and decreasing nutrient availability with horizontal distance between the margin and the center of the peat basin. Variations in the peat type occurring within the deposits reflect the succession and lateral migration of surface vegetation and the associated environment concurrent with coastal progradation [12].

Buwalda [33] (in Paramanathan [6]) performed studies in Sumatra supporting the concept of horizontal zonality occurring in tropical lowland peats. This researcher reported that different plant communities exist in a peat swamp forest depending on peat thickness and distance from the river (peat basin margin). In the central portion of the peat forest, where the thickest peat deposits occurred, he observed that vegetation was poorly developed, with twisted and stunted trees and scattered pools of deep and acidic (pH range of 3.0 to 3.5) brown water compared with those at shallower peat depths (peat deposited near or at the margin/boundary of the peat dome). However, in peat deposits shallower than 3 m, the soils had pH values of 3.5 to 4.5. Buwalda Buwalda [33] (in Paramanathan [6]) reported six vegetation types and zones occurring in the Indragiri area in Sumatra. Anderson [8, 9, 34] also described six vegetation zones occurring in the lowland peat forests of Borneo, including Brunei.

Anderson [8, 11, 34] performed a comprehensive study of the ecology of the tropical lowland peat swamp forests of Borneo. He observed and recorded 253 tree species primarily confined to the periphery of the peat swamp forest. According to Anderson [34], most plant species growing in the forests at the center of the peat domes are those usually found in nutrient-poor soils, such as the podzols of the heath forest. The tropical lowland peat swamp forests in Sarawak, Malaysia and the adjacent Brunei show lateral or horizontal changes in vegetation types from the periphery to the center of the domed-shaped peat swamps, and each of the six dominant lateral vegetation zones was designated as a "phasic community" by Anderson [8]. Six distinct phasic communities or zones were recognized based on their floristic composition and vegetation structure [6, 8]; these were numbered starting with phasic community I at the margin through phasic community VI in the center of the peat swamp (Table 8). Tie [35] and Paramananthan [6] later summarized the main changes characterizing these concentric, horizontal or lateral zonations, which are as follows:

(a) Changes in the floristic composition from one zone to another.

(b) Reductions in the number of tree species per unit area and reductions in the total number of tree species recorded from the margin to the center of the peat dome.

(c) General increases in the number of stems with more than 30-cm girth per unit area from PC1 to PC5 with the exception of PC3 and PC6.

(d) General decreases in the average size of a species from the periphery to the center.

6.2. Association between Predominantly Leafy, Woody or Spore and Pollen Grain Plant Inputs and Their Organic Matter (kerogen) Types

Horizontal zonation and lateral variation of the dominant species of plant assemblages [6, 8, 11, 15, 34] occurring with varying distances from the periphery towards the center of the tropical lowland peat dome are supported by the field observations of this study together with the related petrographic observations and SRA analyses, indicating that woody material (tree logs, broken branches, bark and roots) contributed by the dominant tree species (e.g., Shorea type) may likely produce peat with more of the huminite/vitrinite maceral group and dominant type III organic matter (kerogen) (Table 9). However, waxy leafy material contributed from the dominant species of shrubs and ferns may produce peat that is composed primarily of the liptinite maceral group and type II organic matter (kerogen) (Table 9).

Table 8. Main characteristics of the six phasic communities occurring as horizontal or lateral zonations (adapted from Anderson [8, 11, 34]; Paramananthan [6]).

PC (phasic community)	Forest type	Main tree-species association	Other relevant features of tree and ground flora
I	Mixed Peat Swamp Forest	Gonostylus-Dactylocladua-Neoscortechinia association	Structure and physiognomy similar to a mixed dipterocarp forest on mineral soils; many species with pneumatophores, stilt roots and buttresses.
II	Alan Swamp Forest	Shorea albida-Gonystylus-Stemonurus association	Similar to PC1 but with very large, scattered Shorea Albida trees; large trees are usually hollow with stag-headed crowns; Pandanus andersonii and Nepenthes bicalcarata frequent.
III	Alan Bunga Forest	Shorea albida association	Middle storey sparse; lower storey moderately dense; cauliflower-like crowns of S.albida distinctive in air photo.
IV	Padang Alan Forest	Shorea albida-Litsea-Parastemon association	Very slender stems giving pole-like appearance; dense understory 3-6 m high; Nepenthes spp. frequent.
V	Padang Paya Forest	Tristania-Parastemon-Palaquim association	Understory sparse; herbaceous plants largely absent; some pitcher plants.
VI	Padang Keruntum Forest	Combretocarpus-Dactylocladus association	Stunted, xeromorphic, with pneumatophores; Myrmecophytes spp. and Nepenthes spp. numerous; sedge and sphagnum moss present.

Similarly, the relative abundance of palynomorphs (spores and pollen grains) in the peats may also contribute to the dominance of the liptinite maceral group and type II organic matter (kerogen).

Thus, the dominance of the coal-equivalent premaceral groups of liptinite and huminite/vitrinite and the respective dominant organic matter of types II and III (kerogen) may be related to and occur in close association with certain phasic community vegetation zonations in the tropical lowland peat dome.

6.3. Association between Peat Decomposition Levels and Organic Matter Type

In addition to the type of plant input (more leafy, woody or pollen and spore grain input into the decomposing peat), which may have an influence on the organic matter type within the peats, the decomposition or humification level of the peats may also be associated with the organic matter types, as shown in Table 9. It was observed in this study that the predominantly occurring maceral type (red textinite, gray textinite, texto-ulminite and eu-ulminite or humocollinite and humodetrinite) and the associated predominantly occurring diagenesis stage (phase I, II, III, IV or V or post-phase V, respectively) may be associated with organic matter types II or III (kerogen). Sample KS.TP.02, with lower levels of decomposition (fibric), has relatively higher HI values and hence represents type II organic matter (based on SRA analysis). Although highly decomposed, sample KS.TP.10 (hemic to sapric) still contains a certain amount of structure or plant tissue (hence the 'hemic' level is included in the humification range), is coupled with a relatively higher level of leafy plants or additional spore and pollen grain input (from the proposed mixed phasic communities II to IV) has relatively higher HI values and is primarily composed of type II organic matter (kerogen).

The designated von Post classifications of peats used in this study [1, 18, 36] are fibric peats (H1 to H3), hemic peats (H4 to H6) and sapric peats (H7 to H10). In this study, fibric peats (from the marginal area of the dome, with lower levels of decomposition) and hemic to sapric peats (near the center area of the dome, with relatively higher humification levels) seem to be associated with organic matter type II (?). These fibric- and hemic-classified peats are petrographically similar because they both contain significant amounts of macerals of red to gray textinite (diagenesis phases II and III). The dominant presence of textinite (even in hemic peats exhibiting a certain level of plant cell structure) within these peats indicates that this type of peat consists of plant components with relatively or partially intact cell structures.

Table 9. Organic matter types (based on the SRA method and a visual study of palynological slides) of the tropical lowland peats and predominant stages of peat diagenesis as a function of distance from the margin towards the near-center areas of the tropical lowland peat dome and the proposed (based largely on field observations) phasic communities (PC) of the dominant plant species assemblage.

Sample location	KS.TP.02 (0-0.5 m)	KS.TP.07 (0-0.5 m)	KS.TP.08 (0-0.5 m)	KS.TP.09 (0-0.5 m)	KS.TP.10 (0-0.5 m)
Approximate location in peat dome	Marginal	Marginal	Mid-section	Towards center	Towards/near center of peat basin
HI	357	207	266	322	407
Organic matter (kerogen) type (based on SRA-HI values)	Type II (oil prone)	Type III (gas/oil prone)	Type III (gas/oil prone)	Type II (oil prone)	Type II (oil prone)
Organic matter (kerogen) type (based on palynological slides study)	Type II (oil prone)	Type III (gas/oil prone)	Type III (gas/oil prone)	Type II (oil prone)	Mixed Type II-Type III (oil prone)
Source of organic matter (based on field observations of leafy or woody material input from present plant types)	Relatively more leafy input from shrubs, nepenthes, palms and trees	Woody material from broken branches and wood fragments (from e.g., Shorea type)	Woody material from broken branches and wood fragments (from e.g., Shorea type)	Woody material from broken branches and wood fragments (from e.g., Shorea type) and increasingly more leafy input from ferns and shrubs (intermediate)	Relatively more shrubs and ferns (relatively more leafy input than woody material input)
Proposed phasic community (PC) zonation (based on Anderson [8, 1,34] and Paramananthan [6])	PC I (Mixed Peat Swamp Forest)	Mixed PC I-II (Mixed Peat Swamp Forest- Alan Swamp Forest) (?)	PC II (Alan Swamp Forest)	Mixed PC II-III-IV (Mixed Alan Swamp Forest-Alan Bunga Forest-Padang Alan Forest) (?)	Mixed PC II-III-IV (Mixed Alan Swamp Forest-Alan Bunga Forest-Padang Alan Forest) (?)
Wood fragments in peat (%)	5-10% in fibric peat	20-30% in fibric to hemic peat	20-30% in sapric peat	20-30% in sapric peat, >granular/amorphous granules, hard when dried	40% in hemic to sapric peat, >granular/amorphous granules, hard when dried
Dominant stage/phase of peat diagenesis (phase I-V or post-phase V/ fragment or colloidal cell stage) at 0- to 0.5-m depth.	Dominant phase: phase II (Von Post field classification: FIBRIC)	Dominant phase: phase II and post-phase V (II=V, same amount %) (Von Post field classification: FIBRIC-HEMIC)	Dominant phase: post-phase V, followed by phase II (V>II) (Von Post field classification: SAPRIC)	Dominant phase: post-phase V (Von Post field classification: SAPRIC	Dominant phase: post-phase V, followed by phase II (Von Post field classification: HEMIC to SAPRIC)
Major macerals occurring with depth of peat (0-0.5 m)	Fresh yellow to orange cells and red textinite	Fresh yellow to orange cells, red textinite and dark humodetrinite and humocollinite	Red textinite and humodetrinite and humocollinite)	Humodetrinite and humocollinite	Humodetrinite and humocollinite

6.4. General Discussion of Palynofacies

This section discusses the general petrographic and palynological characteristics of the organic facies occurring in the tropical lowland peat swamp from the margin to the midsection and further to the near-center or deeper regions of the peat dome in the study area. The classification proposed for organic matter is based on a visual study of palynological slides under transmitted light. The classification proposed for the peats under this investigation with respect to the different coal-equivalent organic matter (kerogen) types is primarily based on the classification system proposed by Ercegovac and Kostić [25].

6.5. Palynofacies and General Classification of Organic Matter (Coal-Equivalent Kerogen)

In general, most of the analyzed peat samples are characterized by a mixture of 'palynomacerals' [37–39] or 'phytoclasts' [25], including degraded yellow plant tissue, brown woody tissue, biostructured woody tissue [25] with moderate proportions of black woody tissue (with brown edges) [40], cuticles and spore and pollen grains [25, 40], with the rare occurrence of black opaque and highly oxidized plant tissue, fungal debris (hypae and spores) [25] and amorphous (structureless) organic matter [25] (Table 5). All of these types of palynodebris (referred to as 'palynomacerals' by Whitaker [37, 38] and Van der Zwan [39] and referred to as 'phytoclasts' and 'palynomorphs' by Ercegovac and Kostić [25]) originate from terrestrial land plant sources. For example, cuticles (liptinite maceral group) arise from leaf-epidermal tissue, woody tissues (vitrinite maceral group) come from gymnosperm and angiosperm tracheid tissue or structured gelified tissue, and fungal debris (inertinite maceral group) originates from hyphae and spores [25] (Table 5 and Table 7).

In general, according to the peat palynological slides examined, degraded yellow plant tissue accounts for more than 30% of the total palynomacerals. These peat phytoclast particles often display irregular shapes and are yellow in color, with the original cellular structures still visible. The other dominant palynomaceral is brown woody tissue (Figure 11), which comprises approximately 30% of the total palynomaceral percentage. These peat phytoclast particles are commonly observed as yellowish brown in color with vague and slightly visible cellular structures.

Biostructured woody tissue (Figure 12) [25] and cuticles (Figure 11) are also well-preserved but are only present in moderate quantities together with palynomorphs and the rare occurrence of resins. Cuticles are derived from leaf-epidermal tissues, which are categorized as cutinite macerals and are equivalent to the liptinite coal maceral group [25]. With respect to peat organic matter classification, these cuticle 'palynomacerals' [37, 39] or 'phytoclasts' [25] may constitute the coal-equivalent organic matter of type II (kerogen) [25]. Biostructured woody tissues [25] are believed to originate from either angiosperm or gymnosperm tracheid tissue and are described as equivalent to the telinite and telocolinite coal maceral of the huminite/vitrinite maceral group and may constitute the coal-equivalent organic matter of type III (kerogen) [25].

Other peat palynomacerals that are frequently present in the samples include black opaque and highly oxidized plant tissues (Figure 11), black woody tissues [40], amorphous organic matter (structureless) [25, 40] and fungal debris (hypae and spores) [25], but all are present only at low percentages. The black opaque and highly oxidized plant tissues, together with fungal debris (Figure 11), are equivalent to the inertinite coal maceral group and may constitute the coal-equivalent organic matter of type IV (kerogen).

The presence of the dominant huminite/vitrinite peat maceral group (organic matter type III (kerogen)) occurring as degraded yellow plant tissue (original cellular structures still visible) and brown woody tissue together with moderate percentages of the liptinite maceral group (organic matter type II (kerogen)) represented by phytoclast cuticles and palynomorphs (pollen and spores) in the peats suggests the coal-equivalent organic matter range of type II to type III (coal equivalent-kerogen).

7. Conclusions

Based on field identification, von Post classifications, petrographic studies and source rock analyses of five augered peat samples (KS.TP.02 to KS.TP.10) from the western peat forest of the study area, the following conclusions are derived:

1. Field identification and classification (von Post) indicate a lateral variation in peat decomposition levels in the form of predominantly occurring fibric, fibric to hemic, sapric and hemic to sapric peat located progressively from the margin towards the near-center area of the tropical lowland peat dome or basin.

2. Petrographic studies show that the humification or decomposition levels of peat are related to the predominantly occurring peat macerals (premacerals) present in the form of yellow fresh/unaltered plant cells, red textinite, gray textinite, texto-ulminite, eu-ulminite and humodetrinite or humocollinite. The observed relationships are as follows:

   (a) Predominantly fibric peats (basin margin) primarily consist of fresh yellow to orange cells and red textinite premacerals.

   (b) A range of fibric to hemic peats (near-margin) consists of fresh yellow to orange cells, red textinite and dark humodetrinite and humocollinite premacerals.

   (c) Predominantly sapric peats (midsection area) primarily consist of red textinite with dark humodetrinite and humocollinite or only dark humodetrinite and humocollinite premacerals.

   (d) A range of hemic to sapric peats (near-center area of dome) primarily consists of dark humodetrinite and humocollinite premacerals.

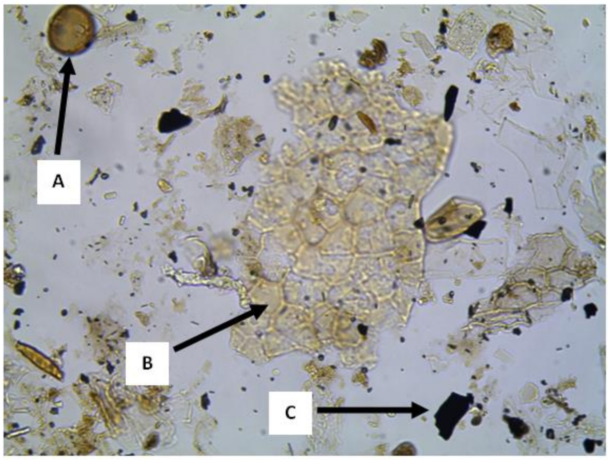

Figure 11. Palynomacerals from auger location KS.TP.02 (A. Fungal Spore. B. Cuticle sheet C. Black opaque, highly oxidized plant tissue).

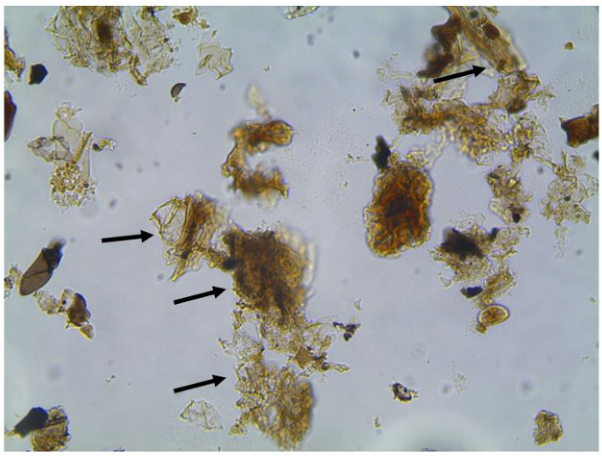

Figure 12. Palynomacerals from auger location KS.TP.07 is characterized by degraded biostructured woody tissue (arrow) along with minor constituents of fungal spore, pollen and brown and black wood.

3. The variations in the main peat maceral types observed in this study are most likely related to the different levels of diagenesis in the humification or peatification process of the tropical lowland peats. The respective progressive stages (and associated dominant premaceral types) observed are phase I (fresh cells), phase II (red textinite), phase III (gray textinite), phase IV (texto-ulminite) and phase V (eu-ulminite) followed by post-phase V (mainly humodetrinite and humocollinite).

4. Visual classification of organic matter indicates a lateral variation in the dominant organic matter types occurring within the top 0- to 0.5-m layer. The dominant organic matter types vary from type II to type III to mixed types II and III (coal-equivalent kerogen) from the margin to the midsection and further towards the near-center areas of the peat dome/basin, respectively.

5. If an association exists (in the current scope of this study) between the variations in the organic

matter types of tropical lowland peat occurring with varying distance from the periphery towards the near-center of the peat dome, it is most likely caused by a combination of factors, which include the following:

(a) Horizontal zonation and lateral variation in the dominant species of plant assemblages occurring with varying distances from the periphery towards the near-center of the tropical lowland peat dome. Woody material contributed by the dominant species (e.g., Shorea type) may likely produce peat with more huminite/vitrinite maceral content and type III organic matter (coal-equivalent kerogen). Waxy leafy material (cuticle phytoclasts, leaf epidermal tissue) contributed from the dominant species of shrubs and ferns and the relative abundance of palynomorphs (spores and pollen grains) in the peats may produce peat that consists primarily of the liptinite maceral group and type II organic matter (coal-equivalent kerogen).

(b) Lateral variations in the peat humification levels (von Post humification levels of H1 to H10) and the related dominant diagenesis peatification stages (phase I, II, III, IV and V and post-phase V) occur from the periphery towards the center of the tropical lowland peat dome in the study area. In this study, fibric peats (from the marginal area of the dome, with lower levels of decomposition) and hemic to sapric peats (near the center area of the dome, with relatively higher humification levels) seem to be associated with organic matter type II (coal-equivalent kerogen). These fibric and hemic von-Post-classified peats are petrographically similar in the sense that both are likely to contain significant amounts of red to gray textinite (diagenesis phases II and III) peat macerals. The dominant phases of textinite occurring within these peats imply that these types of peat consist of plant components that are relatively intact or contain partially intact cell structures.

6. The observations in this study may support the concept of vegetation lateral variation and horizontal zonation. The proposed phasic communities (PCs) that were observed to occur in the tropical lowland peat dome are PC I (Mixed Peat Swamp Forest), mixed PC I-II (Mixed Peat Swamp Forest-Alan Swamp Forest (?)), PC II (Alan Swamp Forest) and mixed PC II-III-IV (Mixed Alan Swamp Forest-Alan Bunga Forest-Padang Alan Forest (?)).

7. Based on the visual organic matter classification of peat palynological slides, a mixed type or a combination of organic matter types may exist, including type II, type III and mixed types II and III occurring within the tropical lowland peat basin near the surface. Hence, lateral vegetation succession, phasic community zonation and organic matter type (type II, type III and mixed types II to III) are likely related in lowland tropical peat domes. The peat organic matter types (based on visual transmitted light classification) that occur from the basin periphery to the mid-section and further towards the basin near-center area consist of organic matter of type II to type III and mixed types II and III, respectively.

8. Generally, the visual peat organic matter (coal-equivalent kerogen) classification method supports the organic geochemical SRA peat organic matter (kerogen) classification method except for the dominant organic matter type at the near-center areas, in which visual palynomaceral studies indicate a dominant range or mixture of organic matter types II and III (compared with only organic matter type II (kerogen) from the SRA analyses).

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