PEAT STABILIZATION, ORGANIC GEOCHEMISTRY AND RELATED PALYNOLOGICAL CHARACTERISTICS OF A TROPICAL LOWLAND PEAT BASIN IN THE KOTA SAMARAHAN-ASAJAYA AREA, WEST SARAWAK, MALAYSIA.

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Abstract :

Tropical lowland peat basin was characterized prior to stabilization tests which used the cement-filler-air curing technique. Topogenic, clayey, high-ash, shallow peats (with more naturally occurring in-situ mineral soil filler content) at the basin periphery have higher stabilized strength compared to the deeper, intermediate topogenic to ombrogenic, low-ash peats at the mid-section area (near location KS.TP.08). Nearly all the stabilized cement-filler-peat mix specimens with added mineral soil (silt, clay and fine sands) fillers tested, exhibited brittle or shear failures with no barrelling failure. Stabilized peat specimens from topogenic, marginal, transitional mangrove to shallow peat areas (location KS.TP.0 and KS.TP.02) also exhibited dominantly shear/brittle failures, relatively better, uniform and consistant cylindrical shape, with less deformation, are denser and harder, has lesser cracks, less holes, less indentations or lesser joints/discontinuities at the tamped layer planes. Cement-peat stabilization strength may probably depend highly on the amount of natural/insitu or added mineral soil filler contained within the peat. Strength enhancement by improved densification of the stabilized peat-cement-mineral soil filler mix can be achieved by supplying increasingly more solid particles in the form of mineral soil fillers content. This study indicates that stabilized strength is at the maximum near the dome/basin margin/periphery, decreases at mid-section and increases back again towards basin centre. Stabilized peat strength may be related to basinal lateral vegetation succession. Field identification and von Post classification of the tropical lowland peat shows that there is a lateral variation of peat humification levels and range, corresponding to fibric, fibric to hemic, sapric and hemic to sapric peats, occurring progressively, from margin towards the near-centre of the tropical lowland peat dome or basin. Variations of dominant peat maceral types observed in this study are probably associated with different levels of diagenesis in the humification or peatification process of the tropical lowland peats. Source Rock Analyses (compatible Rock-Eval) results show that there is a lateral variation of organic matter types occurring within the top 0 to 0.5 metres peat layer. The hopanes are the dominant pentacyclic triterpanes in the peat alkane fractions sampled from basin periphery to mid section and further towards the near centre of a tropical lowland peat basin (at 0 to 0.5 m depth). The biomarker hopane compounds have 13 to 39 carbons and all show odd over even predominance indicating the true terrestrial depositional environment of the peats. The ββ hopanes biomarkers that indicate immaturity and are commonly present in the peats includes ββ C30 hopane (17 β, 21β (H)-Hopane) and ββ C31 hopane (17β, 21β (H)-Homohopane. The other common hopanes present are C29 hopane (Norhopane), 22Sαβ C31 hopane (17α, 21β (H)-Homohopane) and 22Rαβ C31 hopane (17α, 21β (H)-Homohopane). Logging observations indicate a vertical, downwards, general decrease of peat humification levels with depth. Based on pollen analyses and field observations, the studied peat profiles can be interpreted as part of a progradational deltaic succession. Continued regression of sea levels, gave rise to the development of peat in a transitional mangrove to floodplain/floodbasin environment, followed by a shallow, topogenic peat depositional environment with riparian influence at approximately 2420 ± 30 years (B.P.). Pollen analyses indicates that estuarine and deltaic, brackish to saline water influence may have gradually ceased at approximately 0.5 metres below the lithological boundary between peat and underlying soil (floodplain deposit) in the tropical lowland peat basin.

Abstrak:

Lembangan gambut telah dijalankan kerja pencirian sebelum ujian penstabilan dengan kaedah simen-pengisian-gambut dan pengawetan kering dilakukan. Gambut topogenik, bertanah-liat, berkandungan abu-tinggi dan berkedalaman cetek serta mengandungi bahan isian mineral semulajadi yang dimendapkan di kawasan berdekatan pinggir lembangan berkecenderungan untuk mempunyai kekuatan penstabilan yang lebih, relatif kepada gambut yang lebih dalam, bersifat pertengahan ke ombrogenik dan berkandungan abu-rendah di kawasan pertengahan (berdekatan lokasi KS.TP.08). Hampir kesemua specimen campuran simen-pengisi-gambut yang distabilkan dengan bahan pengisian tanah mineral (butiran kelodak, tanah liat dan pasir halus) yang diuji untuk kekuatan menunjukkan kegagalan rapuh atau ricih dengan tiada kegagalan 'barrelling'. Spesimen ujian yang distabilkan dari kawasan gambut topogenik, bertanah-liat, berkandungan abu-tinggi atau zon pertengahan 'mangrove' ke gambut berkedalaman cetek (lokasi KS.TP.0 and KS.TP.02) juga menunjukkan kegagalan ricih/rapuh, bentuk silinder yang lebih baik, sekata dan konsisten dengan kurang deformasi, secara relatif. Spesimen tersebut juga adalah lebih keras, padat, menunjukkan bilangan retakan, lubang, lekukan dan ketidakselanjaran yang kurang, secara relatif, di bahagian sambungan-pelapisan. Penstabilan simen-gambut diperhatikan adalah bergantung ke atas amaun bahan isian ditambah atau kandungan semulajadi ("in–situ") di dalam gambut tersebut. Penambahan kekuatan penstabilan melalui penambahan pemadatan (densifikasi) campuran gambut-simen-bahan isian tanah mineral boleh di capai dengan menambahkan kuantiti partikel pepejal dalam bentuk penambahan kandungan bahan isian tanah mineral. Kajian ini member indikasi bahawa kekuatan penstabilan gambut adalah maksima dari kawasan berdekatan sempadan lembangan enapan gambut, berkurang di bahagian pertengahan lembangan dan mula bertambah semula apabila menuju ke arah kawasan berdekatan pusat

lembangan tersebut. Penstabilan gambut berkemungkinan boleh dikaitkan dengan suksesi vegitasi mendatar lembangan enapan gambut. Identifikasi lapangan dan pengkelasan von Post gambut tanah-rendah tropika menunjukkan variasi mendatar dengan tahap dan julat humifikasi yang sepadan dengan gambut jenis-jenis “fibric”, “fibric” ke “hemic”, “sapric” dan “hemic” ke “sapric” yang berlaku secara progresif dari kawasan pinggir lembangan ke arah kawasan berdekatan pusat lembangan atau “dome” gambut. Variasi jenis “maceral” dominan gambut yang diperhatikan berlaku adalah berkemungkinan berkaitan dengan tahap diagenetik di dalam proses humifikasi gambut tropika tanah rendah. Keputusan analisa dengan kaedah “Source Rock Analyses” (sepadan dengan “Rock-Eval”) menunjukkan adanya variasi mendatar jenis-jenis bahan organik (“kerogen”) pada kedalaman 0 ke 0.5 m lapisan atas gambut. Ini kemungkinan berkaitan atau disebabkan variasi mendatar suksesi spesis dominan kumpulan-kumpulan tumbuhan tertentu yang berlaku dari sempadan lembangan ke pertengahan dan seterusnya ke kawasan berdekatan pusat lembangan enapan gambut tropika tanah-rendah tersebut. Kumpulan “hopane” adalah dominan di dalam bahagian “alkane” gambut yang di sampel. Sebatian “hopane” mempunyai 13 ke 39 karbon dan menunjukkan “odd over even predominance” yang memberi indikasi bahawa gambut adalah di enapkan pada persekitaran daratan. “ ββ hopane biomarkers” yang biasanya hadir di dalam gambut dan juga memberi indikasi serta menyokong ketidakmatangan gambut adalah termasuk “ββ C30 hopane (17 β, 21β (H)-Hopane)” dan “ββ C31 hopane (17β, 21β (H)-Homohopane”. Selain itu, kumpulan “hopane” yang juga biasanya hadir adalah “C29 hopane (Norhopane)”, “22Sαβ C31 hopane (17α, 21β (H)-Homohopane)” dan “22Rαβ C31 hopane (17α, 21β (H)-Homohopane)”. Secara amnya, terdapatnya pengurangan tahap humifikasi gambut secara menegak ke arah bawah dengan kedalaman gambut. Berdasarkan analisa “pollen” dan cerapan lapangan, profil gambut boleh ditafsirkan sebagai sebahagian daripada “progradational deltaic succession”. Regresi aras laut yang berterusan mengakibatkan perkembangan gambut di dalam persekitaran pengenapan “transitional mangrove to floodplain/floodbasin”, di ikuti dengan persekitaran enapan gambut topogenik cetek dengan pengaruh air tawar (riparian influence) lebih kurang pada 2420 ± 30 (“B.P.”) tahun dahulu. Analisa debunga juga memberi indikasi bahawa pengaruh air masin “estuarine” dan “deltaic” telah beransur-ansur tamat pada kedalaman lebih kurang 0.5 meter ke bawah sempadan litologi gambut dengan lapisan tanah di bawahnya (floodplain deposit).

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Term	**Description**
UCS	Unconfined Compressive Strength
cm	centimetre
m	metre
kPa	kilo pascal
ºC	degrees Celcius
GCMS	Gas Chromatography Mass Spectrometry
SRA	Source Rock Analyses
Before Present	BP
mineral soil filler	msf, MSF

CHAPTER 1

1.0 INTRODUCTION

1.1 Background on peat stabilization and problem statement

In many countries of the world, including Malaysia, peat covers a substantial land area. Peat and organic soils commonly occur as extremely soft, wet, unconsolidated surficial deposits of wetland systems. Peats are problematic soils known for their high compressibility and low shear strength and are unsuitable for construction and foundation purposes. Pressure on land use by industry, housing, infrastructure as well as agriculture is leading to more frequent utilisation of such peat lands. Therefore, it is necessary to expand knowledge of the geotechnical properties and mechanical behaviour of tropical peat soils and possibly the use of the stabilized form of peat soils, for general construction and foundation purposes. The study of peat occurrence in the Kota Samarahan-Asajaya area adjacent to Kuching city would involve detailed mapping, characterization and classification. The possibility or potential of cement-filler-peat stabilization with use of mineral soils to help or improve future construction works on these problematic peat and organic soils was investigated in this study. Geological-peat mapping was carried out to provide important information for land-use planning to developers and planners alike. Peats are potential coal-precursors upon reaching sufficient burial depth and thermal maturity. Tropical lowland peats need to be studied as a potential coal analogue to help in the interpretation of coal palaeodepositional environments in oil and gas exploration work.

1.1.1 Introduction for tropical lowland peat stabilization study

In previous geotechnical peat stabilization studies, no study was focused on the relevant morphological effects of the tropical lowland peat dome on stabilized peat strength. Hence, the effects of vegetation lateral variation and basin 'dome' shape on tropical lowland peat stabilization was investigated in this study. Field mapping involving observation, identification, characterization, classification to map and identify the natural extent and occurrence of tropical lowland peat deposits was carried in the Kota Samarahan-Asajaya study area in West Sarawak (Malaysia). Field identification and classification of peats was carried out to study the lateral variation of peat humification levels (by the von Post method) occurring from basin margin and towards the centre of the tropical lowland peat dome or basin. The use of mineral soil as fillers (silt, clays and fine sands) obtained from nearby Quaternary floodplain deposits and residual soil (weathered schist) in cement-peat stabilization was investigated. The Unconfined Compressive Shear strength (UCS) variation of the stabilized cement-mineral soil filler-peat mixture with the further addition of selected mineral soil filler (msf) in increasing quantities was analyzed. Further investigation was carried out to study the lateral variation of stabilized peat strength (UCS) occurring on the top 0 to 0.5 metre peat-soil layer, from basin margin to midsection and further towards the centre (or near the centre) areas of the tropical lowland peat dome. The physical characteristics of stabilized cement-filler-peat mix UCS test specimens that were added with msf (silt, clay and fine sands) before and after testing were also observed and studied.

Variations (and trend) of UCS strength of stabilized tropical lowland peats occurring with varying distance from periphery to midsection and further towards the near-centre areas of the peat dome in the current scope of this study, is probably caused by a combination of factors due to variations of mineral soil content (or ash content) in the peat and horizontal vegetation zonation or, lateral variation of dominant species of plant assemblages (due to peat swamp forest successive vegetation zonations). The probable association between lateral vegetation succession (phasic community zonation) and unconfined compressive shear strength of the stabilized cement-mineral soil filler-peat mix in tropical lowland peat basins/domes were studied, discussed and concluded in the following chapters.

1.2 Introduction to tropical lowland peat organic geochemical analyses

The study of the geological occurrence of tropical lowland peats and some of its related organic geochemical properties were also included in this study. Petrographic study, Source Rock Analyses (SRA) and biomarker analyses by the Gas Chromatography Mass Spectrometry (GCMS) method was performed on augered peat samples from the western peat forest of the Kota Samarahan-Asajaya study area. Petrographic studies were carried out to investigate the lateral trend and association between humification or decomposition levels of peat with the dominantly occurring peat macerals present. Source Rock Analyses (SRA-compatible Rock-Eval) results show that there is a lateral variation of organic matter types occurring within the top 0 to 0.5 metre layer, from margin towards the near-centre, of the tropical lowland peat dome studied. SRA data and field observations coupled with pollen analyses was applied to help determine what factors control these lateral variations of organic matter or kerogen type which may be useful in the interpretation of coal palaeoenvironment depositional conditions assuming that the peats are potential coal-precursors upon reaching sufficient burial depth and thermal maturity. This variation is probably caused by a combination of factors, such as: (a) Horizontal vegetation zonation and lateral variation of dominant species of plant assemblages occurring with varying distances from periphery towards the centre of the tropical lowland peat dome. Woody material (tree logs, broken branches, bark and roots) contributed by dominant species (e.g. *Shorea* type) may likely produce highly decomposed peat with organic matter Type III (kerogen). However, waxy, leafy material derived from dominant species of trees, shrubs and ferns accompanied with the relative abundance of spores and pollen grains may likely produce peat with organic matter consisting predominantly of Type II (kerogen); (b) Lateral variations of peat humification levels (von Post Humification levels of H1 to H10) and its associated dominant diagenesis peatification stages (Phase I, II, III, IV, V and post phase V) occurring from periphery towards the near-centre of the tropical lowland peat dome. In this study, fibric peats (from the marginal area of the dome, with lower levels of decomposition) and hemic to sapric peats (near the centre area of the dome, with relatively higher humification levels), seems to be associated also with organic matter Type II (kerogen). The observations in this study may support the concept of lateral variation and horizontal zonation (Anderson 1961; 1963; 1983 and Paramanathan, 2011). Generally speaking, there are a mixed or a combination of organic matter of types II and III (kerogen) occurring on the tropical lowland peat basin surface and these lateral variations in organic matter types may support the lateral vegetation variation concept. And, the results of this study indicates that the trend of these organic matter types (interpreted from SRA-HI) occurring from basin periphery to mid-section and towards basin centre areas are organic matter types II to III and, again to II, respectively. From the overall SRA data of the auger samples taken from the Kota Samarahan-Asajaya study area, S2 versus TOC and HI versus OI plots were derived and interpreted to categorize the organic matter quality of the peat and organic soil samples that were analyzed.

GCMS analyses was performed on the peat alkane fraction of EOM (Extracted Organic Matter) of peats sampled from basin periphery to mid-section and further towards near-centre areas of the tropical lowland peat basin (Plaie peat forest, at 0 to 0.5 m depth) studied for the determination of biomarker distributions. The terrestrial depositional environment of the peats was interpreted, supported and indicated from the predominance of odd over even number of carbon atoms in the biomarker hopane compounds. Dominance of hopane peaks was identified. The variation of Pr/Ph ratios for the peats located from margin ("moat-area") to mid-section and further towards the relatively elevated near-centre area of the peat basin/dome was determined and interpreted to indicate varying anoxic to suboxic to again, suboxic depositional environmental conditions, respectively. The Pr/n-C_{17} and Ph/n-C_{18} ratios for the peat samples from periphery to midsection and further towards the dome centre were determined and interpreted to indicate and support the reducing depositional environmental conditions of the wet, tropical lowland peats. The S/(S+R) ratios for the peat samples from periphery to midsection and further towards dome centre were calculated and interpreted to indicate the immaturity of the peats in terms of hydrocarbon production. In addition, the presence of ββ hopanes were also determined and interpreted to support and indicate the immaturity of the peats. Hopane peak identification was carried out to determine the dominant biomarker distribution present in the tropical lowland peats from periphery to near-centre area of the basin.

1.3 Introduction to pollen (palynomorph) analyses of tropical lowland peats

Peat morphology and the related palynology study of the tropical lowland peat swamp in the western part of the Kota Samarahan-Asajaya area was also carried out in this study. Field identification and classification from the top to the bottom, vertical profile of the peat layer shows that there is a vertical variation of peat humification levels (whether sapric, hemic or fibric or mixed). Based on pollen analyses and logging observations, the depositional environment of the mentioned peat profiles from auger location KS.TP.10 and KS.TP.09 was interpreted. Within the scope of this study, from the bottom to the top of the auger log profiles studied, the peat swamp phasic communities inferred vegetation succession (as was described by Anderson and Muller (1975)) was identified and concluded. In addition, field observations of the presence of large *Shorea* type trees, were used to give additional evidence to support the presence of the successive vegetational phasic community zonations of the studied tropical lowland peat dome.

The depositional environment at the location of the selected augerlog profiles was interpreted and seems to commence on a mangrove swamp environment which, due to a continued fall of sea levels, gave rise to a more inland mangrove swamp environment with an increased riparian influence. Peat development followed and the following peat vegetation successions and their related depositional environment types was interpreted. Their approximate age were determined by the C_{14} radiocarbon dating method.

Pollen analyses was performed along with field investigation to indicate where and at what actuall depth that estuarine and deltaic, brackish to saline water influence may have gradually ceased below the lithological boundary between peat and soil. This same method was also applied to determine the actual depth and thickness of the riverine/ floodplain deposits.

The Phasic Communities inferred zonations that were concluded from pollen analyses results vary vertically with depth, from bottom to the top of the vertical peat layer profiles located near to the centre of the tropical lowland peat dome. The inferred zonations interpreted to occur were then proposed accordingly.

1.4 Objectives of study

The general aim of this study is to study the tropical lowland peats found to occur in the study area. The individual objectives are:

1) To study the tropical lowland peats with some of its related peat stabilization properties using augered peat samples, cement and mineral soil fillers (msf):

a) To show that the Unconfined Compressive Strength (UCS) of the cement-filler stabilized peat mix can be enhanced and improved with use of mineral soil fillers (silt, clays or fine sands) extracted *in situ* or from locations near to the peat basin.

b) To determine what other physical or geological factors inherent in the peat dome that may also affect the strength of cement-filler stabilized peats.

2) To identify the related organic geochemical characteristics of the tropical lowland peat basin/dome.

3) To find the related palynological characteristics of the peat deposit.

4) To identify, classify and map the distribution and natural occurrence of peat deposits and to determine the depth and thickness of peat where encountered in the Kota Samarahan-Asajaya study area.

1.5 Location and accessibility of study area

The study area covers an extent of approximately 25 square kilometers located between longitudes $01^0$26'30''N and longitudes $01^0$29'46''N (north and south of Sungai Tuang) and latitudes $110^0$27'44''E and latitudes $110^0$30'58''E (east and west of Batang Samarahan). The project/study (Figure 1.0) area is located approximately 30 kilometres from Kuching City and is accessible by sealed road. Within the study area accessibility is possible by means of earth, gravel, bund or sealed roads.

1.6 Organization of the thesis

The thesis consists of 6 chapters. Chapter 1 introduces and provides the background and rationale for the tropical lowland peat stabilization study. It then briefly explains the scope of the peat geochemical research undertaken in this study. This is followed by an introduction to the pollen analyses study that was carried out to support and generally strengthen the overall conclusions for the study.

Chapter 2 concentrates on the literature review of the research. In the review, sufficient information on the background of cement-filler-peat stabilization and tropical lowland peat morphology and classification is provided. This is to support the use of mineral soil fillers and the dry curing technique for the different types of peat samples stabilized according to different peat sample locations on the peat dome studied.

Chapter 3 includes the research methodology and basically provides details on the methods used in the peat stabilization study, organic geochemical analyses and pollen analyses. In addition, the field methodology regarding peat sampling, logging, mapping, classification and characterization is also provided here.

Chapter 4 presents the results and findings of the research and are explained in detail according to section and are further illustrated in table and figure form. Comparisons of the results of different analyses methods as mentioned are compiled into tables for simplicity of analyses and discussion.

Chapter 5 focuses on analyses, comparisons and discussions of the results that are provided in Chapter 4.

Chapter 6 is the final chapter to summarize and conclude all the relevant findings and conclusions derived from the research results and discussions according to the methods that were applied for this study.

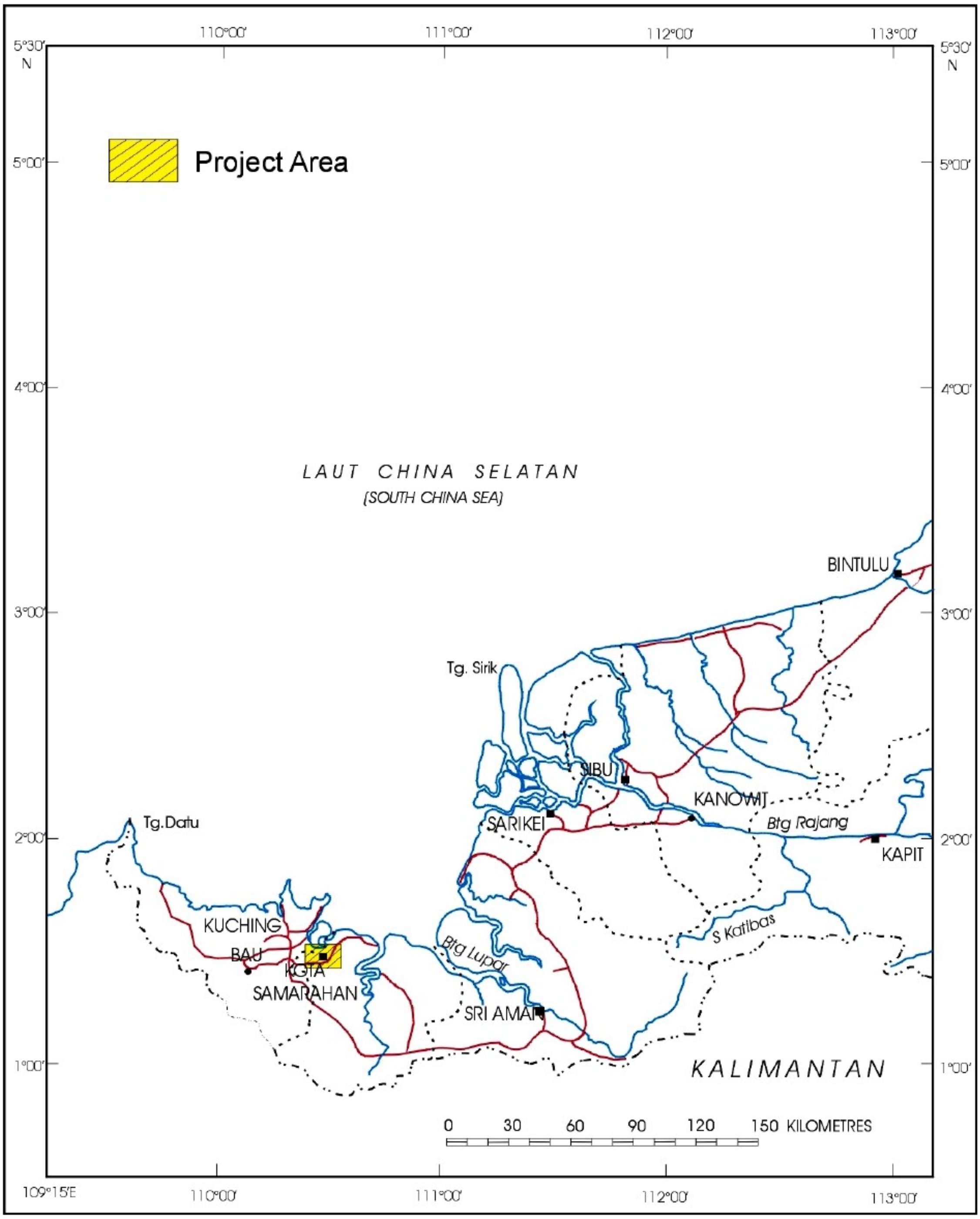


Figure 1.0 Location of project area

CHAPTER 2

2.0 LITERATURE REVIEW

2.1 Introduction (Related definitions and engineering classifications of tropical lowland peats)

Peat classification methods for engineering purposes (such as peat-cement stabilization for ground improvement) and the main factors and aspects of these classification systems will be discussed and reviewed, such aspects include the organic content of peat and the degree of peat humification.

2.2 Definition of peats in general

To understand the formation of peat swamps, it is wise to gain a proper insight into the mode of formation of the deposits and the conditions which have led to their development. The formation or genesis of organic materials is caused by biochemical processes, whereas the process of organic material accumulation is mainly a direct function of the environmental conditions, the climate and ecosystems (peatswamps, bogs or mires) in which the peat is formed. Organic materials only accumulate to form peat under certain conditions, whereby it is essential that the production of biomass (organic materials) is greater than its chemical breakdown to form peat (Andriesse, 1988).

Peats are generally considered to be partly decomposed biomass (vegetation) and show a wide range in degree of decomposition. Kurbatov (1968; in Andriesse, 1988) 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 decides whether any biomass will accumulate and in what form. Distinction was made between forest peat which is more aerated and therefore more decomposed, and peats formed under swampy conditions with strongly anaerobic conditions. In forest peat, lignin and carbohydrates appear to be completely decomposed so it generally has a low content of such organic compounds, whereas under swamp conditions peats are characterized by high contents of cutin and the presence of much unaltered lignin and cellulose (Table 2.1) (Andriesse, 1988).

Table 2.1: Composition Of Swamp And Forest Peat As % Dry Organic Matter (Adapted from Kurbatov 1968; Andriesse, 1988)

Fraction	**Swamp peat**		**Forest peat**
	Carex-swamp 30% decomposed	**Reed-swamp 40% decomposed**	**Birchwood 55% decomposed**
Bitumen	3.3	1.1	8.8
Humic acids	32.2	33.6	52.2
Hemicellulose	15.0	8.6	1.0
Cellulose	3.5	3.7	0.0
Lignins	12.9	18.6	0.0
Cutin	11.9	5.2	16.0
Not determined	21.2	29.2	22.0

Anaerobic, swampy conditions, which prevent the micro-biological activity needed 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. The anaerobic conditions are created by a specific hydro-topography whether marsh, swamp, bog or mire. Properties of such hydro-topographic units depend on many environmental factors, including climate, landform, local geology and hydrology (Andriesse, 1988).

The definition of peat also refers to the net accumulation of purely one hundred percent organic matter and the difference between soil and organic or vegetative accumulation varies (Murtedza et al., 2002; Andriesse, 1992) probably due to varying definitions from the different academic fields associated with the practical study of peat and its' properties (agriculture, botany, geology and engineering, for instance). 'Peat' has been alternately referred to as 'organic soils' and Histosols. Peat is referred to as organic soils on the basis of mass composition (Murtedza et al., 2002), 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 that is based on profile partition, i.e. soils that have 50 cm or more organic soil matter within 100 cm or more than twice that of mineral soil materials overlying bedrock within 50 cm (Murtedza et al, 2002).

On the other hand, 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 having interstices filled with organic materials (Murtedza et al., 2002).

2.2.1 Definition of tropical lowland peats in general

Peats are formed by 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 have undecomposed and partly decomposed branches, logs or twigs (Figure 2.1). Tropical lowland peat basins form a fragile ecosystem because of its' domed shape and is almost purely organic (Paramananthan, 2011). Tropical Lowland Soils have an isohyperthermic or warmer soil temperature regime (with a mean annual soil temperature of more than 22°C and a monthly variation of less than 5°C) and a common elevation of less than 750 metres or 2,500 feet (Paramananthan, 2011). According to Paramananthan (2011) lowland organic soils are soils in which the thickness of organic soil layers make up more than half the soil to 100 cm or shallower if rocks or parent materials occur at less than 100 cm. Lowland organic soils are sub-divided based on the thickness of the organic soil layer. Lowland organic soils (including peat) or histosols soils are subdivided into ombrogambists or deep organic soils (that are more than 150 cm thick) and topogambists or moderately deep and shallow organic soils (50 to 150 cm thick).

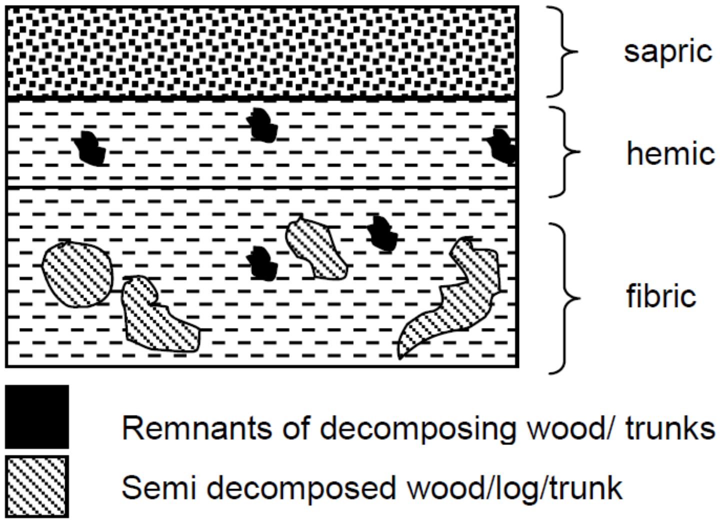


Figure 2.1: Profile morphology of drained peat soil (adapted from Mutalib et al., 1991). Refer to Table 2.4 for further subdivision and definition of peat.

2.2.2 Definition of peat for engineering classification purposes

Peat deposits or paludal deposits are superficial deposits or soils with high organic matter content usually occurring as an integral part of the wetland systems as extremely soft, wet, unconsolidated superficial deposits. Paludal deposits sometimes occur as underlying strata or layers under other superficial deposits. Bujang (2004), describes peats as naturally occurring highly organic substances derived primarily from plant materials and is formed when the accumulation of plant organic matter occurs more quickly than it humifies (decomposes), usually when organic matter is preserved below high water tables such as in swamps or wetlands. Depending on the purpose of classification, the cut-off value of the percentage of organic matter which is necessary to classify a superficial deposit or soil as peat and also to differentiate actual peats from soils with lesser amounts of organic content, varies throughout the world (Bujang, 2004).

Generally, soils with organic contents of greater than 20% are termed organic soils. The definition of peat varies between the fields of soil science and engineering. In soil science, peat is defined as soils with organic content of greater than 35%, whereas in geotechnical engineering, all soils with organic contents greater than 20% are known as organic soils. In geotechnical engineering, organic soils with organic contents greater than 75% are known as 'peats' (Jarret, 1995; Bujang, 2004). These variations in definition are due to the mechanical properties of the soil which changes when the organic content of the soil is greater than 20%. The ASTM (D4427) and Jarret's (Jarret, 1995; Bujang, 2004) classification of peat by laboratory testing is shown in Table 2.2 and Table 2.3.

Table 2.2: ASTM D4427 Organic Content Ranges (adapted from Bujang, 2004).

Basic soil type	Description	Organic Content(%)
Clay or silt or sand	Slightly organic	2-20
Organic soil		25-75
Peat		>75

Table 2.3: Organic soil classification based on organic content ranges (Jarret, 1995; Bujang, 2004).

Basic soil type	Description	Symbol	Organic Content(%)
Clay or silt or sand	Slightly organic	O	2-20
Organic soil		O	25-75
Peat		Pt	>75

According to the Malaysian Soil Classification System for Engineering Purposes and Field Identification (adapted from 'Guideline for Engineering Geological Investigation in Peat and Soft Soils'-Minerals and Geoscience Department, 2007), soils that have organic content from 3 to 20% are termed Slightly Organic Soils, and soils with organic content in the range of 20 to 75% are classified as Organic soils and finally, peats have a more than 75% organic content (Chapter 3, Table 3.1).

2.2.3 Classification of peat for engineering purposes

According to the Alaska Guide for Description and Classification of Peat and Organic soils (2007), peat is a naturally occurring, highly organic substance composed primarily of vegetable matter in various stages of decomposition. It is fibrous to amorphous in texture, is usually dark brown to black, and has an organic odor. Ash content will be less than 25 percent when tested under ASTM D2974. The classification of peat and organic soils requires special attention beyond that needed to classify other soils. Several existing classification schemes exist for peat and organic soils, but, there is no single system that allows classification of any soil that contains any amount of organic material. Some of the peat classification systems rely on biologic descriptions of plant constituents. However, engineers and geologists tend to rely on methods that use numerical values as part of the system for nomenclature (The Alaska Guide for Description and Classification of Peat and Organic soils, 2007).

The procedure for classifying peat is outlined in Standard Classification of Peat Samples by Laboratory Testing (ASTM D 4427). Whereby, this method includes use of the ASTM D 5715 field test method (Fiber content by field testing for degree of humification-ASTM D 5715). The humification test (Von Post Classification system) was developed in the early 1920s in Sweden, and is related to the fiber content of the peat. This simple field classification test consists of taking a sample of peat and squeezing it in the hand (Chapter 3, Table 3.2). The material that is extruded between the fingers is examined and the soil is identified as one of ten (H1 to H10) humification or decomposition categories (Stanek and Silc, 1977; The Alaska Guide for Description and Classification of Peat and Organic soils, 2007; Andriesse, 1988).

The organic fibre content (or the fabric of organic soil) is determined usually from the dry weight of fibers retained on the 150 micron openings of the #100 mesh sieve (> 0.15mm opening size) as percentage of oven-dried mass. Fibers may be fine (woody or non-woody) or coarse (woody) and is defined as more than (>) 0.15 mm in diameter (Bujang, 2004). The Von Post Scale is a useful means to classify peat based on the fibre content of peat and its' related degree of humification or decomposition. Peat soil classification (Von Post) and qualifying terms and symbols with description are as shown in (Table 2.4) (Bujang, 2004). The USDA (United States Department of Agriculture) classification based on fibre content as a result of humification is described in Table 2.5 (Bujang, 2004).

Table 2.4: Peat soils qualifying terms, symbols and description (adapted from Bujang, 2004).

Organic	Von Post scale	Qualifying terms	Symbol	Description and colour
Peat			Pt	(>75% organic content)
	H1-H3	Fibric/Fibrous	f	Mostly undecomposed, typically tan to light reddish brown in colour
	H4-H6	Hemic/Moderately decomposed	h	Intermediate in degree of decomposition, organic content and bulk density, dark, reddish brown in colour
	H7-H10	Sapric/Amorphous	a	Highly decomposed with the highest organic content and bulk density. Relatively darker in colour than fibric or hemic peat

Table 2.5: USDA peat classification (adapted from Bujang, 2004).

Type of Peat	Fiber Content	Von Post scale
Fibric peat	Over 66%	H4 or less
Hemic peat	33-66%	H5 or H6
Sapric peat	Less than 33%	H7

Further classification of peat may be made by dividing the peat into one of three types based on the degree of humification/decomposition (ASTM D 5715) or the fiber content (The Alaska Guide for Description and Classification of Peat and Organic soils, 2007; Stanek and Silc, 1977; Riley, 1986; Levesque and Dinel, 1976) of the peat soil (Table 2.6).

Table 2.6: Classification of peat based on fibre content (The Alaska Guide for Description and Classification of Peat and Organic soils, 2007).

Name	**Fiber Content**	**Degree of Humification**
Fibric Peat	>67%	H1-H3
Hemic Peat	33%-67%	H4-H6
Sapric Peat	<33%	H7-H10

The Malaysian Soil Classification System for Engineering Purposes and Field Identification ('Guideline for Engineering Geological Investigation in Peat and Soft Soils'-Minerals and Geoscience Department, 2007; BS5930, after Jarret, 1995; Bujang, 2004) includes the factors of organic content and degree of humification for classification of peat. Soils that have organic content from 3 to 20% are termed Slightly Organic Soils, and soils with organic content in the range of 20 to 75% are classified as Organic soils and finally, peats have a more than 75% organic content. Fibric or fibrous peats (Ptf) have a humification range of H1 to H3 whereas hemic or moderately decomposed peats (Pth) have a range of H4 to H6. Sapric or amorphous peats range (Chapter 3, Table 3.2) from H7 to H10 on the humification scale (BS5930, after Jarret, 1995; Bujang, 2004).

2.2.4 Description and Classification of Organic Soil

Organic soil has enough organic content/matter to significantly affect its' soil characteristics. The most common and current practice for laboratory classification of organic soil, is to use the ignition test for determination of organic content (ASTM D 2974). When used in conjunction with Standard Practice for Classification of Soils for Engineering Purposes (Unified Soil Classification System) (ASTM D 2487), the ignition test provides a quick and inexpensive means of determining organic content of soils and is, usually, the only laboratory test needed for classification of organic soil (The Alaska Guide for Description and Classification of Peat and Organic soils, 2007).

2.2.5 Concluding remarks for classification of tropical lowland peats for engineering purposes

The past sections have reviewed some classification methods for engineering purposes and the main aspects of the classification systems are as summarized below:

(1) The Malaysian Soil Classification System for Engineering Purposes and Field Identification ('Guideline for Engineering Geological Investigation in Peat and Soft Soils'-Minerals and Geoscience Department, 2007; BS5930, after Jarret, 1995; Bujang, 2004) includes the factors of organic content and degree of humification for classification of tropical lowland peats. The percentage of organic content determines whether an organic soil is a peat or not:

- Slightly Organic Soils (3 to 20% organic content),

-Organic soils (20 to 75% organic content),

-Peats (more than 75% organic content).

Peats have an organic content of more than 75% and are further subdivided into Fibric or fibrous peats (Ptf) (humification range of H1 to H3), hemic or moderately decomposed peats (Pth) (H4 to H6) and Sapric or amorphous peats (H7 to H10).

(2) The method of classifying peat is outlined in Standard Classification of Peat Samples by Laboratory Testing (ASTM D 4427) which includes the use of the ASTM D 5715 field test method that is (Fiber content by field testing for degree of

humification-ASTM D 5715). The Von Post humification test (Von Post Classification system) involves squeezing the peat and the material that is extruded between the fingers is then examined and the soil is identified or classified as one of ten (H1 to H10) humification or decomposition categories (Stanek and Silc, 1977; The Alaska Guide for Description and Classification of Peat and Organic soils, 2007; Andriesse, 1988).

(3) The classification of organic soil or peat for engineering purposes involves mainly using the ignition test for determination of organic content (ASTM D 2974) to determine the percentage of organic content lost during ignition.

2.2.6 Classification of peat for soil science purposes.

2.2.6.1 Soil Science Definition

. The definition of peat varies between the fields of soil science and engineering. In soil science, peat is defined as soils with organic content greater than 35%. The main criteria used in the soil science classification for tropical lowland peats involves the use of the key classification method to classify and identify soils and tropical lowland peats using parent materials (Paramananthan, 2011). The procedure involves the distinction between tropical highland and lowland soils, the division between organic and mineral soil materials, followed by the definition of an organic soil profile. Lowland organic soil profiles are soils in which the thickness of organic soil layers makes up more than half the soil profile to 100 cm or shallower if rocks or parent materials are present at less than 100 cm. Lowland organic soils are sub-divided based on the thickness of the organic soil layer. Lowland organic soils (or peat) or histosols soils are subdivided into ombrogambists or deep organic soils (>150 cm thick) and topogambists or moderately deep and shallow organic soils (50 to 150 cm thick) (Paramananthan, 2011).

2.2.6.2 Criteria for soil science classification

The criteria used in the classification of tropical lowland peats (Paramananthan, 2011) into different categoric levels are the minimum cumulative thickness, drainage class (poor or well drained), thickness of organic layer (ombro or topo), dominant component in the sub-surface (50-100 cm) tier (Terric, Sapric, Hemic or Typic /Fibric), nature of substratum (whether marine or riverine/terrestrial clay/sand), soil temperature regime (isohyperthermic or isomesic), presence and nature of wood (woody decomposed or undecomposed or non-woody) and mode of origin (whether autochthonous or allochthonous) (Table 3.8 in section 3.6).

2.3 Introduction to Cement-Peat Stabilization

The concept of soil-cement stabilization involves the addition of water to cement resulting in a chemical process known as cement hydration. Hydration of cement occurs when the pore water or ground water in soil interacts with Ordinary Portland Cement to form cement paste containing primary cementation products that hardens to create a system of interlocking crystals that weaves the material together, thus stabilizing the peat soil.

Stabilization of peat by cement requires significant strength increase in cement-stabilized peat/organic soil. Peat stabilization by cement is attributed largely to the physio-chemical reactions that occur which includes cement hydration and hardening of the resulting cement paste and the interaction between soil substances with the primary and secondary cementation hydration products.

2.3.1 Soil improvement in peat

Peat is an extreme form of soft soil and is subject to instability and massive primary and long-term settlement when subjected to load increases during construction work on peat ground (Bujang, 2004). Access to peat sites can be difficult and sometimes inaccessible especially in swampy, water-logged peat areas thus leading to difficulty in sampling peat for laboratory tests. The tests involving peat also often results in large variations in peat index properties.

Buildings constructed on peat are usually suspended on piles driven into underlying mineral soil or bedrock, but the soft ground around it may still settle resulting in pavement and driveway cracks and broken drains built around the building structure. Settling of roads built on peat ground may result in bulging and tilting of houses built near or alongside the roads (Bujang, 2004). Due to settlement and difficulty in construction on peat ground, and the inevitable high costs and resulting high maintainance costs involved, engineers and developers tend to avoid construction and building on problematic peat ground. But, this is not always possible due to the scarcity and unavailability of suitable construction ground especially in coastal lowland areas where there is often high pressure for land development, hence the option of peat land development is now becoming more and more unavoidable. Because of this problem, ground improvement methods in peat ground are now being developed for tropical lowland peats.

According to Edil (2003) and Sina et al. (2011), these are some current construction methods that can be applied on peat ground:

1) Avoidance: consider avoidance of peat lands, if possible.

2) Excavation-Displacement/Replacement: practical in peats that are up to 5 metres peat depth.

3) Ground Improvement and/or Reinforcement for Enhancement of Soil Strength and Stiffness:

    a) Stage Construction and Preloading: this method is used to overcome problems of instability in fills constructed over weak deposits, such as peat ground. It is time consuming but can be accelerated by construction and use of vertical wick drains and geosynthetic reinforcement to enhance stability. Placement of loads on the surface or vacuum consolidation can be used to achieve loading.

    b) Deep *In Situ* Mixing (Lime-Cement Columns): This involves forced mixing of lime, cement, or both with soft mineral soil deposits to form stabilized soil columns (this method of peat stabilization is still being developed).

    c) Stone Columns: Compacted gravel is used to fill water jetted holes in soft ground.

d) Piles: Piling is an expensive solution but reliable for building foundations with suspended floors and also embankment supports.

e) Thermal Precompression: The ground is heated moderately (15^0C-25^0C) to accelerate settlement and reduce long-term compression upon cooling (field tested but not yet applied commercially)

f) Preload piers (Geopiers): This method which is currently being developed involves packing stones in dense layers in a hole to allow radial precompression in the ground.

4) Reduction of Driving Forces by use of Light-weight fill: Lighter but sufficiently strong and stiff fill materials are used such as woodchips, sawdust, tire chips, geofoam and expanded shale.

The Deep *In Situ* Mixing (Lime-Cement Columns) method is a deep stabilization technique which was popularly used in Sweden and Finland to strengthen soft soils such as silt and clay by using cement or lime mixes or pure cement. The strength gain was reported to be up to 30 fold. Strength gain in peats may not be high due to the high water content and low strength of peats and is further inhibited by the high organic content of peats (Bujang, 2004). However, by adding enough stabilizers and with the appropriate type of binders, soil stabilization with suitable chemical admixture enables increments in shear strength and bearing capacity, reductions in permeability and compressibility, and improves the swelling characteristics of soft soils.

The Deep Mixing Method (DMM) is suitable for deep peat stabilization (Axelsson et al., 2002; Janz and Johansson, 2002; Wong, 2010). In DMM, columnar soil reinforcement is used in the form of *in situ* stabilized peat columns which are constructed by a deep mixing rig. The rig mixes the injected binder with peat soil by dispersing the binder into the soil so as to provide conducive conditions for the binder's chemical reaction to take place (Larson, 2003). The DMM technique involves mechanically mixing binder and soil (or peat) with a mixing head equipped with a nozzle for binder feeding. The mixing tool is connected to the rotating Kelly of the rig (EuroSoilStab, 2002). The formation of stabilized peat columns by the dry method of deep peat stabilization usually begins by penetrating the rotating shaft and mixing tool down to the desired depth and this is followed by simultaneously lifting the mixing tool while feeding the binder into the peat ground.

For shallow peat deposits, the mass stabilization technique is used to stabilize the soil instead of the removal and replacement method which is costly and problematic in terms of transportation and disposal of the replaced unsuitable soil (Axelsson et al., 2002). The mass stabilization method is a soil reinforcement technique whereby the entire soil layer is blended with stabilizing binders resulting in a stabilized "block" of the shallow peat layer (Axelsson et al., 2002). The mass stabilization machines used are essentially excavators installed and modified with mass stabilization mixers. The binder is fed into the mixing head while the mixer simultaneously moves vertically and horizontally while rotating (EuroSoilStab, 2002).

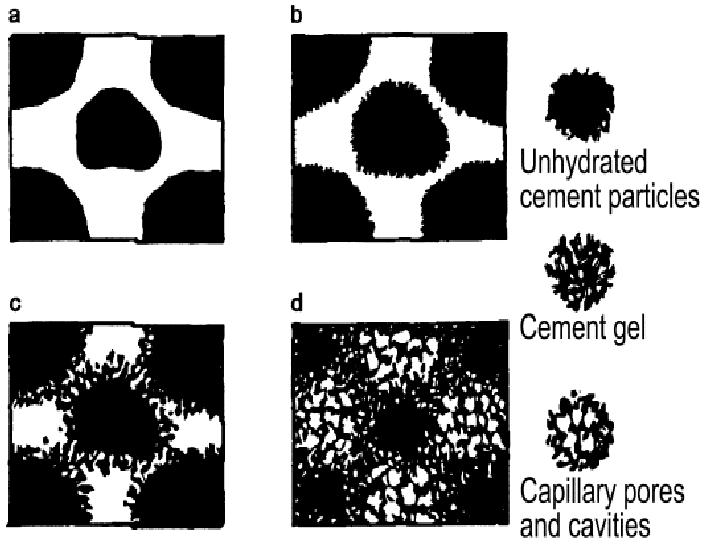
2.3.2 Concept of soil-cement stabilization

The addition of water to cement results in a chemical process known as hydration. Hydration of cement occurs when the pore water or ground water in soil interacts with Ordinary Portland Cement to form primary cementation products which are hydrated calcium silicates (C3S2H4), ettringite (C6AS3H32), monosulfate (C4ASH12) and hydrated lime (CH) (Janz and Johansson, 2002; Wong, 2010). During hydration, a cement paste is produced that hardens to create a system of interlocking crystals that weave the material together (Elbadri, 1998). During hydration or the addition of water to a cement particle, an extremely fine-pored cement gel (also known as tobermorite or C-S-H gel) is formed around the cement particle (Janz and Johansson, 2002). The binding agent that acts as a stabilizer is not the cement itself but it is the mixture of cement and water forming the cement gel (Elbadri, 1998). The cement gel which includes C-S-H gel, ettringite and monosulfate (Janz and Johansson, 2002; Wong, 2010) would gradually fill the void spaces between cement and soil particles during the hydration reaction of water and cement in the soil (Figure 2.2). The hardening cement gel is porous with chemically combined water (water of crystallization), so the volume of the hardened cement paste will be greater than the cement particle prior to reaction and will set, harden and grow denser and stronger with time (Janz and Johansson, 2002). The cement gel would act as a binder between adjacent cement grains to form a hardened skeleton matrix, which encloses the unaltered peat/soil particles hence, stabilizing the soil (Bergado et al., 1996). This hardening soil-cement paste would eventually grow denser and stronger with time. If the binder is insufficient and not well dispersed into the soil or has a high water-cement ratio, such cement particles may widely be separated from each other, probably resulting in a high porosity and low strength of the soil-cement paste or mix.

A high water-cement ratio means more water is present for hydration resulting in a higher porosity and lower strength of the hardened soil-cement paste. According to Janz and Johansson (2002), the strength of the hardened cement paste depends largely on its porosity and separation between particles. Wider separation between particles results in higher porosity and lower strength. The water:cement ratio, *wcr*, gives a measure of the cement content, and hence of the separation between particles (Janz and Johansson, 2002). A high *wcr* implies wide separation and higher porosity between cement particles, and hence lower strength.

$$wcr = W/C$$

where W is the weight of mixing water [kg] and C is the weight of cement [kg].



a) Structure of cement paste or mix immediately after mixing
b) Structure of cement paste or mix after a few minutes
c) Structure of cement paste or mix upon setting
d) Structure of cement paste or mix after some month

Figure 2.2: Structure of cement paste, mix or cement gel (from Fagerlund, 1994, in Janz and Johansson, 2002)

In the cement paste, the four clinker minerals contributing as major strength enhancing compounds are namely, tricalcium silicate, dicalcium silicate, tricalcium aluminate and tetracalcium aluminate ferrite (Ferrit) (Table 2.7). The oxide components of cement, is conveniently represented by the simplified notations such as CaO=C, SiO_2=S, Al_2O_3=A, Fe_2O_3=F, SO_3=S, MgO=M and H_2O=H (Janz and Johansson, 2002; Wong, 2010).

Table 2.7: The clinker minerals contributing as major strength enhancing compounds of Ordinary Portland Cement (Janz and Johansson, 2002).

Name	Chemical formula[1)]	Abbreviation
Tricalcium silicate	$3CaO.SiO_2$	C_3S
Dicalcium silicate	$2CaO.SiO_2$	C_2S
Tricalcium aluminate	3CaO.Al2O3	C_3A
Tetracalcium aluminate ferrite (Ferrit)	$4CaO.Al_2O_3.Fe_2O_3$	C_4AF[2)]

Note:

1) Although e.g. tricalcium silicate is written as $3CaO.SiO_2$, it does not imply that the oxides are present individually.
2) Although the composition of Tetracalcium aluminate ferrite ranges between C_6A_2F and C_6AF, the average composition is close to C_4AF.

The chemistry of the transformation of Ordinary Portland Cement into cement paste with the addition of water according to Bergado et al., (1996) are as follows:

$$2\,(3CaO.SiO_2) + 6H_2O \;=\; 3CaO.2SiO_2.3H2O \;+\; 3Ca\,(OH)_2 \tag{2.1}$$

(tricalcium silicate) (water) (tobermorite gel = primary cementation product) (calcium hydroxide)

$$2\,(2CaO.SiO_2) + 6H_2O \;=\; 3CaO.2SiO_2.3H2O \;+\; 3Ca\,(OH)_2 \tag{2.2}$$

(bicalcium silicate) (water) (tobermorite gel = primary cementation product) (calcium hydroxide)

$$4CaO.Al_2O_3.Fe_2O_3 + 10H_2O + 2Ca(OH)_2 = 6CaO.Al_2O_3.Fe_2O_3.12H_2O \quad (2.3)$$

(tetracalcium aluminoferrite) (calcium aluminoferrite hydrate)

$$3CaO.Al_2O_3 + 12H_2O + Ca(OH)_2 = 3CaO.Al_2O_3.Ca(OH)_2.12H_2O \quad (2.4)$$

(tricalcium aluminate) (calcium aluminoferrite hydrate)

$$3CaO.Al_2O_3 + 10H_2O + CaSO4.2H_2O = 3CaO.Al_2O_3.CaSO_4.12H_2O \quad (2.5)$$

(tricalcium aluminate) (gypsum) (calcium monosulfoaluminate)

Calcium silicates form 75% of Ordinary Portland Cement where Equations 2.1 and 2.2 indicate the hydration reactions of tricalcium silicate and bicalcium silicate produce two new compounds that are lime and tobermorite gel. Tobermorite gel is also known as primary cementation product or C-S-H gel or hydrated gel. The bonding strength and volume variations in the soil-cement mixture are governed by tobermorite gel (Bergado et al., 1996; Janzz and Johansson, 2002; Wong 2010).

When the clinker mineral tricalcium silicate, C_3S, is mixed with water, hydroxide ions are formed and calcium ions are rapidly released into solution, causing the pH to rise above 12 within a few minutes. When the concentration of calcium and hydroxide ions reaches a certain threshold, calcium hydroxide $Ca(OH)_2$ crystallizes out of solution, while a layer of calcium silicate hydrate gel (CSH) or tobermorite gel forms on the surface of the C_3S particles. As the CSH layer grows it forms a 'barrier' which the water must then penetrate to reach the unhydrated C_3S for further hydration reaction to occur and through which ions must diffuse out. This hydration reaction is now diffusion-controlled when initially the hydration rate is temperature-dependent, but the temperature dependency lessens after the reaction becomes diffusion-controlled (Janzz and Johansson, 2002). The hydration reaction of dicalcium silicate, C_2S is similar but reacts more slowly due to its lower reactivity.

The reactions of tricalcium silicate, C_3S and dicalcium silicate, C_2S are:

$$2C_3S + 7H \longrightarrow C_3S_2H_4 + 3CH \quad (2.6)$$

$$2C_2S + 5H \longrightarrow C_3S_2H_4 + CH \quad (2.7)$$

whereby $C_3S_2H_4$ is the CSH gel (Janzz and Johansson, 2002).

Hydrous silica and alumina are produced from base reactions with acidic soil silica and alumina. Secondary pozzolanic reactions occur when secondary cementation products or insoluble compounds are produced by the reaction between hydrous silica and alumina with the calcium ions from cement hydrolysis. The secondary cementation products harden upon curing to stabilize the soil. In addition, further strength is acquired by the solution of both soil silicates and aluminates. The bonding strength of the primary cementation product (tobermorite gel) is much greater than the secondary cementation products (Bergado et al., 1996).

2.3.3 Stabilization of peat by cement

Organic soils can retard or prevent the hydration of chemical binders such as cement in binder-soil mixtures (Hebib and Farrell, 2003). The high organic content and significantly lesser amounts of solid particles in peat (e.g. ombrogenic peats have very high organic content and hence very low ash values) is the reason why cement alone is insufficient to provide the desirable stabilization strength in peat ground improvement. Mud and peats have fewer solids to stabilize, when compared to mineral soils such as silt or clay, hence more stabilizer is needed to bind these solid particles together (Janz and Johansson, 2002). Peat has a considerably lower content of solid clay particles that can enter into secondary pozzolanic reactions (Janz and Johansson, 2002; Wong, 2010) when compared to clay or silt. Therefore, no significant strength gain can probably be achieved from use of cement binder alone in peat stabilization unless cement is added to to the soil in large, but, uneconomical dosages.

Ahnberg et al. (1995) showed that cement stabilized peat alone and cement stabilized peat with the highest water to cement ratio achieved the lowest shear strength when compared to cement stabilized mud, silty clay, clayey silt and other types of soil. The high water: soil ratio in peats gives a high water to cement ratio resulting in lower stabilization strength. The increase in the *wcr* ratio means that more stabilizer must be added for strength increase (Janz and Johansson, 2002).

Axelsson et al. (2002) stated that there are indications that soils with high organic content (such as in peats) have a threshold effect whereby the quantity of binder used must exceed a certain threshold before any stabilization is obtained. This ‘threshold effect’ was possibly because a sufficient amount of binder must be added to neutralize the humic acids in peats.

It was concluded by Chen and Wang (2006) that with lesser amounts of solid particles and higher amounts of organic matter present in peat, the organic matter content in peat tends to impede the hydration of cement in peat stabilization. This impediment to the cementation and hardening of the peat-cement admixture is due to the presence of black humic acid and fulvic acid in peat. Humic substances which include humic acid, fulvic acid, and humin are the major components of the organic matter in peat.

Black humic acid reacts strongly with calcium liberated from cement hydrolysis to form insoluble calcium humic acid (Chen and Wang, 2006; Wong et al., 2009). The strong affinity of humic acid to calcium retards calcium crystallization, thus impeding the increase of peat soil-cement mixture strength.

Fulvic acid in peat tends to associate mineral particles containing aluminium, leading to the destruction or decomposition of the layered crystal lattice within the peat soil-cement mixture. The chemical interaction due to initial hydration between fulvic acid and the cement minerals would result in the production of an absorbed layer that impedes further hydration of cement. In addition fulvic acid may decompose the calcium aluminate hydrate, calcium sulphate-aluminate hydrate and calcium ferrite-aluminate hydrate crystals, thus further preventing the formation of the soil-cement structure (Chen and Wang, 2006; Wong, 2010).

The peat organic acids may cause the soil pH to drop and dampens the reaction rate of the hydrated cement binder used, resulting in a slower strength gain in peat (Axelsson et al., 2002; Wong, 2010). Unless a large (and probably uneconomical) quantity of cement is mixed with the soil for stabilization, the mixture of organic acids, soil and cement produces a pH lower than 9 in the pore solution which is too low to allow secondary mineral or secondary cementation product formation, hence, retarding the stabilization effect (Tremblay et al., 2002; Wong, 2010).

Thus, it should be clear now that the significant strength increase in cement-stabilized peat or organic soil is attributed largely to the physio-chemical reactions that occurs which includes the hydration reaction, hardening of cement paste and the interaction between soil substances and the primary and secondary cementation hydration products.

According to Chen and Wang (2006), excessive organic matter in peat implies that the peat has a high water retention capacity and high natural moisture content that causes the absorption of organic particles on the surface of the cement and solid mineral soil particles, resulting in hindrance of formation of cement hydration products and the hindrance of hydration reaction between solid soil particles and hydration products. This would then result in a limited increment in peat-cement admixture strength.

2.4 Effect of clay particles as pozzolan and secondary additive in peat stabilization

Small amounts of pozzolans such as kaolinite can be added to cement stabilized peats to enhance the secondary pozzolanic reaction in the stabilized soil. The reactivity of cement and pozzolan in peat stabilization with water (in the soil), is dependant on the ratio of lime to silica ($CaO:SiO_2$). Higher lime to silica ratio means that the material is more hydraulic (Janz and Johansson, 2002). In Table 2.8, it is observed that the cement and pozzolan have calcium to silica ratio of approximately 3 and 0 respectively. The relatively higher calcium to silica ratio in cement is indicative of cement as a hydraulic material which upon its reaction with water, results in a rapid initial strength gain followed by a secondary pozzolanic reaction. However, the almost zero calcium to silica ratio in a pozzolan such as kaolinite (or kaolinic clay) shows that it is a pozzolanic material which reacts with water when activated by calcium hydroxide from cement hydration (Janz and Johansson, 2002).

Table 2.8: Stabilized strength enhancement reactions of cement and pozzolan (Janz and Johansson, 2002).

Binder	CaO/SiO_2	Reaction	Co reagents	Time scale
Cement	Approximately 3	Hydraulic	Water	Days (relatively rapid)
Pozzolan	Approximately 0	Pozzolanic	Water +$Ca(OH)_2$ from cement	Weeks

Cement + H_2O = $3CaO.2SiO_2.3H_2O$ + $Ca(OH)_2$ [primary reaction] (2.8)

(Tobermorite gel
/C-S-H gel)

$Ca(OH)_2$ + Pozzolan + H_2O = $3CaO.2SiO_2.3H_2O$ [secondary reaction] (2.9)

(Kaolinitic clay) (Tobermorite gel
/C-S-H gel)

Equations 2.8 and 2.9 show the general chemical reactions between cement and pozzolan with water. Tobermorite gel ($3CaO.2SiO_2.3H_2O$), which acts as a glue binding the soil particles together, is formed in cement hydration in peat stabilization (Equation 2.8). However, humic acid present in peat, reacts with calcium ions (from $Ca(OH)_2$) to form insoluble calcium humic acid. Thus, the secondary pozzolanic reaction (in Equation 2.9) and the production of additional tobermorite gel is hereby inhibited and slows the rate of strength gain in the soil-cement mixture. Organic soils and peats often do not contain enough pozzolanic mineral soil particles in themselves to consume and react with all the $Ca(OH)_2$ that is formed when latent hydraulic cement is hydrated. In addition, peat especially ombrogenic peats or peats with high organic content have very low mineral clay or silt particles content (low ash content) indicating that the peat has a considerably low silica and alumina content to enter into secondary pozzolanic reactions (Janz and Johansson, 2002). Fortunately, cement is less sensitive to humic acid and this still enables secondary tobermorite or C-S-H gels to form when pozzolans react with calcium hydroxide [$Ca(OH_2)$] (Equation 2.9). However, as stated before, the pozzolan is non reactive and if it is to be used as an effective binder, it must be activated by an activator, which in this case is cement. With the inclusion of pozzolans such as kaolin in peat-cement stabilization, hydration of cement is accelerated when the pozzolan reacts with calcium hydroxide [$Ca(OH_2)$] and water to form more secondary tobermorite gels (Equation 2.9) that further contributes to stabilization strength gain.

Clays can act as pozzolans that can provide silica as a result of mineralogical breakdown in a high pH environment. With the addition of lime, aluminous and silicious minerals in clay reacts with the lime to produce calcium silicates and aluminates that bond the particles together. Cement, however, provides its own pozzolans and therefore only requires a supply of water. Pozzolanic reactions are time and temperature dependant (Jacobson and Filz, 2002).

Furthermore, after activation by cement, pozzolans containing excess silica and alumina, will neutralize the peat acids and create an alkaline environment that enhances the secondary pozzolanic reaction within the cemented soil, hereby generating more and more secondary tobermorite gels that eventually hardens and blocks the pore space between soil particles and reduces the permeability while increasing the stabilized strength of the cemented soil (Wong, 2010).

2.5 Effect of siliceous sand (fine aggregates) particles as filler in peat stabilization

Maximum densification to the stabilized soil mix can be provided by introducing a suitable amount of well sorted or well graded fine siliceous material in the form of siliceous sand into it (Wong, 2010). Well sorted sand is necessary to minimize void spaces occurring within the stabilized soil mix structure. Interstices of interconnected void space are filled and packed with well graded, fine to coarse grained particles of fine aggregates like sand when applied as filler material. The use of fillers such as siliceous sand functions to enhance the strength of the stabilized peat-cement mix by supplying more solid particles available for the binder to unite, minimizing unbridged ‘gaps’ in the pore interstices and thus, forming a stabilized, load sustainable structure. According to Abu Bakar (2008), peat contains fewer solid particles to stabilize, thus peat requires greater quantities of stabilizer than clay does. Peat also has a considerably higher water/soil ratio than other soils such as clay. Higher amounts of water in peat imply larger voids, hence requiring more stabilizers (Abu Bakar, 2008). Thus, the use of filler materials such as siliceous sands to fill these voids are necessary to minimize or off-set the amount of cement or chemical stabilizer to be used in the peat stabilization process.

Different binding agents stabilize the soil by different mechanisms. When cement binder is used, the reaction products (tobermorite gel) that bind the soil particles together ‘grows’ on the surface of the cement particles (Janz and Johansson, 2002). It is therefore important for the cement to be uniformly distributed throughout the soil. The cementation effect of siliceous sand as a filler occurs when cementation products or C-S-H gels (tobermorite gel) from primary cement hydration reaction and secondary pozzolan reaction ‘glues’, welds or binds the solid particles of the sand filler particles together at its contact points (‘spot welding’). These result in the further restriction, constriction and confinement of the peat particles that fill up the spaces between interstices of interconnected cement paste/gel now reinforced further by siliceous sand particles acting as filler material to the binder mix. Hence, the organic particles of the peat are ‘stabilized’, ‘confined’ and locked-up by the cementation of siliceous solid particles due to the hardening of cement paste or gel. Thus, no continuous peat matrix is formed, the peat soil is ‘stabilized’ and strength gain is achieved with the hardening and cementation effect (spot welding) of the filler material in the cement paste of the peat-cement-filler mixture. If failure due to fracturing occurs, it would then depend on the strength of interparticle bonds of solid particles or the natural strength of the solid particles itself (Kezdi, 1979).

The excellent cementation effect of sand particles is due to the spherical particle shape of rounded sand-quartz grains that are almost spherical and uniform with no internal voids (Ismail et al., 2002). This is true especially where well weathered and rounded sedimentary quartz grains occur or are deposited, and extracted for use as construction material. The spherical shape of the quartz grains allows the sand-quartz grain to be exposed and in contact with more, surrounding quartz grains via contact points that are welded or binded in the cementation-stabilizing process, thus contributing to the structure of the cemented particle matrix of many, welded, point to point contacts among the sand-filler particles in the hardened cement paste-peat-filler stabilized soil mixture.

There is a possibility that siliceous sand fillers can be activated or enter into secondary pozzolanic reactions but due to their relatively larger particle size and therefore low specific particle surface area, only a small portion of the said surface area of siliceous sand filler particles is actually exposed to calcium hydroxide for secondary pozzolanic reactions resulting in probably negligible reactions or inertness (Janz and Johansson, 2002). According to Wong (2010), the inclusion of siliceous sand as filler may allow it to act as a pozzolan and enter into the secondary pozzolanic reaction with calcium hydroxide [$Ca(OH)_2$] to produce more tobermorite gel and contribute to strength gain (Equation 2.9) in peat-cement stabilization, but this was inhibited due to the low specific, reaction-surface area of the particles of sand filler. Wong (2010) further stated that, theoretically, it may be possible to replace a certain portion of the cement binder with fillers that may also act as pozzolans to reduce the cost of stabilization. However, if the fillers itself were siliceous and of smaller particle sizes, such as in fine sand, silt or clay sized particles, than theoretically, this pozzolan effect may then be possible and the ‘fillers’ can and would doubly act as a pozzolan for stabilization strength gain in the cement-peat mixture.

Abu Bakar (2008) studied the properties of stabilized peat (Banting peats) with and without the addition of sand. In his study, he concluded that the liquid limit of stabilized peat without sand decreased when binder cement (Ordinary Portland Cement) and sodium bentonite was added and when curing time was prolonged. The plasticity index was only significantly reduced by addition of cement with sodium bentonite only after a longer or prolonged curing time (wet curing method) of 28 and 56 days. The addition of cement with sodium bentonite to the stabilized peat with sand caused a significant reduction in liquid limit, plastic limit and plasticity index of the stabilized mixture. The curing time had a slight effect in reducing the liquid limit, plastic limit and plasticity index of the stabilized mixture. Abu Bakar (2008) concluded that the shrinkage of stabilized peat without sand was reduced with the increase of admixture content and curing time. The linear shrinkage was significantly reduced by the addition of admixture and curing period of stabilized peat with sand.

The unconfined compressive strength (UCS) of stabilized peat by addition of chemical admixtures was greater than untreated, unstabilized peat. Stabilized peat using admixtures with dosages of less than 200 kg/m^3 of blast furnace slag and gypsum or blast furnace slag alone (without sand) did not significantly improve its' unconfined compressive strength due to the high organic content of peat soil which causes retardation of the hydration process of the chemical admixture (Abu Bakar, 2008). Unconfined compressive strength of stabilized peat without sand reached the maximum strength of 58 kPa after 56 days curing with an admixture dosage of 250 kg/m^3 of sample CB3C. The unconfined compressive strength of stabilized materials (peat+cement+sodium bentonite+sand) formed with sand as filler was significantly greater than stabilized peat without sand. The highest compressive strength of 850 kPa after 28 days of curing was achieved with an admixture dosage of 300 kg/m^3 and 41% sand filler content (of sample CBS-4C) in stabilized peat. It was concluded that the unconfined compressive strength of stabilized peat with sand filler increased significantly with increase of admixture dosage and sand filler content (Abu Bakar, 2008). Wong et al. (2011), Wong (2010) and Wong et al. (2009) concluded that high organic, stabilized peats (sampled from Klang) showed a marked improvement relative to untreated peats in terms of unconfined compressive strength with the addition of calcium chloride as cement accelerator, rapid settling cements (Type I-Portland Composite Cement and Portland Pulverised Fuel Ash Cement) as binding agents, kaolinite and sodium bentonite as pozzolans and siliceous sand as filler into the peat-cement mix. The best experimental mix design by Wong (2010) and Wong et al. (2009) was stabilized peat at 300kg m^{-3} binder dosage, 100% Portland Pulverized Fuel Ash Cement (PPFAC) (with superplastisizer as a cement dispersing agent), 4% Calcium Chloride (as an accelerator) binder composition and 25% siliceous sand filler by volume of peat at a natural moisture content of 668% (Wong, 2010). Wong et al. (2009) concluded that high strength cemented peat can be produced when MASCRETE (MASCRETE is a rapid setting pulverized fuel ash cement formed with high fineness with added superplasticizer as a cement dispersing agent) and kaolinite stabilized peat admixture with siliceous sand acting as a filler, was activated by calcium chloride that accelerated the rate of cement hydration in the soil giving it the highest unconfined compressive strength of 413.0 kPa after 7 curing days in water. Sadeq et al. (2008) also concluded that cement binder-sand stabilized peat soils showed an increase in the unconfined compressive strength.

The addition of cement admixture to the stabilized peat without sand reduced the coefficient of compression C_c relative to untreated peat. However, the coefficient of permeability (k), was not reduced due to flocculation which occurs during the hydration process between peat soil particles with admixture (without sand) to form porous crystalline material with larger voids (Abu Bakar, 2008). The increase of admixtures content to the stabilized peat with sand also reduced the coefficient of compression (Cc). Consolidation test results done by Abu Bakar (2008) indicated that sand increments to stabilized peat with sand significantly reduced the coefficients of consolidation (Cv) and permeability (k) compared to stabilized peat without sand filler. The addition of sand to the stabilized peat significantly reduced the permeability by 8 times for stabilized peat with 250 kg/m3 admixture dosage and 41% sand content (for CBS-4B) when compared to the permeability of stabilized peat without sand with the same admixture dosage (CB-3C).

Addition and increment of admixture content to the stabilized peat without sand had resulted in an increase in pH values. Similarly, an increment of pH values was observed with the increase of admixture content of stabilized peat with sand filler.

From laboratory vane shear tests, the highest undrained shear strength of 265 kPa was achieved after a 7 day wet curing period for stabilised peat with an admixture binder dosage of 300 kg/m^3 and 41% sand filler content (sample CBS-4C). Similarly, the undrained shear strength (from laboratory vane shear tests) of stabilized peat with 250 kg/m^3 admixture dosage with 41% sand filler content was 1.70 times higher compared to stabilized peat with the same dosage and admixture type but without using sand as filler **(**Abu Bakar, 2008**)**.

According to Abu Bakar (2008), the minimum DMM (Deep Mixing Method) requirement for soil-cement pile/columns was 250 kg/m^3 admixture dosage of cement with sodium bentonite to stabilized peat with sand filler and the minimum sand content was 34% by weight of *in situ* peat for the same admixture dosage (250 kg/m^3). The minimum 18% sand content for admixture dosage of 300 kg/m^3 still fulfilled the DMM strength requirement of 300-4000 kPa.

2.6 Effect of curing time in water for peat stabilization

The effect of curing time in water on the unconfined compression strength for Ballydermot peat stabilization was studied by Hebib and Farrel (2003) for a duration of 7, 28, 90 and 360 days and proved that temperate peats can be stabilized by using different laboratory mix designs and the strength increased with curing time in water. The unconfined compressive strength of Soderhamn, Sweden stabilized peats also showed an increase in strength after 360 days curing time in water by using different binder mixes such as cement-blast furnace and cement-fly ash mixes (EuroSoilStab, 2002). Generally, these studies show that the strength of stabilized peats increased with longer or increased curing periods in water (Wong, 2010; Abu Bakar, 2008; Janz and Johansson, 2002).

The effect of curing time in water for the peat stabilization process differs according to type of binder mix (Wong, 2010; Abu Bakar, 2008; Janz and Johansson, 2002; EuroSoilStab, 2002; Sadeq et al., 2008; Roslan and Shaidul, 2008). The reaction of cement as a binder for peat stabilization almost totally ends after 28 days or during the first month of curing (Wong, 2010; Abu Bakar, 2008; Janz and Johansson, 2002; Axelsson, 2002; EuroSoilStab, 2002), while stabilization reaction process for binders such as furnace slag or fly ash continues for months (Wong, 2010; Janz and Johansson, 2002). Roslan and Shahidul (2008) conducted tropical peat soil stabilization tests after 1 day, 3 days, 7 days and 28 days curing time to examine the effects of curing time on unconfined compressive strength and found that strength increased with an increase in curing time. The unconfined compressive strength of cement stabilized peat with sand filler also showed increment with curing time from 7 days to 14 days curing period (Sadeq et al., 2008).

Most of the peat stabilization studies so far reviewed was done by using the water curing technique. However, in the field, the peat stabilization process and procedure would involve vehicle mobilization mounted with heavy machinery and transportation of these equipment would most probably be impeded by the soft ground and waterlogged swampy terrain of tropical lowland peats such as is found to occur in most parts of peatlands in Malaysia and in the tropics in general. Thus, the practical stabilization procedure would usually involve the initial draining of the targeted peat area for stabilization, resulting in an improved, relatively drier ground condition. Because of this, the author believes that the air curing peat stabilization technique should be studied to imitate the actual, drained peat ground conditions such as described earlier. The air curing technique involves the use of *in situ* or naturally occurring peat water (natural moisture content) for the cement hydration reaction in the peat stabilization process.

2.7 The Air Curing or Dry Curing Technique for Peat Stabilization

Tropical lowland peat swamps are usually waterlogged for most of the duration in a year. Drainage is needed to make these water-logged lands suitable for agriculture or other land use, such as infrastructure and housing development. Water management practices require avoiding flooding by evacuating excess rainfall within a certain period of time. The rapid removal of excess rainfall in combination with the high permeability of the peat results in the lowering of overall water levels. This has various negative consequences such as land subsidence (Drainage and Irrigation Department, 2001).

Water management for agriculture development (and development of the associated infrastructure), involves draining of tropical lowland peat lands occurring largely as coastal peat swamps. This will result in the lowering of ground water tables, drying and the reduction of the 'Natural Moisture Content' of the paludal deposits involved, especially in the top layer of the peat deposit. Furthermore, wet, soft peaty ground conditions must first be conventionally drained to enable movement, transport, mobility and access of vehicles and machinery for the development and building of access roads beforehand. Therefore, there is a need to investigate ways to improve or stabilize drained peat ground conditions for such reasons mentioned earlier. *In situ* drained peat is usually relatively drier compared to undrained, wet tropical lowland peats.

2.7.1 Stabilization of peat by cement and the Air Curing Technique

Behzad and Bujang (2008) did a laboratory study of stabilized peat (sampled from Kampung Jawa, West Malaysia from a depth of 0 to 60 cm) using Ordinary Portland Cement (OPC) as a binding agent with Polypropylene fibers as an additive by using the Air Curing Technique. This technique involves the curing of stabilized peat specimens without immersion in water during the curing period. Due to the high natural moisture content of the peat tested, no additional water was added or deducted from the peat during the mixing process of peat, cement and fibers. In order to gradually reduce their moisture content, the stabilized peat samples were kept in normal air temperature and out of water immersion and were then allowed to dry during the curing period. The Air Curing periods used by Behzad and Bujang (2008) were 28, 90, 180 days for the Unconfined Compression Tests and 90 days for the CBR (soaked, and un-soaked) tests. As the air curing time for the stabilized peat samples was increased, the moisture content decreased, thus weight of Water/weight of Cement (W/C) was reduced, and as a result the stabilized peat samples were hardened and gained significant strength. The addition of polypropylene fibers to the stabilized peat samples with cement gave more strength values and added uniformity and intactness to the stabilized peat as well (Behzad and Bujang, 2008).

2.7.2 Unconfined Compression Strength (UCS) of stabilized peat using the Air Curing method

Unconfined Compression Strength tests were conducted by Behzad and Bujang (2008) on the undisturbed peat soil as well as stabilized peat soil with OPC and fibers. 38 mm diameter and 76 mm length sample sizes were used for the experiments**.** Disturbed samples used for the stabilized peat soil's Unconfined Compression Strength tests were the peat soil samples at their natural *in situ* moisture content. The peat soil was screened using sieve size 6.3 mm (0.3″) first in order to remove the larger sizes of vegetal wooden fibers and then, specified amounts of OPC and polypropylene fibers were then added to screened peat soil, and mixed well for their homogeneity. Then the mixtures were placed in three consequent layers in the Unconfined Compresion Strength test moulds with an inside mould diameter of 38 mm and a minimum Length/Diameter ratio of 2. For each sample, each of the three layers were given 10 constant full thumb pressures of approximately 10 seconds as was used in Sweden by Axelsson et al. (2002) for compacting stabilized peat soil samples in their moulds. Specimens were then trimmed at both ends, extracted by extractor jack, and subsequently wrapped in plastic sleeves for the following air curing procedure. The Unconfined Compresion Strength tests done by Behzad and Bujang (2008) for stabilized peat samples were then conducted immediately after mixing (0 day) and after being air cured at ages of 28, 90 and 180 days.

2.7.3 Curing procedure (Air Curing Technique) for UCS tests

With the Air Curing Technique (Behzad and Bujang, 2008), the stabilized peat samples for UCS tests were kept in normal air temperature of 30±2 ºC and out of reach of water intrusion during the curing period. This technique was used to strengthen the stabilized peat soil samples by gradual moisture content reduction, instead of the usual water curing technique or water submergence method which has been a common practice of past experiments for stabilizing peat using cement as described by Axelsson et al. (2002), Janz and Johansson (2002), Duraisamy et al. (2007), Abu Bakar (2008), Behzad and Bujang (2008) and Wong (2010). The principle of using the Air Curing Technique for strengthening stabilized peat is that, peat soil at its natural moisture content when mixed with cement, has enough water (water content from 198 to 417%) for the curing process to take place, and hence, does not need more or additional water (or does not need submergence of samples in water) for the curing process to take place (Behzad and Bujang, 2008). This technique will cause the stabilized peat soils to gradually lose their moisture content through the curing period to become drier and harder (Behzad and Bujang, 2008). Peat stabilization studies by previous researchers (Axelsson et al., 2002 and Janz and Johansson, 2002) were done by using the water curing technique set to cold or temperate room temperatures and were supposed to imitate actual ground conditions in Sweden. However, the cold and periodically, near frozen or below zero Celcius physical soil and peat ground conditions in such cold climate countries such as in Sweden are very different when compared to the very soft and wet tropical lowland peat ground conditions.

2.7.4 Mixtures dosages

For UCS tests (Behzad and Bujang, 2008), each set of samples consists of peat soil with natural (field or insitu) moisture contents plus 15%, 30%, and 50% of Ordinary Portland Cement (e.g. 15% cement means for each 100 gr. of wet, insitu peat soil, 15 gr. ordinary portland cement powder is added) with and without polypropylene fibers. The polypropylene fibers amounts used for the stabilized UCS soil samples were 0.1%, 0.15%, and 0.25 % (e.g. 0.15% fibers means for each 100 gr. of wet peat soil, 0.15 gr. of polypropylene fibers is added).

2.8 Concluding remarks

The Deep Mixing Method (DMM) in the form of insitu stabilized peat columns is suitable for deep peat stabilization. Whereas, for shallow peat deposits, the Mass Stabilization technique is used to stabilize the soil instead of the more costly and problematic removal and replacement method.

The concept of soil-cement stabilization involves the addition of water to cement resulting in a chemical process known as cement hydration. Cement hydration forms primary cementation products in the form of hydrated calcium silicates (C3S2H4), ettringite (C6AS3H32), monosulfate (C4ASH12), and hydrated lime (CH). During hydration, a cement paste (also known as tobermorite or C-S-H gel) is produced that fills the void spaces between the cement and soil particles and hardens to create a system of interlocking crystals that weaves the material together. A high water-cement ratio for the paste means that more water is present for hydration resulting in a higher porosity and lower strength of the hardened soil-cement paste. The four clinker minerals contributing as major strength enhancing compounds in the cement paste are namely; tricalcium silicate, dicalcium silicate, tricalcium aluminate and tetracalcium aluminate ferrite (Ferrit). Stabilization of peat by cement which requires a significant strength increase in cement-stabilized peat or organic soil is attributed largely to the physio-chemical reactions that occurs which includes cement hydration and hardening of the resulting cement paste and the interaction between soil substances with the primary and secondary cementation hydration products. The factors involving physio-chemical reactions and interactions of peat soil-cementation products influencing peat stabilization are the amount of solid particles, water : soil ratio, quantity of binder, humic acids and fulvic acids, soil pH and the amount of organic matter in the peat.

Clay particles act as pozzolans and secondary additives in peat stabilization. Secondary pozzolanic reactions occur when secondary cementation products or insoluble compounds (which harden upon curing thus stabilizing the soil) are produced by the reaction between hydrous silica and alumina with the calcium ions from cement hydrolysis. The bonding strength of the primary cementation product (tobermorite gel) is much greater than the secondary cementation products. Small amounts of pozzolans such as kaolinite can be added to cement stabilized peats to enhance the secondary pozzolanic reaction in the stabilized soil. The reactivity of cement and pozzolan in peat stabilization with water (in the soil), is dependant on the ratio of lime to silica ($CaO:SiO_2$). Higher lime to silica ratio means that the material is more hydraulic. Clays act as pozzolans providing silica as a result of mineralogical breakdown in a high pH environment. With the addition of lime, aluminous and silicious minerals in clay reacts with the lime to produce calcium silicates and aluminates that bond the particles together. However, cement provides its own pozzolans and only requires a supply of water. Pozzolanic reactions are time and temperature dependant. After activation by cement, pozzolans containing excess silica and alumina neutralizes the peat acids in peat to create an alkaline environment further enhancing the secondary pozzolanic reaction within the cemented stabilized soil. This hereby generates more secondary tobermorite gels that eventually hardens and blocks the pore space between soil particles, thus reducing the permeability while increasing the stabilized strength of the cemented soil.

Siliceous sand (fine aggregates) particles act as a filler in peat stabilization. Maximum densification to the stabilized soil mix can be provided by introducing a suitable amount of well sorted or well graded siliceous material in the form of well sorted fine to coarse grained siliceous sand into it to minimize void spaces occurring within the stabilized soil mix structure by filling and packing interstices of interconnected void space with well graded fine to coarse grained particles of sand aggregates. The strength of the stabilized peat-cement mix can be enhanced by supplying more solid, sand-filler particles available for the binder to unite, minimizing unbridged ‘gaps’ in the pore interstices and thus, forming a stabilized, load sustainable structure. The cementation effect of the uniformly distributed siliceous sand as a filler occurs when cementation products or C-S-H gels (tobermorite gel) from primary cement hydration reaction and secondary pozzolan reaction welds or binds the solid particles of the sand filler particles together at its contact points (spot welding) thus, futher inhibiting the continuous peat matrix. Strength of the cemented stabilized peat structure depends on the strength of interparticle bonds or the natural strength of the solid particles of cement and filler material. Filler materials are necessary to minimize or off-set the amount of cement or chemical stabilizer to be used in the peat stabilization process. The excellent cementation effect of sand particles is due to the almost spherical and uniform particle shape of rounded sand-quartz grains. There is a possibility that siliceous sand fillers can be activated or enter into secondary pozzolanic reactions but these fillers are relatively inert.

The addition of cement and sodium bentonite to the stabilized peat with sand added as filler caused a significant reduction in liquid limit, plastic limit and plasticity index of the stabilized mixture. The unconfined compressive strength of stabilized materials (peat+cement+sodium bentonite+sand) with sand added as a filler and using the wet curing method was significantly greater than stabilized peat without sand. High organic stabilized peats showed a marked improvement relative to untreated peats in terms of unconfined compressive strength with the addition of calcium chloride as cement accelerator, rapid settling cements (Type I-Portland Composite Cement and Portland Pulverised Fuel Ash Cement) as binding agents, kaolinite and sodium bentonite as pozzolans and siliceous sand as filler into the peat-cement mix. The increase of admixture content to the stabilized peat with sand added as filler material also reduced the coefficient of compression (Cc). Consolidation tests indicated that sand increments to stabilized peat with sand significantly reduced the coefficients of consolidation (Cv) and permeability (k) compared to stabilized peat without sand filler. pH values of the stabilized peat mix were observed to increase with the increment of admixture content of stabilized peat with and without sand filler. Laboratory vane shear tests have shown that the undrained shear strength of stabilized peat with 250kg/m^3 admixture dosage and with 41% sand added filler content was 1.70 times higher compared to stabilized peat with the same dosage and admixture type but without using sand as filler.

The effect of curing time in water for the peat stabilization process differs according to the type of binder mix. The reaction of cement as a binder for peat stabilization usually ends after 28 days or during the first month of curing while the stabilization reaction process for binders such as furnace slag or fly ash continues for months. Tropical peat soil stabilization tests concluded that strength increased with an increase in curing time in water. The unconfined compressive strength of cement stabilized peat with sand filler also showed increment with curing time.

With the Air Curing Technique, the stabilized peat samples for UCS tests were kept in normal air temperature of 30±2 ºC and was used to strengthen the stabilized peat soil samples by gradual moisture content reduction, instead of the usual water curing technique or water submergence method which has been a common practice of past experiments for stabilized peat with cement. The principle of using the Air Curing Technique for strengthening stabilized peat is that, peat soil at its natural moisture content when mixed with cement, has enough water (water content from 198% to 417%) for the curing process to take place, causing the stabilized peat soil to gradually lose their moisture content through the curing period to become drier and harder and hence, does not need more or additional water.

2.8.1 Comments

Hebib and Farrel (2003) argued that for different peats with similar water and organic content, the unconfined compressive strength of different peat-binder mixes can differ. Huttunen and Kujala (1996) reported that the stabilization strength of peats decreased with advanced decomposition. Studies by Abu Bakar (2008) and Wong (2010) have shown how tropical peats can be stabilized by using different chemical additives with and without siliceous sand fillers, but most of the studies that were reviewed did not indicate properly what type of tropical peats were used for the study and what or which part of the peat ‘dome’ was sampled for their stabilization tests? Classification and characterization of these peats especially tropical lowland peats is therefore necessary in order to gain proper insight and to further knowledge of tropical lowland peat stabilization. As mentioned before, tropical lowland peats occur as domed shaped deposits whereby these peats have different characterization and engineering properties according to and depending on the location or which part of the peat ‘dome’ morphology is targeted for the peat-stabilization process and procedure.

Effective stabilization in peats can be achieved by adding solid fillers with cement. Previous works by Abu Bakar (2008) and Wong (2010) have successfully shown that cement-peat stabilization by using siliceous sands as fillers is possible. However, sand is becoming more expensive along with its’ transportation costs and these may make sand unsuitable for stabilizing peats unless they are readily available on site and in large quantities. On the other hand, mineral soil can be readily available on site or *in situ*. Mineral soils that are usually discarded after levelling during earthworks can be used instead of transported river sands as fillers. Clays contained within the mineral soil can also provide clay pozzolanic reactions as described above which further helps in cement-peat stabilization. Hence, this study focuses on cement-peat stabilization by using solid mineral soils as fillers to achieve stabilization strength. Probable variations in stabilized strength occurring laterally from margin towards peat dome centre were also investigated. These strength variations may hopefully help in future stabilization works (Site Investigation) by proper planning and cost-saving through the economizing of cement/filler use. Use of soil fillers can off-set/reduce the volume of cement to be used in stabilization. Further knowledge of the location of topogenous peat or phasic community II areas or zones within the peat basin can also help reduce stabilization costs by reducing the amount of cement or filler material to be used in these areas/zones (refer to chapter 5).

2.9 Petrology and Geochemistry

The hydrocarbon generation potential of coals has been widely discussed in the literature (Khorasani, 1987; Thompson et al., 1985; Wan Hasiah and Abolins, P., 1998; Wan Hasiah, 1999; Mohd. Farhaduzzaman et al., 2012). Conventional coal petrographic studies are usually carried out to evaluate the evolutionary history of the analysed coals whereby the macerals, microlithotypes and lithotypes provide evidence on the nature and type of plant community, duration and intensity of decomposition in the peatification process and the related depositional setting. The interpreted coal evolutionary history provides the basis for further interpretation of the related paleogeography and paleoclimate of the peat-coal precursor basins (Teichmuller, 1989; Stach et al., 1982, Mohd. Farhaduzzaman et al., 2012).

2.9.1 Horizontal or lateral variation in tropical lowland peat domes

Previous workers that include mainly Anderson (1961; 1964 and 1983) have studied the domed topography of tropical peat deposits and the relationship between the concentric zonation of surface vegetation with horizontal distance between margin and centre of the peat basin.

Buwalda (1940, in Paramanathan, 2011) earlier did work in Sumatra which supported the hypotheses/idea of horizontal zonality occurring in tropical lowland peats. He reported that different plant communities exist in the peat swamp forest depending on the thickness of the peat and the distance from the river (peat basin margin). Buwalda (1940, in Paramanathan, 2011) and Anderson (1961; 1963 and 1964) described six vegetation zones occurring in the lowland peat forests of Borneo including Brunei.

Anderson (1961; 1963; 1983) did a comprehensive study of the ecology of the Tropical Lowland Peat Swamp Forests of Borneo. He observed and recorded 253 tree species that are mostly confined to the the periphery of the peat swamp forest. According to Anderson (1963), most of the plant species that grow in the forests at the centre of the peat domes are mostly those that are usually found on nutrient poorer soils, such as podzols of the heath forest (Anderson, 1963). The Tropical Lowland Peat Swamp Forests in Sarawak, Malaysia and adjacent Brunei show lateral or horizontal changes in vegetation types from its periphery to the centre of the domed-shaped peat swamps and each of the six dominant lateral vegetation zones was designated "Phasic Community'' by Anderson (1961) and Esterle and Ferm (1994). The relationship between these phasic communities and successive vegetation zonations with observed variations of various parameters and characteristics of the peats will be discussed further in the following chapters.

CHAPTER 3

3.0 METHODOLOGY

3.1 Field methods

The study area is located in the Kota Samarahan-Asajaya area, west Sarawak (section 1.5 and Figure 1.0). Quaternary peat and soft soils field mapping was done on foot in swampy, jungle areas where deemed inaccessible by motor vehicle. Augering was done using hand augers (Figures 3.0 and 3.1). Auger holes and sampling points were located using a Garmin GPS device (models GPS 76 and GPSmap 76CSx).

Hand auger core samples were extracted, photographed and logged in the field. Peat classification was carried out on a scale of H1 to H10 in the field using the Von Post Classification method described in the 'Guideline for Engineering Geological Investigation in Peat and Soft Soils' (Minerals and Geoscience Department, 2007) and Von Post (1922).

The peat or Russian-type sampler (Figure 3.0) was mainly used for peat sampling. It consists of an anchored fin and a movable sampling chamber. The latter is a semi-circular cylinder measuring 50 cm in length and 5 cm in diameter, with one end forming the sharp pointed edge that penetrates the peat sequence while the other end is connected to the T-shaped handle. Like the gouge auger, the peat sampler operates quite similarly, the difference being the latter is only rotated through a 180^0 turn during sampling. Samples collected using the peat sampler is not disturbed compared to those collected with the gouge auger (Guts auger). This is because the core sample remains enclosed within the sampling chamber throughout the process of sampling.

Figure 3.0: Peat auger (Russian-type sampler) is used for sampling.

Figure 3.1: Logging and Classification (von Post Scale) of peat and soft soils auger core samples.

3.2 Field Description

3.2.1 Peat and Organic Soils.

For field description, slightly organic silts or clays will appear as inorganic fine grained soils, probably black or dark brown in colour, with an organic odour and possibly some visible organic remains. Peat on the other hand may well appear to be completely organic, contain many recognizable plant remains, have a low density and also being black or dark brown in colour.

Description of peat in the field was attempted by using the Von Post Description as described in Chapter 8.1.1-‘Guideline for Engineering Geological Investigation in Peat and Soft Soils’ (Minerals and Geoscience Department, 2007) and as shown in Tables 3.0 and 3.1.

3.2.2 Von Post Description

The peat material was described using the Von Post Squeeze test and results were provided according to the Von Post Degree of Humification with values between H1 and H10 (Table 3.1).

3.2.3 Soft Soils Classification and Description

In the field the cores were logged and described by visual observation and feel (Figure 3.2). The samples were described according to the Malaysian Soil Classification System for Engineering Purposes and Field Identification (Table 3.0) (‘Guideline for Engineering Geological Investigation in Peat and Soft Soils’- Minerals and Geoscience Department, 2007; BS5930, after Jarret, 1995; Bujang, 2004) which includes the factors of organic content and degree of humification for classification of peat. Soils that have organic content from 3 to 20% are termed Slightly Organic Soils, and soils with organic content in the range of 20 to 75% are classified as Organic soils and finally, peats have a more than 75% organic content. Fibric or fibrous peats (Ptf) have a humification range of H1 to H3 whereas hemic or moderately decomposed peats (Pth) have a range of H4 to H6. Sapric or amorphous peats range from H7 to H10 on the humification scale (Table 3.0) (BS 5930, after Jarret, 1995; Bujang, 2004).

Table 3.1: Organic soils and peat section of Malaysian Soil Classification System for Engineering Purposes (from BS5930:1981, after Jarret, 1995; Bujang, 2004; Minerals and Geoscience Department, 2007).

Soil groups		Sub-group and laboratory identification						
		Description	Group Symbol	Sub-group symbol	Liquid Limit%	Degree of Humification	Sub-group name	Field Identification
ORGANIC SOILS AND PEATS	SLIGHTLY ORGANIC SOILS	Slightly Organic SILT	Mo	Mo			Slightly Organic SILT(subdivide like Co)	Usually very dark to black in colour, small amount of organic matter may be visible. Often has distinctive organic smell.
	Organic content 3% to 20%	Slightly Organic CLAY	Fo	CLo	<35%		Slightly Organic CLAY of low plasticity	
			Co	Clo	35-50		Slightly Organic CLAY of intermediate plasticity	
				Cho	50-70		Slightly Organic CLAY of high plasticity	
				Cvo	70-90		Slightly Organic CLAY of very high plasticity	
				CEo	>90		Slightly Organic CLAY of extremely high plasticity	
	ORGANIC SOILS Organic content 20% to 75%	ORGANIC SOILS	O				Subdivision of organic soil is difficult, as neither the plasticity tests nor the humification tests are reliable for them. As such, the "best attempt" is the probable outcome of subdivision leading to descriptions such as "Fibrous Organic Soils" or "Amorphous Organic Soils of Intermediate Plasticity"	

	PEATS Organic content more than 75%	PEAT	Pt	Ptf		H1-H3	Fibric or fibrous peats	Dark brown to black in colour. Material has low density so seems light. Majority of mass is organic, so if peat is fibrous, the whole mass will be recognizable plant remains. If highly humified, the peat will more likely to smell strongly.
				Pth		H4 to H6	Hemic or moderately decomposed peats.	
				Pta		H7 to H10 (Von Post Humification scale)	Sapric or amorphous peats.	

NOTES:

NOTE 1. When describing soils, the name of the soil group should always be given, supplemented if required by the group symbol, although for some additional applications (e.g. longitudinal applications) it may be convenient to use the group symbol alone.
NOTE 2. Where appropriate, gravel and sand may qualify as sandy GRAVEL and gravelly SAND.
NOTE 3. If laboratory methods have not been used for identification, the group symbol or sub-group symbol should be placed in brackets. e.g. (GC)
NOTE 4. When it is not possible or not required to distinguish between SILT, M or CLAY, C, the designation FINE SOIL or FINES, F may be used.
NOTE 5. If more than 50% of coarse material is of gravel size, the term GRAVELLY is used. The description term, SANDY is used if more than 50% of coarse material is sand sized.
NOTE 6. Materials passing below the A-Line on the Casagrande Plasticity chart and has a restricted plastic range in relation to its liquid limit and has a low cohesion, are termed SILTS, M. Slightly organic soils also usually plot below the A-line on the plasticity chart and are termed SLIGHTLY ORGANIC SILTS, Mo.
NOTE 7. Materials passing above the A-line on the plasticity chart, and are fully plastic in relation to its liquid limits, are classified as CLAY, C.

Table 3.2: The Von Post Classification system and Von Post Degree of Humification (H1 to H10) for peat (adapted from Andriesse, 1988).

Symbol	Description
H1	Completely undecomposed peat which, when squeezed, releases almost clear water. Plant remains easily identifiable. No amorphous material observed present.
H2	Almost entirely undecomposed peat which, when squeezed, releases clear or yellowish water. Plant remains still easily identifiable. No amorphous material present.
H3	Very slightly decomposed peat which, when squeezed, releases muddy brown water, but from which no peat passes between the fingers. Plant remains still identifiable, and no amorphous material present.
H4	Slightly decomposed peat which, when squeezed, releases very muddy dark water. No peat is passed between the fingers but the plant remains are slightly pasty and have lost some of their identifiable features.
H5	Moderately decomposed peat which, when squeezed, releases very “muddy” water with a very small amount of amorphous granular peat escaping between the fingers. The structure of the plant remains is quite indistinct although it is still possible to recognize certain features. The residue is very pasty.
H6	Moderately highly decomposed peat with a very indistinct plant structure. When squeezed, about one-third of the peat escapes between the fingers. The residue is very pasty but shows the plant structure more distinctly than before squeezing.
H7	Highly decomposed peat. Contains a lot of amorphous material with very faintly recognizable plant structure. When squeezed, about 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 very indistinct plant structure. When squeezed, about 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 fibres that resist decomposition.
H9	Practically 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 the wet peat escapes between the fingers.

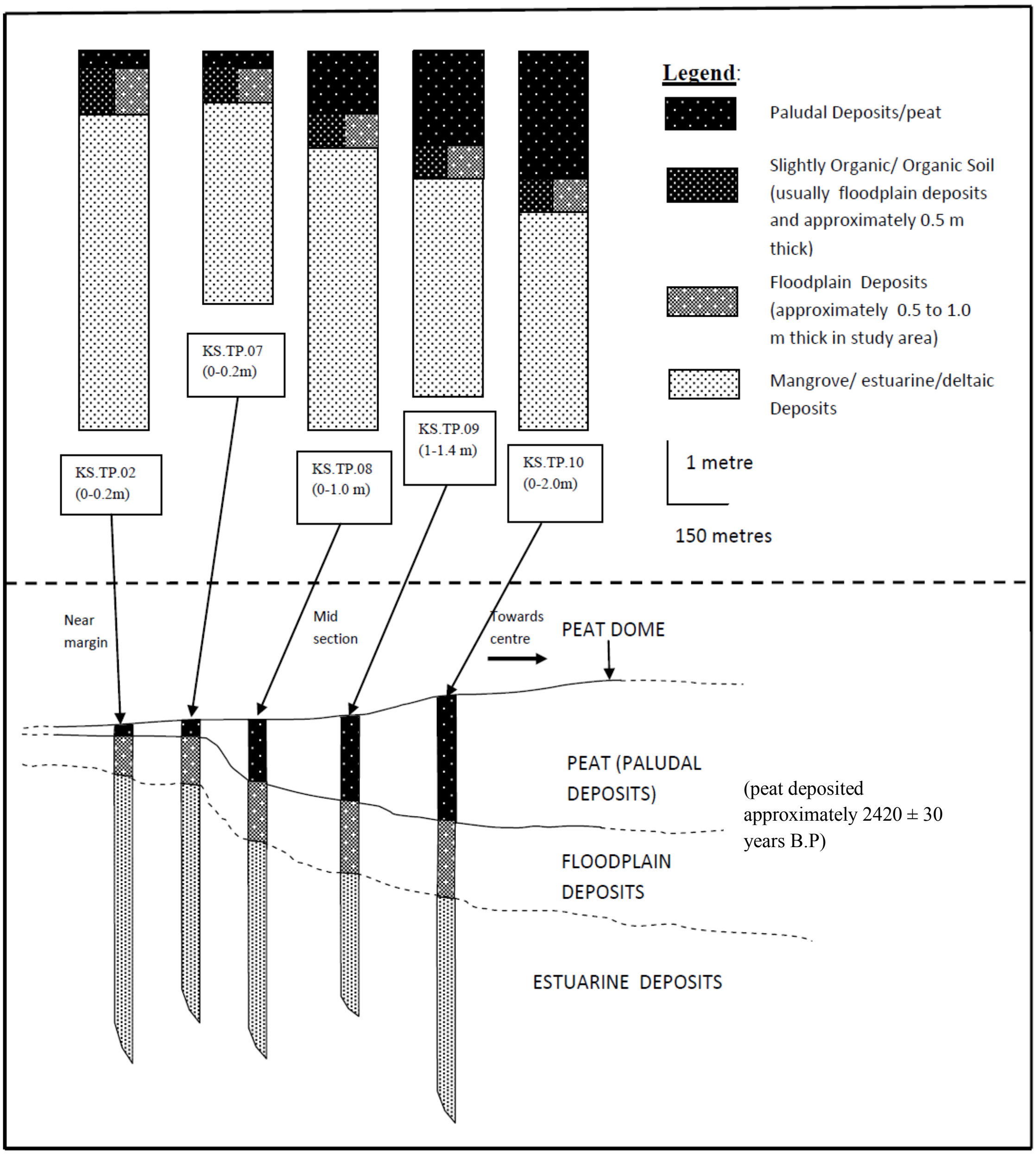


Figure 3.2: Approximate basin cross-section showing general location and log profile of peat cores KS.TP.02, KS.TP.07, KS.TP.08, KS.TP.09 and KS.TP.10 within the peat basin/dome/deposit (refer to Figures 3.8 and 3.9.4) and relative depth or thickness of peat (lithological depth based on field, logging observations and pollen analyses data).

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		**DEPTH (M)**	**SOIL DESCRIPTION**	**REMARKS**
SYMBOL	**GRAPHIC LOG**			
(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 3.3: Auger log for sample location KS.TP.02 (Mo-slightly organic silt, M-silt, Ptf-fibric peats)

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
M		4.5	Gray, soft to firm SILT. Wood fragments <5%, 1-2cm. Moist to wet. Plastic. Shell fragments, black, 5-10% 1-2cm	10 YR 5/1
M		5	Gray, soft to firm SILT. Wood fragments <5%, 1-2cm. Saturated/Wet. Plastic.	10 YR 5/1
M		5.5	Gray, soft to firm SILT. Wood fragments <5%, 1-2cm. Saturated/wet. Plastic.	10 YR 5/1
		6	(Augering stopped at 6.0m due to consistant soil type return)	

LEGEND:

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

Figure 3.3: Auger log for sample location KS.TP.02 (Mo-slightly organic silt, M-silt, Ptf-fibric peats)

*(continued from previous page)

KS.TP.0	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' 12.9"		
AUGERHOLE NO.	KS.TP.0	22/10/2011	9.47 am
GROUND WATER LEVEL	0.4m	**TOP OF AUGERHOLE [(Above m.s.l)]**	9
RECORD BY	MOHAMAD TARMIZI BIN MOHAMAD ZULKIFLEY	**CHECKED BY**	MOHAMAD TARMIZI BIN MOHAMAD ZULKIFLEY

CLASSIFICATION SYMBOL		**DEPTH (M)**	**SOIL DESCRIPTION**	**REMARKS**
SYMBOL	**GRAPHIC LOG**			
(Pta)		0 **(Pt 0.5m)**	Very dark brown SAPRIC PEAT. Amorphous material present.Plant struct hardly identifiable. High moisture content.Very pasty.Moderate to high decomposition. Wood fragments10-20% 1-2cm. Rootlets 1 to 4 cm long ,1mm thick. Wet.Groundwater table 0.4m)	7.5 YR 2.5/3 H8B4F2W1
(Mo)		0.5	Dark gray, banded, soft SLIGHTLY ORGANIC CLAYEY SILT. Wood fragments 20-30%,1-2cm.Wet.	10 YR 4/1
(M)		1	Grayish brown, soft CLAYEY SILT. Wood fragments <5%,1-2cm Wet.Plastic.	10 YR 5/1
(M)		1.5	Grayish brown, soft to firm CLAYEY SILT. Wood fragments <5%, 1-2cm. Moist to wet. Intermediate plasticity.	10 YR 5/1
(M)		2	Gray, soft to firm CLAYEY SILT. Wood fragments <5%, 1-2cm. Moist to wet. Intermediate plasticity.	10 YR 6/1
(M)		2.5	Gray, soft to firm CLAYEY SILT. Wood fragments <5%, 1-2cm. Moist to wet. Intermediate plasticity.	10 YR 6/1
(M)		3	Gray, soft to firm CLAYEY SILT. Wood fragments <5%, 1-2cm. Moist to wet. Intermediate plasticity.	10 YR 6/1
M		3.5	Gray, soft to firm CLAYEY SILT. Wood fragments <5%, 1-2cm. Moist to wet. Intermediate plasticity.	10 YR 6/1
M		4	Gray, soft to firm CLAYEY SILT. Wood fragments <5%, 1-2cm. Moist to wet. Intermediate plasticity.	10 YR 6/1

LEGEND:

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

Figure 3.3.1: Auger log for sample location KS.TP.0 (Mo-slightly organic silt, M-silt, Pta-sapric peats)

KS.TP.0	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' 12.9"		
AUGERHOLE NO.	KS.TP.0	22/10/2011	9.47 am
GROUND WATER LEVEL	0.4m	TOP OF AUGERHOLE [(Above m.s.l)]	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
(M)		4.5	Gray, soft to firm CLAYEY SILT. Wood fragments <5%, 1-2cm. Moist to wet. Intermediate plasticity.	10 YR 6/1
		5	(Augering stopped at 5.0 m due to consistant soil type return)	

LEGEND:

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

Figure 3.3.1: Auger log for sample location KS.TP.0 (Mo-slightly organic silt, M-silt, Pta-sapric peats)

*(continued from previous page)

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	M-silt 'vy' -very	
	Estuarine/Deltaic Deposits(marin	'frag'-fragment	

Figure 3.4: Auger log for sample location KS.TP.07 (M-silt, Ptf-fibric peats, Ph-hemic peats).

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
(Pta)		0	Very dark brown SAPRIC PEAT.Muddy water and peat extruded. 1/3 residue left.Pasty.Plant struc.indistinct to very indistinct.Amorph. content high.Decomposition strong.Rootlets 4-5cm long,1-2cm thick Wood frag. 20-30%, 2-10cm. Very wet. (ground water level 0.3m)	7.5 YR 2.5/2 H7B3F2W1 to H8B3F2W1
(Pth-Pta)		0.5	Very dark brown HEMIC to SAPRIC PEAT.Muddy water and peat extruded.1/3 to1/2 residue left.Pasty.Plant structure indistinct to very indistinct.Amorphous cont. considerable.Decomposition moderately strong to strong.Rootlets 4-5cm long,1-2cm thick. Wood fragments 10-20%, 2-10cm.	7.5 YR 2.5/2 H6B4F2W1 to H7B4F2W1
M (Vy.poorly sorted silt)		1	Banded Gray to dark gray, very soft SILT. Wood fragments 10 to 20%, 0.5 cm long	10 YR 5/1 to 10 YR 4/1
(M)		1.5	Gray ,very soft SILT. Wood fragments 10 to 20 %,0.5cm long Intermediate plasticity	10 YR 5/1
M (Vy.poorly sorted silt)		2	Gray ,soft SILT. Wood fragments 20 to 30%, 1.0 to 2.0cm long Intermediate plasticity	10 YR 5/1
(M)		2.5	Gray ,soft SILT. Wood fragments 10 to20%. Intermediate plasticity	10 YR 5/1
M (poorly sorted silt)		3	Gray , soft SILT. Wood fragments< 5% Intermediate plasticity	10 YR 5/1
(M)		3.5	Gray , soft SILT. Wood fragments 10 % Intermediate plasticity	10 YR 5/1
(M)		4	Gray , soft SILT. Wood fragments 10 to 20% Intermediate plasticity	10 YR 5/1

LEGEND:

	Paludal Deposits/Peat		Slightly Organic Soil
	Floodplain Deposits	M-silt 'vy' -very	
	Estuarine/Deltaic Deposits	'frag'-fragment	

Figure 3.5: Auger log for sample location KS.TP.08 (M-silt, Pth-hemic peats, Pta-sapric peats).

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		DEPTH (M)	SOIL DESCRIPTION	REMARKS
SYMBOL	**GRAPHIC LOG**			
(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 3.5: Auger log for sample location KS.TP.08 (M-silt, Pth-hemic peats, Pta-sapric peats).

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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° 28' 26.4" E110° 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: SYMBOL	CLASSIFICATION SYMBOL: GRAPHIC LOG	DEPTH (M)	SOIL DESCRIPTION	REMARKS
(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 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 peat
(M)		1.5	Banded, dark yellowish brown to yellowish brown ,very soft SLIGHTLY ORGANIC SILT. Wet. Plastic	10 YR , 4/6 to 10 YR , 5/4
			Light gray, very soft SILT. Wet. Plastic	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.)	'Dk.'-Dark
		'vy' -very	'Extrud'-extruded
	Estuarine/Deltaic Deposits	'frag'-fragment	

Figure 3.6: Auger log for sample location KS.TP.09 (M-silt, Pth-hemic peats, Pta-sapric peats).

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° 28' 26.4" E110° 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 BIN MOHAMAD ZULKIFLEY	CHECKED BY	MOHAMAD TARMIZI BIN MOHAMAD ZULKIFLEY

CLASSIFICATION SYMBOL		DEPTH (M)	SOIL DESCRIPTION	REMARKS
SYMBOL	GRAPHIC LOG			
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.)	'Dk.'-Dark
	Estuarine/Deltaic Deposits	'vy' -very	'Extrud'-extruded
		'frag'-fragment	

Figure 3.6: Auger log for sample location KS.TP.09 (M-silt, Pth-hemic peats, Pta-sapric peats).

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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	N01^0 28' 25.7" E110^0 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		**DEPTH (M)**	**SOIL DESCRIPTION**	**REMARKS**
SYMBOL	**GRAPHIC LOG**			
(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		Slightly Organic Soil
	Floodplain Deposits	M-silt (L.P.S.A.)	'Dk.'-Dark
	Estuarine/Deltaic Deposits	'vy' -very	'Extrud'-extruded
		'frag'-fragment	
		Pt.-peat	

Figure 3.7: Auger log for sample location KS.TP.10 (M-silt, Ptf-fibric peats, Pth-hemic peats, Pta-sapric peats)

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	Mohamad Tarmizi Mohd Zulkifley

CLASSIFICATION SYMBOL: SYMBOL	CLASSIFICATION SYMBOL: GRAPHIC LOG	DEPTH (M)	SOIL DESCRIPTION	REMARKS
M		4.5	Dark gray,soft to firm SILT. Plastic. Wood fragments 5 to10%. Wet.	10 YR ,4/1 (colour changes from dark to light)
M		5	Very pale brown,very soft SILT. Plastic.Wet/saturated No wood fragments. Gritty feel	10 YR ,8/3
M		5.5	Very pale brown, very soft SILT. Plastic. Wet/saturated No wood fragments. Gritty feel	10 YR ,8/2
(M)		5.8	Yellow , very soft, SILT. Plastic. Wet/saturated No wood fragments. Gritty feel	10 YR , 8/8
(M)		6	Very pale brown, very soft SILT. Plastic. Wet/saturated No wood fragments. Gritty feel	10 YR ,8/2
			(augering stopped at 6.0 m due to consistant soil type return)	

LEGEND:

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

Figure 3.7: Auger log for sample location KS.TP.10 (M-silt, Ptf-fibric peats, Pth-hemic peats, Pta-sapric peats)

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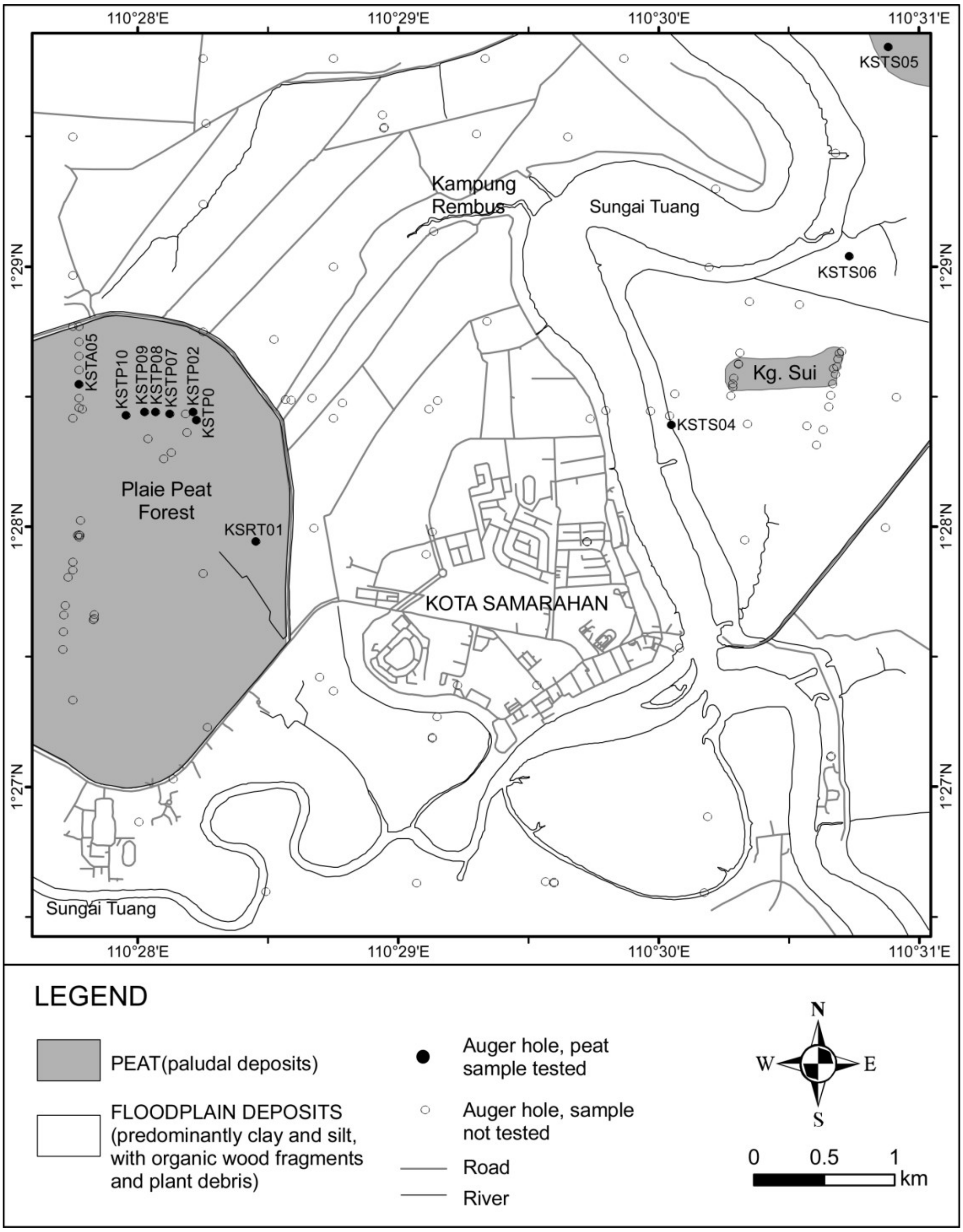

Figure 3.8: Geological map of the Kota Samarahan-Asajaya study area, West Sarawak showing sampling locations in the western Plaie peat forest area. The locations of the major peat cores selected for this study are on the top left hand corner of the map. Refer to Fig. 4.4.4 for other test types done according to sample location.

3.3 Sample preparation and testing methods for peat stabilization tests

A total of five auger samples were collected from a tropical lowland peat basin from the periphery towards the centre of the peat dome at a tropical lowland peat forest of Western Kota Samarahan-Asajaya area for peat stabilization tests. The samples were collected from the top 0 to 0.5 meter peat layer of the peat dome from the margin to mid-section and further towards the peat basin center at locations labeled KS.TP.02, KS.TP.07, KS.TP.08, KS.TP.09 and KS.TP.10 (Figures 3.2 and 3.8).

3.3.1 Unconfined Compressive Strength (UCS) Test Method

3.3.1.1 Preparation and curing of stabilized cement-filler-peat mix

A total of 9 cement-mineral soil filler stabilized peat specimens of the different mix design were prepared and air-cured for 28 days before testing. For homogeneity, the naturally saturated peat was allowed to pass through a 2 mm size sieve for separation of pebbles, isolated roots, large fibers and wood fragments. A kitchen mixer was used to mix the wet peat to ensure the uniform distribution of moisture in the peat or organic soil. Next, the peat or organic soil is mixed with ordinary Portland cement as binder and mineral soil (silt and clays) as fillers. The mixture is mixed for 10 minutes before it was filled and tamped into 3 layers up to 76 mm in height in a plastic PVC tube of 38 mm internal diameter and a minimum Length/Diameter ratio of 2. For each sample, each of the three layers were given 10 constant full thumb pressures of approximately 10 seconds as was used in Sweden by Axelsson et al. (2002) for compacting stabilized peat soil samples in their moulds. By adapting and using the dry curing technique: specimen mixes in moulds are left standing upwards, arranged vertically and left to air dry (air cured) in aerated plastic containers/drawers at room temperature for a 28 day curing period.

With the Air Curing Technique (Behzad and Bujang, 2008), the stabilized peat samples for UCS tests were kept in normal air temperature of 30±2 ºC and out of reach of water intrusion during the curing period. This technique was used to strengthen the stabilized peat soil samples by gradual moisture content reduction, instead of the usual water curing technique or water submergence method which has been a common practice of past experiments for stabilized peat with cement as described by Axelsson et al. (2002), Janz and Johansson (2002), Duraisamy et al. (2007), Abu Bakar (2008), Behzad and Bujang (2008), Wong et al. (2008; 2009; 2011) and Wong (2010). The stabilized peat mixture dosage of 20 g of ordinary Portland cement binder for each 100 g of wet peat (sample KS.TS.05, from 0 to 0.5 m sampling depth) was mixed with 5 g, 15 g, 25 g and 50 g of mineral soil filler (auger sample KS.TS.06 from 0 to 0.5 m sampling depth) to investigate the effects of mineral soil filler quantity on cement-filler-peat stabilization.

From the peat samples KS.TP.0, KS.TP.02, KS.TP.08, KS.TP.09 and KS.TP.10, five different specimen batches were prepared by using 20 g of ordinary Portland cement binder for each 100 g of wet peat (from 0 to 0.5 m sampling depth) and added a constant amount of 25 g mineral soil (silt, clays or fine sand) filler material (obtained from auger location KS.RS.01 at 0 to 0.5 m depth) to investigate the effects of lateral or horizontal peat type variations occurring on the peat dome surface in cement-filler-peat stabilization.

3.3.1.2 Method of testing

After 28 days of air curing, each stabilized peat specimen was extracted and extruded from the plastic tube and trimmed prior to immediate testing. A total of 9 samples were tested for their unconfined compressive strengths. All laboratory test procedures were done in accordance to British (BS.1377, 1990) and U.S. (ASTM, 1995) standards. The various test specimen compositions of cement binder, mineral soil fillers and peat type according to location on the peat dome are presented in Table 3.3 and Figure 3.8. Sample testing was done in triplicates and the average unconfined compressive strength values yielded are as provided in Chapter 4 (Tables 4.1 and 4.1.1).

3.3.1.3 Principle of unconfined compression test

Figure 3.9: Cement with mineral soil filler stabilized peat test specimen with peat from location KS.TP.0 (near basin margin) exhibited shear/brittle failure and yielded the relatively highest unconfined compressive shear strength.

In the unconfined compressive shear strength test, a cylindrical soil specimen of 38 mm diameter and 76 mm height is placed between the top and lower platens as shown in Figure 3.9. An axial load is then gradually applied vertically in such a way that the constant rate of strain on the soil specimen is 1.5 mm per minute. In other words, 1.5 % strain is applied vertically and constantly on the specimen every minute. This strain rate is considered so rapid (Terzaghi et al., 1996) relative to the rate of specimen drainage that there is no time for significant volume change although the membrane to seal the specimen is absent (unconfined condition).

The unconfined compressive strength is considered as the peak stress of the soil stress-strain curve or the maximum stress when the vertical strain reaches 20% if no peak stress is identified in the said curve. Failure of the soil specimen in the test normally implies the condition in which the specimen can no longer sustain any further increase in stress, that is, the point of maximum resistance to deformation in terms of axial stress (Bowles, 1978; Head, 1994).

Table 3.3: Compositions of binder and mineral soil filler of stabilized cement-filler-peat specimens in unconfined compression tests.

Peat specimen code and sample locality on peat dome from basin fringe (shallow peats) towards basin centre (deeper peats)	Composition of stabilized cement-filler-peat mix (air-cured for 28 days)
KS.TP.0	20g OPC + 25g MSF + 100g peat KSTP.0 (0-0.5m sampling depth)
KS.TP.02	20g OPC + 25g MSF + 100g peat KSTP.02 (0-0.5m sampling depth)
KS.TP.08	20g OPC + 25g MSF + 100g peat KSTP.08 (0-0.5m sampling depth)
KS.TP.09	20g OPC + 25g MSF + 100g peat KSTP.09 (0-0.5m sampling depth)
KS.TP.10	20g OPC + 25g MSF + 100g peat KSTP.10 (0-0.5m sampling depth)

Note: OPC=Ordinary Portland Cement; msf= mineral soil filler obtained from location KS.RS.01 (0-0.5m sampling depth); all peats for each mix are sampled from 0 to 0.5 m sampling depth according to varying sample locations from basin fringe towards basin centre at the peats' natural or (insitu) moisture content.

3.4 Organic Geochemical (SRA and GCMS) Analyses Methods

A total of five auger samples were collected from a tropical lowland peat basin from the periphery towards the centre of the peat dome at a tropical lowland peat forest in the Western Kota Samarahan-Asajaya area for geochemical analyses by the Source Rock Analyses (SRA) and the GCMS (Gas Chromatography Mass Spectrometry) methods. These samples were collected from the top 0 to 0.5 meter peat layer of the peat dome from the margin towards the peat basin near-center at the locations labeled as KS.TP.02, KS.TP.07, KS.TP.08, KS.TP.09 and KS.TP.10 (Figures 3.2 and 3.8).

3.4.1 SRA sample preparation method

The samples were oven dried at 40^0C for three days before they were crushed into fine powder and analyzed using the Source Rock Analyzer (SRA Weatherford) which is equivalent to the conventional Rock-Eval instrument used for evaluating source rock quality in petroleum exploration.

3.4.2 Sample extraction method for GCMS analyses

Organic matter extraction was performed on the powdered samples using Soxhlet apparatus (Figure 3.9.1) with an azeotropic mixture of dichloromethane (DCM) and methanol (CH_3OH) (93:7) for 72 hours. The extracted organic matter (EOM) (Figure 3.9.2) is then separated by using column liquid chromatograpy method into three fractions of aliphatic, aromatic and polar fractions (Figure 3.9.3) using petroleum ether, dichloromethane and methanol respectively. Subsequently, the aliphatic hydrocarbon fractions were analyzed by gas chromatography (Agilent 6890 N Series GC) and Gas Chromatography Mass Spectrometry (GCMS). An FID gas chromatograph with HP-5MS column and programmed temperature from 40 to 300^0C at a rate of 4^0C/min and held for 30 minutes at a temperature of 300^0C, was used for GC analysis. GCMS analysis was performed on a V 5975B inert MSD mass spectrometer with a gas chromatograph attached directly to the ion source (70eV ionization voltage, 100mA filament emission current, 230^0Celcius interface temperature). The fingerprints acquired from GC and GCMS analysis were used for biomarker identification of the peat samples based on retention time and comparison with previously published data (e.g. Philp, 1985) according to their locations on the studied peat dome.

3.4.3 Polished Block Preparation Method for Petrographic Analyses

For petrographic maceral identification, the dried peat samples (oven dried at 40^{0}C for 3 days) were prepared by mounting crushed auger peat sample fragments in slow setting polyester (serifix) together with resin hardener and allowed to set, then grounded flat on a diamond lap and subsequently polished using silicon carbide paper of different grades (P800, P2400 and P4000) with water as a lubricant. By using finer alumina suspensions (sizes 1 micron, 0.3 micron and 0.05 microns), the polished block sample surfaces are finally polished to be highly reflective and the polished sections are then ready for petrographic analysis. Petrographic examination was carried out under oil immersion in plane polarised reflected light using a LEICA DM6000M microscope and LEICA CTR6000 photometry system equipped with fluorescence illuminators. BP 340-380 excitation filters, a RKP 400 dichromatic mirror and a LTP 425 suppresion filter are used for the filter system. Maceral identification was done under both normal reflected 'white' light and UV (ultra violet) light for all 5 peat samples and correlated with the identified von Post field Classification and Humification (H1 to H10) levels and range (see Table 3.2). Petrographic maceral study of the peat samples was done to identify the diagenetic stages involved in the peatification or humification process and was based on peat diagenetic studies done by Stout and Spackman (1987) and Mohd. Zaid (1998).

3.4.4 Source Rock Analyses Method

The SRA is a non-isothermal open-system Source Rock Analyzer (compatible with Rock-Eval) used to measure parameters such as S1, S2, S3, TOC and Tmax values as described below. Peat parameters measured by the SRA (TPH/TOC mode) for peat samples from the margin of the peat dome towards the centre of the peat dome at locations KS.TP.02, KS.TP.07, KS.TP.08, KS.TP.09 and KS.TP.10 (Figures 3.2 and 3.8) from a depth of 0 to 0.5 metres.

3.4.4.1 S1 (milligrams of hydrocarbon per gram of rock)

The S1 value (measured in mg/g of rock) represents the thermally extractable hydrocarbons or volatiles in the peat samples. These are the free, thermally extractable hydrocarbons present in the whole rock sample which vaporize at approximately 330^0C. The heavier, free hydrocarbons and non-hydrocarbons (resins and asphaltenes) will vaporize and crack at only higher temperatures and will be included in the S2 peak (Clementz, 1979).

3.4.4.2 S2 (milligrams of hydrocarbon per gram of rock)

The S2 value represents the amount of hydrocarbons released from kerogen cracking and high molecular weight free hydrocarbons (mg HC per gram of rock). These are the hydrocarbons which result from the cracking of kerogen and high molecular weight free hydrocarbons which do not vaporize in the S1 peak. Table 3.4 shows the range of S2 values and related quality of source potential (Espitalie, 1982).

Table 3.4: Range of S2 values and related quality of source potential (based on Espitalie, 1982).

S2 range	Quality of source potential
0-2.00	Poor source potential
2.00-5.00	Fair source potential
>5.00	Good source potential

3.4.4.3 S3 (milligrams of organic carbon dioxide per gram of rock)

The S3 parameter (mg CO^2 per gram of rock) is the quantity of CO^2 evolved during low temperature ($<400^0C$) pyrolisis (mg CO^2 per gram of rock).

3.4.4.4 S4 (milligrams per gram of rock)

The S4 is the residual organic carbon and its value is obtained by:

$$S4 = 10^* \text{ TOC}-0.83^*(S1+S2)$$

(0.83 is the average carbon content of hydrocarbon by atomic weight and this could be as high as 0.89)

3.4.4.5 TOC (weight percent of carbon/ unit weight of carbon per unit weight of whole rock)

The TOC or Total Organic Carbon value is measured in weight percentage (%). The TOC value is composed of two fractions: a convertible fraction which represents the hydrocarbons already generated (S1) and the potential to generate hydrocarbons (S2).

$$TOC = (S4+0.83\{S1+S2\})/10$$

3.4.4.6 Tmax

The Tmax parameter represents the temperature (^{0}C) at which the maximum release of hydrocarbons occur from cracking of kerogen during pyrolisis (top of S2 peak). Table 3.5 shows the range of Tmax values and related hydrocarbon type and maturity (Espitalie et al., 1985)

Table 3.5: Range of Tmax values and related hydrocarbon type and maturity (based on Espitalie et al., 1985)

Type I	Type II	Type III	Maturity
	<430^{0}C	<430^{0}C	Immature
440-445^{0}C	430-450^{0}C	430-465^{0}C	Oil window
	>450^{0}C	>465^{0}C	Gas window

3.4.4.7 Hydrogen Index or HI (S2x100/TOC)

The Hydrogen Index or HI (mg HC per gram TOC) is 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, whilst Type II kerogens are intermediate between Type I and III (Table 3.6). The HI values decrease with sample maturity. The hydrogen index may be lowered by weathering or mineral matrix interactions which cause a reduction in the S2 value (Espitalie et al., 1977).

Table 3.6: Relationship between HI values and kerogen type (based on Espitalie et al., 1977).

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

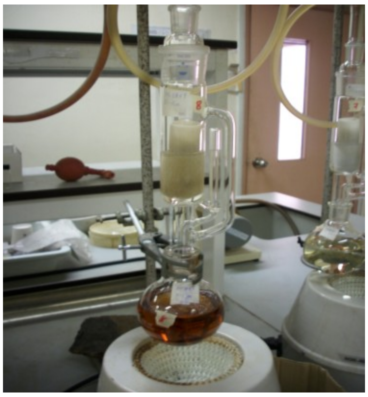

Figure 3.9.1

Figure 3.9.2

Figure 3.9.3

Figure 3.9.1: Soxhlet extraction for peat organic matter in progress. Dichloromethane (DCM) is used as the main extraction solvent. Location: Organic Geochemistry Laboratory, Department of Geology, University of Malaya.

Figure 3.9.2: Peat extracted organic matter (EOM) after Soxhlet extraction. Location: Organic Geochemistry Laboratory, Department of Geology, University of Malaya.

Figure 3.9.3: Column separation of peat extracted organic matter (EOM) into aliphatic, aromatic and polar fractions prior to GCMS analyses. Location: Organic Geochemistry Laboratory, Department of Geology, University of Malaya.

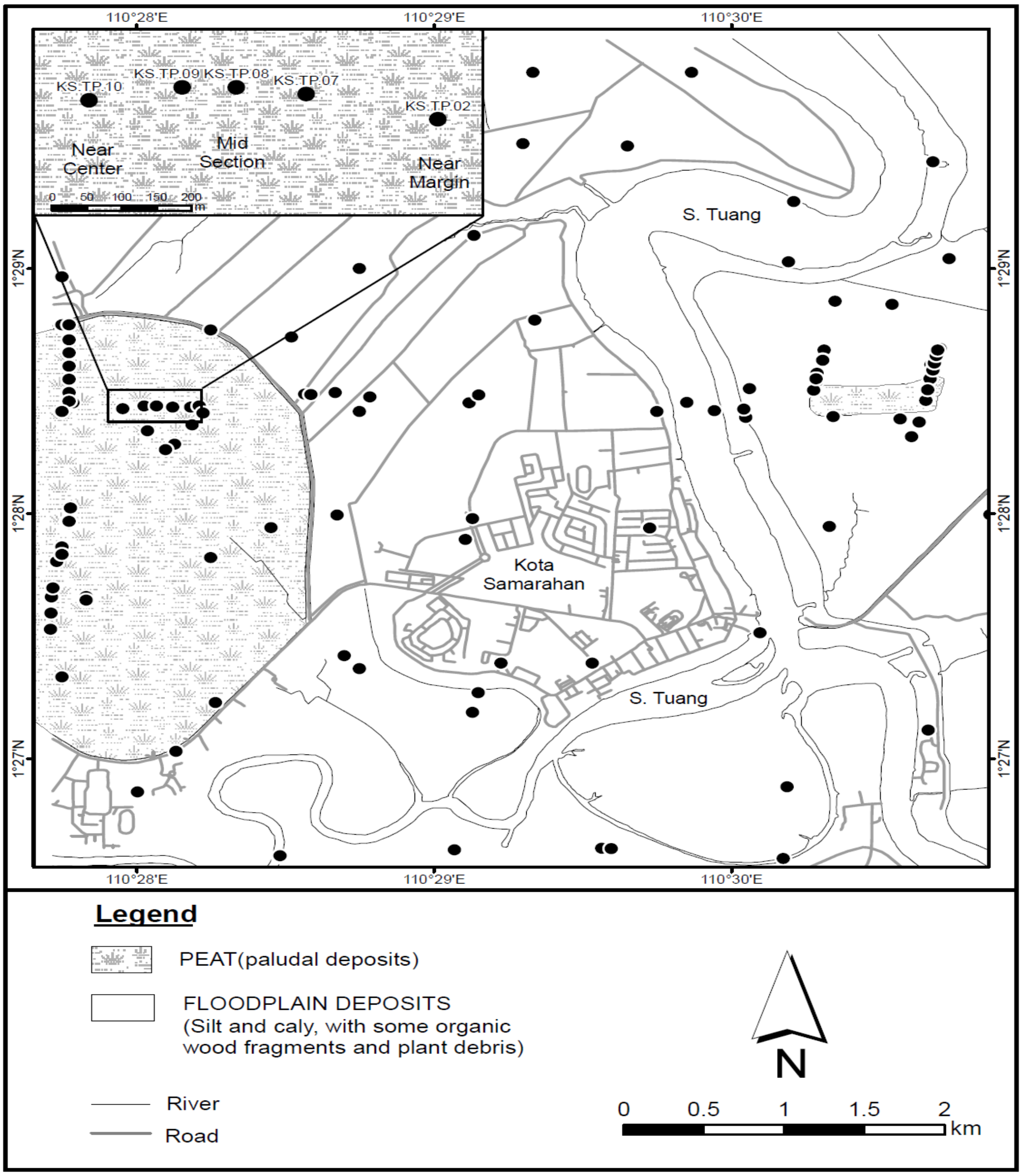

Figure 3.9.4: Geological map of the Kota Samarahan-Asajaya study area, West Sarawak. Sample locations for pollen and geochemical analyses are as shown in the enlarged, inverted section on the top left hand corner of the map (refer to Fig. 4.4.4 for test types according to sample location).

3.5 Sample preparation method for Pollen analyses

A total of 8 samples were collected for every 0.5 m interval from the surface to a depth of 5.5 m for borehole KS.TP.10 and 4 samples were collected from the surface to a depth of 2.0 m for KS.TP.09. These samples for pollen analyses were representatively taken every 10 cm along each core for general core sampling intervals such as shown in Table 3.7 except for surface samples and three samples for radiocarbon dating which was taken at the 0 to 20 cm (general interval 0 to 0.5 m), 130 to 150 cm (general interval 1.0 to 1.5 cm) and 180 to 200 cm intervals (general interval 2.0 to 1.5 cm) from borehole location KS.TP.10 (Figure 3.9.4).

Table 3.7: General and exact sampling intervals of auger cores from locations KS.TP.10 and KS.TP.09 for pollen analyses and C_{14} dating.

Augerhole location	General Sampling interval (m)	*Exact sampling interval (cm)*	Lithology
KS.TP.09	0-0.5	*0-20 cm*	Peat
KS.TP.09	0.5-1.0	-	Peat
KS.TP.09	1.0-1.4	-	Peat
KS.TP.09	1.4-2.0	-	Soil
KS.TP.10	0-0.5	*0-20 cm, (C_{14})*	Peat
KS.TP.10	0.5-1.0	-	Peat
KS.TP.10	1.0-1.5	*130-150 cm,(C_{14})*	Peat
KS.TP.10	1.5-2.0	*180-200 cm,(C_{14})*	Peat
KS.TP.10	2.0-2.5	-	Soil
KS.TP.10	3.0-3.5	-	Soil
KS.TP.10	4.0-4.5m	-	Soil
KS.TP.10	5.0-5.5m	-	Soil

The samples were treated in the laboratory with 10% KOH, sieved to remove larger pieces of plant material, undergone acetolysis and heavy liquid separation in zinc bromide/hydrochloric acid for the samples in which some mineral residue was present especially in some clayey peat or organic soil samples (Wood et al., 1996). The samples revealed considerable quantities of pollen grains and spores and counts varied from 26 to 266 grains per slide for KS.TP.10 and from 51 to 110 grains per slide for KS.TP.09.

The results of the pollen analyses are as shown on the pollen diagram inclusive of all pollen and pteridophyte spores (Chapter 4). Pollen types which could not be identified with any certainty were excluded from the pollen sum. In the analyses of the borehole peat profile of KS.TP.10, no extreme over-representation were observed and hence all pollen and spore types have been included in the pollen sum. However, the over representation of some peat pollen types may occur (for e.g. the *Cephalomappa* pollen) in peat swamps due low pollen dispersal when only a single prolific tree may produce the maximum pollen representation (Anderson and Muller, 1975). In addition, misrepresentation or misinterpretation due to the absence of S*horea* type pollen may also occur because large, *Shorea* type trees were observed to be present in the field at the locations of the the studied augerholes (KS.TP.09 and KS.TP.10). Absence of pollen from *Shorea* type trees maybe due to the low pollen producing capability of the tree species.

The affinity of the types recognized is indicated on the pollen diagram either by reference to a living taxon or, if the type occurs in more than one taxon, by adding "type'. The comparison was mainly limited to taxa known to occur in peat swamp forest, and in adjacent vegetational environments such as mangrove and riverine (or riparian) vegetation.

3.6 Peat soil science Key Classification Method

Selected peat samples were classified further by adapting to the Key to the Identification of Lowland Soils (Histosols) method as was proposed by Paramananthan (2011). The criteria used at the different categoric levels is summarised in Table 3.8. The keys to the identification of lowland organic soils are as provided in Table 3.8.1. The method applies to peats that are more than 0.5 metres thick (minimum cumulative thickness of 50 cm within 100 cm or more than half to lithic/paralithic or terric layer). In this study, peats at a depth interval of 0.5 to 1.0 metres are initially determined as either sapric, hemic or fibric peats (topogambists and ombrogambists) and are then further classified according to the criteria and methods as shown and summarized in Table 3.8. The criteria for the percentage of clay (< or > 15% clay) in the underlying sample substrate layer below the peat layer was initially determined at either the same sample location or nearby to it.

Table 3.8: Summary of criteria used for the classification of tropical lowland organic soil or peat of Malaysia (Paramananthan, 2011).

CATEGORIC LEVEL	CRITERIA USED	EXAMPLE
ORDER	• Minimum cumulative thickness of 50 cm within 100 cm or more than half to lithic/paralithic or terric layer	HISTOSOLS
SUB-ORDER	• Drainage Class – poor, well	GAMBIST – poorly drained FOLIST – well drained
GREAT GROUP	• Thickness of organic layer – Ombro: >150 – Ombro – Topo: 50-150 – Topo	Ombrogambist Topogambist
SUB-GROUPS	• Dominant in sub-surface (50-100 cm) tier – Terric, Sapric, Hemic, Typic (Fibric)	Hemic Topogambist Sapric Ombrogambist
FAMILY	• Nature of substratum – marine clay/sand – riverine clay/sand • Soil temperature regime – isohyperthermic/isomesic	BARAM FAMILY ADONG FAMILY
SOIL SERIES	• Presence and nature of wood – no wood – wood decomposed – wood undecomposed • Mode of origin autochthonous/allochthonous*	Baram Series: Sapric Topogambist, marine-sandy, isohyperthermic, non-woody, autochthonous. Adong Series: Hemic Ombrogambist, marine-sandy, isohyperthermic, decomposed wood, autochthonous.
PHASE	• Depth – shallow: 50-100 cm – moderately deep: 100-150 cm – deep: 150-300 cm – very deep: 300+ cm	Baram/shallow Baram/moderately deep Adong/deep Adong/very deep

* allochtohonous: organic deposits which have been transported and redeposited

Table 3.8.1: Keys to the identification of Lowland Peats (Gambists) (Paramananthan, 2011).

Depth of Organic Soil Materials	Soil Moisture Regime	Poorly Drained (Aquic) — GAMBIST								
	Dominant in Su (50-	Sapric			Hemic			Fibric		
	Nature of Underlying Substratum Mineral Materials	Non Woody	Wood Decomposed	Wood Undecomposed	Non Woody	Wood Decomposed	Wood Undecomposed	Non Woody	Wood Decomposed	Wood Undecomposed
Shallow (50-100 cm) and Moderately Deep (100-150 cm) TOPOGAMBISTS	Marine Clay Sulfidic (> 15% clay)	PENOR			BAKRI			MERAPOK		
		Penor			Nipis	Bakri			Merapok *Mahat*	
	Marine Clay (> 15% clay)	LINGGI			EPAI			MUKAH		
		Linggi		Trus			Epai		Mukah	Bino
	Marine Sand Calcareous (< 15% clay)	MENGALUM								
		Mengalum								
	Marine Sand Sulfidic (<15% clay)	LONG PUTAT								
		Long Putat								
	Marine Sand (< 15% clay)	BARAM						IGAN		
		Baram	Kabala	Simalau					Igan	
	Riverine/Colluvial Clay (> 15% clay)	ERONG			GALI			CHANGKAT LOBAK		
		Erong				Gali		Changkat Lobak		
	Riverine/Colluvial Sand (< 15% clay)				PAK BONG					
					Pak Bong					
Deep (150-300) and Very Deep (>300 cm) OMBROGAMBISTS	Marine Clay Sulfidic (> 15% clay)	PRIMALUCK			PONTIAN			KLIAS		
		Primaluck		Teraja		Pontian		Arang	Klias *Luk*	
	Marine Clay (> 15% clay)	NAMAN			BAYAS			ANDERSON		
		Naman	Retus	Kenyana		Bayas	Gedong			Anderson
	Marine Sand Calcareous (< 15% clay)									
	Marine Sand Sulfidic (<15% clay)									
	Marine Sand (< 15% clay)	TELONG			ADONG					
			Telong	Suai		Adong	Alan			
	Riverine/Colluvial Clay (> 15% clay)	LIKU			GONDANG			SALLEH		
		Liku		Karap		Gondang	Taniku		Salleh	Tinjar
	Riverine/Colluvial Sand (< 15% clay)	KABOK								
			Kabok							

KEY: BAYAS Soil Family; Bayas Soil Series. *Luk* = allochthonous

CHAPTER 4

4.0 RESULTS

4.1 General Geology

The results for the investigation on the effects of vegetation lateral variation and basin 'dome' shape on tropical lowland peat stabilization of the targetted peat basin in the western part (Plaie) of the Kota Samarahan-Asajaya area, West Sarawak, Malaysia are presented (in section 4.7.1) which follows the results of geological field-investigation and field-mapping presented in the following sections.

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

4.2 Peat (Paludal) Deposits

The term paludal deposits has been introduced to define a Holocene unit made up of mainly peat (Lam, 1989). According to the Malaysian Soil Classification System (Table 3.1 in Chapter 3) soils with more than 75% organic content are described as peat. Peats are organic deposits consisting of partially decomposed plant matters with or without clastic sediments. Paludal deposits are formed in swampy basins by the rapid accumulation of plant remains. In this environment, decomposition of plant debris occurs at a much slower rate allowing a net accumulation which forms peat.

Peat covers a small portion of the western part of the study area (also referred here as ‘Plaie area’). The thickness of the peat in the western part/Plaie area ranges from 0.2 to 2.3 m.

The types of peat encountered in the study area are:

(a) topogenous peat: also known as clayey peat; composed of plant remains and clastic sediments (with ash content); formed in topographic depressions by plants that extracted nutrients from the mineral subsoil. Topogenous peat is influenced by flood waters which supplies the mineral components (mainly clays and silts).

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

The topogenous peat is composed of slightly to moderately decomposed plant matters. Topogenous peat with a humification range of H3 to H8 on the Von Post Humification scale was augered, logged and classified at the peat forest, in the Plaie area, on the western part of the Kota Samarahan-Asajaya study area (Figure 3.8 in Chapter 3 and Table 4.0 below). Ombrogenous peat is formed above tidal flood levels. Ombrogenous peat is characterized by a high water content, an extremely low bulk density, a relatively higher decomposition rate and a relatively lower pH, and is composed of mainly loose trunks, branches, roots, fruits and leaves (Paramananthan, 2011). Ombrogenous peat encountered in the study area is moderately to highly decomposed and ranges from H4 (hemic) to H7 (sapric) on the Von Post Scale of Humification (Table 4.0). The Munsell colour value is 7.5YR 2.5/2 (very dark brown) based on the Munsell Soil Colour Chart depending on the degree of humification.

4.3 Peat in the western peat forest of the study area (Plaie area)

Peat in the Plaie area is composed of slightly to moderately decomposed plant material ranging from H4 to H8 on the Von Post Degree of Humification scale (Table 3.1 in Chapter 3). The peat that was encountered vertically at location KS.TP.10 can be classified as hemic to sapric, hemic and fibric to hemic peat. The thickness of the peat layers from the margin (KS.TP.02) towards the basin centre (KS.TP.10) ranges from 0.2 to 2.0 m thick, and getting thicker westwards. The vertical peat profiles encountered at locations KS.TP.09 and KS.TP.10 (Table 4.0) has a dark brown to very dark brown colour ranging from 7.5 YR 3/3 and 7.5 YR 3/2 (dark brown) to 7.5 YR 2.5/2 (very dark brown) according to the Munsell Soil Colour Chart. The groundwater levels in the western part of Kota Samarahan (Plaie) peat area are approximately 0.3 to 0.5 meters below ground surface at auger locations KS.TP.02 to KS.TP.10 (Figures 3.2, 3.3, 3.4, 3.5, 3.6 and 3.7).

Field identification and classification (von Post) of the top to the bottom peat layer of the tropical lowland peat dome shows that there is a vertical variation of peat humification levels (von Post) with every 0.5 m interval of depth in the form of dominantly occurring hemic to sapric (H6 to H7), hemic (H5 to H6), hemic (H4 to H6) and fibric to hemic (H3 to H5) humification levels, respectively, at augerhole location KS.TP.10 (Figure 3.7); and sapric (H7 to H8), hemic to sapric (H6 to H7) and hemic (H5 to H6) humification levels, respectively, at auger location KS.TP.09 (Figures 3.6), with both profiles generally indicating a vertical decrease of peat humification levels with peat depth.

4.4 Floodplain Deposits

The exposed floodplain deposits covers the northern, eastern and southern parts of the Kota Samarahan area, including the cross river Asajaya areas clockwise from Kg. Sui, Kg. Tanjung Parang, Kg. Tanjung Tuang to the Sg. Paloh area and westwards. The deposits are observed to be overlain by peat deposits in the western Plaie area and a portion of the Kg. Sui area (Figures 3.2 and 3.8).

Floodplain deposits, also known as Riverine Deposits, were formed by the deposition of river sediments during floods in flood basins (backswamp deposits) or on levees along the river banks (levee deposits). These floodplain deposits are confined to 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 behind the levees consists predominantly of clays and silts with minor to abundant plant remains (Lam, 1989).

The lithology of the Quaternary riverine or floodplain (backswamp) deposits observed to occur in the area consists of mainly clay, silt and fine sand with minor to abundant plant matters (wooden fragments 0.5 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 colour and sometimes greenish gray to dark bluish gray or bluish gray in colour with Munsell colour 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 as shown in Figures 3.6 and 3.7 (log no KS.TP.09 and KS.TP.10). For the profile section of KS.TP.10 and the related pollen diagram (Figure 4.4.1), from the beginning of the interval 3.5 to 2.5 m, begins the rise in pollen abundance followed by peaking at 2.5 m for the *Elaeocarpus* pollen. The interval 2.5 to 2.0 m shows an increase for *Eugenia* type pollen and pollen abundance peaks at 2.0 m. Thus, it is interpreted here that an influx of pollen from riparian type vegetation had occurred due to increasing freshwater influence from 2.5 to 2.0 m and that this interval represents an increasingly riverine/floodplain depositional environment. From the profile section of KS.TP.09 (Figure 4.4), at the interval 2.0 to 1.4 m, the presence of riparian type pollen of both *Eugenia* and *Elaeocarpus* again supports the deposition of a layer of floodplain/floodbasin deposits (approximately 0.5 m thick) immediately below the peat layer and overlying the estuarine and deltaic deposits.

4.5 Estuarine/Deltaic Deposits

The estuarine/deltaic deposits are found to underlie the floodplain and peat deposits in the study area. From pollen analyses and the pollen diagram (Figure 4.4.1) of the soil samples at interval 2.5 to 2.0 m of the profile section at KS. TP.10, the pollen abundance of *Rhizophora* type pollen starts to decline from 2.5 to 2.0 m and disappears at 2.0 m, which generally marks the probable end of mangrove type vegetation and related mangrove depositional environment. From the beginning of the interval 3.5 to 2.5 m, begins the rise in pollen abundance followed by peaking at 2.5 m for the

Elaeocarpus pollen. The interval 2.5 to 2.0 m shows an increase for *Eugenia* type pollen and pollen abundance peaks at 2.0 m. Hence, it is interpreted from pollen abundance of riparian type vegetation that freshwater influence had increased from 2.5 to 2.0 m and that this interval probably represents an increasing floodplain depositional environment with lesser mangrove/estuarine or marine influence. Hence, it is interpreted from this part of the profile section that the estuarine/mangrove type sediment depositional environment had decreased and saline or brackish water influence has begun to lessen due to continued sea level fall from 2.5 m to 2.0 m and, that the mangrove/estuarine or deltaic depositional environment is more predominant from 2.5 m and below the mentioned profile (KS.TP.10).

Likewise, from pollen analyses and the related pollen diagram (Figure 4.4) of the soil samples at interval 2.0 to 1.4 m of the profile section at KS. TP.09, the pollen abundance of *Rhizophora* type pollen starts to decline from 2.0 to 1.4 m and disappears at 1.4 m, signifying the gradual cessation of mangrove type vegetation and related mangrove type depositional environment from 2.0 to 1.4 m. Thus, estuarine and deltaic brackish to saline water influence may have gradually ceased at approximately 0.5 metres below the peat-soil boundary as indicated from the auger core profiles of both KS.TP.10 and KS.TP.09. As a result, this approximately 0.5 m thick layer consisting of floodplain, riverine or floodbasin deposits was deposited by flooding river waters after or with the gradual decline of mangrove influence due to receding sea levels.

Generally, the underlying estuarine/deltaic deposits are composed of mainly soft to very soft, marine, clayey silts and silt, clay and sometimes thin layers of fine sand accompanied with shell debris/fragments as observed in augerholes KS.TS.05 and KS.TS.06. These deposits are greenish gray to dark bluish gray or bluish gray in colour with Munsell colour values of GLEY 2, 6/1, GLEY 2, 5/1, GLEY 2, 4/1 and 10YR, 4/2.

The estuarine and deltaic deposits are probably marine in origin and in the field, these deposits can usually be differentiated from the overlying floodplain deposits because the former has a very soft consistency, has a gritty feel when rubbed between the fingers, greenish gray to dark bluish gray or bluish gray in colour, is saturated or very wet in appearance and is sometimes accompanied by marine shell fragments (Lam, 1989). These deposits are observed in the field to have little or no wooden fragments when compared to the overlying floodplain deposits. They are usually sulphidic (acidic) and are observed in the field to produce yellow coloured minerals known as jarosite after oxidation and exposure to the atmosphere (Fitzpatrick et al., 1998).

4.6 Peat characterization

Characterization of logged peat samples, at augerholes KS.TP.02, KS.TP.07, KS.TP.08, KS.TP.09 and KS.TP.10 from locations near and towards the centre of the peat dome, in the western peat forest of the Kota Samarahan-Asajaya study area are as described in Table 4.0 below.

Table 4.0: Description of sampled peats occurring from the peat basin margin (near location KS.TP.02) towards the approximate centre 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 (m)	0.2	0.2	1.0	1.4	2.0
Classification of peat type with depth (Von Post Classification)	0 to 0.2m : H3	0 to 0.2m : H3-H4	0 to 0.5m: H7 to H8 0.5-1.0m: H6 to H7	0 to 0.5m : H7 to H8 0.5-1.0m: H6 to H7 1.0 to1.4m: H5 to H6	0 to 0.5m : H6 to H7 0.5-1.0m: H5 to H6 1.0 to1.5m: H4 to H6 1.5 to 2.0m: H3 to H6
Classification/ Type of Peat with depth	0 to 0.2m: Fibric	0 to 0.2m: Fibric to hemic	0-0.5m : Sapric (amorphous) 0.5-1.0m : Hemic to Sapric (amorphous)	0 to 0.5m : Sapric (amorphous) 0.5-1.0m: Hemic to Sapric (amorphous) 1.0 to.4m: Hemic	0 to 0.5m : Hemic to sapric 0.5-1.0m: Hemic 1.0 to1.5m: Hemic 1.5 to 2.0m: Fibric to Hemic
Groundwater level (distance from surface in metres)	0.3m (below surface)	0.3m (below surface)	0.3m (below surface)	0.3m (below surface)	0.5m (below surface)
Colour of peat (Munsell colour code)	0 to 0.2m: 10YR 3/3	0 to 0.2m: 7.5YR 3/4	0-0.5m: 7.5YR 2.5/2 0.5-1.0m: 3.5YR 2.5/2	0 to 0.5m : 7.5 YR 3/3 0.5-1.0m: 7.5YR 3/2 1.0 to.4m: 7.5YR 3/2	0 to 0.5m : 7.5YR 2.5/2 0.5-1.0m: 7.5YR 2.5/2 1.0 to1.5m: 7.5YR 2.5/2 1.5 to 2.0m: 7.5YR 2.5/2
Elevation (Garmin GPS) a.m.s.l.	7.9	6	7	9.2	9.2

4.7 Results of Unconfined Compressive Strength (UCS) Analyses of Stabilized Peats.

4.7.1 Results of UCS Analyses for the effect of different quantities of mineral soil filler (msf) on cement-peat stabilization.

Unconfined Compressive Strength test results of cement-filler stabilized peat with peat selected and sampled from a peat basin in the eastern part of the study area at augerhole KS.TS.05 (0 to 0.5m) and silt-clay filler obtained from a nearby location at KS.TS.06 (0 to 0.5 m sampling interval) that were then added in increasing quantities are as shown in Table 4.1. Figure 4.1 shows the relationship between unconfined compressive stress and vertical strain of stabilized peat specimens for comparison of the effect of different quantities of mineral soil filler on cement-peat stabilization.

After stabilization of 28 air-curing days, 4 samples were tested in triplicates at a specimen composition of 20 g of ordinary Portland cement binder for each 100 g of wet peat (sample KS.TS.05, from 0 to 0.5 m sampling depth) and was mixed with increasing quantities of 5 g, 15 g, 25 g to 50 g of mineral soil filler (from auger sample KS.TS.06 at 0 to 0.5 m sampling depth). From these, the specimens mixed with only 5 g of silt/clay mineral soil filler yielded an average unconfined compressive strength of 42.5 kPa and average strength values increased significantly to 67.0 kPa, 77.0 kPa and 106.6 kPa with increasing silt/clay mineral soil filler quantities of 15 g, 25 g and 50 g, respectively (Table 4.1 and Figure 4.1).

4.7.2 Results of UCS analyses for the effect of peat types and sampling distance from basin margin towards peat dome centre, on cement-peat stabilization.

The results of the Unconfined Compression Strength (UCS) tests of peat and organic soils sampled (from margin towards centre of peat dome) from the tropical lowland peat forest of Western Kota Samarahan-Asajaya area, West Sarawak are as shown in Table 4.1.1. Figure 4.1.1 shows the relationship between unconfined compressive stress and vertical strain of cement-mineral soil filler stabilized peat specimens of the same fixed cement binder composition but with peat types augered from the top 0 to 0.5 m layer at varying distances from basin margin towards centre.

After stabilization of 28 air-curing days, the two specimens from topogenic or shallow peat near the margin of the peat basin, sampled from KS.TP.0 and KS.TP.02 yielded the relatively highest average unconfined compressive strength of 203.67 kPa and 169.8 kPa, respectively. Sample KS.TP.08 (0-0.5m) with sapric, intermediate topogenic to ombrogenic peats augered from the middle section between basin margin and centre was tested to yield an average stabilized strength value of 61.03 kPa which is an intermediate value between the values for marginal peats (KS.TP.0 and KS.TP.02) and peats located near the basin centre (KS.TP.09 and KS.TP.10). In contrast, the ombrogenic specimens of sapric peat type and hemic to sapric peat type with hard amorphous grains (when dried) from auger locations KS.TP.09 and KS.TP.10, were tested to yield comparatively higher average strength values of 122.57 kPa and 152.33 kPa, respectively. The relationship between peat sample locations with distance from margin to midsection and further towards dome centre and their average strength values are as presented in Table 4.1.1 and Figure 4.1.1. All the sample specimens tested, exhibited brittle or shear failures with no barrelling except for the specimen with peat obtained from KS.TP.08 which exhibited dominantly more shear failure than barrelling failure. Besides this observation, test specimens with peat from location KS.TP.08 also exhibited relatively medium to higher shrinkage of specimen size; relatively more bending and a not so uniform, cylindrical shape due to some deformation; relatively more indentations and discontinuities in the form of small holes and cracks at some layer planes when compared to samples augered from the other locations as mentioned above.

Table 4.1: Quantity (g) of added mineral soil filler (KSTS.06 (0-0.5m)) with its' related unconfined compressive strength values of cement-filler stabilized tropical lowland peats (peat sampled at KS.TS.05 (0-0.5m)).

Weight (g) of added mineral soil filler from KS.TS.06 (0-0.5m) (added to a fixed composition of 20 g opc and 100 g peat)	**Unconfined Compressive Strength (average) in kPa units.**
5	42.5
15	67.0
25	77.0
50	106.6

Notes: opc-Ordinary Portland Cement

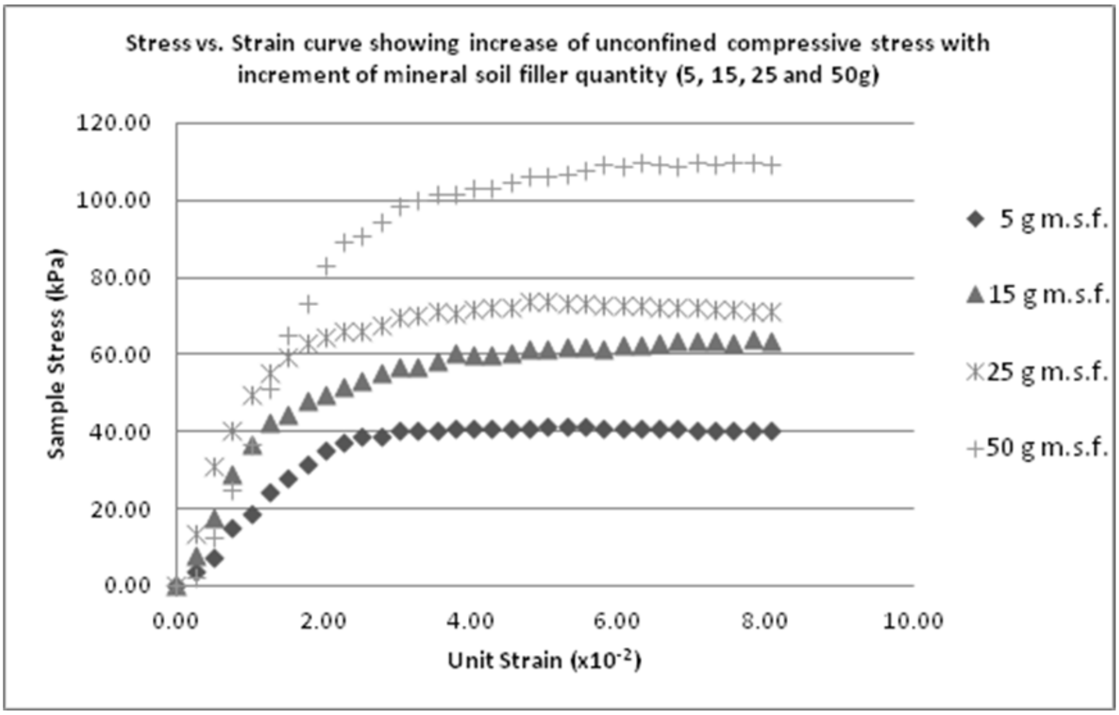

Figure 4.1: Effect of added mineral soil filler quantity (g) (KS.TS.06 (0-0.5m)) on unconfined compressive strength of cement-filler stabilized tropical lowland peats (peats from KS.TS.05 (0-0.5m)).

Table 4.1.1: Comparison of stabilized specimen characteristics (immediately after curing period prior to testing) and unconfined compressive strengths (UCS) of cement-mineral soil filler stabilized peats (or organic soils) sampled (from margin and towards centre of peat dome) from a tropical lowland peat forest of Western Kota Samarahan-Asajaya area (Plaie), West Sarawak.

Auger location (0 to 0.5 m sampling interval)	Unconfined compressive strength (kPa)	Failure type (fast or slow failure)	Specimen Shape (cylindrical or deformed?) and colour. Specimen surface texture.	Discontinuity type at layer plane (cracks/indentations/holes)	Shrinkage	Peat type/ Location on peat dome surface.
KS.TP.0 (0-0.5m)	203.67	All brittle/shear failure (fast)	Shape very cylindrical, no deformation, dense, hard. Colour is light brown to brown, not moist. Smooth surface.	No cracks, no indents, no joints, some holes at layer plane.	Very little	Topogenic, shallow peat/ Margin.
KS.TP.02 (0-0.5m)	169.8	All brittle/shear failure (very fast)	Shape cylindrical, dense, hard. Colour is cream-pale brown. Smooth surface.	A few cracks at layer plane, Very little/no holes, no indentations.	Very little	Topogenic, shallow peat/ Margin.
KS.TP.08 (0-0.5m)	61.03	More shear than barrelling failure (slow)	Shape less cylindrical with some deformation and indentation. Lesser density. Colour is dark brown, moist. Smooth somewhat bumpy surface.	Holes, cracks, indentations at all layer planes.	High shrinkage	Intermediate Topogenic-Ombrogenic peat/Midsection.
KS.TP.09 (0-0.5m)	122.57	All brittle/shear failure, very fast to fast	Shape cylindrical, dense, hard. Colour is dark brown. Smooth surface.	A few small holes, no cracks, no indentations.	Medium to high shrinkage	Intermediate Topogenic-Ombrogenic peat/Towards centre
KS.TP.10 (0-0.5m)	152.33	All brittle/shear failure, very fast to fast no nat. msf, ombro. pt	Shape less cylindrical. Lesser density. Colour is dark brown. Intermediate uneven to smooth surface.	Many holes, all layers for all specimens with cracks and indentations with some deformation.	Medium to high shrinkage	Ombrogenic peat/Further towards or near centre.

Notes: msf=mineral soil filler, nat.=natural, ombro.=ombrogenic

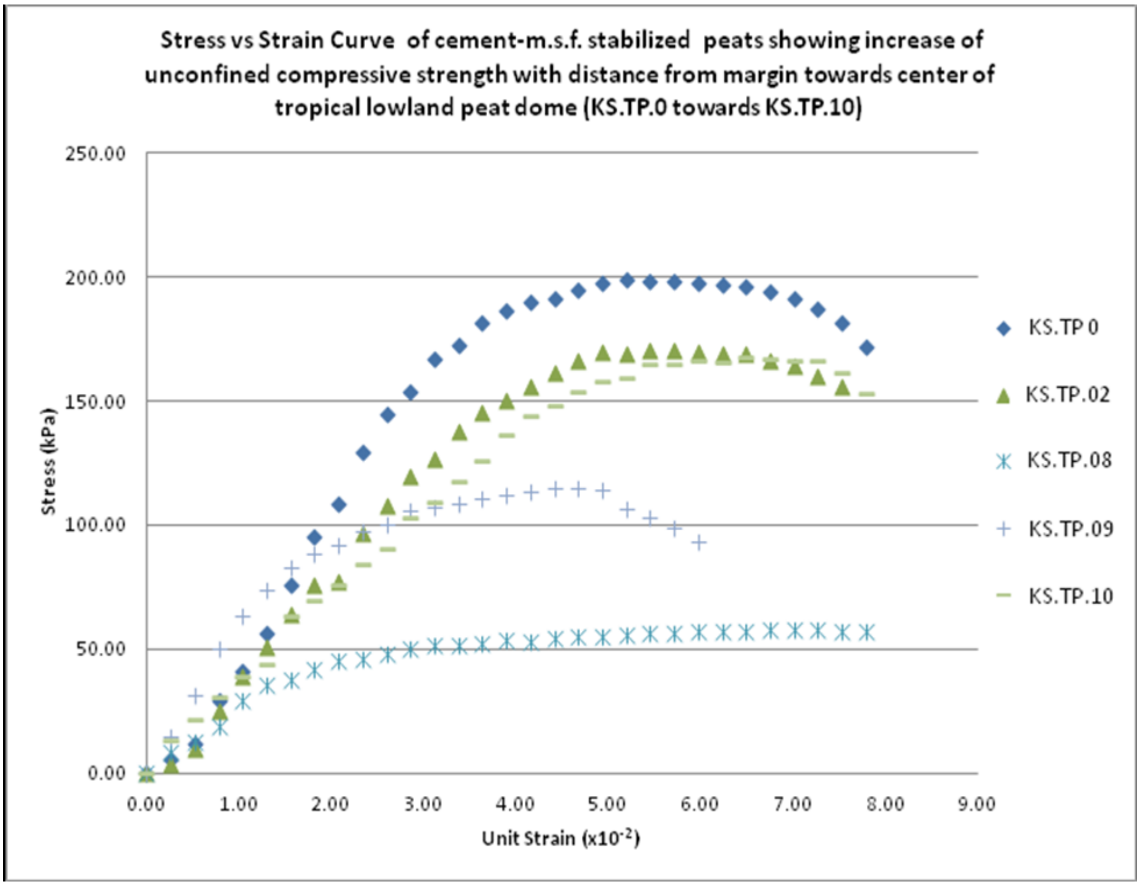

Figure 4.1.1: Comparison of relationships between unconfined compressive stress and vertical strain of cement-mineral soil filler stabilized peat specimens at the same composition of 20% cement binder and 25% mineral soil filler by weight of 100 grams of wet, insitu peat, but with peat types augered at varying distances from basin margin to midsection and further towards basin centre (KS.TP.0 to KS.TP.10).

Figure 4.1.2: Ordinary Portland cement-filler-stabilized peat specimen KS.TP.0 exhibits some shrinkage, uniform cylindrical shape with no deformation but with some holes present at layer plane before testing. After testing,

the stabilized peat specimens from location KS.TP.0 (near basin margin) all exhibited shear/brittle failures and yielded the relatively highest unconfined compressive strength values.

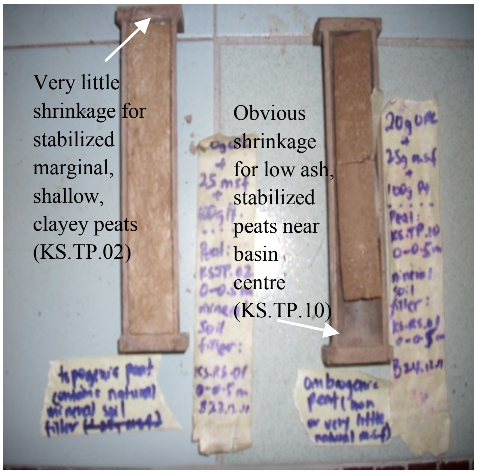

Figure 4.1.3

Figure 4.1.4

Figure 4.1.5

Figure 4.1.3: Cement-filler-stabilized peat (topogenic, shallow, clayey peat) specimen KS.TP.02 exhibits very little shrinkage after 28 days of air-curing. Sample specimens cannot slip out of mold and needs to be opened for extraction prior to testing;

Figure 4.1.4: Ordinary Portland cement-filler-stabilized peat specimen from topogenic, marginal peat area of location KS.TP.02 shows very little shrinkage compared to stabilized peat from location KS.TP.10, which is nearer to the peat basin centre;

Figure 4.1.5: Cement-filler-stabilized peat specimens from KS.TP.02 after 28 air-curing days and before testing exhibits acceptably uniform cylindrical shape with little deformation and with no holes or indentations present at layer planes except for a few small cracks. After testing, all specimens exhibited brittle/shear failures.

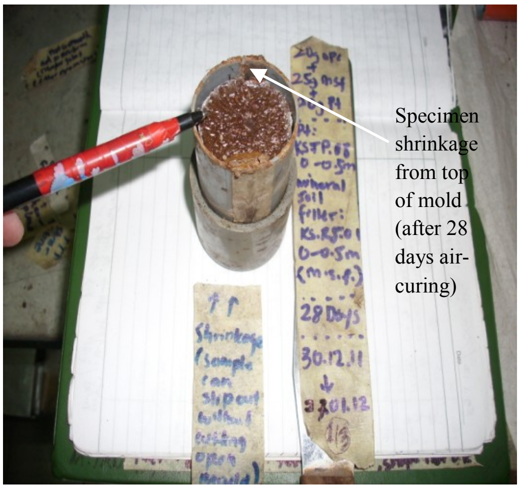

Figure 4.1.6

Figure 4.1.7

Figure 4.1.6: Cement-filler-stabilized peat specimen KS.TP.08 exhibits high shrinkage after 28 days of air-curing. Sample specimens slips out of mold easily and mold does not need to be opened for extraction prior to testing;

Figure 4.1.7: Cement-filler-stabilized peat specimens from KS.TP.08 after 28 air-curing days and before testing exhibits cylindrical shape but with some shrinking, deformation and with holes, indents and cracks present at all layer planes. Colour is dark brown with moist appearance and smooth but ‘bumpy’ surface. Observe a hole in the top layer plane. During testing, all specimens fail slowly and exhibits dominantly brittle/shear failure but with some minor barrelling.

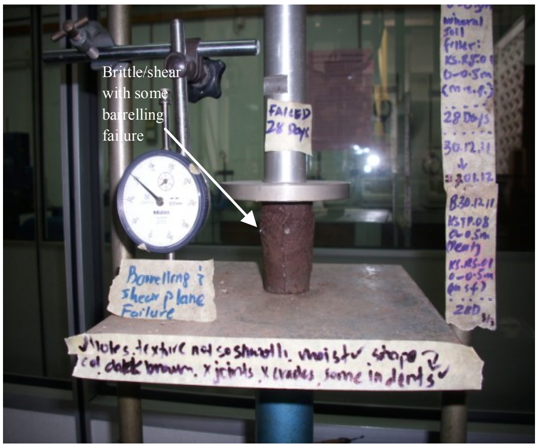

Figure 4.1.8 Figure 4.1.9

Figure 4.1.8: Cement-mineral soil filler-stabilized peat specimen KS.TP.08 tested for U.C.S. and exhibits shear failure with some barrelling;

Figure 4.1.9:Cement-mineral soil filler-stabilized peat specimens from midsection location of KS.TP.08 all exhibit slow shear failure with some barrelling and yields strength values that are relatively lower and intermediate between peat specimens from topogenic, marginal peat areas (locations KS.TP.0 and KS.TP.02) and locations nearer to the peat basin centre (KS.TP.09 and KS.TP.10);

Figure 4.2: Cement-filler-stabilized peat specimens from KS.TP.09 after 28 air-curing days and before testing exhibits medium to high shrinkage, uniform cylindrical shape with no deformation, with a few small holes and no indentations present at layer planes except for a few small cracks. Colour is dark brown; no moist appearance and surface is smooth not ‘bumpy’. During testing, all specimens exhibited fast, brittle/shear failure.

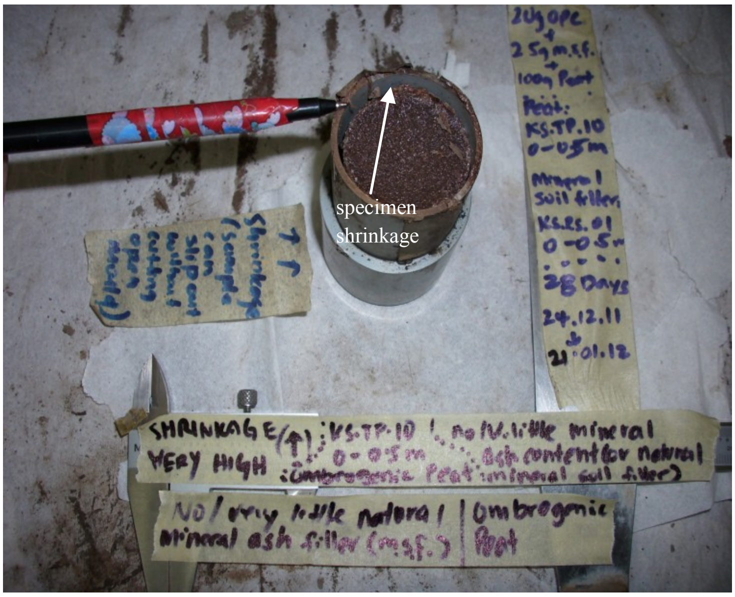

Figure 4.2.1

Figure 4.2.2

Figure 4.2.1:Cement-filler-stabilized peat specimen KS.TP.10 exhibits medium to high shrinkage after 28 days of air-curing. Sample specimens slip out of mold easily and do not need to be opened for extraction prior to testing;

Figure 4.2.2:Ordinary Portland cement-filler-stabilized peat specimens from near and towards peat basin centre at location KS.TP.10 all exhibited fast shear/brittle failure but with relatively higher, average unconfined compressive strength values compared to peats from KS.TP.09 and are generally competent to strength of topogenic, marginal peats. Observe shear planes present.

Figure 4.2.3: Cement-filler-stabilized ombrogenic peat specimens from KS.TP.10 after 28 air-curing days and before testing all exhibited medium to high shrinkage, relatively less uniform cylindrical shape with little deformation, with some holes, cracks and indentations present at all layer planes. Observe cracks/discontinuity along layer plane. Colour is dark brown, no moist appearance and surface is relatively smooth not 'bumpy';

Figure 4.2.4: Ordinary Portland cement-filler-stabilized peat specimens from near and towards peat basin centre at location KS.TP.10 all exhibited fast shear/brittle failure but with relatively higher, average unconfined compressive strength values compared to peats from KS.TP.09 and KS.TP.08 and are generally competent to strength of cement-filler-stabilized topogenous peats. Observe shear planes present;

Figure 4.2.5: Observe the crushed (mortar and pestle), hard (when dried), highly decomposed-sapric, amorphous peats sampled from KS.TP.09 or KS.TP.10 located near and towards peat basin centre. These low ash, ombrogenic peats were cement-mineral soil filler stabilized and air-cured to yield relatively high unconfined compressive strength values that are although slightly lower but relatively quite comparable to those of similarly stabilized topogenic, shallow, marginal peats from the basin periphery, and, these peats also yield relatively higher stabilized strengths compared to cement stabilized intermediate peats occurring at midsection of the traverse section (e.g. at location KS.TP.08).

4.8 Results of Geochemical (SRA and GCMS) Analyses

4.8.1 Results of SRA analyses.

The results of Source Rock Analyses (SRA) of peat and organic soils sampled (from margin towards centre of peat dome) from the tropical lowland peat forest of the Western Kota Samarahan-Asajaya area, West Sarawak are as shown in Table 4.2.

4.8.1.1 TOC values

The recorded TOC values of the five samples currently being studied ranges from 15.43 to 50.8 wt. % (Table 4.2). The TOC value of the peat sample collected from the marginal area of the peat basin (KS.TP.02) is 15.43 wt. % and the TOC value generally increases relatively towards the center of the peat basin to 49.62 wt. % at KS.TP.10. However the TOC value is observed to maximize at 50.8 wt. % at sample location KS.TP.08 in the midsection area of the traversed section.

4.8.1.2 S1 values

The S1 value of the peats (Table 4.2) is observed to generally increase relatively from 11.83 mg/g (at KS.TP.02, at the margin of the peat dome) to 26.10 mg/g (at KS.TP.10, towards the centre) and the S1 value ranges from 11.83 mg/g (at KS.TP.02) to 31.46 mg/g (maximizing at KS.TP.09).

4.8.1.3 S2 values

The S2 value of the peats is clearly observed to increase relatively while increasing and ranging from 52.05 mg/g (at KS.TP.02, at the margin of the peat dome) to 202.08 mg/g (at KS.TP.10, towards the centre). The range of S2 values for the peats are more than 5 mg/g (Table 4.2) and implies good source potential (Espitalie, 1982).

4.8.1.4 S3 values

The S3 value of the peats is observed to generally increase relatively and ranges from 6.89 mg/g (at KS.TP.02, at the margin of the peat dome) to 13.43 mg/g (at KS.TP.08 and KS.TP.10).

4.8.1.5 Tmax value

All the SRA Tmax values of the Quaternary peat deposits analysed as expected indicates immaturity (Table 3.4 in Chapter 3 section 3.4.4.6) and all values are below 430^0C with a range of 387 to 413 (^{0}C) (Table 4.2). The marginal peats at KS.TP.02 show the highest Tmax of 413^0C while KS.TP.09 has the lowest Tmax of 387^0C (Table 4.2).

4.8.1.6 HI value

The marginal peats at KS.TP.02 have a HI (Hydrogen Index) value of 337 HC/g TOC (Type II-oil prone). The HI value is then observed to increase from the margin of the peat basin towards the centre, which is from 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. There is a lateral variation trend of organic matter types from Type II (oil prone) at the margin, to Type III (gas/oil prone) in the midsection area and back again to Type II (oil prone) towards the basin centre (see Table 3.5 in section 3.4.4.7, Chapter 3 and Table 4.2 below). In general, there is a mixture or combination of organic matter of types II and III (kerogen) occurring horizontally on the tropical lowland peat basin within a 0 to 0.5 m depth interval.

4.8.1.7 OI value

The marginal peats for sample KS.TP.02 has an OI (Oxygen Index) value of 45 mg CO_2/ g and a value of 35 mg CO_2/ g for KS.TP.07 sample. The OI value is observed to generally decrease relatively from the margin of the peat basin towards the centre, although, a slightly higher value is recorded in sample KS.TP.10 which is nearest to the centre of the peat deposit (that is from 45 mg CO_2/ g at KS.TP.02 to 27 mg CO_2/ g at KS.TP.10).

Table 4.2: Source Rock Analyses (SRA) data of peat and organic soil sampled from a tropical lowland peat forest in Western Sarawak in relation to organic matter/kerogen type (based on Espitalie et al., 1977).

Sample code	**TOC**	**S1**	**S2**	**S3**	**Tmax**	**HI**	**OI**	**S2/S3**	**Organic matter/kerogen type** (based on Espitalie et al., 1977)
KS.TP.02 (0-0.2m)	15.43	11.83	52.05	6.89	413	337 (Type II)	45	7.55	Type II (oil prone)
KS.TP.07 (0-0.2m)	32.69	13.07	67.70	11.43	393	207 (Type III)	35	5.92	Type III (gas/oil prone)
KS.TP.08 (0-0.5m)	50.80	24.96	134.95	13.43	391	266 (Type III)	26	10.05	Type III (gas/oil prone)
KS.TP.09 (0-0.5m)	48.61	31.46	156.45	12.63	387	322 (Type II)	26	12.39	Type II (oil prone)
KS.TP.10 (0-0.5m)	49.62	26.10	202.08	13.43	397	407 (Type II)	27	15.05	Type II (oil prone)

TOC- Total Organic Carbon, wt. %

Tmax- temperature (^{0}C) at which the maximum release of hydrocarbons occur from cracking

S1- volatile hydrocarbon (HC) content, mg HC/ g rock/source material

HI- Hydrogen index = S2 x 100 / TOC, mg HC/ g TOC

S2- remaining HC generative potential, mg HC/ g rock /source material

OI - Oxygen Index = S3 x 100 / TOC, mg CO_2/ g

S3- carbon dioxide content, mg CO_2 / g rock

PI- Production Index = S1 / (S1+S2)

4.8.2 Results of GCMS analyses-Biomarker Distributions

4.8.2.1 GCMS Analyses Results for sample KS.TP.02 (0-0.5 m)

Figure 4.3 shows the TIC gas chromatogram of the alkane fraction from sample KS.TP.02 (0-0.5 m) and Figure 4.3.1 shows the m/z 85 fragmentogram obtained from the same sample. The alkane fractions from the said sample are predominantly composed of long chained n-alkanes greater than n-C_{13} that extends up to n-C_{33}. Within the range of n-C_{13} to n-C_{33} the most dominant peak is n-C $_{29}$. Within the terrestrial or land plants envelope that ranges from n-C_{23} to n-C_{33} in the fragmentogram (m/z 85), the odd numbered n-alkanes dominate (shows strong odd over even predominance), indicative of the true terrestrial depositional environment of the peats.

The n-alkanes from n-C_{13} to n-C_{22} lie mainly within the bacteria and fungi envelope of the m/z 85 fragmentogram (Figure 4.3.1). From the m/z 85 gas chromatogram of the alkane fraction from sample KS.TP.02 (0-0.5 m), the pristane/phytane ratio is 0.97 and is less than 1 (<1) (Table 4.3.2).

The hopanes are the dominant pentacyclic (Waples and Machihara, 1991) triterpanes in the peat alkane fraction of sample KS.TP.02 (0 to 0.5m) (Figure 4.3.2). C_{31}-hopane is the most abundant hopanoid and dominant homohopane observed with the R-isomer clearly being more dominant than the S-isomer. S / (S+R) ratio for the isomers 17α, 21β (H)-Homohopane (S-configuration) and 17α, 21β (H)-Homohopane (R-configuration) gives a low value (0.18). Very immature ββ hopanoids such as ββ C_{30} hopane (17 β, 21β (H)-Hopane) and ββ C_{31} hopane (17β, 21β (H)-Homohopane) are present. Figure 4.3.2 shows the m/z 191 chromatogram for the peat core sample KS.TP.02 (0-0.5 m). The peak identification for sample KS.TP.02 (0-0.5m) is as shown in Table 4.3.

Besides homohopane, the other hopanoids found to occur in sample KS.TP.02 (0-0.5 m) are C_{29} hopane (Norhopane) and ββ C_{30} hopane (17β, 21β (H)-Hopane). Steranes do not appear to be common or may occur in too low concentrations and are unable to be detected by m/z 217 ion fragmentograms in this study.

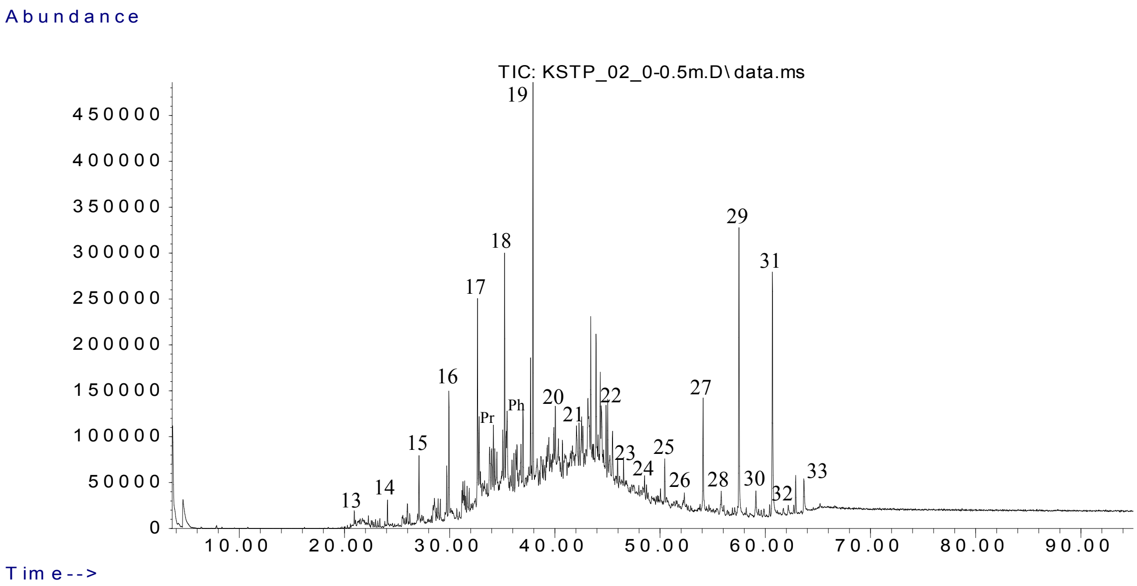

Figure 4.3:TIC gas chromatogram of the alkane fraction (showing n-Alkane series n-C_{13} to n-C_{33}) from sample KS.TP.02 (0-0.5 m).

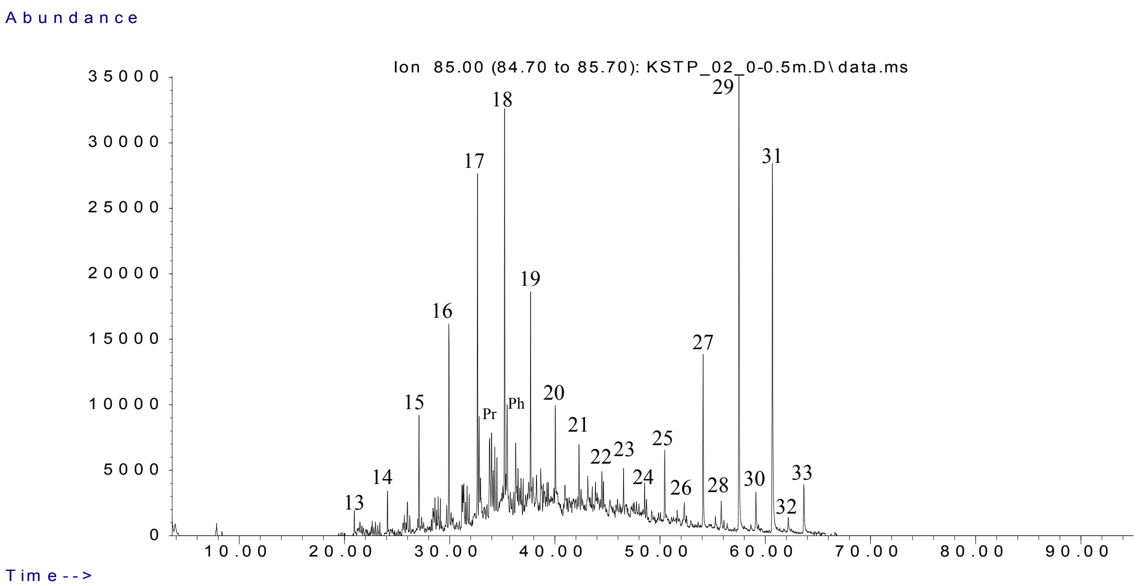

Figure 4.3.1:*m/z* 85 mass fragmentogram of peat alkane fraction from a lowland tropical peat swamp at auger sample location KS.TP.02 (0-0.5 m) showing n-Alkane series (n-C_{13} to n-C_{33}), Pristane (Pr) and Phytane (Ph) peaks.

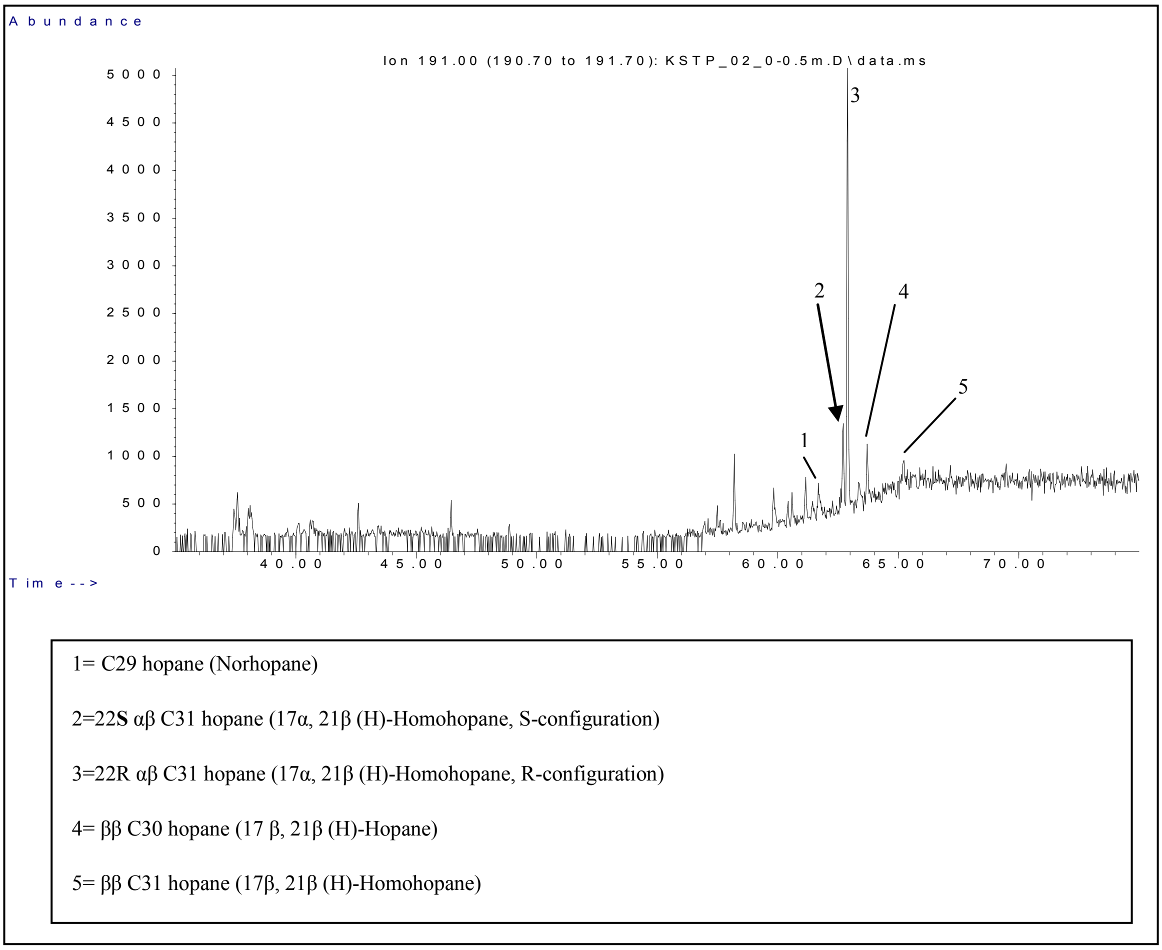

Figure 4.3.2:*m/z* 191 mass fragmentogram of peat from a lowland tropical peat swamp at auger sample location KS.TP.02 (0-0.5m).

4.8.2.2 GCMS Analyses Results for sample KS.TP.08 (0-0.5 m)

Figure 4.3.3 shows the TIC gas chromatogram of the alkane fraction from sample KS.TP.08 (or KS.TP.08BB) at 0 to 0.5 m sampling depth and Figure 4.3.4 shows the m/z 85 fragmentogram obtained for the same sample. The alkane fractions from the mentioned sample are predominantly composed of long chained n-alkanes greater than n-C_{15} that extends up to n-$C_{39.}$ Within the range of n-C_{15} to n-C_{39} the most dominant peak is n-C $_{31.}$ Within the terrestrial or land plants envelope of the fragmentogram (m/z 85) and in the range of n-C_{23} to n-C_{39}, the odd numbered n-alkanes dominate, indicative of the terrestrial depositional environment of the peats and, maximizing at n-C_{31}, as mentioned.

The n-alkanes from n-C_{15} to n-C_{22} lie mainly within the bacteria and fungi envelope of the m/z 85 fragmentogram (Figure 4.3.4). From the m/z 85 gas chromatogram of the alkane fraction from sample KS.TP.08 (or KS.TP.08BB) (0-0.5 m), the pristane/phytane ratio is 1 and is in the range of 1 to 3 indicative of a relatively suboxic environment of deposition which is still indicative of wet tropical lowland peats with high ground water tables (Table 4.3.5).

The hopanes are also the dominant pentacyclic triterpanes (Waples and Machihara, 1991) in the peat alkane fraction of sample KS.TP.08BB (0 to 0.5m) (Figure 4.3.5). C_{31}-hopane is also the most abundant hopanoid and dominant homohopane observed with the R-isomer clearly being more dominant than the S-isomer. S / (S+R) ratio for the isomers 17α, 21β (H)-Homohopane (S-configuration) and 17α, 21β (H)-Homohopane (R-configuration) gives a low value (0.12). Again, very immature ββ hopanoids such as ββ C_{30} hopane (17 β, 21β (H)-Hopane) and ββ C_{31} hopane (17β, 21β (H)-Homohopane) are still present.

Figure 4.3.5 shows the m/z 191 chromatogram for the peat sample from the peat core KS.TP.08 (0-0.5 m). The peak identification of peat core KS.TP.08 (0-0.5 m) is as presented in Table 4.3. Besides homohopane, the other hopanoids found to occur in the tropical lowland peats at location KS.TP.08BB (0-0.5m) are C_{29} hopane (Norhopane) and ββ C_{30} hopane (17 β, 21β (H)-Hopane) as shown in Figure 4.3.5.

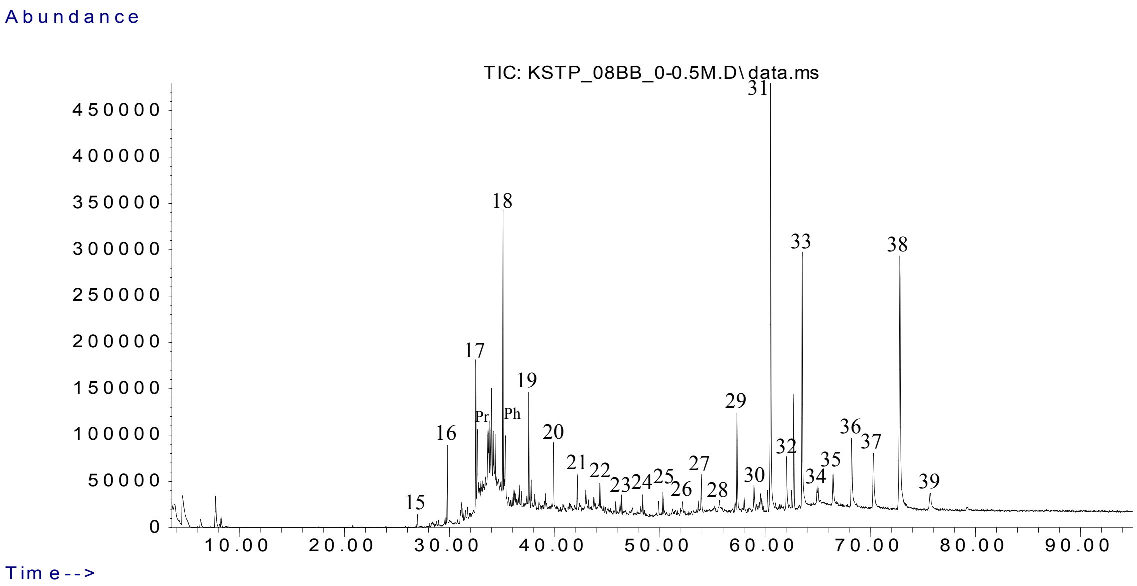

Figure 4.3.3:TIC gas chromatogram of the alkane fraction (showing n-Alkane series n-C_{15} to n-C_{39}) from sample KS.TP.08 (0-0.5m).

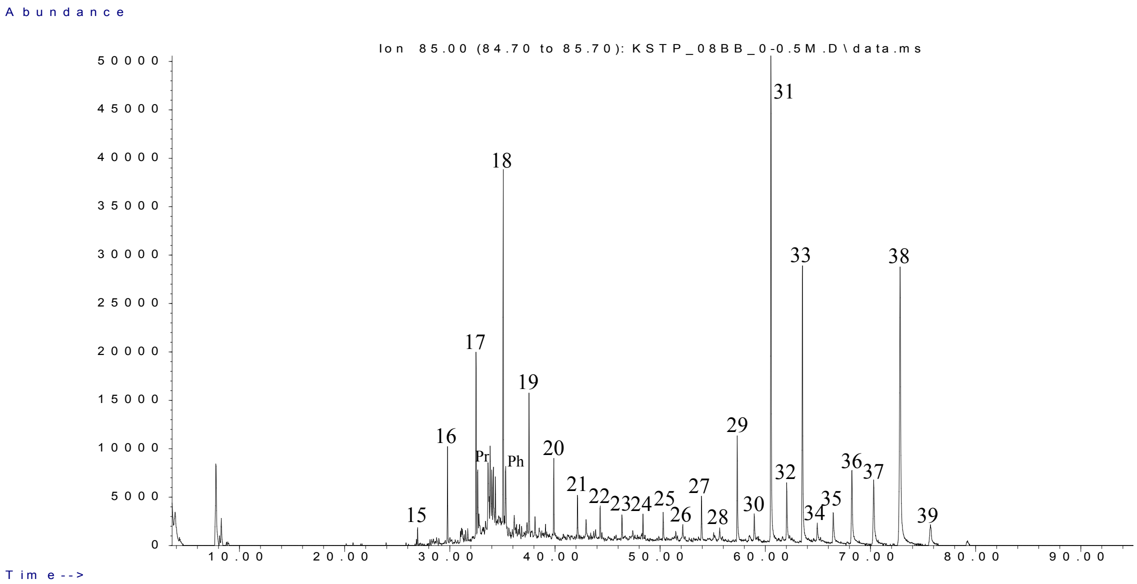

Figure 4.3.4:*m/z* 85 mass fragmentogram of peat alkane fraction from a tropical lowland peat swamp at auger sample location KS.TP.08 (0-0.5m) showing n-Alkane series (n-C_{15} to n-C_{39}), Pristane (Pr) and Phytane (Ph) peaks.

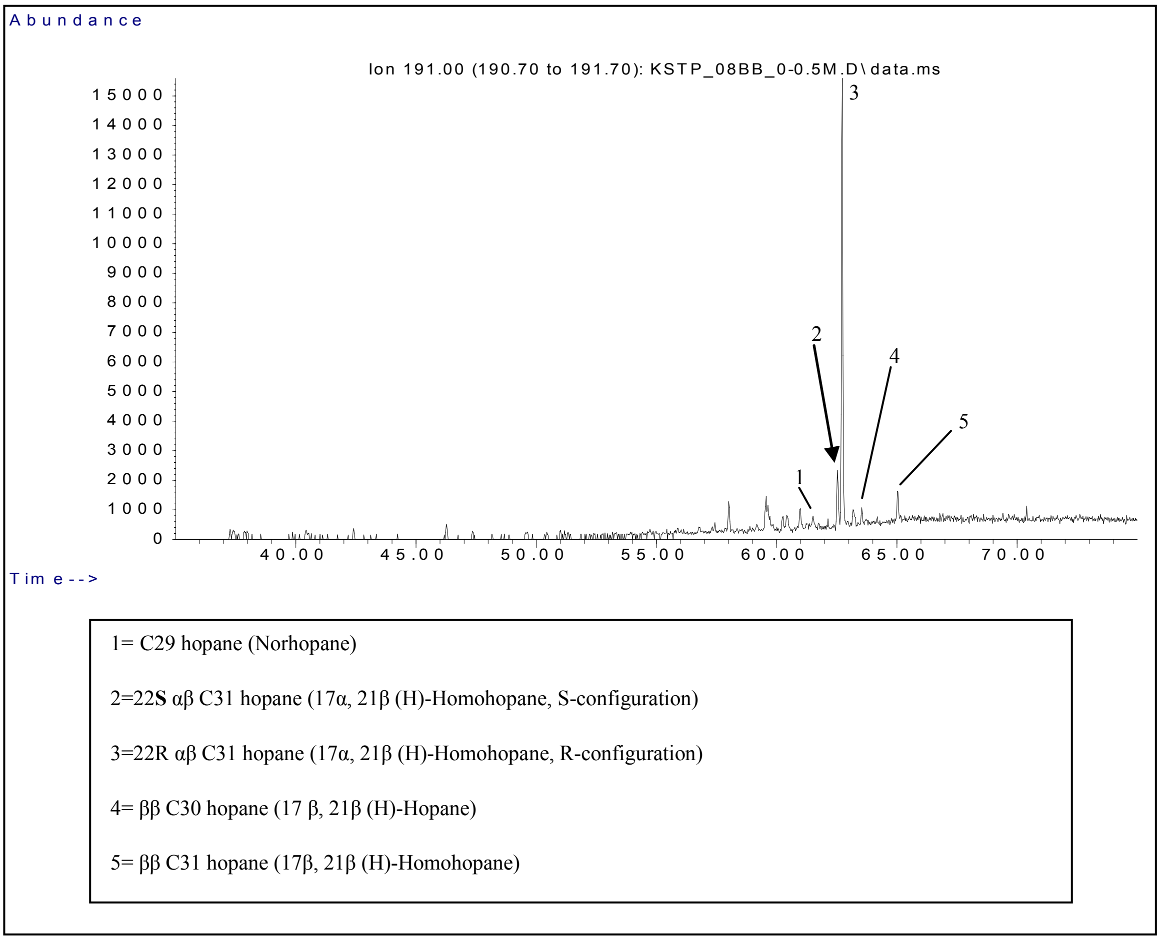

Figure 4.3.5: *m/z* 191 mass fragmentogram of peat from a lowland tropical peat swamp at auger sample location KS.TP.08 (0-0.5 m).

4.8.2.3 GCMS Analyses Results of sample KS.TP.09 (0-0.5m).

Figure 4.3.6 shows the TIC gas chromatogram of the alkane fraction from sample KS.TP.09 (0-0.5 m) and Figure 4.3.7 shows the m/z 85 fragmentogram obtained from the same sample. The alkane fractions from the above mentioned sample are predominately composed of long chained n-alkanes greater than n-C_{13} that extends up to n-C_{33}. Within the range of n-C_{13} to n-C_{33} the most dominant peak is n-C $_{27}$. Within the terrestrial or land plants envelope that ranges from n-C_{23} to n-C_{33} in the fragmentogram (m/z 85), the odd numbered n-alkanes dominate, indicative of the terrestrial depositional environment of the peats. The n-alkanes from n-C_{13} to n-C_{22} lie mainly within the bacteria and fungi envelope of the m/z 85 fragmentogram (Figure 4.3.7).

From the m/z 85 gas chromatogram of the alkane fraction from sample KS.TP.09 (0-0.5m), the pristane/phytane ratio is 1 and lies within the 1 to 3 range indicative of a suboxic environment of deposition. The Pr/nC_{17} ratio is 0.21 whereas the Ph/nC_{18} ratio is 0.18 indicative of reducing environmental conditions.

The hopanes are again the dominant pentacyclic triterpanes in the peat alkane fraction (Figure 4.3.8). C_{31}-hopane is again the most abundant hopanoid and dominant homohopane observed with the R-isomer clearly being more dominant than the S-isomer. S / (S+R) ratio for the isomers 17α, 21β (H)-Homohopane (S-configuration) and 17α, 21β (H)-Homohopane (R-configuration) gives a low value (0.12) supporting the immaturity of the peat samples as coal precursors. Again the presence of ββ hopanoids such as ββ C_{30} hopane (17 β, 21β (H)-Hopane) and ββ C_{31} hopane (17β, 21β (H)-Homohopane) is observed here.

Figure 4.3.8 shows the m/z 191 chromatogram for the peat sample KS.TP.09 (0-0.5 m) with the peak identification for this sample as shown in Table 4.3. Besides homohopane, the hopanoids still found to occur near the basin centre at sample location KS.TP.09 (0-0.5m) are Norhopane and 17 β, 21β (H)-Hopane as shown in Figure 4.3.8.

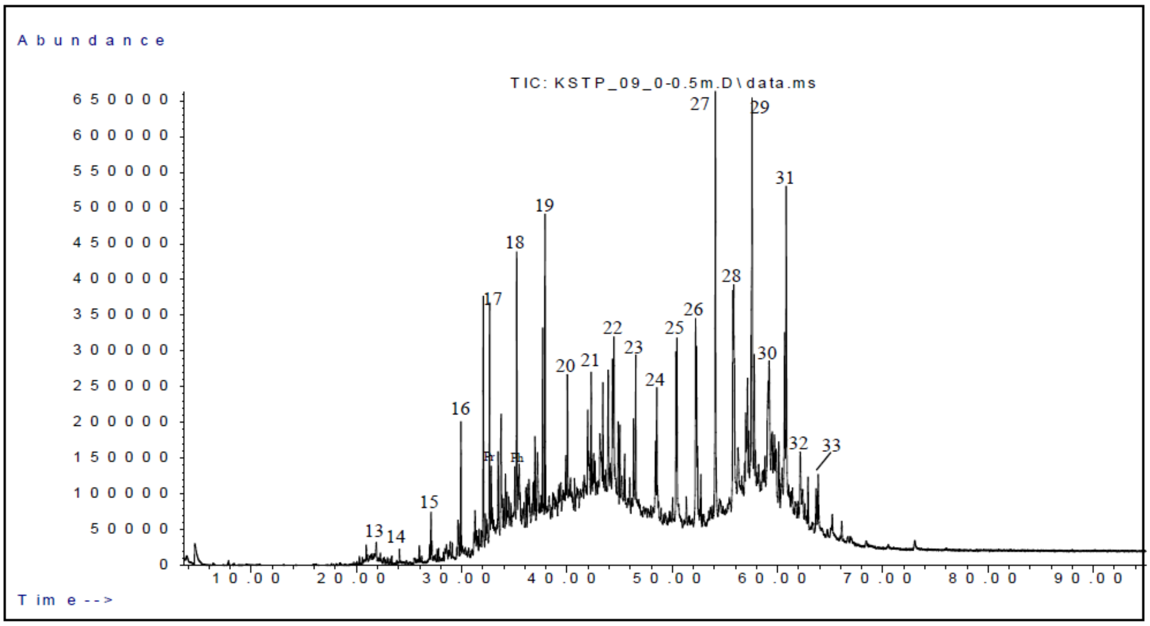

Figure 4.3.6:TIC gas chromatogram of the alkane fraction (showing n-Alkane series nC_{13} to nC_{33}) from sample KS.TP.09 (0-0.5 m).

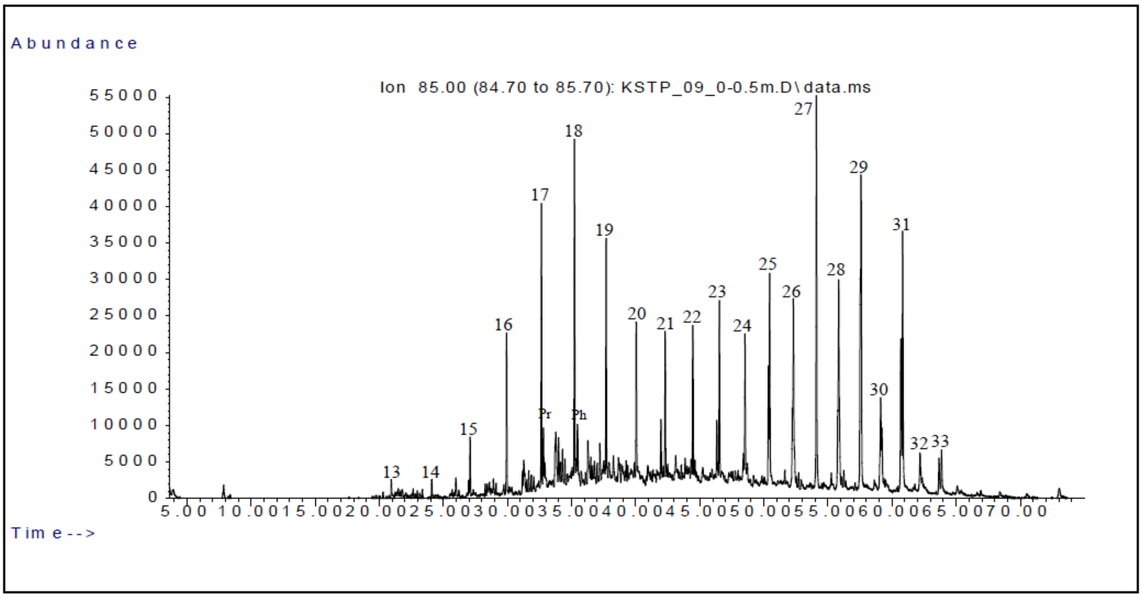

Figure 4.3.7:*m/z* 85 mass fragmentogram of peat alkane fraction from a tropical lowland peat swamp at auger sample location KS.TP.09 (0-0.5 m) showing n-Alkane series (nC_{13} to nC_{33}), Pristane (Pr) and Phytane (Ph) peaks.

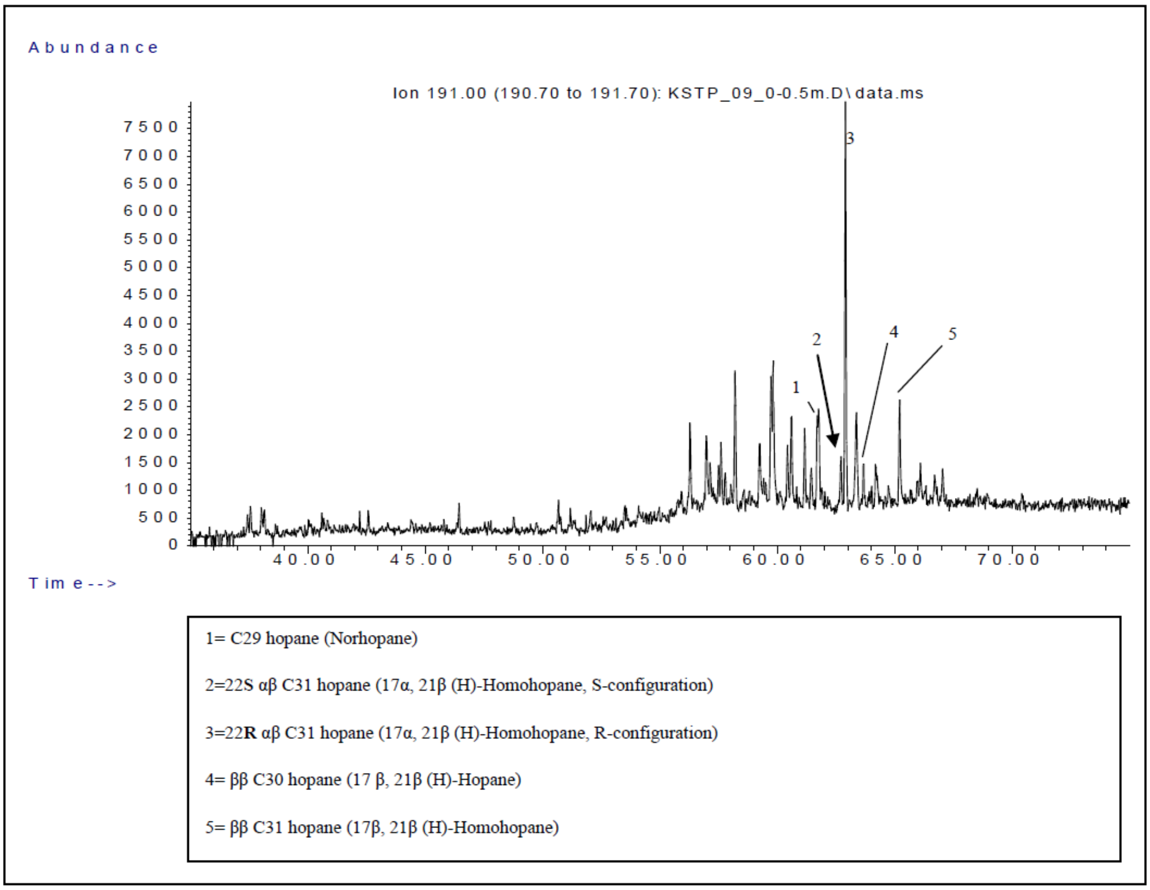

Figure 4.3.8: *m/z* 191 mass fragmentogram of peat from a tropical lowland peat swamp at auger sample location KS.TP.09 (0-0.5 m).

4.8.2.4 Biomarker peak identification, geochemical ratios and characteristics.

The peak identification (Philp, 1985) of compounds is as listed in Table 4.3. The hopanes listed are the dominant aliphatic compounds found to occur repetitively in the top 0 to 0.5 m layer of peats from basin margin to mid-section and further towards the near-centre areas of the tropical lowland peat dome studied.

The normal and branched alkane parameters of the peats sampled are presented in Table 4.3.1. The aliphatic content is observed to relatively increase from basin margin to midsection and increase further towards the near-center area of the dome.

Peats sampled from the near-center area (KS.TP.09 (0-0.5 m) are observed to have the highest relative aliphatic content of 2200 ppm compared to the marginal area (700 ppm). Geochemical (GCMS) ratios and related geochemical characteristics of 3 aliphatic fractions of peat sampled from basin periphery to mid-section and further towards the near centre area of the peat basin are presented in Table 4.3.2.

Table 4.3: Peak identification for Figures 4.3.2, 4.3.5 and 4.3.8.

Peak	Compound	Literature
1	C29 hopane (Norhopane)	Philp, 1985
2	22Sαβ C31 hopane (17α, 21β (H)-Homohopane, S-configuration)	Philp, 1985
3	22Rαβ C31 hopane (17α, 21β (H)-Homohopane, R-configuration)	Philp, 1985
4	ββ C30 hopane (17 β, 21β (H)-Hopane)	Philp, 1985
5	ββ C31 hopane (17β, 21β (H)-Homohopane)	Philp, 1985

Table 4.3.1: Normal and branched alkane parameters of peat sampled from basin periphery to mid-section and further towards near-centre area of a tropical lowland peat basin (Plaie peat forest), in the Kota Samarahan-Asajaya area.

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Sample No	EOM (ppm of whole rock/sample)			
	Total extract	Aliphatic	Aromatic	Polar (NSO)
KS.TP.02 (0-0.5m)	63313	700	900	3800
KS.TP.08 (0-0.5m)	168101	1600	4800	19400
KS.TP.09 (0-0.5m)	161941	2200	3000	7100

Table 4.3.2: Geochemical (GCMS) ratios and characteristics of 3 aliphatic fractions of peat sampled from basin periphery to mid-section and further towards the near-centre area of a tropical lowland peat basin (Plaie peat forest), in the Kota Samarahan-Asajaya area.

Sample No/ approximate location on dome	n-alkane range	Odd Over Even Predominance (OEP)	Maximum Peak	Pr/Phy (< or >1)/anoxic to suboxic	Pr/n-C_{17}	Ph/n-C_{18}	S/(S+R)	Organic matter type/ kerogen (based on SRA-HI data)
KS.TP.02 (0-0.5m)/ margin	n-C_{13} to n-C_{33}	OEP	n-C_{29}	0.97 (<1)/anoxic	0.31	0.27	0.18	II
KS.TP.08BB (0-0.5m)/ midsection	n-C_{15} to n-C_{39}	OEP	n-C_{31}	1 (>1)/suboxic	0.36	0.18	0.12	III
KS.TP.09 (0-0.5m)/ nearer to dome centre (relatively higher elevation with lower groundwater tables)	n-C_{13} to n-C_{33}	OEP	n-C_{27}	1 (>1)/suboxic	0.21	0.18	0.12	II

4.9 Results of Pollen Analyses (Pollen Diagrams)

The results of the pollen analyses are as shown on the pollen diagrams (Figures 4.4 and 4.4.1) inclusive of all pollen and pteridophyte spores (Plate I). Pollen types which could not be identified with any certainty were excluded from the pollen sum. In the analyses of the borehole peat profile of KS.TP.10, no extreme over-representation were observed and hence all identified pollen and spore types have been included in the pollen sum. However, the over representation of some peat pollen types may occur (for e.g. the *Cephalomappa* pollen) in peat swamps due low pollen dispersal when only a single prolific tree may produce the maximum pollen representation (Anderson and Muller, 1975). However, misrepresentation (or misinterpretation) of the absence of S*horea* type pollen may also occur as *Shorea* type trees were observed present in the field at the locations of the the studied augerholes (KS.TP.09 and KS.TP.10). Hence, the absence of pollen from *Shorea* type trees maybe due to the low pollen producing capability of the tree species.

The affinity of the types recognized is indicated on the pollen diagram either by reference to a living taxon or, if the type occurs in more than one taxon, by adding "type'. The comparison was mainly limited to taxa known to occur in peat swamp forest, and in adjacent vegetational environments such as mangrove and riverine (or riparian) vegetation (Germeraad et al., 1968 and Anderson and Muller, 1975).

4.9.1 Description of the diagram

From the pollen diagram, it is possible to interpret the inferred succession of a number of forest types present in the locality of the augerholes (KS.TP.09 and

KS.TP.10), and that these can be used to assess the past and present depositional environments represented by different sampling intervals from the augerhole profiles mentioned. The inferred succession of the different forest types are described and discussed in the following sections.

4.9.1.1 Description of pollen diagram for borehole KS.TP.09

A total of 4 samples were analyzed from the locality of borehole KS.TP.09 (Figures 3.6 and 3.8 in Chapter 3). Based on the pollen diagram (Figure 4.4) for the core profile from this augerhole and from the general interval of 2.0-1.5 m, the *Rhizophora* and *Oncosperma* pollen is dominant along with a few grains of the *Excoecaria aggulocha* pollen. This interval is also marked well by the occurrence of pollen originating from riparian vegetation which are *Elaeocarpus* and *Eugenia*. The *Asplenium* type spores with *Acrostichum aureum* and *Stenochlaena palustris* are also present which represents non arboreal pollen and spores. The sampling from 1.4 to 1.0 m shows a major change in pollen assemblage, characterized by a decrease in the mangrove elements of *Oncosperma* and *Rhizophora*. This decrease continues with only 2 grains of *Oncosperma* pollen occurring at 0.5 to 1.0 m and the marked disappearance of the *Rhizophora* pollen from 1.4 to 1.0 m.

From 2.0 to 1.4 m, there is a marked increase of the peat swamp pollen type *Campnosperma* and a decrease of the mangrove elements. At 1.4 m and the actual beginning of initial peat deposition, there is a noted peak for *Campnosperma*. From 1.4 to 1.0 m, there is a marked decrease of *Campnosperma* and is accompanied by other peat swamp species which, however are only present in low numbers such as *Gonystylus, Cyrtostachys, Cephalomappa* and *Zalacca*. The upper section between 1.4 to 0 m shows a decreasing trend of *Campnosperma* abundance but still shows dominance compared to other pollen types. The other types of peat swamp pollen present from 1.4 to 0 m in the peat section of the profile are *Alangium, Calophyllum, Dillenia, Durio, Parastemon, Timonius, Shorea, Melanorrhea* and *Stemonurus*. The pollen types *Casuarina* and *Podocarpus* are also recorded in this interval. The non arboreal pollen and spores which characterize this interval are represented by *Asplenium* type, *Stenochlaena palustris*, *Polypodium*, *Pteris* type and *Lygodium microphyllum*. *Stenochlaena palustris* has shown a significant trend as this spore is highly abundant from 1.4 to 1.0 m and shows a decreasing trend from 1.0 to 0 m.

From 1.0 to 0.5 m, the pollen types found to occur include *Cephallomappa, Callophyllum, Campnosperma, Palaquim, Parastemon, Zalacca* followed by *Oncosperma, Casuarina, Magnolia, Polypodium, Stenochlaena palustris, Durio* and *Eugenia.*

From 0.5 to 0 m, the significant pollen types that make up the peat swamp catena as reported by Anderson and Muller (1975) and observed to occur here are *Stemonurus, Campnosperma, Palaquim* and *Dactylocladus*. These are followed by less significant types such as *Cephallomappa, Callophylum* and *Blumeodendron*.

The abundance of *Rhizophora* and *Oncosperma* along with minor amounts of *Excoecaria aggulocha* between 2.0-1.5 m has revealed that the lower part of the inferred succession probably represents a former mangrove or estuarine swamp vegetational/depositional environment (section 4.5). The other significant non-mangrove pollen types which are present in this zone are *Elaeocarpus* and *Eugenia* which are locally subject to transportation by tidal action and are a common species of riparian vegetation in Sarawak (Malaysia). These riparian type pollens may indicate and support the presence of a floodplain or a riverine depositional environment within this

2.0 to 1.4 m interval (section 4.4). A sharp floristic boundary is marked at 1.4 m. The zone between 2.0 to 1.4 m locally shows a sudden decrease in mangrove pollens such as *Oncosperma* and *Rhizophora* with the latter virtually disappearing at 1.4 m. This sharp decrease strongly indicates a transition zone from mangrove to floodplain/riverine followed by a peat swamp depositional environment. This zone may be comparable to the inferred succession of the peat swamp catena as was studied and described by Anderson and Muller (1975) because it is characterized by the presence of significant pollen types of *Campnosperma*, *Cyrtostachys* and *Zalacca.* Hence, it may strongly be comparable to the *Campnosperma-Cyrtostachys-Zalacca* sub-association characteristic of the transitional mangrove to shallow peats phase occurring before the vegetational succession of Phasic Community I (Anderson and Muller, 1975). This is further supported by the abundance of typical climbing ferns, of the spore type *Stenochlaena palustris* especially at the lower part of the succession (1.5 m); as this spore is common during the early development of peat swamps and is largely confined to the transitional mangrove-shallow peats (*Campnosperma-Cyrtostachys-Zalacca* sub-association) phase which occurs before the succession of Phasic Community I (Anderson and Muller 1975).

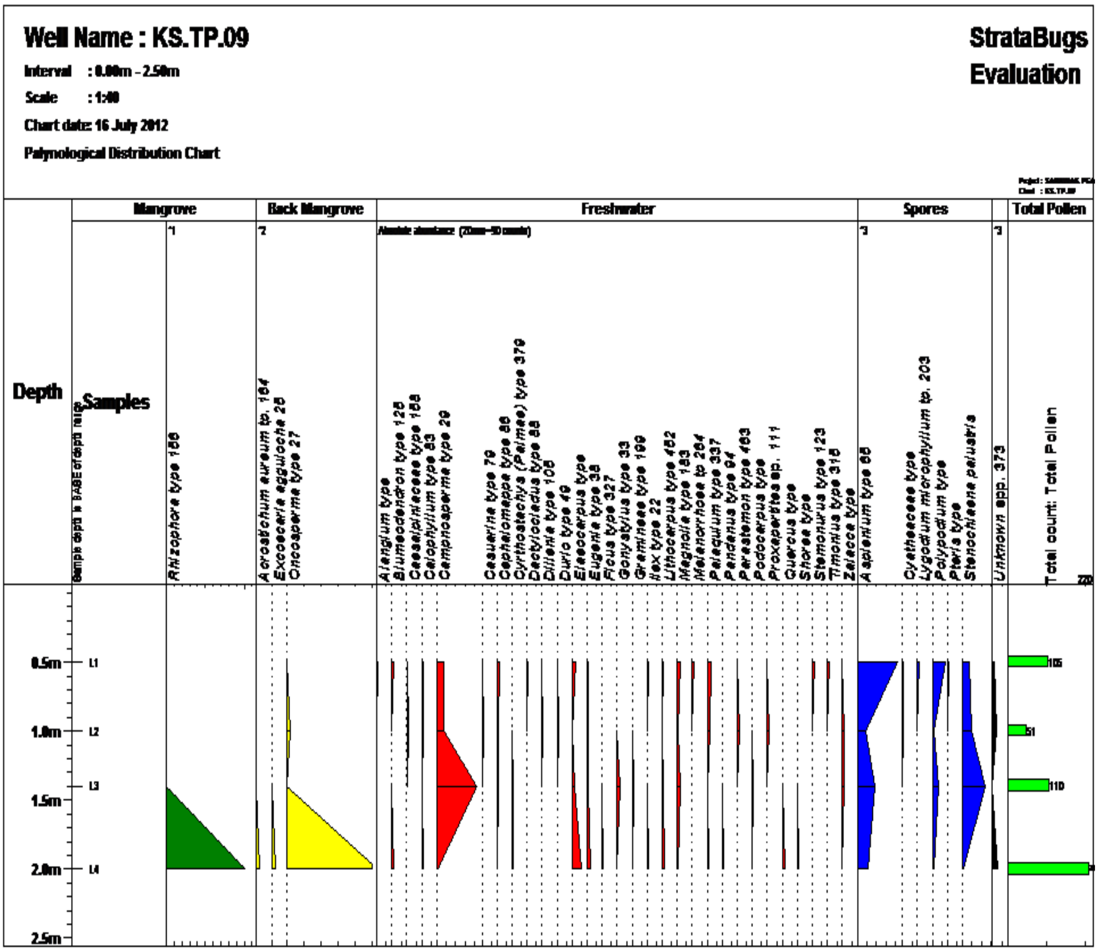


Figure 4.4: Pollen and spores assemblage (KS.TP.09)

4.9.1.2 Description of pollen diagram for borehole KS.TP.10.

A total of 8 samples were analyzed from the locality of borehole KS.TP.10 (Figures 3.7). From 5.5 to 3.5 m, the *Rhizophora* pollen is present in relatively high percentages along with relatively high counts of the *Oncosperma* pollen. The *Rhizophora* pollens are still dominant from 3.5 to 2.0 m, however, this interval is marked by an increase of *Campnosperma*, along with minor proportions of other mangrove pollens such as *Nypa fruticans, Avicennia* and *Excoecaria aggulocha*. This interval also records some prominent peaks from the riparian type pollens which are represented by *Elaeocarpus* and *Eugenia* (Figure 4.4.1).

Towards the top of the succession between 1.5 to 1.0 m, the mangrove elements show sharp decreasing percentages, especially the *Oncosperma* and the *Rhizophora* pollen with the latter virtually disappearing (at 2.0 m). This interval represents a transitional assemblage and is characterized by a major change in pollen assemblage which is then dominated by peat swamp taxa. The *Campnosperma* pollen is relatively dominant and is associated with typical peat swamp pollens such as *Blumeodendron, Cyrtostachys, Zalacca* and *Parastemon*.

In the upper part of the section from 1.0 to 0 m, the *Campnosperma* pollen is still dominant and is associated with other pollen types such as *Gonystylus, Dillenia, Cephalomappa* and *Eugeissona*. A peak from the Dactylocladus pollen is recorded at 1.0 m.

In the uppermost part of the assemblage, from 0.5 to 0 m, the dominant pollen types observed to occur are *Campnosperma* followed by the presence of *Blumeodendron, Gonostylus, Parastemon* and *Stemonurus.*

The dominant non arboreal pollens are represented by *Asplenium* type spores throughout the succession especially from 0.5 to 0 m, with some minor occurrences of *Polypodium* and *Stenochlaena palustris*. The *Stenochlaena palustris* is relatively more prominent from 2.0 to 1.0 m and shows an increasing trend before it virtually disappears at the interval 0.5 to 0 m.

Based on the analyses of the pollen assemblage from this locality, the assemblage can be divided to represent four main vegetational phases or environments of deposition. At the interval 5.5 to 3.5 m (KS.TP.10), the dominance of *Rhizophora* and *Oncosperma* clearly demonstrates a former mangrove or estuarine swamp environment (section 4.5). This interval is locally overlied by the interval 3.5 to 2.0 m (KS.TP.10) that is characterized by the abundant occurrence of *Oncosperma* which is associated with the *Nypa fruticans* pollen. The dominance of *Oncosperma* and *Nypa fruticans* are largely confined to the inland zone of mangrove or estuarine vegetation (section 4.5). The peak of *Elaeocarpus* within this interval is probably related to tidal action or flooding which has brought an influx of this pollen type from riparian vegetational areas and this relates to and supports a floodplain or riverine depositional environment (section 4.4). This zone may probably be comparable to the *Campnosperma-Cyrtostachys-Zalacca* sub-association zone as was studied by Anderson and Muller (1975) and is interpreted to occur within the 2.0 to 1.0 m interval (KS.TP.10). This zone which is observed as shallow, topogenic peat is interpreted and derived from the association of the *Campnosperma, Cyrtostachys* and *Zalacca* pollen which is related to the initial development of peat or transitional phase from mangrove-floodplain to peat swamp environment. This is further supported by the abundance of *Stenochlaena palustris* peaking at 1.0 m (KS.TP.10). The age of the initial development of the peats is dated at 2420 ± 30 years B.P (section 4.9.2) from the sampling interval of 1.5 to 2.0 m. At the interval of 1.0 to 0.5 m (KS.TP.10), approximately 2380 ± 30 years B.P. (section 4.9.2), the vegetation is still interpreted as a combination of shallow peats, which probably begins to change to Phasic Community I (Anderson and Muller, 1975) as this zone is locally characterized by the peak of *Dactylocladu*s and the appearance of a single pollen grain of *Gonystylus*. From 0.5 to 0 metres near the surface, or approximately 1780 ± 30 years ago till present time (section 4.9.2), the pollen *Gonostylus* (at location KS.TP.10) are observed present (and *Stemonurus* at the same interval at location KS.TP.09) which indicates that successive vegetational zonation of phasic community II may have been reached, but without the appearance of the *Shorea* type pollen (however, large, 'stag-horned' *Shorea* type trees have been observed present in the field near to locations KS.TP.09 and KS.TP.10 and this supports that phasic community II is present).

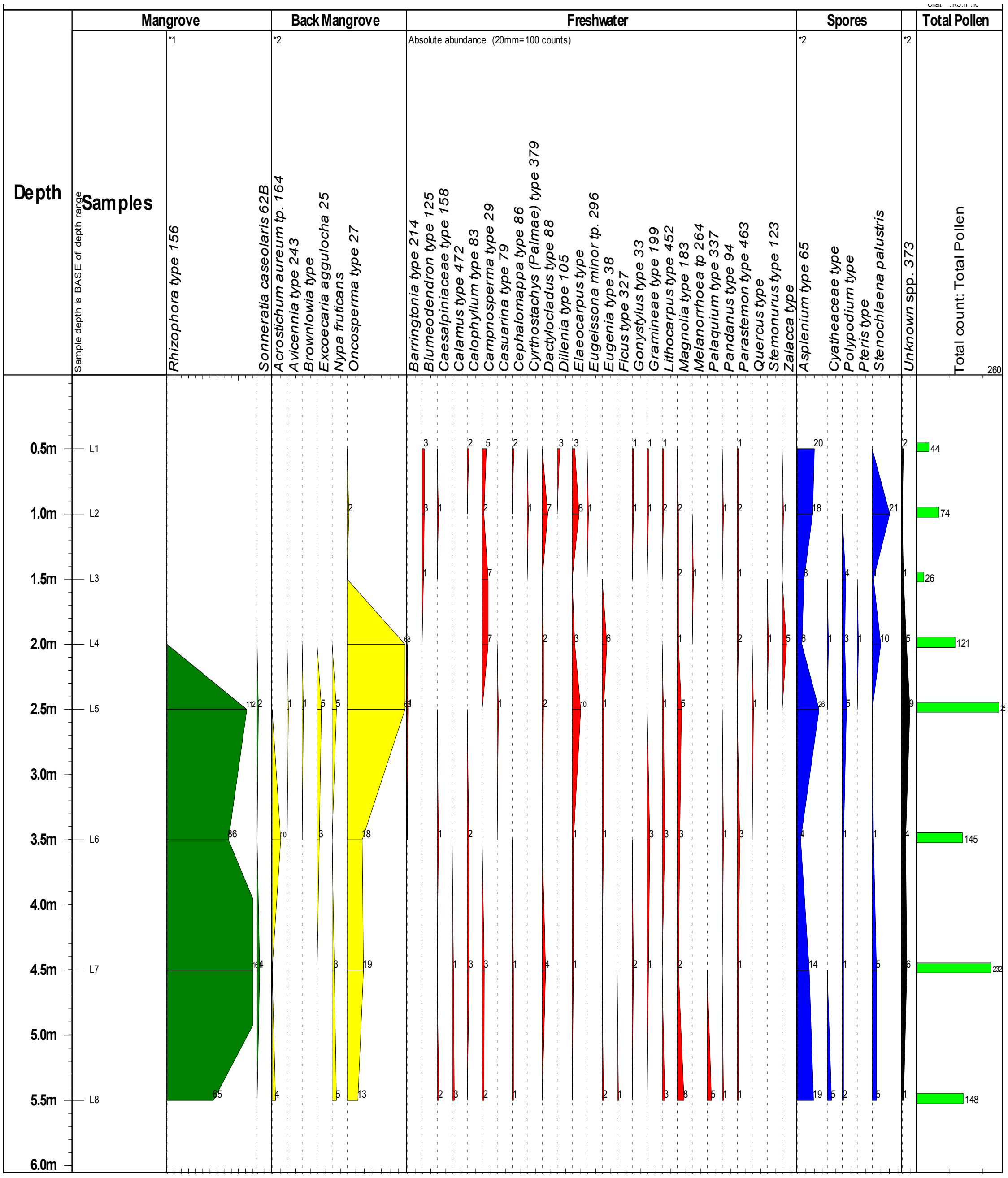


Figure 4.4.1: Pollen and spores assemblage (KS.TP.10).

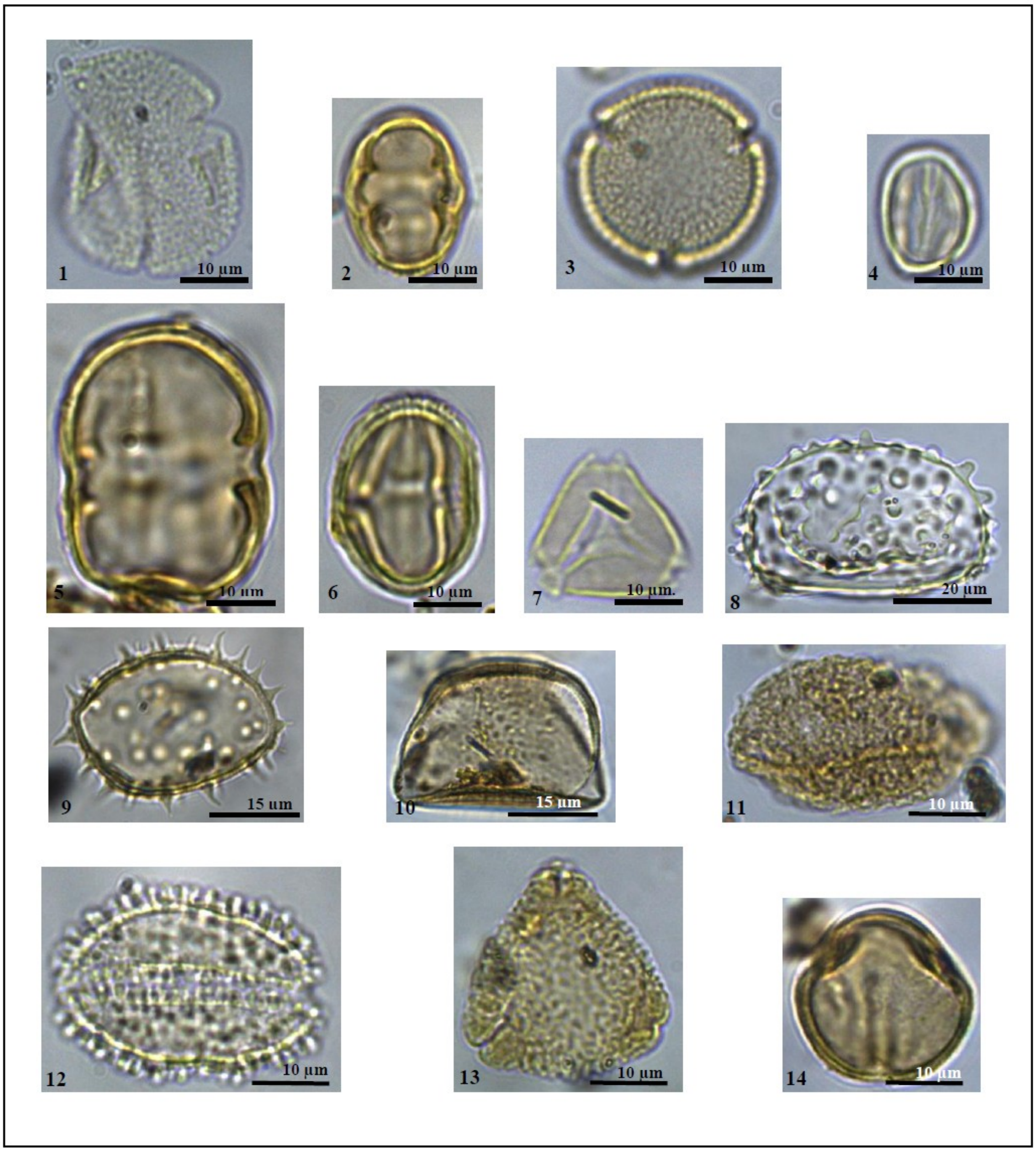


Plate 1

Plate 1: Photomicrographs of pollen types present in the lowland tropical peat dome/basin at the western part of Kota Samarahan-Asajaya study area: 1. *Shorea* type 2. *Rhizophora* 3. *Blumeodendron* 4. *Dactylocladus* 5. *Palaquium* 6. *Campnosperma* 7. *Tristania/Eugenia* 8. *Stenochlaena palustris* 9. *Nypa fruticans* 10. *Calamus* 11. *Gonystylus* 12. *Oncosperma* 13. *Cephalomappa* 14. *Parastemon*

4.9.2 ^{14}C age of peat samples

Peat starts developing just above 200 cm from the profile at location KS.TP.10 which is near the centre of the peat basin and radiocarbon (^{14}C) dating was attempted on a sample taken between 180 and 200 cm. An age determination of 2420 ± 30 years B.P. for the general sampling interval 1.5-2 m (180-200 cm) was obtained for the age of initial deposition of peat into the peat basin (Table 4.4).

Table 4.4: ^{14}C age of peat sampling intervals (quoted in conventional years BP (before 1950 AD)).

Auger hole location	General Sampling interval	^{14}C age (quoted in conventional years BP (before 1950 AD))	Past to present depositional environments and proposed phasic community inferred succession (Anderson and Muller, 1975)
KS.TP.10	0.5-0 m	1780 ± 30 years B.P	Peat swamp, Phasic Community II/Alan Swamp Forest.
KS.TP.10	1.0-0.5 m	2380 ± 30 years B.P	Peat swamp, Phasic Community I/Mixed Peat Swamp Forest.
KS.TP.10	2.0-1.5 m	2420 ± 30 years B.P	Transitional mangrove to peat swamp environment.

4.9.3 Results of petrographic study

Photomicrographs of polished sections of peat macerals are as shown in Figures 4.4.2 (a) to (p). Peat maceral (premacerals) types are observed to vary with humification levels together with their peat diagenetic stages from basin margin towards the near-centre of the peat dome. The description of dominant maceral types and dominant peat diagenesis stages (after Stout and Spackman, 1987 and Mohd. Zaid, 1998) are as shown in Table 4.5.

Field identification and classification (von Post classification) of the tropical lowland peat shows that there is a lateral or horizontal variation of peat humification levels and trend in the form of dominantly occurring fibric, fibric to hemic, sapric and hemic to sapric peat, occurring progressively, from margin towards the centre of the tropical lowland peat dome or basin, at 0 to 0.5 m sampling depth. Petrographic studies show that humification or decomposition levels of peat are related to the dominantly occurring peat macerals in the form of yellow fresh or unaltered plant cells, red textinite, gray textinite, texto-ulminite, eu-ulminite and humodetrinite or humocollinite. At the margin of the peat basin (at location KS.TP.02), dominantly fibric peats are identified which consists of mainly fresh, yellow to orange cells and red textinite macerals. From the margin towards the midsection area (at location KS.TP.07), a range of fibric to hemic peats is classified in the field consisting of mainly fresh, yellow to orange cells, red textinite and dark humodetrinite and humocollinite macerals. At the midsection area (at location KS.TP.08), dominantly sapric peats are observed to occur consisting of mainly red textinite with dark humodetrinite and humocollinite or just mainly dark humodetrinite and humocollinite macerals. From the midsection towards the basin centre (at location KS.TP.09), sapric peats occur and they consist of mainly dark humodetrinite and humocollinite macerals. Further again towards the basin centre (at location KS.TP.10) hemic to sapric peats occur and are also made up of mainly dark humodetrinite and humocollinite macerals (Table 4.5). Variations of dominant peat maceral types observed in this study are probably related to different levels of diagenesis in the humification or peatification process of the tropical lowland peats. The respective progressive stages (and the associated dominant maceral types) that are observed to occur 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).

Table 4.5: Description of dominant maceral types and dominant peat diagenesis stages (after Stout and Spackman, 1987 and Mohd. Zaid, 1998) observed to occur in sampled peats deposited from the peat basin margin (near location KS.TP.02) and towards the approximate centre 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 (m)	0.2	0.2	1.0	1.4	2.0
Colour of peat (Munsell colour code)	0 to 0.2m: 10YR 3/3	0 to 0.2m: 7.5YR 3/4	0-0.5m: 7.5YR 2.5/2	0 to 0.5m : 7.5 YR 3/3	0 to 0.5m : 7.5YR 2.5/2
Major macerals occurring with depth of peat(0-0.5m)	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 present in peatification/ decomposition process	I, II, post- phase V.	I, II, post- phase V.	I, II, post-phaseV.	II, III, IV, V or post-phase V.	II, V and post phase V.
and approximate percentage of peat macerals undergoing Diagenetic Phase (I, II, III, IV, V or post V), colour of cells or maceral types	-Fresh cells-yellow to whitish yellow: 0-10% -Red textinite (II) :**40-50%** -Humodetrinite and Humocollinite (post V):10-20% -Clastic fragments/mineral soil: 30-50%	-Fresh cells-yellow to whitish yellow: 10-25% -Red textinite (II) :**30-40%** -Humodetrinite and Humocollinite (post V) **30-40%** -Clastic fragments: 5-15% -Some gray texto-ulminite present <5%	-Wood fragments-fresh cells-yellow to orange: 5-10%, -Red textinite (II): 30-40%, -Humodetrinite and Humocollinite (post V):**60-70%**	-Red textinite (II): 5-10% **-** Gray textinite (phase III):5-10% - texto-ulminite (Phase IV): 5-10% -eu-ulminite (Phase V):5-10% -cell fragments/ Humodetrinite and humic colloidal material/ Humocollinite (post V)**:70-80%**	-cell fragments/ Humodetrinite and humic colloidal material/ Humocollinite (post V): **60-70%** -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 0-0.5m depth.	Dominant Phase:phase II (Von Post field classiffication: FIBRIC)	Dominant Phase :phase II **&** post -phase V (II=V, same amount%) (Von Post field classiffication: FIBRIC to 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)
Organic Matter (kerogen) Type (from SRA data)	II	III	III	II	II
Dominant plants growing presently (and proposed PC -from pollen analyses interpretation)	Waxy leafy plants, shrubs, with more palynomorphs present (transitional mangrove to shallow peat)	Relatively more trees with woody stems (Mixed transitional mangrove to shallow peat - PC I)	Relatively more trees with woody stems (PC I)	Trees, relatively more waxy, leafy plants, ferns, with more palynomorphs (Mixed PC 1-PC II)	Trees (woody), relatively more waxy, leafy plants, ferns, with more palynomorphs present

					(PC II)
Peat Pre-Maceral photos	Figures 4.4.2 (a), (b), (c) and (d).	Figures 4.4.2 (e), (f), (g) and (h).	Figures 4.4.2 (i), (j), (k) and (l).	Figures 4.4.2 (m) and (n).	Figures 4.4.2 (o) and (p).
Peat depth	0.2 m, very shallow	0.2 m, shallow	1.0 m, medium	1.4 m, medium	2.0 m, medium to deep
Peat type (Paramananthan, 2011)	Topogenous peat	Topogenous peat	Topogenous peat	Topogenous peat	Ombrogenous peat

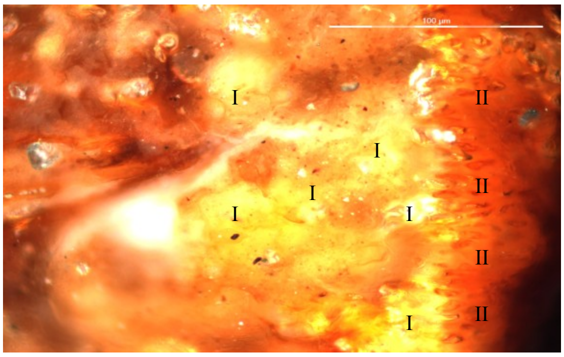


Figure 4.4.2 (a)

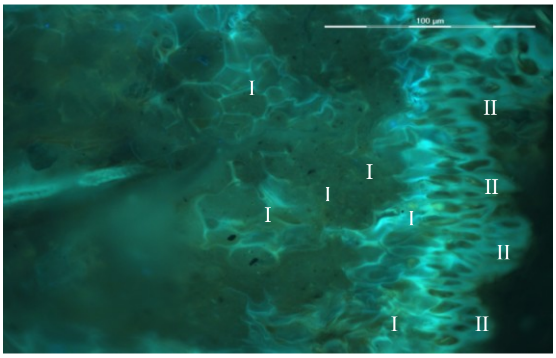


Figure 4.4.2 (b)

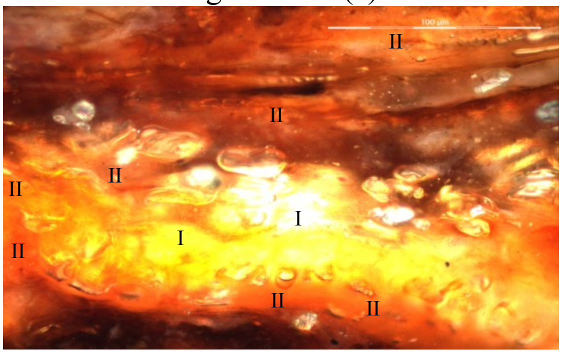


Figure 4.4.2 (c)

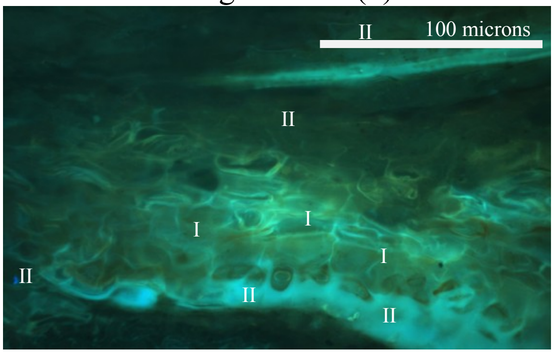


Figure 4.4.2 (d)

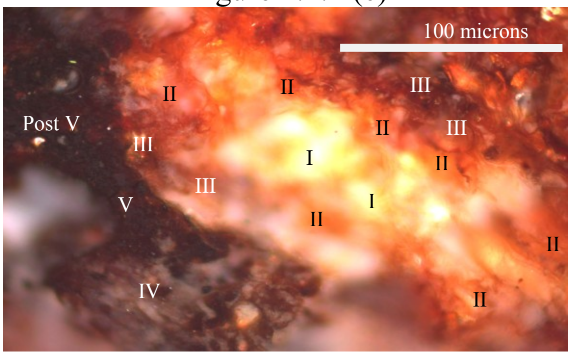


Figure 4.4.2 (e)

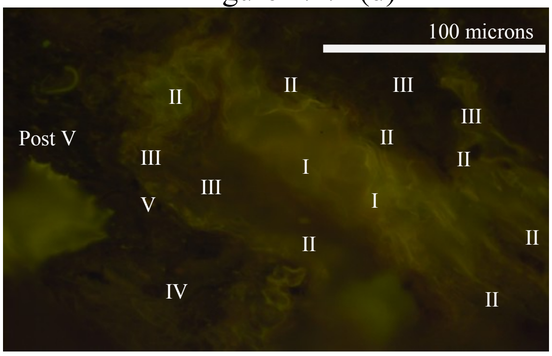


Figure 4.4.2 (f)

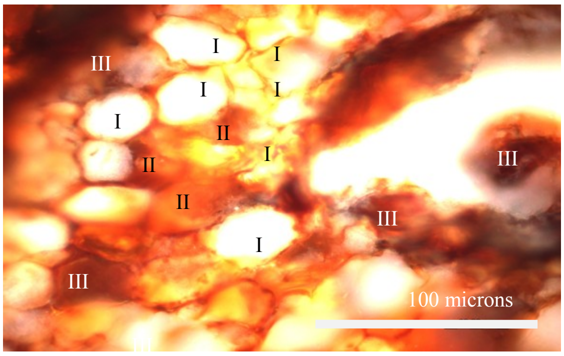


Figure 4.4.2 (g)

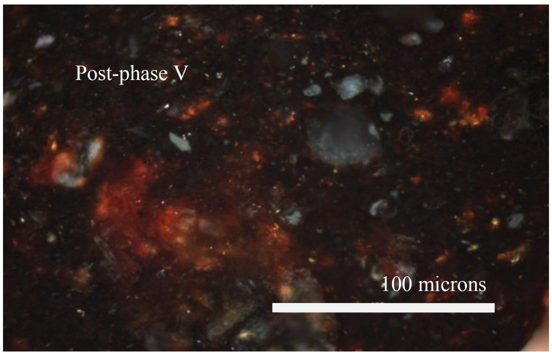


Figure 4.4.2 (h)

Figure 4.4.2 (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.

Figure 4.4.2 (b): Same view as Plate 4.4.2 (a) but under UV light excitation.

Figure 4.4.2 (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.

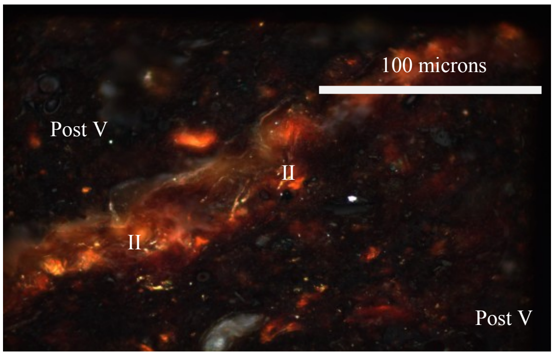
Figure 4.4.2 (d): Same view as Plate 4.4.2 (c) but under UV light excitation.

Figure 4.4.2 (e): White to yellow still fresh cells (phase I), cell structure and lumen quite distinct (this shows 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 still distinct cell wall structure and lumen intact. 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, gelified and cell structure destroyed with no lumen-this explains 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.

Figure 4.4.2 (f): Same view as Plate 4.4.2 (e) but under UV light excitation.

Figure 4.4.2 (g): White to yellow still fresh cells (phase I), cell structure and lumen distinct (this explains why Von Post Classification is also 'Fibric'). Yellow cells (Phase I) altering 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 with paste present when squeezed). Reflected 'white' light, 50 x magnification, oil immersion. Sampling location: KS.TP.07 (0-0.5 m), Kota Samarahan-Asajaya area.

Figure 4.4.2 (h):Matrix of humodetrinite and humocollinite with no intact cell structure with lumen observed. Diagenetic phase: post phase V (humodetrinite and humocollinite) (this phase explains why 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 with paste present when squeezed). Reflected 'white' light, 50x magnification, oil immersion. Sampling location: KS.TP.07 (0-0.5 m), Kota Samarahan-Asajaya area.



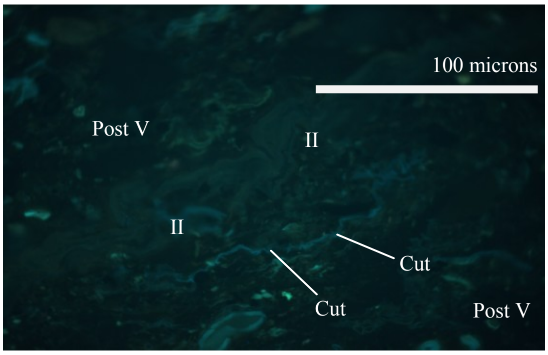
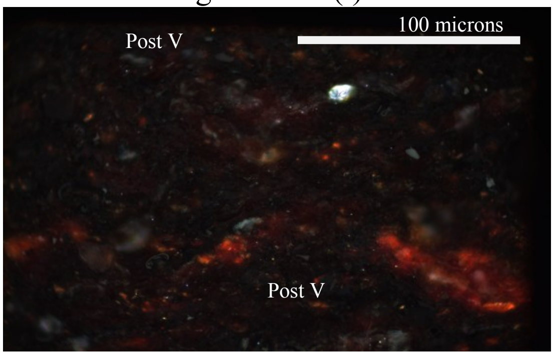


Figure 4.4.2 (i)

Figure 4.4.2 (j)



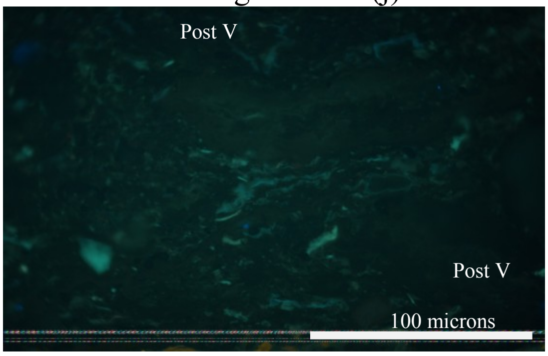
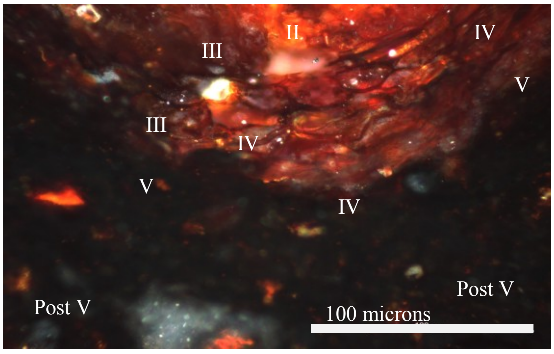


Figure 4.4.2 (k)

Figure 4.4.2 (l)



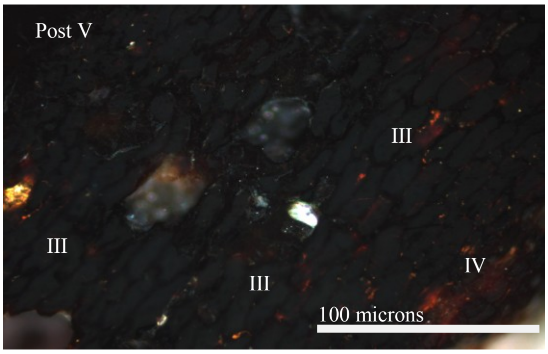
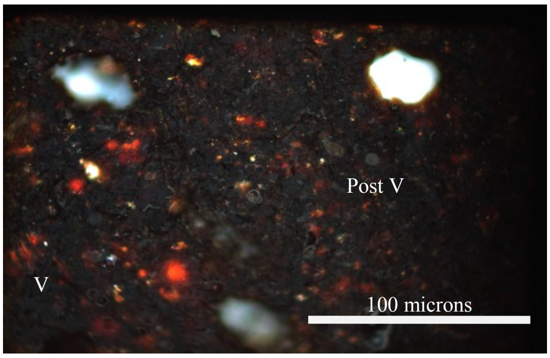


Figure 4.4.2 (m)

Figure 4.4.2 (n)



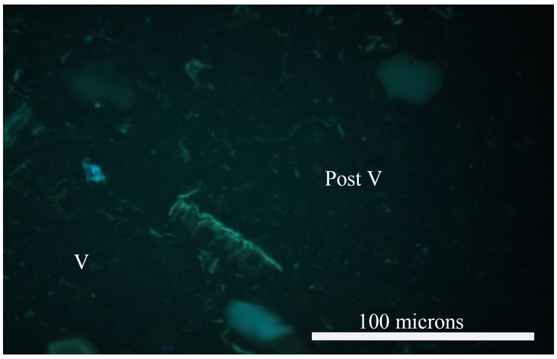


Figure 4.4.2 (o)

Figure 4.4.2 (p)

Figure 4.4.2 (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 'white' light, 50x magnification, oil immersion. Sampling location: KS.TP.08 (0-0.5 m), Kota samarahan-Asajaya area.

Figure 4.4.2 (j):Same view as in Figure 4.4.2 (i) but under UV light excitation. Observe red textinite (Phase II) with cutinite, in matrix humodetrinite or humocollinite (Post phase V).

Figure 4.4.2(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 (0-0.5 m), Kota Samarahan-Asajaya area.

Figure 4.4.2 (l): Same view as in Figure 4.4.2 (k) but under UV light excitation.

Figure 4.4.2(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 (0-0.5 m), Kota Samarahan-Asajaya area.

Figure 4.4.2 (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 (0-0.5 m), Kota Samarahan-Asajaya area.

Figure 4.4.2 (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: Hemic to Sapric. Reflected 'white' light, 50x magnification, oil immersion. Sampling location: KS.TP.10 (0-0.5 m), Kota Samarahan-Asajaya area.

Figure 4.4.2 (p): Same view as in Figure 4.4.2 (o) but under UV light excitation.

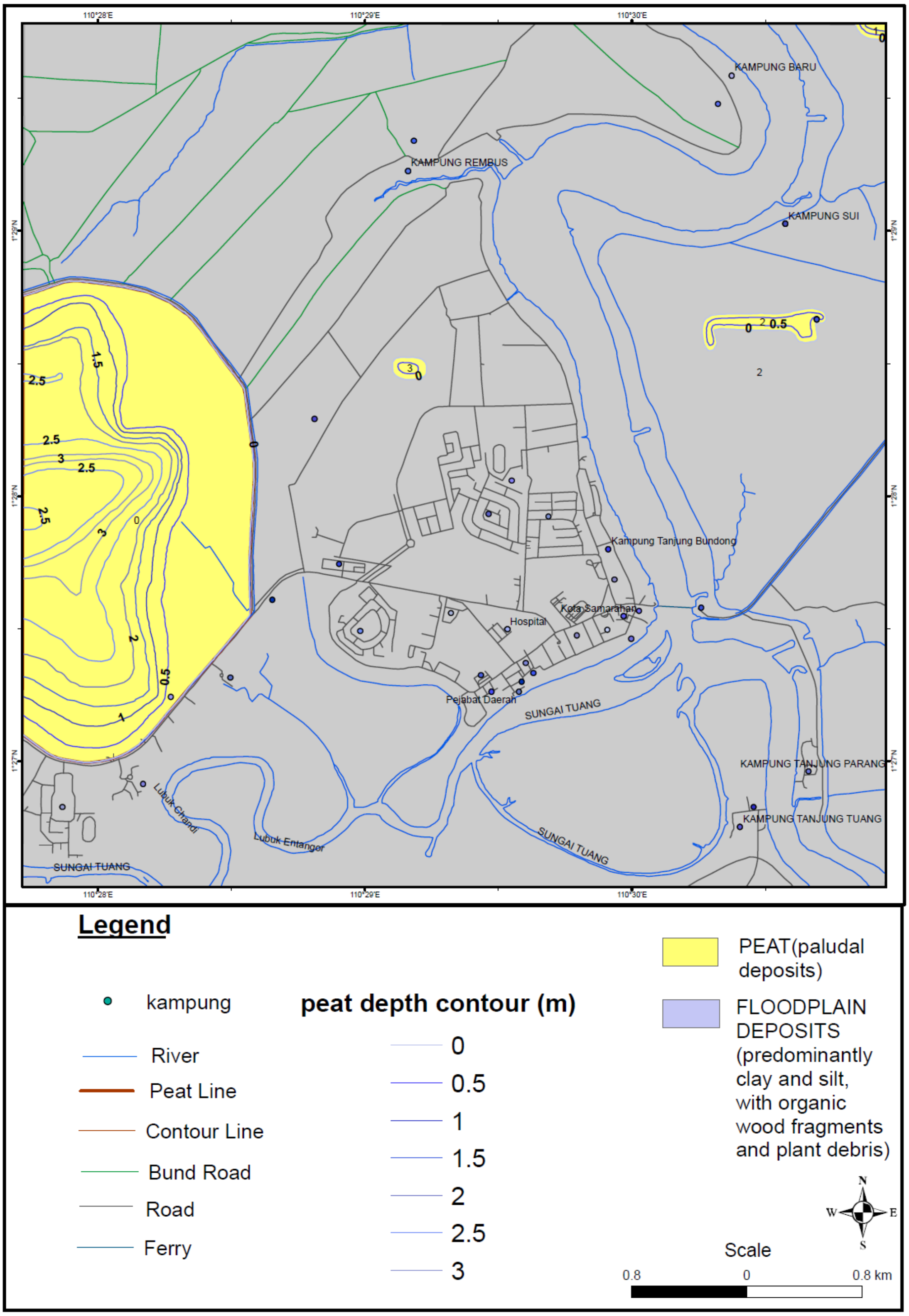
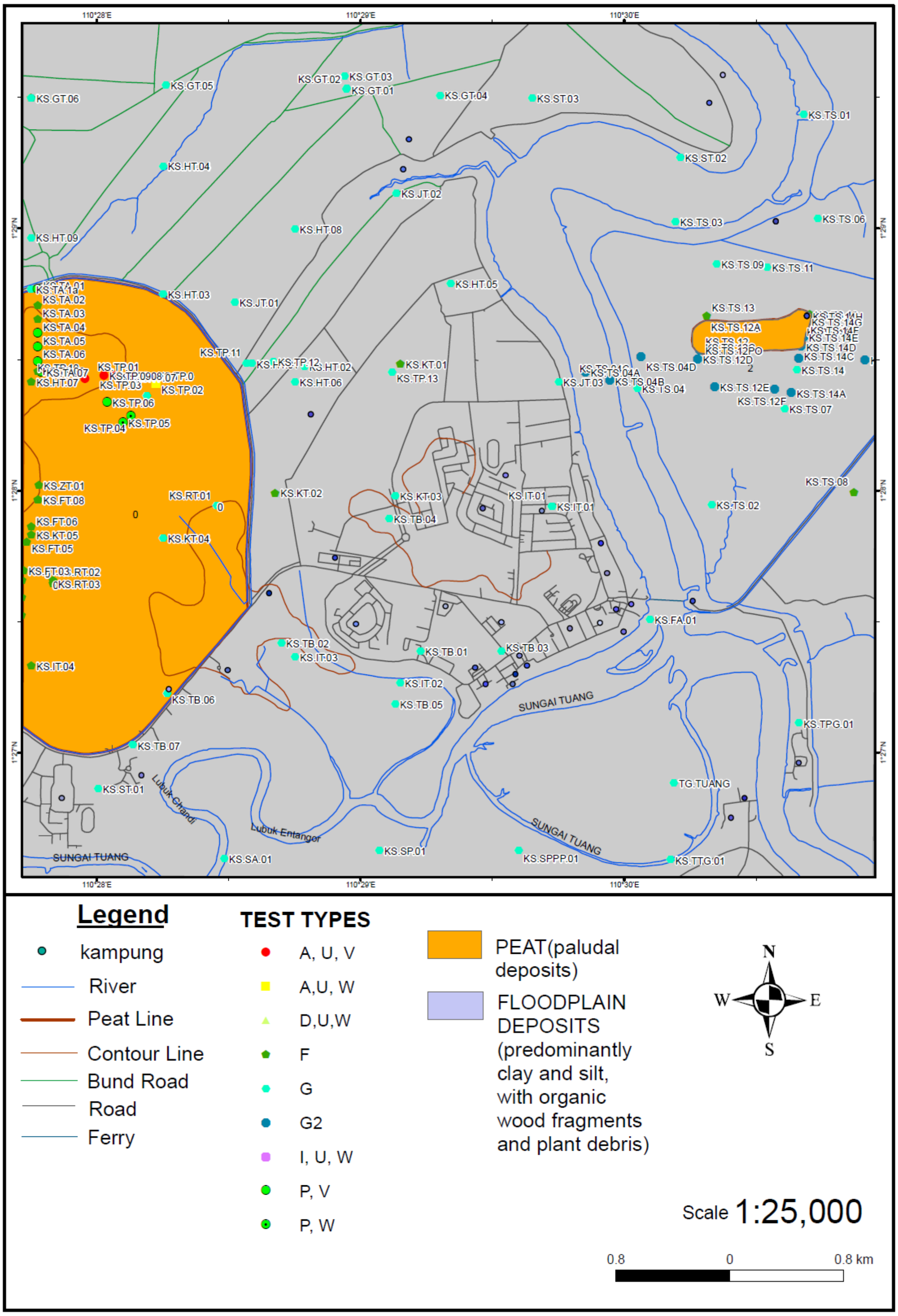


Figure 4.4.3: Peat Depth, Thickness or Isopach Map of the study area


Legend
kampung
River
Peat Line
Contour Line
Bund Road
Road
Ferry
TEST TYPES
A, U, V
A,U, W
D,U,W
F
G
G2
I, U, W
P, V
P, W
PEAT(paludal deposits)
FLOODPLAIN DEPOSITS (predominantly clay and silt, with organic wood fragments and plant debris)
N
W
E
S
Scale 1:25,000
0.8
0
0.8 km
110°28'E
110°29'E
110°30'E
SUNGAI TUANG
Lubuk Entanger
KS.GT.06
KS.GT.05
KS.GT.02
KS.GT.03
KS.GT.01
KS.GT.04
KS.ST.03
KS.TS.01
KS.ST.02
KS.HT.04
KS.JT.02
KS.TS.03
KS.TS.06
KS.HT.09
KS.HT.08
KS.TS.09
KS.TS.11
KS.HT.03
KS.JT.01
KS.HT.05
KS.TS.13
KS.TS.12A
KS.TA.02
KS.TA.03
KS.TA.04
KS.TA.05
KS.TA.06
KS.HT.07
KS.TP.01
KS.TP.03
KS.TP.02
KS.TP.06
KS.TP.04
KS.TP.05
KS.TP.11
KS.HT.02
KS.HT.06
KS.KT.01
KS.TP.13
KS.JT.03
KS.TS.04D
KS.TS.04
KS.TS.12D
KS.TS.12E
KS.TS.12F
KS.TS.14
KS.TS.14A
KS.TS.14C
KS.TS.14D
KS.TS.14E
KS.TS.07
KS.TS.08
KS.ZT.01
KS.FT.08
KS.RT.01
KS.KT.02
KS.KT.03
KS.IT.01
KS.TS.02
KS.FT.06
KS.KT.05
KS.FT.05
KS.KT.04
KS.TB.04
KS.RT.03
KS.FA.01
KS.TB.02
KS.IT.03
KS.TB.01
KS.TB.03
KS.IT.04
KS.IT.02
KS.TB.05
KS.TB.06
KS.TPG.01
KS.TB.07
KS.ST.01
TG.TUANG
KS.SA.01
KS.SP.01
KS.SPPP.01
KS.TTG.01

SYMBOL LEGEND FOR TEST TYPES:

A	LOGGING	VON POST CLASSIFICATION	STABILIZATION TESTS (UCS)	SRA	GCMS	POLLEN ANALYSES	
D	LOGGING	VON POST CLASSIFICATION	STABILIZATION TESTS (UCS)				
F	LOGGING	VON POST CLASSIFICATION					
G	LOGGING	VON POST CLASSIFICATION					
I	LOGGING	VON POST CLASSIFICATION		SRA			
P	LOGGING	VON POST CLASSIFICATION	ORGANIC MATTER	NMC	ASH CONTENT		
U			ORGANIC MATTER	NMC	ASH CONTENT		
V						SOIL CLASSIF.	
W						ENG. CLASSIF.	
G2							AUGER CHECK

NOTES:

UCS=Unconfined Compression Test

SRA=Source Rock Analyses

GCMS=Gas Chromatography Mass Spectrometry

SOIL CLASSIF.=Soil Science Classification (Paramananthan, 2011)

ENG CLASSIF.=Conventional Geotechnical/ Civil Engineering Classification

SOIL & ENG. CLASSIF.= Soil Science Classification (Paramananthan, 2011) and conventional Geotechnical/ Civil Engineering Classification

Figure 4.4.4: Map with symbol legend showing type of tests done according to sample location.

4.9.4 Tropical lowland peat classification (by the Key classification method)

The key identification of tropical lowland peats in the study area at selected auger locations (Paramananthan, 2011) and the criteria used for classification of Histosols soil series (where applicable) are as shown in Table 4.5.1 and Figure 4.4.4.

Table 4.5.1:Proposed Key method classification (Paramananthan, 2011) for the tropical lowland peats in the study area.

Sample Code	Depth	Soil science classification criteria for classification of soil series of Histosols in Malaysia (Paramanathan, 2011)	KEYS: SF:Soil Family, SS:Soil Series. Classification **(based on 0.5 to 1.0 m depth interval criteria according to Paramanathan, 2011)**
KS.TP.02	0 to 0.2 m	<0.5 m-organic soil. Riverine Colluvial clay (19.5% >15% clay at 0.2-0.5 m, Woody.	Not applicable
KS.TP.07	0 to 0.2 m	<0.5 m-organic soil. Riverine Colluvial clay (26.3>15% clay at 0.3-0.5 m), Woody.	Not applicable
KS.TP.08	0 to 0.5 m	Sapric peat	Aquic, Gambist-Topogambist, SF and SS ranges from: **HEMIC TOPOGAMBIST (SF=GALI, SS=Gali) to SAPRIC TOPOGAMBIST (SF=ERONG, SS=Muara Tuang)**
KS.TP.08	**0.5 to 1.0 m**	Hemic to sapric Topogambists (HBB), Underlying mineral soil: Riverine Colluvial clay =28.54% (>15% clay) at 1-1.5 m, woody, decomposed wood.	
KS.TP.09	0 to 0.5 m	Sapric peat.	Aquic, Gambist-Topogambist. SF and SS ranges from **HEMIC TOPOGAMBIST (SF=GALI, SS=Gali) to SAPRIC TOPOGAMBIST (SF=ERONG, SS=Muara Tuang)**
KS.TP.09	**0.5 to 1.0 m**	Hemic to Sapric Ombrogambists (HBA), Underlying mineral soil: Riverine Colluvial clay =28.6% (>15% clay) at 2-2.5 m, woody, decomposed wood.	
KS.TP.09	1.0 to 1.4 m	Hemic peat.	
KS.TP.10	0 to 0.5 m	Hemic to Sapric peat.	Aquic, Gambist-Ombrogambist, SF and SS: **HEMIC OMBROGAMBIST, (SF=SAMARAHAN, SS=Samarahan)**
KS.TP.10	**0.5 to 1.0 m**	Hemic peat. Ombrogambists (HBA), Underlying mineral soil: Riverine Colluvial clay=5.16% (<15% clay) at 2.5 to 3.0 m, woody, decomposed wood	
KS.TP.10	1.0 to 1.5 m	Hemic	
KS.TP.10	1.5 to 2.0 m	Fibric to hemic	
KS.TP.0	0 to 0.5 m	Sapric	Not applicable
KS.TP.01	0 to 0.2 m	Sapric, Organic soil/Histosols, woody, decomposed wood.	Not applicable
KS.TP.03	0 to 0.5 m	Not applicable	Not applicable
KS.TP.04	0 to 0.5 m	Sapric, Organic soil/Histosols, woody, decomposed wood.	Not applicable
KS.TP.05	0 to 0.5 m	Fibric, organic soil/Histosols, woody, decomposed wood.	Not applicable

KS.TP.06	0 to 0.5 m	Hemic	Aquic, Gambist-Topogambist, SF and SS: **HEMIC TOPOGAMBIST (SF=PAK BONG, SS=Meretuang 2) to SAPRIC TOPOGAMBIST (SF=MUARA TUANG, SS=Meretuang)**
KS.TP.06	**0.5 to 1.2 m**	Hemic to sapric Topogambists (HBB), underlying mineral soil:Riverine Colluvial sand. Clay=12.2% (< 15% clay) at 1-1.5 m, woody, decomposed wood	
KS.TA.01	0 to 0.3 m	<0.5 m organic soil/ histosols, fibric to hemic, woody-decomposed wood	Not applicable
KS.TA.02	0 to 0.5 m	0.5 m organic soil/ histosols, fibric to hemic Histosols, woody-decomposed wood	Not applicable
KS.TA.03	0 to 0.5 m	Hemic to sapric peat.	Aquic, Gambist-Topogambist, SF and SS: **HEMIC TOPOGAMBIST, (SF=GALI, SS=Gali)**
KS.TA.03	**0.5 to 1.0 m**	Hemic Topogambists (HBB), Underlying min.soil: Riverine Colluvial clay=18.9% (>15% clay) at 1-1.5 m, woody, decomposed wood	
KS.TA.04	0 to 0.5 m	Hemic to Sapric peat.	Aquic, Gambist-Topogambist, SF and SS: **HEMIC TOPOGAMBIST, (SF=GALI, SS=Gali)**
KS.TA.04	**0.5 to 1.0m**:	Hemic Topogambists (HBB), Underlying mineral soil: Riverine Colluvial clay=35.96% (>15% clay) at 2-2.5m, Woody, decomposed wood	
KS.TA.04	1.0 to 1.3 m	Hemic peat	
KS.TA.05	0 to 0.5 m	Sapric peat	Aquic, Gambist-Ombrogambist, SF and SS: **HEMIC OMBROGAMBIST: SF-GONDANG, SS-Gondang to SAPRIC OMBROGAMBIST:SF=LIKU to Samarahan 3**
KS.TA.05	**0.5 to 1.0 m**	Hemic to Sapric Ombrogambists (HBA), underlying mineral soil: Riverine Colluvial clay =23.73% (>15% clay) at 2.3-3 m, woody, decomposed wood.	
KS.TA.05	1.0 to 1.5 m	Hemic peat.	
KS.TA.05	1.5 to 2.0 m	Hemic peat.	
KS.TA.05	2.0 to 2.3 m	Hemic peat.	
KS.TA.06	0 to 0.5 m	Sapric	Aquic, Gambist-Ombrogambist, SF and SS: **SAPRIC OMBROGAMBIST, (SF=LIKU, SS=Samarahan 3)**
KS.TA.06	**0.5 to 1.0 m**	Sapric Ombrogambists (HBA), underlying mineral soil:Riverine Colluvial clay=22.85% (>15% clay at 2.3-3 m), woody, decomposed wood.	
KS.TA.06	1.0 to 1.5 m	Hemic	
KS.TA.06	1.5 to 2.0 m	Hemic	

From this study and by using the key classification method, 2 new Soil Family and 5 new Soil Series names or classifications were proposed and assigned for tropical lowland peats occurring in the Kota Samarahan-Asajaya, West Sarawak study area and these are as shown and highlighted in Table 4.5.2. The proposed new Soil Family names are MUARA TUANG and SAMARAHAN (Table 4.5.2). The proposed new soil series names are Muara Tuang, Meretuang, Samarahan, Samarahan 2 and Samarahan 3 (Table 4.5.2).

Table 4.5.2: Keys to the identification of Lowland Peats (Gambists) (Paramananthan, 2011) and proposed classification for peats in the Kota Samarahan-Asajaya study area.

Depth of Organic Soil Materials	Soil Moisture Regime	Poorly Drained (Aquic) — GAMBIST								
	Dominant Material in Subsurface (50–100 cm)	Sapric			Hemic			Fibric		
	Nature of Underlying Tier Substratum/ Mineral Materials	Non Woody	Wood Decomp-osed	Wood Undeco-mposed	Non Woody	Wood Decomp-osed	Wood Undeco-mposed	Non Woody	Wood Decomp-osed	Wood Undeco-mposed
Shallow (50-100 cm) and Moderately Deep (100-150 cm) TOPOGAMBISTS	Marine Clay Sulfidic (> 15% clay)	PENOR			BAKRI			MERAPOK		
		Penor			Nipis	Bakri			Merapok *Mahat*	
	Marine Clay (> 15% clay)	LINGGI			EPAI			MUKAH		
		Linggi		Trus			Epai		Mukah	Bino
	Marine Sand Calcareous (< 15% clay)	MENGALUM								
		Mengalum								
	Marine Sand Sulfidic (<15% clay)	LONG PUTAT								
		Long Putat								
	Marine Sand (< 15% clay)	BARAM						IGAN		
		Baram	Kabala	Simalau					Igan	
	Riverine/Colluvi-al Clay (> 15% clay)	ERONG			GALI			CHANGKAT LOBAK		
		Erong	Muara Tuang			Gali		Changkat Lobak		
	Riverine/Colluvi-al Sand (< 15% clay)	MUARA TUANG			PAK BONG					
			Meretuang		Pak Bong	Samarahan 2				
Deep (150-300) and Very Deep (>300 cm) OMBROGAMBISTS	Marine Clay Sulfidic (> 15% clay)	PRIMALUCK			PONTIAN			KLIAS		
		Primaluck		Teraja		Pontian		Arang	Klias *Luk*	
	Marine Clay (> 15% clay)	NAMAN			BAYAS			ANDERSON		
		Naman	Retus	Kenyana		Bayas	Gedong			Anderson
	Marine Sand Calcareous (< 15% clay)									
	Marine Sand Sulfidic (<15% clay)									
	Marine Sand (< 15% clay)	TELONG			ADONG					
			Telong	Suai		Adong	Alan			
	Riverine/Colluvi-al Clay (> 15% clay)	LIKU			GONDANG			SALLEH		
		Liku	Samarahan 3	Karap		Gondang	Taniku		Salleh	Tinjar
	Riverine/Colluvi-al Sand (< 15% clay)	KABOK			SAMARAHAN					
			Kabok			Samarahan				

KEY: BAYAS Soil Family; Bayas Soil Series; *Luk* = allochthonous

4.9.5 Engineering classification of tropical lowland peat samples

The peats were also classified based on the organic soils and peat section of the Malaysian Soil Classification System for Engineering Purposes (from BS5930:1981, after Jarret 1995; Bujang 2004; Minerals and Geoscience Department, 2007) as described in Table 3.1. The organic content criteria for this classification are obtained from tests done according to the ASTM D2974 Standard Test Method for Moisture, Ash and Organic Matter of Peat and other Organic Soils (Appendix A2). The percentages of organic content and related moisture and ash contents are as provided in Table 4.5.3. Based on organic content, the peats occurring from basin margin towards centre or towards the thicker part of the dome can be classified to range from Organic soils to Peats (Table 4.5.3).

Table 4.5.3: Moisture content, ash content and organic content of peats (ASTM D 2974: Standard Test Method for Moisture, Ash and Organic Matter of Peat and other Organic Soils) and related organic soil and peat engineering classification (from BS5930:1981, after Jarret 1995; Bujang 2004; Minerals and Geoscience Department, 2007).

Sample Code	Depth	Organic Content (%) (Dry weight)	Natural Moisture Content (Dry weight)%	Ash Content% (dry weight)	Peat Type and Classification (with symblogy) based on the Malaysian Soil Classification System for Engineering Purposes
KS.TP.02	0 to 0.2 m	40.31	292.12	59.70	ORGANIC SOIL, O
KS.TP.07	0 to 0.2 m	88.81	810.04	11.20	PEAT, Pt
KS.TP.08	0 to 0.5 m	96.86	881.50	3.14	PEAT, Pt
KS.TP.08	0.5 to 1.0 m	36.74	373.71	63.26	ORGANIC SOIL, O
KS.TP.09	0 to 0.5 m	94.53	498.74	5.47	PEAT, Pt
KS.TP.10	0 to 0.5 m	100	821.25	0	PEAT, Pt
KS.TP.10	0.5 to 1.0 m	95.35	921.17	4.65	PEAT, Pt
KS.TP.10	1.0 to 1.5 m	98.57	1277.81	1.43	PEAT, Pt
KS.TP.10	1.5 to 2.0 m	48.22	511.32	51.79	ORGANIC SOIL, O
KS.TP.0	0 to 0.5 m	60.01	326.53	39.99	ORGANIC SOIL, O

Note: PEAT, Pt (with organic content of more than 75 %); ORGANIC SOIL, O (with organic content range of 20% to 75%)

CHAPTER 5

5.0 DISCUSSION

5.1 Discussion on UCS analyses for the effect of different quantities of mineral soil filler on cement-peat stabilization.

In this chapter and the following sections, the results of the stabilization tests, geochemical and pollen analyses that were done and that will eventually lead to the conclusions of this study, will be discussed accordingly. The effects of msf and the different quantities of mineral soil filler on cement-peat stabilization will be discussed in this section and in the following section.

5.1.1 Effect of mineral soil filler particles (clay, silt or fine sand) as filler on cement-peat stabilization.

Maximum densification to the stabilized soil mix can be provided by introducing a suitable amount of well sorted or well graded fine siliceous material in the form of siliceous sand into it (Wong, 2010). However, in this study, mineral soil filler particles in the form of clays, silts or fine sands are used instead of well sorted sand to minimize void spaces occurring within the stabilized soil mix structure. Interstices of interconnected void space are filled and packed with fine aggregates of mineral soil filler particles in the form of clay, silt or fine sand particles acting as filler material. The use of fillers such as siliceous sand, clay or silt mineral soil filler particles functions to enhance the strength of stabilized peat-cement mix by supplying more solid particles available for the binder to unite, minimizing unbridged ‘gaps’ in the pore interstices and thus, forming a stabilized, load sustainable structure. According to Abu Bakar (2008), peat contains fewer solid particles to stabilize, thus peat requires greater quantities of stabilizer than clay does. Peat also has a considerably higher water/soil ratio than other soils such as clay. Higher amounts of water in peat imply presence of larger voids within the peat matrix, hence requiring more stabilizers (Abu Bakar, 2008). Thus, mineral soil filler particles in the form of clay, silt or fine sands can be used to fill these voids and is necessary to minimize or off-set the amount of cement or chemical stabilizer to be used in the peat stabilization process.

Different binding agents stabilize the soil by different mechanisms. When cement binder is used, the reaction products (tobermorite gel) that bind the soil particles together ‘grows’ on the surface of the cement particles (Janz and Johansson, 2002). It is therefore important for the cement to be uniformly distributed throughout the soil. The cementation effect with mineral soil as a filler occurs when cementation products or C-S-H gels (tobermorite gel) from the primary cement hydration reaction (Equation 1) and the secondary pozzolanic reaction (Equation 2) ‘glues’, welds or binds the solid mineral soil filler particles (in the form of clay, silt or fine sand) together at its contact points (spot welding). This results in the further ‘restriction/constriction/confinement’ of the peat particles that fills up the spaces between interstices of interconnected, hardened cement paste/gel now reinforced further by mineral soil filler particles acting as filler material to the binder mix. Hence, the organic particles of the peat are ‘stabilized’, ‘confined’ and interlocked up (locked-up) by the cementation of solid mineral soil filler particles due to the drying and hardening of cement paste or gel. Thus, no continuous peat matrix is formed, the peat soil is ‘stabilized’ and strength gain is achieved after drying and air-curing with the hardening and cementation effect of the cement paste of the peat-cement-mineral soil filler mixture. If failure due to fracturing occurs, it would then depend on the strength of interparticle bonds of solid particles or the natural strength of the solid particles itself (Kezdi, 1979).

Mineral soil like clays, silts or fine sands are easier, cheaper and convenient to use as fillers as they are readily available on or near the site. Furthermore, due to the increasing costs of construction river sand and its' transportation, mineral soil fillers (clays, silts and fine sands) obtained at or near the site should be a good and readily available option for use as fillers instead of sand for cement-peat stabilization. In addition, use of clay (kaolinitic clay) as a filler may also enhance the unconfined compressive strength in cement or lime stabilized tropical lowland peats through clay pozzolanic, secondary reaction by producing more tobermorite gel (Equation 2).

$$\text{Cement} + H_2O = \underset{\text{(Tobermorite gel /C-S-H gel)}}{3CaO.2SiO_2.3H_2O} + Ca(OH)_2 \quad \text{[primary reaction]} \quad (1)$$

$$Ca(OH)_2 + \underset{\text{(Kaolinitic clay)}}{\text{Pozzolan}} + H_2O = \underset{\text{(Tobermorite gel /C-S-H gel)}}{3CaO.2SiO_2.3H_2O} \quad \text{[secondary reaction]} \quad (2)$$

5.1.2 Effect of the quantity of mineral soil filler particles (clay, silt or fine sand) on cement-filler-peat stabilization.

After stabilization of 28 air-curing days, specimen compositions of 20 g of ordinary Portland cement binder for each 100 g of wet peat (sample KS.TS.05, from 0 to 0.5 m sampling depth) and mixed with increasing quantities of 5 g, 15 g, 25 g to 50 g of mineral soil filler (from auger sample KS.TS.06 at 0 to 0.5m sampling depth) showed significant increments of unconfined compressive strength from 42.5 kPa, 67.0 kPa, 77.0 kPa to 106.6 kPa, respectively (Table 4.1 and Figure 4.1). This significant strength increment with increasing amounts of mineral soil filler indicates that cement-peat stabilization depends significantly on the amount of natural/insitu or added mineral soil filler contained within the peat. Increased densification to the stabilized soil mix is provided by increasing the amount of mineral soil filler particles in the form of clays, silts or fine sands to minimize void spaces occurring within the stabilized soil mix structure. More and more interstices of interconnected void spaces are filled and packed with fine aggregates of filler material to enhance stabilization. Thus, the findings of this study indicates that improved enhancement of the strength of the stabilized peat-cement mix can be achieved by supplying increasingly more solid particles in the form of mineral soil fillers (clays, silts or fine sands) available for the cement binder to unite to form a stabilized, load sustainable structure. This observation also supports and explains why cement stabilized marginal-topogenic peats with relatively more natural mineral soil fillers show relatively greater strength values than cement stabilized low ash, ombrogenic peats located near or towards the peat dome (section 4.7.2).

5.2 The effects of peat type and sampling distance from basin margin towards peat dome centre on peat stabilization.

Huttunen and Kujala (1996) reported that the stabilization strength of peats decreased with advanced decomposition. This study is only partially in agreement with their study (Huttunen and Kujala, 1996). In this study, it is observed that stabilized strength for peats increased relatively at locations (KS.TP.09 and KS.TP.10) with hemic to sapric peats from phasic community II (Alan Batu Swamp Forest) when compared to stabilized strength of sapric peats located at KS.TP.08. Although highly decomposed, the peats from PC II showed an increase in stabilized strength relative to highly decomposed, sapric peats from KS.TP.08 which showed the least stabilized strength in this study. Studies by Abu Bakar (2008) and Wong (2010) have shown how tropical peats can be stabilized by using different chemical additives with and without siliceous sand fillers, but most of the studies reviewed did not indicate properly what type and class of tropical peats were used for the study in relation to what or which part (location) of the tropical lowland peat basin ‘dome’ was sampled for their stabilization tests (e.g.: whether basin margin, midsection or near centre)? Field mapping, classification and characterization of these peats is therefore necessary in order to gain proper understanding and to further knowledge of tropical lowland peat stabilization. As mentioned before, tropical lowland peats frequently occur as domed shaped deposits whereby these peats have different characterization and engineering properties according to and depending on which part of the peat dome morphology is targeted for the peat-stabilization process and procedure. Topogenous, transitional peats usually deposited at the basin/dome margin (at locations KS.TP.0 and KS.TP.02) have relatively higher natural, mineral soil filler (msf) content (or higher ash content) and are hence relatively easier and cheaper to stabilize with cement-filler additives because these peats already have natural fillers deposited within the peat matrix and do not require so much fillers to be added for stabilization. In contrast, topogenous to ombrogenous (KS.TP.08) or ombrogenous peats located away from the margin and at the midsection area with relatively lower natural msf content (or lower ash content) are relatively harder and costlier to stabilize because relatively more solid fillers need to be added to stabilize the peats. However, ombrogenous peats located within PC II (Alan Batu Swamp Forest) on the peat dome may also be easier to stabilize because of the hard, lignified woody material or amorphous grains (when dried) decomposed and deposited in these peat areas (from decomposed e.g.: hardwood *Shorea* type trees) that may also acts as fillers as they harden and solidify upon curing during stabilization.

5.2.1 The effect of the degree of decomposition and vegetation lateral zonation of peats on peat stabilization

In this study, peat stabilization with use of mineral soils as fillers has shown significant unconfined compressive strength yields although the peats used in the stabilized mix are highly decomposed from hemic to sapric (KS.TP.10) or sapric (KS.TP.08 and KS.TP.09) peats. Huttunen and Kujala (1996) reported that the stabilization strength of peats decreased with advanced decomposition. The results of their studies may partially agree with the observation of this study whereby strength of the stabilized peats at location KS.TP.08 (where sapric, intermediate topogenic to ombrogenic peats occur), is relatively lower compared to stabilized cement-filler-peats from basin margin (fibric to hemic, topogenic peats) and near-centre (ombrogenic, sapric and hemic to sapric peat) areas of the peat dome. The decrease of unconfined compressive strength may depend on the degree of decomposition of peat, to a certain degree, but in this study this observation is confined only to the mid-section area (KS.TP.08) from the near-centre of the peat dome. In contrast, cement-mineral soil filler stabilized peat strength may however, increase, most probably due to a combination of high decomposition levels, coupled with the presence of the resultant, hard (when dried) amorphous grains (from decomposed hardwood) in the decomposed hemic to sapric peat near or at location KS.TP.10, for instance. Hence, unconfined compressive strength of stabilized lowland tropical peats may also indirectly depend further on the phasic community successive vegetation zones that occur from basin margin towards dome centre, or where ever hardwood fragments (from hardwood-species like *Shorea* type) eventually decomposes into sapric/amorphous peat, and, wherever (laterally or vertically) the peat that may contain these hard (solidifies when dried) amorphous grains occur. During the cement-filler-peat stabilization process, these hard (solidifies when dried in the curing process) amorphous grains would then be incorporated into the interconnected matrix of hardened tobermorite gel (from primary cement hydration reaction or pozzolanic reaction), filler (natural /*in situ* or added mineral soil filler of clays, silts or sands) and/or other additives to give comparatively higher stabilization strength of the then, relatively drier stabilized mix. The relatively higher strength values yielded by stabilized peats from KS.TP.09 and KS.TP.10 support this concept.

Decomposition is necessary to produce the hard (solidifies when dried) amorphous grains (from decomposed hardwood fragments) that is incorporated into the relatively drier, hardened stabilized mix to give higher unconfined compressive strength. Mapping and identification of the vegetational zonations or phasic communities occurring within the targeted area for stabilization is relevant because it was discovered that hardwood-tree species like the *Shorea* type species is usually known to occur in vegetation phasic communities of II, III and IV (Anderson, 1961;

1964; 1976 and 1983; Anderson and Muller, 1975). These hardwood-tree species, dies or breaks off into smaller pieces to decompose and produce hardwood fragments (probably with high lignin contents) which eventually further decomposes and may then produce the hard, amorphous grains that then solidifies when dried to form hard to very hard, amorphous grainy material. Therefore, a combination of factors like vegetational zonation (phasic community) and related high peat decomposition levels (sapric or hemic to sapric) resulting in the decomposition and presence of these hard (when dried), amorphous grains may also affect the strength of cement stabilized tropical lowland peats (besides the percentage of mineral soil content occurring as an insitu/natural or added filler in the form of clays, silts or sands). Thus, vegetational zonation occurring laterally or vertically may contribute as an additional factor in tropical lowland peat stabilization because it is probably due to vegetational succession that produces these vegetation types with hardwood, that would then decompose to produce these hard (when dried), amorphous grains. These, then eventually enhances the stabilized peat strength, upon gradual drying and hardening of the cement (tobermorite/CSH gel)-filler-peat mix with interconnected soil structure or matrix during the cement-peat stabilization process.

5.2.2 The effect of peat sampling distance (peat types) from basin margin to midsection and further towards peat dome centre on peat stabilization

The *in situ* mineral soil content in the form of clay, silt or sands in the peats helps to enhance and increase the unconfined compressive strength of cement stabilized peat by acting as a “natural filler” that fills the voids (densification) that are interconnected in the peat matrix while simultaneously bonding with the hardening

CSH or tobermorite gel (produced by cement hydration). This helps to form a continuous, interconnected/matrix and load sustainable structure of the stabilized peat mix. Hence, stabilized marginal/shallow topogenic peats have a relatively higher unconfined compressive strength, most probably due to the relatively higher mineral soil content occurring naturally in the peats acting as “natural fillers” for the stabilization process. This is indicated by the relatively higher average unconfined compressive strengths of stabilized topogenous, clayey, marginal peats yielded from KS.TP.0 and KS.TP.02 near the basin periphery (Table 4.5.3). In contrast, ombrogenous, low ash peats have lower strength due to a relatively lower mineral soil (or ash) content and hence, lower natural filler content (Table 4.5.3). This is indicated by the relatively lower average unconfined compressive strength values of stabilized peat from KS.TP.08 which yields a lower value compared to marginal, topogenic peats from KS.TP.0 and KS.TP.02 (Figure 4.1.1 and Table 4.1.1).

The ordinary Portland cement-filler-stabilized peat specimens from topogenic, marginal shallow, transitional peat areas (location KS.TP.02) also shows relatively very little shrinkage compared to ombrogenic, low ash stabilized peats (location KS.TP.10), which is nearer to the peat basin centre (Figures 3.8, 4.1.3 and 4.1.4 and Table 4.1.1). Cement-filler-stabilized peat specimens from topogenic, marginal, shallow, transitional peat areas (at locations KS.TP.0 and KS.TP.02) also exhibit relatively better, uniform and consistant cylindrical shapes, less deformation, are denser, are harder, has lesser cracks, lesser holes, lesser indentations or lesser joints/discontinuities at the tamped layer planes (Figures 4.1.2, 4.1.3 to 4.1.5 and Table 4.1.1). These observations may reflect the actual, enhanced field conditions of the stabilized peat columns, if added mineral soil fillers are applied for cement-peat stabilization and, when applied or targetted at the marginal/fringe, topogenous peat areas of the peat dome.

5.2.3 Effect of Size and Location on tropical lowland peat dome or basin

Topogenous or ombrogenous peats usually occur at different locations on the peat dome or basin. Generally topogenous peats occur near the basin margin, near the underlying mineral soil/rock layer or near the boundary between peat and mineral soil/rock. Ombrogenous peats occur near the middle/centre of the dome or usually where the peat layer is thicker. Hence, the degree or effectiveness of peat stabilization varies with location on the dome due to the natural mineral soil filler content in the peat. Peat stabilization with or without the addition of fillers into the peat-cement mix, is relatively greater, more effective and more enhanced near the basin margin, where the topogenous, clayey peats with naturally occurring mineral soil filler is deposited and relatively more abundant. In contrast, peat stabilization strength with or without the addition of fillers into the peat-cement mix, is relatively lesser near or towards the basin centre where the thicker ombrogenous peat with none or very little naturally occurring mineral soil filler is deposited and is less abundant.

The greater the size of dome or peat basin, the wider or greater the area and width of its' marginal topogenic, shallow peat usually is. If peat stabilization is carried out near the basin margin, relatively less filler and less cement stabilizer could be used resulting in probably relatively lesser and lower costs for cement peat stabilization of the marginal topogenous peats. On the other hand, a greater area width accompanied with a deeper or thicker layer of ombrogenic peats near or towards the centre of the peat dome (if targeted for stabilization) would mean that relatively more fillers and cement stabilizer would probably be needed resulting in an increased cost of peat stabilization.

5.3 Horizontal zonation of the tropical lowland peat dome

Anderson (1961; 1964 and 1983) and Anderson and Muller (1975) studied the domed topography of tropical peat deposits and the relationship between the concentric zonation of surface vegetation and increasing peat thickness, acidity and decreasing nutrient availability with horizontal distance between margin and centre of peat basin.

Anderson (1961; 1963; 1983) did a comprehensive study of the ecology of the Tropical Lowland Peat Swamp Forest. The Tropical Lowland Peat Swamp Forests in Sarawak, Malaysia and adjacent Brunei show lateral or horizontal changes in vegetation types from its periphery to the centre of the domed-shaped peat swamps and each of the six dominantly lateral vegetation zone was designated "Phasic Community'' by Anderson (1961). Six distinct Phasic Communities or zones were recognized based on their floristic composition and structure of vegetation in each Phasic Zone (Anderson, 1961; Paramananthan, 2011) and were numbered Phasic Community I at the margin to Phasic Community VI in the centre of the peat swamp. However, in this study, the proposed phasic community vegetation succession that was field-observed and inferred (from pollen analyses) to occur laterally and further towards the near-centre area of the dome, may have reached phasic community II (Alan Swamp Forest), at the least (Table 5.0).

Table 5.0: Unconfined compressive strength of tropical lowland peats, dominant stage of peat diagenesis-humification with distance from margin towards centre of tropical lowland peat dome and the proposed inferred lateral vegetation succession of the related phasic communities.

Sample location/ sample depth	**KS.TP.02 (0 to 0.5m)**	**KS.TP.07 (0 to 0.5m)**	**KS.TP.08 (0 to 0.5m)**	**KS.TP.09 (0 to 0.5m)**	**KS.TP.10 (0 to 0.5m)**
Approximate location on peat dome	Basin margin	Near basin margin	Midsection	Towards centre	Towards /near centre of peat basin
Proposed phasic community zonation (based on Anderson and Muller (1975) inferred succession and field observations).	Transitional mangrove to marginal, shallow, topogenic peats	Mixed transitional-PC I (Mixed Transitional mangrove to marginal, shallow, topogenic peats to Mixed Peat Swamp Forest) (?)	PC I (Mixed Peat Swamp Forest)	Mixed PC I to PC II (Mixed Peat Swamp Forest to Alan Swamp Forest) (?)	PC II (Alan Swamp Forest)
Wood fragments in peat (%) (from field observations and logging)	5-10% in fibric peat	20-30% in fibric to hemic peat	20-30% in sapric peat	20-30% in sapric peat, with hard (when dried) granular/ amorphous granules	40% in hemic to sapric peat, with hard (when dried) granular/ amorphous granules.
UCS of cement-mineral soil filler stabilized peats (kPa)	169.8	NA	61.03	122.57	152.33
Dominant stage/phase of peat diagenesis (Phase I-V or post phase V) at 0-0.5 m depth.	Dominant Phase: phase II (Von Post field classiffication: FIBRIC)	Dominant Phase: phase II & post-phase V (II=V, same amount or %) (Von Post field classiffication: 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 peat macerals occurring at 0 to 0.5 m depth	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

Note: PC=phasic community vegetation succession

5.4 Discussion on the results of peat geochemical (SRA and GCMS) analyses.

5.4.1 Discussion on the results of peat geochemical (SRA) analyses.

The hydrocarbon generation potential of coals has been widely discussed in the literature (Khorasani, 1987; Thompson et al., 1985; Wan Hasiah and Abolins, 1998; Wan Hasiah, 1999; Mohd. Farhaduzzaman et al., 2012). Conventional coal petrographic studies are usually carried out to evaluate the evolutionary history of the analysed coals whereby the macerals, microlithotypes and lithotypes provide evidence on the nature and type of plant community, duration and intensity of decomposition in the peatification process and the related depositional setting. The interpreted coal evolutionary history provides the basis for further interpretation of the related paleogeography and paleoclimate of the peat-coal precursor basins (Teichmuller, 1982; Mohd. Farhaduzzaman et al., 2012). Hence, this study attempts to study the relationship or association between the present tropical lowland peat depositional environment with their peat maceral types, kerogen types (from SRA data) and biomarker distributions based on organic petrological and geochemical experimental methods of augered peat samples.

From SRA analyses, it is observed that there appears to be an association between organic matter (kerogen) type and related maceral types (at different levels of decomposition and diagenesis) for the peat samples located within the distance from the periphery towards the centre of the peat basin. This then further relates to or supports the concept of horizontal variation as was proposed by Anderson (1961; 1964; 1976 and 1983) and Anderson and Muller (1975). This concept of horizontal/lateral variation and zonation may then explain or provide the reason on why there is a mixture or combination of organic matter types (kerogen) occurring together within a peat basin or dome. Furthermore, this concept may also explain the reason why, how and where there is relatively more leafy, waxy material or palynomorphs input into certain zones within the basin that may give rise to the formation of dominantly Type II organic matter or higher HI values in the peats, as was mentioned earlier (section 4.8.1.6). Similarly, this study attempts to improve our understanding of how woody material which may give rise to dominantly Type III organic matter peats can occur dominantly at different zones within a tropical lowland peat basin. Also, what dominant plant type or assemblage of tree, shrubs or plant species may contribute to relatively more input of either waxy leafy (cuticle) material, palynomorphs or more woody material into the peat located along the horizontal or near surface layer of the peat basin from its' margin concentrically towards the centre of the tropical lowland peat dome (Table 5.0 and Table 5.2). If these or similar types of tropical lowland peats may then succeed as coal precursors and eventually become coals which are productive as either gas or oil prone hydrocarbon source material upon sufficient burial and thermal maturity, then the results of this study may then perhaps contribute towards our understanding of the paleo-depositional environment of coals in relation to its' associated organic matter (kerogen) types and its'occurrence.

5.4.1.1 Horizontal or lateral zonation in tropical lowland peat domes

Anderson (1961; 1964 and 1983), Anderson and Muller (1975), Dehmer (1993) and Esterle and Ferm (1994) studied the domed topography of tropical peat deposits and the relationship between the concentric zonation of surface vegetation and increasing peat thickness, acidity and decreasing nutrient availability with horizontal distance between margin and centre of peat basin. Variations that occur in peat type within the deposits reflect the succession and lateral migration of the surface vegetation and the associated environment concurrent with coastal progradation (Anderson and Muller, 1975).

Buwalda (1940, in Paramanathan, 2011) earlier did work in Sumatra which supported the hypotheses/idea of horizontal zonality occurring in tropical lowland peats. He reported that different plant communities exist in the peat swamp forest depending on the thickness of the peat and the distance from the river (peat basin margin). In the central part 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, acidic (pH value range of 3.0 to 3.5) brown water compared to those at shallower depths of peat (peat deposited near or at the margin/ boundary of peat dome). However, on the peat deposits shallower than three metres deep, the soils had a pH of 3.5 to 4.5. Buwalda (1940, in Paramanathan, 2011) reported six different vegetation types and zones occurring in the Indragiri area in Sumatra. Anderson (1961; 1963 and 1964) also described six vegetation zones occurring in the lowland peat forests of Borneo including Brunei.

Anderson (1961; 1963; 1983) did a comprehensive study of the ecology of the Tropical Lowland Peat Swamp Forests of Borneo. He observed and recorded 253 tree species that are mostly confined to the the periphery of the peat swamp forest. According to Anderson (1963), most of the plant species that grow in the forests at the centre of the peat domes are mostly those that are usually found on nutrient poorer soils, such as podzols of the heath forest (Anderson, 1963). The Tropical Lowland Peat Swamp Forests in Sarawak, Malaysia and adjacent Brunei show lateral or horizontal changes in vegetation types from its periphery to the centre of the domed-shaped peat swamps and each of the six dominant lateral vegetation zone was designated "Phasic Community'' by Anderson (1961). Six distinct Phasic Communities or zones were recognized based on their floristic composition and structure of vegetation in each Phasic Zone (Anderson, 1961; Paramananthan, 2011) and were numbered phasic community I at the margin to phasic community VI in the centre of the peat swamp (Table 5.1 and 5.2). Tie (1990) and Paramananthan (2011) later summarized the main changes that characterized these concentric, horizontal or lateral zonations which are:

a) Changes in the floristic composition of one zone to another.
b) Reductions in the number of tree species per unit area and reduction in the total number of tree species recorded from margin to centre of peat dome.
c) General increase of number of stems having more than 30 cm girth per unit area from PC I to PC V, with the exception of PC III and PC VI.
d) General decrease in the average size of a species from periphery to the centre.

Table 5.1: Characterictics of the the six phasic communities occurring as vegetation horizontal or lateral zonation (based on Anderson, 1961; 1963 and 1983; Paramananthan, 2011).

PC	Emergent Height (m)	Girth	Stems* per ha	Species + per 0.2 ha	Canopy	Occurrences
I	40-50	n.a.#	600-700	30-55	Uneven; multi-storeyed	Periphery zone of swamps, especially Rajang Delta and near the coast.
II	up to 60	2-4m, few up to 7m	n.a.	40-45	Uneven; multi-storeyed	Common; extensive in Rajang Delta
III	45-60	1-3m	350-600	10-20 usually <15	Even	Extensive in Lupar-Saribas and Baram swamps, largely absent in Rajang Delta
IV	30-40	60-120cm	650-850	10-25	Mainly even; dense	Common in central areas of swamps in Rajang Delta and as transition zones in Baram.
V	15-20	Mostly <60cm	1,200-1,350	11-18	Even; dense	At transition zones in Baram and Brunei swamps.
VI	Few>12	45cm, few 75-90 cm	Few	<5	Open; Shrub-like	Only in central areas of swamps along middle reaches of Baram River.

*Stems with 30cm girth or larger, + Tree species with 30 cm girth or larger, # information not available

Table 5.2: The main characteristics of the six phasic communities occurring as horizontal or lateral zonation (based on Anderson, 1961; 1963 and 1983; Paramananthan, 2011).

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 similar to 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 PC I 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 on air photo.
IV	Padang Alan Forest	*Shorea albida-Litsea-Parastemon* Association	Very slender stems giving pole-like appearance; dense understory 3-6m high; *Nepenthes spp*. quite 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 occurs.

Table 5.3: Organic matter types (kerogen) of tropical lowland peats and dominant stage of peat diagenesis with distance from margin towards centre of tropical lowland peat dome and the proposed (based on palynology and field observations) phasic communities (PC) of dominant plant species assemblage.

Sample location	**KS.TP.02 (0 to 0.5m)**	**KS.TP.07 (0 to 0.5m)**	**KS.TP.08 (0 to 0.5m)**	**KS.TP.09 (0 to 0.5m)**	**KS.TP.10 (0 to 0.5m)**
Approximate location on peat dome	marginal	marginal	mid section	towards centre	towards /near centre of peat basin
HI	357	207	266	322	407
Organic Matter 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)
Source of organic matter (leafy or woody material input from present plant types)	Relatively more leafy and palynomorph than woody material input from shrubs, nepenthes, palms and trees.	Relatively more woody material from broken branches, bark, roots and wood fragments than leafy material or palynomorphs input.	Relatively more woody material from broken branches, bark, roots and wood fragments than leafy material or palynomorphs input.	Woody material from broken branches, bark and wood fragments with **increasingly relatively more leafy input** from ferns and shrubs (intermediate)	Relatively more shrubs and ferns (**relatively more leafy and palynomorphs input**) with woody material input.
Proposed phasic community zonation (based on Anderson and Muller (1975) inferred succession and field observations).	Transitional mangrove to marginal, shallow, topogenic peats	Mixed transitional- PC I (Transitional mangrove to marginal, shallow, topogenic peats to Mixed Peat Swamp Forest) (?)	PC I (Mixed Peat Swamp Forest)	Mixed PC I to II (Mixed Peat Swamp Forest to Alan Swamp Forest) (?)	PC II (Alan Swamp 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 (hardens when dried)	40% in hemic to sapric peat, >granular/amorphous granules, (hardens when dried)
Dominant stage/phase of peat diagenesis (Phase I-V or post phase V/ fragment or **colloidal cell stage) at 0-0.5 m depth.**	Dominant Phase: phase II (Von Post field classiffication: FIBRIC)	Dominant Phase: phase II **&** post - phase V (II=V, same amount %) (Von Post field classiffication: 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(0-0.5m)	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

5.4.1.2 Association between dominantly leafy or woody plant input and organic matter/kerogen type

Horizontal zonation and lateral variation of dominant species of plant assemblages (Anderson 1961; 1963; 1983; Paramanathan, 2011) occurring with varying distance from periphery towards centre of the tropical lowland peat dome supported by the field observations of this study with its' related petrographic observations and SRA analyses indicates that woody material (tree logs, broken branches, bark and roots) contributed by dominant tree species (e.g. *Shorea* type) may likely produce peat with relatively more or predominantly Type III organic matter (kerogen) (Table 5.3). However, waxy leafy material and palynomorphs contributed from dominant species of trees, shrubs and ferns may produce peat that constitutes predominantly organic matter of Type II (kerogen) (Table 5.3).

Thus, the organic matter of types II and III (kerogen) may be related to and occur in association with certain phasic community successive vegetation zonations on the tropical lowland peat dome.

5.4.1.3 Association between peat decomposition levels and organic matter type

Besides the type of plant input (whether more leafy (leaf-epidermal tissue material) material, palynomorphs (spores and pollen grains) or woody material input into the decomposing peat) that may have an influence on the organic matter type (kerogen) within the peats, the decomposition or humification level of the peats may also be associated with the organic matter types as shown in Table 4.2. It is observed that the dominantly occurring maceral type (whether red textinite, gray textinite, texto-ulminite and eu-ulminite or humocollinite or humodetrinite) and the associated dominantly occurring diagenesis stage (whether Phase I, II, III, IV, V or post phase V respectively) may also be associated with organic matter Type II or III in this study. Sample KS.TP.02 with lower levels of decomposition (fibric) has relatively higher HI values (Table 5.3) and are Type II organic matter (based on SRA interpretation). Sample KS.TP.10 (hemic to sapric) although highly decomposed still has some structure or plant tissue (hence, the 'hemic' level included in the humification range) and coupled, with relatively higher leafy material and palynomorphs input has therefore, also relatively higher HI values and thus may also constitute mainly Type II organic matter (kerogen) (?).

Von Post classification of peats used in this study (Andriesse, 1988; Minerals and Geoscience Department, 2007; Bujang, 2004) includes 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 centre area of the dome, with relatively higher humification levels), seems to be associated also with organic matter Type II (?). These von Post classified fibric and hemic peats are similar in the sense that petrographically, they both contain significant amounts of red to gray textinite (diagenesis phases II and III) peat macerals (premacerals). The dominant presence of textinite within these peats means that these type of peats still consists of plant components with relatively intact or partially intact cell structure.

5.4.1.4 Overall discussion of SRA results for the whole study area

From the overall SRA data of the auger samples taken from the Kota Samarahan-Asajaya study area, the S2 versus TOC (Figure 6.0) and HI versus OI (Figure 5.1) plots were derived and interpreted. Based on the S2 versus TOC graph (Figure 5.0), it is observed that the peats and organic soil samples analyzed are interpreted and shown to consist of Type III to IV gas prone, mixed Type II to III oil-gas prone and Type II oil prone source material. However, the majority of the sample plots lie in the Mixed Type II-III oil-gas prone area of the plot. The HI versus OI graph (Figure 5.1) indicates that the organic matter types of the peat and organic soil samples from the whole study area are mostly plotted within the organic matter of Type II to Type III (kerogen) region. These overall observation and results supports and corresponds well with the discussion in section 5.4.1.2 and Table 5.3. Hence, this observation indicates that most of the tropical lowland peats sampled within the study area generally constitutes organic matter types that range from Type II to Type III (kerogen) based on SRA (HI) data.

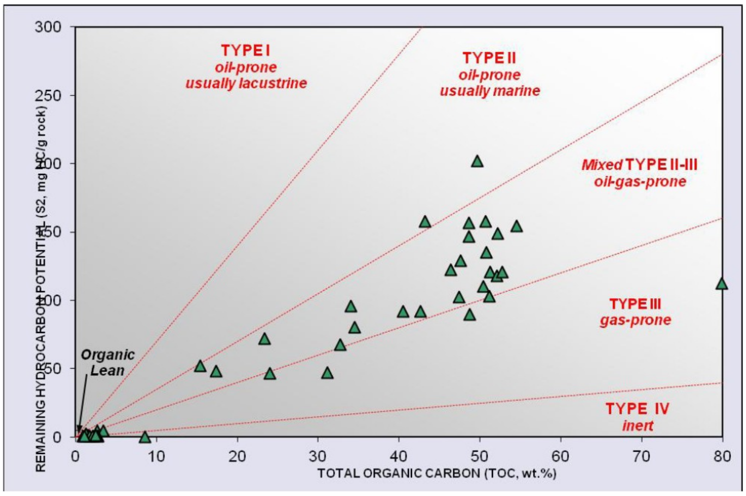


Figure 5.0: S2 versus Total Organic Carbon (TOC) plot from SRA data of peat, organic soil and silt/clay soil (less than 4 % TOC) samples from the Kota Samarahan-Asajaya area.

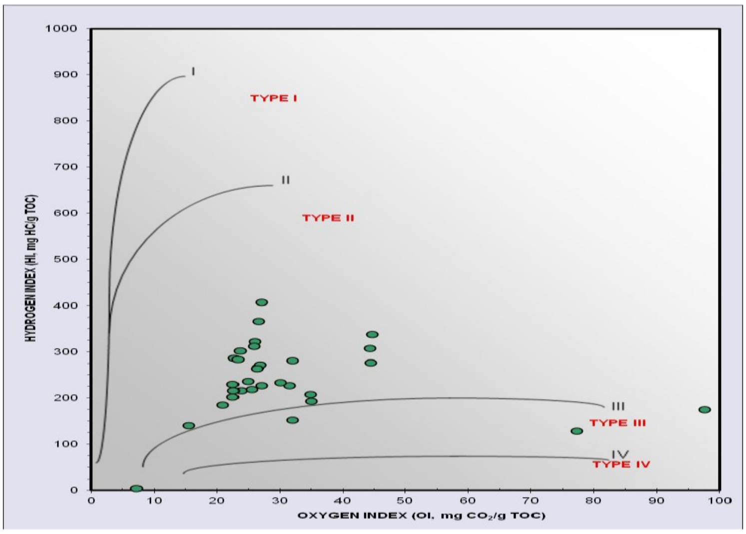


Figure 5.1: Hydrogen Index (HI) versus Oxygen Index (OI) plot from SRA data of peat and organic soil samples from the Kota Samarahan-Asajaya area.

5.4.2 Discussion on the results of peat geochemical (GCMS) analyses.

The aliphatic fractions of 3 extracted representative peat samples from basin periphery (KS.TP.02 (0-0.5 m)) to mid section (KS.TP.08 (0-0.5 m)) and further towards basin centre (KS.TP.09 (0-0.5 m)) has been subjected to GCMS analyses. The TIC (total ion current), m/z 85 and m/z 191 fragment ions has been used for this study and are as displayed in Figures 4.3 to 4.3.8. The peaks of these fragmentograms have been identified on the basis of retention times and available literature (Mohd. Farhaduzzaman et al., 2012; Hakimi et al., 2010, Wan Hasiah, 1999; Waples and Machihara, 1991; Philp, 1985). Geochemical ratios are as presented in Table 4.3.2.

5.4.2.1 Discussion on GCMS Analyses Results for sample KS.TP.02 (0-0.5 m).

Figure 4.3 shows the TIC gas chromatogram of the alkane fraction from sample KS.TP.02 (0-0.5 m) and Figure 4.3.1 shows the m/z 85 fragmentogram obtained from the same sample. The alkane fractions from the sample mentioned are predominantly composed of long chained n-alkanes greater than n-C_{13} that extends up to n-C_{33}. Within the range of n-C_{13} to n-C_{33} the most dominant peak is n-C $_{29}$. Within the terrestrial or land plants envelope that ranges from n-C_{23} to n-C_{33} in the fragmentogram (m/z 85), the odd numbered n-alkanes dominate (shows strong odd over even predominance), indicative of the true terrestrial depositional environment of the peats.

The n-alkanes from n-C_{13} to n-C_{22} lie mainly within the bacteria and fungi envelope of the m/z 85 fragmentogram (Figure 4.3.1). From the m/z 85 gas chromatogram of the alkane fraction from sample KS.TP.02 (0-0.5 m), the pristane/phytane ratio is 0.97 and is less than 1 (<1) indicative of an anoxic/reducing environment of deposition which is indicative of wet tropical lowland peats with relatively high ground water tables (Table 4.3.2). Near the relatively ‘wetter’ margin area (moat area) of the peat dome, the Pr/Ph ratio is slightly <1 and indicates a relatively more anoxic/reducing environment of deposition for the peats due to relatively higher groundwater tables, and relatively more aquatic/subaquoes conditions with relatively lower elevations near the margin of the peat dome. The relatively higher phytane (Ph) value of the Pr/Ph ratio may be due to the generally near aquatic conditions of the tropical lowland peat swamp which is usually wet and waterlogged especially during the monsoon seasons. The ratio of Pr/Ph has been used extensively as an indicator of oxic conditions of a terrestrial depositional environment (Brooks et al., 1969; Powell and McKirdy, 1973; Philp, 1985; Mohd. Farhaduzzaman et al., 2012) which is based on the formation of pristane from phytol by oxidation and decarboxylation reactions and the formation of phytane by the hydrogenation and dehydration of phytol which is sourced from chlorophyll side chains. Pristane is likely to occur in oxidizing environments, such as swampy peat bogs, whereas phytane formation occurs in reducing subaqueos type environments. Samples with Pr/Ph<1 are more likely to be formed in reducing environments, whereas samples with Pr/Ph >1 are formed in oxidizing environments (Philp, 1985). The relatively higher phytane abundance in the peat studied may occur in reducing environments with anoxic to suboxic conditions occurring in wet (with relatively higher ground water tables), swampy, near aquatic, tropical lowland peat swamps. The extent and plan view shape of the peat deposits varies from circular to ellipsoidal and irregularly involuted that correspond to the available space between water courses crossing the area. On the flanks of these water courses, the peat domes are surrounded by wet, marginal ‘moats’ often in the form of water-filled back levee depressions that lead to the sloped margin of the domes. These slopes can be steep, gradual or flatten out towards the centre, near centre or the thicker part of the peat deposit (Anderson, 1961; Tie, 1990; Esterle and Ferm 1994).

The Pr/nC_{17} ratio is 0.31 whereas the Ph/nC_{18} ratio is 0.27 (reducing environmental conditions). Thus, these ratios support the presence of anoxic and reducing depositional environmental conditions of tropical lowland peat sample KS.TP.02 (Table 4.3.2).

The hopanes are the dominant pentacyclic (Waples and Machihara, 1991) triterpanes in the peat alkane fraction of sample KS.TP.02 (0 to 0.5m) (Table 4.3). C_{31}-hopane is the most abundant hopanoid and dominant homohopane observed with the R-isomer clearly being more dominant than the S-isomer, indicating the thermal immaturity of the peat-coal precursor for hydrocarbon generation. S / (S+R) ratio for the isomers 17α, 21β (H)-Homohopane (S-configuration) and 17α, 21β (H)-Homohopane (R-configuration) gives a low value (0.18) supporting the immaturity of the peat samples as coal precursors. The presence of very immature ββ hopanoids such as ββ C_{30} hopane (17 β, 21β (H)-Hopane) and ββ C_{31} hopane (17β, 21β (H)-Homohopane) indicates and supports the present, shallow burial conditions (very shallow sampling depth of 0 to 0.5 m) and this further supports the immaturity of the peats (Waples and Machihara, 1991) as coal precursors or hydrocarbon source material (as also concluded based on T_{max} of SRA data in section 4.8.1.5 in Chapter 4).

Figure 4.3.2 shows the m/z 191 chromatogram for the peat core sample KS.TP.02 (0-0.5 m). The peak identification for sample KS.TP.02 (0-0.5m) is as shown in Table 4.3. Besides homohopane, the other hopanoids found to occur in sample KS.TP.02 (0-0.5 m) are C_{29} hopane (Norhopane) and ββ C_{30} hopane (17 β, 21β (H)-Hopane). Steranes do not appear to be common or may occur in too low concentrations and are unable to be detected by m/z 217 ion fragmentograms in this study.

5.4.2.2 Discussion on GCMS Analyses Results for sample KS.TP.08 (0-0.5 m).

Figure 4.3.3 shows the TIC gas chromatogram of the alkane fraction from sample KS.TP.08 (or KS.TP.08BB) at 0 to 0.5 m sampling depth and Figure 4.3.4 shows the m/z 85 fragmentogram obtained for the same sample. The alkane fractions from the mentioned sample are predominantly composed of long chained n-alkanes greater than n-C_{15} that extends up to n-$C_{39.}$ Within the range of n-C_{15} to n-C_{39} the most dominant peak is n-$C_{31.}$ Within the terrestrial or land plants envelope of the fragmentogram (m/z 85) and in the range of n-C_{23} to n-C_{39}, the odd numbered n-alkanes dominate, indicative of the terrestrial depositional environment of the peats and, maximizing at n-$C_{31,}$ as mentioned.

The n-alkanes from n-C_{15} to n-C_{22} lie mainly within the bacteria and fungi envelope of the m/z 85 fragmentogram (Figure 4.3.4). From the m/z 85 gas chromatogram of the alkane fraction from sample KS.TP.08 (or KS.TP.08BB) (0-0.5 m), the pristane/phytane ratio is 1 and is in the range of 1 to 3 indicative of a relatively more suboxic environment of deposition (Table 4.3.5). At the midsection area and further towards the peat basin centre, the pristane/phytane ratio (=1) for the peats and lies in the range of 1 to 3 which is indicative of a relatively more suboxic environment of deposition, less aquatic/subaqueous conditions probably with relatively deeper, fluctuating groundwater levels due to the relatively increasing elevation from the midsection area and further towards the dome centre (compared to the Pr/Ph<1 ratio for marginal peats, e.g. sample KS.TP.02). Again it is observed that there is relatively higher phytane abundance in the peat sample probably due to reducing environments with anoxic to suboxic conditions occurring in the usually wet, swampy, near aquatic tropical lowland peat swamp. The Pr/nC_{17} ratio is 0.36 whereas the Ph/nC_{18} ratio is 0.18 (indicative of reducing environmental conditions). Thus, these ratios support the present suboxic and reducing depositional environment during deposition of the peat sample KS.TP.08.

The hopanes are again the dominant pentacyclic triterpanes (Waples and Machihara, 1991) in the peat alkane fraction of sample KS.TP.08BB (0 to 0.5m) (Figure 4.3.5). C_{31}-hopane is also the most abundant hopanoid and dominant homohopane observed with the R-isomer clearly being more dominant than the S-isomer, indicating the thermal immaturity of the peat-coal precursor for hydrocarbon generation. S / (S+R) ratio for the isomers 17α, 21β (H)-Homohopane (S-configuration) and 17α, 21β (H)-Homohopane (R-configuration) gives a low value (0.12) supporting the immaturity of the peat samples as coal precursors. Again, the presence of very immature ββ hopanoids such as ββ C_{30} hopane (17 β, 21β (H)-Hopane) and ββ C_{31} hopane (17β, 21β (H)-Homohopane) indicates and supports the present, shallow burial conditions (very shallow sampling depth of 0 to 0.5m) and this further supports the immaturity of the peats (Waples and Machihara, 1991) as coal precursors or hydrocarbon source material (as concluded based on Tmax of SRA analyses in section 4.8.1.5 in Chapter 4).

Figure 4.3.5 shows the m/z 191 chromatogram for the peat sample from the peat core KS.TP.08 (0-0.5 m). The peak identification of peat core KS.TP.08 (0-0.5 m) is as shown in Table 4.3. Besides homohopane, the other hopanoids found to occur again (compared to location KS.TP.02) in the tropical lowland peats at location KS.TP.08BB (0-0.5m) are C_{29} hopane (Norhopane) and ββ C_{30} hopane (17 β, 21β (H)-Hopane) and are as presented in Figure 4.3.5.

5.4.2.3 Discussion on GCMS Analyses Results for sample KS.TP.09 (0-0.5m).

Figure 4.3.6 shows the TIC gas chromatogram of the alkane fraction from sample KS.TP.09 (0-0.5 m) and Figure 4.3.7 shows the m/z 85 fragmentogram obtained from the same sample. The alkane fractions from the above mentioned sample are predominately composed of long chained n-alkanes greater than n-C_{13} that extends up to n-$C_{33.}$ Within the range of n-C_{13} to n-C_{33} the most dominant peak is n-C $_{27}$. Within the terrestrial or land plants envelope that ranges from n-C_{23} to n-C_{33} in the fragmentogram (m/z 85), the odd numbered n-alkanes dominate, indicative of the terrestrial depositional environment of the peats. The n-alkanes from n-C_{13} to n-C_{22} lie mainly within the bacteria and fungi envelope of the m/z 85 fragmentogram (Figure 4.3.7).

There is still relatively higher phytane abundance in the peat sample studied probably due to reducing environments with wet, anoxic to suboxic conditions. However, from the m/z 85 gas chromatogram of the alkane fraction from sample KS.TP.09 (0-0.5m), the pristane/phytane ratio is also 1 and lies within the 1 to 3 range indicative of a suboxic environment of deposition. Further towards the peat basin centre, the pristane/phytane ratio is in the range of 1 to 3 and this is indicative of a relatively more suboxic environment of deposition, less aquatic/subaqueous conditions with relatively deeper, fluctuating groundwater tables due to increasing elevations from midsection and further towards dome centre (compared to the Pr/Ph<1 ratio for marginal peats, e.g sample KS.TP.02). The Pr/nC_{17} ratio is 0.21 whereas the Ph/nC_{18} ratio is 0.18 indicative of reducing environmental conditions. Thus, these ratios still support the presence of a suboxic and reducing depositional environment during the deposition of tropical lowland peat sample KS.TP.09.

The hopanes are again the dominant pentacyclic triterpanes in this peat alkane fraction (Figure 4.3.8) and sample location. C_{31}-hopane is again the most abundant hopanoid and dominant homohopane observed with the R-isomer clearly being more dominant than the S-isomer, indicating the thermal immaturity of the peat-coal precursor for hydrocarbon generation. S / (S+R) ratio for the isomers 17α, 21β (H)-Homohopane (S-configuration) and 17α, 21β (H)-Homohopane (R-configuration) gives a low value (0.12) supporting the immaturity of the peat samples as coal precursors. Again, the presence of ββ hopanoids such as ββ C_{30} hopane (17 β, 21β (H)-Hopane) and ββ C_{31} hopane (17β, 21β (H)-Homohopane) indicates and supports the present shallow burial condition (very shallow sampling depth of 0 to 0.5 m) and this further supports the immaturity of the peats as coal precursors or hydrocarbon source material (as concluded based on T_{max} of SRA analyses in section 4.8.1.5 in Chapter 4).

Figure 4.3.8 shows the m/z 191 chromatogram for the peat sample KS.TP.09 (0-0.5 m). The peak identification of this sample is shown in Table 4.3. Besides homohopane, the other hopanoids still found to occur again (compared to locations KS.TP.02 and KS.TP.08) in the tropical lowland peat at the location of sample KS.TP.09 (0-0.5m) are Norhopane and 17 β, 21β (H)-Hopane and are as shown in Figure 4.3.8.

5.4.2.4 Final Discussion

For samples KS.TP.08 and KS.TP.09 which are located at the midsection area and further towards the peat basin centre, respectively, the pristane/phytane ratios are in the range of 1 to 3 (Table 4.3.2) and are indicative of a relatively more suboxic environment of deposition, relatively lesser aquatic/subaqueous conditions with relatively deeper, fluctuating groundwater tables due to increasing elevations from the midsection area and further towards the tropical lowland peat dome centre (when compared to the Pr/Ph<1 ratio for the relatively wetter (moat area), marginal peat sample location KS.TP.02 where the elevation and groundwater table is lower and relatively more anoxic).

The most common hopanoid observed to occur for the three samples are 17α, 21β (H)-Homohopane (S-configuration) and 17α, 21β (H)-Homohopane (R-configuration). According to Waples and Machihara (1991), the concentration of homohopanes or extended hopanes varies considerably from sample to sample and this accounts for their importance as paleoenvironmental indicators. According to Peters and Moldowan (1991), the C_{33} to C_{35} extended hopanes are all probably derived from bacteriohopanetetrol. Homohopane is formed by mainly decarboxylation reactions under oxidative conditions of the C_{35}- compound, bacteriohopantetrol (Ourisson et al., 1987; Dehmer, 1993). According to Talbot et al. (2008), bacteria are the only known source of C-35 hopanepolyols (bacteriohopanepolyols or BHPs). BHPs are biosynthesized with the biological 17β, 21β (*H*) stereochemistry in the hopanoid skeleton. During diagenesis, BHPs undergo a series of defunctionalisation and isomerisation reactions, including the formation of structures with a more stable "geological" 17α, 21β (*H*) stereochemistry (Peters et al., 2005). Acidic environments are thought to further induce isomerisation to produce 17α, 21β Homohopane instead of the 17 β, 21β Homohopane type (van Dorsselaer et al., 1975; Dehmer, 1995). Hopanoid structures with the 17α, 21β (*H*) configuration are considered to be indicative of diagenetic transformation of hopanoids to more stable "geohopanoids" and are also considered as a product of diagenetic reactions and rapid isomerisation of ββ isomers in peat (Talbot et al., 2007). The results and conclusions of this study argues against the still common view that αβ-epimers form only in the geological environment and that hopanoids do not occur in strictly anaerobic bacteria and are not generated in anoxic settings (Thiel et al., 2003). In fact, the latter opinion had also been challenged by observations of αβ-geohopanoids in Holocene peats and modern lacustrine sediments (Dehmer, 1992). These occurrences were explained by rapid catalytic epimerization of ββ-hopanoids under acidic conditions (van Dorsselaer et al., 1977; Thiel et al., 2003) or by microbial mediation (Quirk et al., 1984). According to Quirk et al. (1984) and Dehmer (1995), 17α, 21β Homohopane is also said to be produced by bacterial degradation. The concentrations of C_{31} hopanes depend on diagenetic conditions in peat-forming environments (Waples and Machihara, 1991). Steranes do not appear to be common or may occur in too low concentrations and were unable to be detected by m/z 217 ion fragmentograms in this study.

5.5 Discussion on Pollen Analyses

5.5.1 Discussion on palynological analyses

In general, palynological analyses have provided information regarding the local inferred succession of tropical lowland peat swamp vegetation. The pollen succession interpreted from the location at KS.TP.10 near the lowland tropical peat dome centre is comparable to normal peat development which basically starts on mangrove clay. Based on the pollen analyses and comparison with the inferred plant succession as was studied and published by Anderson and Muller (1975), the peat deposit investigated here is concluded as local and autothocthonous and includes the phasic communities of the mangrove to shallow peat swamp transition zone followed by PC I (Mixed Peat Swamp Forest) and PC II (Alan Batu Forest). Field observations have noted the presence of large *Shorea* type species of trees with wide girths (1 to 3 metres) along the traverse section from KS.TP.09 to KS.TP.10 which further supports that the peat swamp vegetational zonation and succession has reached Phasic Community II (at a depth interval of 0.5 m to 0 m) even though the pollen of *Shorea* type is scarce and not observed present in the studied profile of KS.TP.10.

From 5.5 to 2.0 m, it is clear that mangrove or estuarine elements dominate. From 5.5 to 3.5 m, the dominance of *Rhizophora* and *Oncosperma* (Plate 1) is evidence of a former mangrove swamp environment (Anderson and Muller, 1975; Haseldonckx, 1977). From 3.5 to 2.0 m there is the abundant occurrence and dominance of the *Oncosperma* and *Nypa fruticans* pollen which largely represents the inland zone of mangrove vegetation. The peak of *Elaeocarpus* at 2.5 m in the 3.0 to 2.5 m interval is probably related to an influx of pollen from riparian type vegetation due to freshwater influx or floodwaters and this interval may thus represent and support a riverine floodplain depositional environment setting.

Overall, the analyses of the pollen succession at 2.0 to 1.5 (or at approximately 2420 ± 30 years B.P.) is indicative of a mangrove to shallow peat swamp transition zone interpreted to have developed near to the coast and which usually occurs before phasic community I (Anderson and Muller, 1975) and is indicated by the *Campnosperma-Cyrtostachys-Zalacca* sub-association (Anderson and Muller, 1975).

From 1.5 to 1.0 m, the presence of peat pollen types (Plate 1) that may support the vegetational successions or zones ranging from phasic community I and phasic community IV to VI is noted (Anderson and Muller, 1975). Pollen types such as *Blumeodendron* that are known to be abundant in phasic community I (Anderson and Muller, 1975), *Campnosperma* (abundant in PC I), *Parastemon* (abundant in PC I and PC IV to VI) and *Stenochlaena palustris* (abundant in mangrove to shallow peat transition zones and/or PC I) are also present (Anderson and Muller, 1975). However peak abundance of *Stenochlaena palustris* occurs at this interval, thus signifying vegetation succession of phasic community I.

From 1.0 to 0.5 m, at approximately 2380 ± 30 years B.P., the presence of peat pollen types that may support the vegetational succession of phasic community zones that range from phasic community I to VI is observed (Anderson and Muller, 1975). Pollen types like *Dactylocladus* (abundant in PC 1 to VI), *Pandanus* (abundant in PC I to V) and *Parastemon* (abundant in PC I and PC IV to VI) are also present in this interval as observed by Anderson and Muller (1975). However, *Stenochlaena palustris* and *Zalacca* (Plate 1) is still present and this implies that the successive vegetation zonation may be considered still to be phasic community I.

From 0.5 to 0 m at location KS.TP.10, or at approximately 1780 ± 30 years ago till present time, the presence of peat pollen types that may support the occurrence of vegetational successions or zones ranging from PC I to PC VI is noted. Pollen types like *Callophylum* (abundant in PC I to PC IV), *Gonostylus* (abundant in PC IV), *Blumeodendron* (abundant in PC I), *Campnosperma* (locally abundant near coastal margin of PC I), *Cephallomappa* (abundant in PC II to III), *Eleocarpus* (abundant in PC I to IV) and *Parastemon* (abundant in PC I and/or PC IV to VI) are present (Anderson and Muller, 1975). In this interval, however, the *Stenochlaena palustris* and *Zalacca* pollen is observed not to be present and this implies that the successive vegetation zonation may no longer be Phasic Community I, anymore. Hence, the zonation may have reached to be at least Phasic Community II (or higher). As mentioned earlier, field observations support and have noted the presence of large, hollow, scattered *Shorea* type species of trees (abundant in PC II to IV as according to Anderson and Muller (1975)).

5.5.2 Discussion on rate of organic soil and peat deposition

From Table 4.4 in section 4.9.2, it is interpreted that peat had begun to accumulate as much as approximately 2.0 metres (from auger log profile of KS.TP.10) over a period of 640 ± 30 years (B.P) from the initial age of deposition of 2420 ± 30 years B.P (for transitional peats) to 1780 ± 30 years B.P (for the upper peat layer of Alan Batu Swamp Forest/PC II). Thus, the possible approximate average rate of peat deposition in the Kota Samarahan-Asajaya study area for the period stated above would probably be 1 metre (100 cm) of peat accumulated over a period of 320 ± 30 years (B.P).

5.6 Discussion on the Key Classification Method for peat and peat engineering classification

For the sample interval of KSTP.08 (0.5-1m) the organic content is classified by the ASTM D2974 engineering method to be categorized as organic soil and not actually peats in terms of engineering classification (Table 4.5.3). In the ombrogenic and the intermediate topogenic to ombrogenic peats, the ash or mineral soil content at the top or upper peat layer is relatively low and this generally increases downwards towards the mineral soil boundary below. Hence, the soil classification usually varies from peats to organic soils to slightly organic soils and finally, to mineral soils. Furthermore, here there is observed to be a vertical variation of peat types and classification (whether fibric, hemic or sapric) due to varying humification levels (by the Von Post Classification method). Due to these changes of classification criteria observed here in this study, a classification/type range (or ranges) was given to the peats that were sampled, tested or classified at the 0.5 to 1.0 m depth interval for accuracy (e.g. HEMIC TOPOGAMBIST (SF=GALI, SS=Gali)) to SAPRIC TOPOGAMBIST (SF=ERONG, SS=Muara Tuang) (Table 4.5.1).

For aquic and poorly drained peats, at or near the relatively wet or submerged basin margin or the moat area, the top 0 to 0.5 m peat layer should be considered and accepted to be used also (?) as accurate criteria for the key classification method. This is because this area of the peat dome is usually wet with relatively higher ground water tables and probably not so easily oxidized or decomposed and hence may still be considered representative for the selected auger profile to be classified.

For the profile KS.TP.09, a peat type (field classification) range should be given because Von Post humification levels (H1 to H10) and peat types generally changes vertically with depth from sample intervals (0.5-1 m) to (1-1.4 m). Thus the overall peat classification here (for sample interval 0.5 to 1.0 m, e.g. HEMIC TOPOGAMBIST (SF=GALI, SS=Gali) to SAPRIC TOPOGAMBIST (SF=ERONG, SS=Muara Tuang)) may not be so representative for the whole (top to bottom peat layer) vertical profile/section because only the 0.5 to 1.0 m interval is taken into account (Table 4.5.1).

For the profile KS.TP.10, note that the humification level again (H) varies vertically. Thus, the overall peat classification here (from sample interval 0.5 to 1.0 m, e.g. HEMIC OMBROGAMBIST, (SF=SAMARAHAN, SS=Samarahan) again may not be so representative for the whole (top to bottom peat layer) vertical profile/section (Table 4.5.1).

For engineering purposes, the core samples from KS.TP.02 and KS.TP.07 were tested in the laboratory by the ASTM D2974 method to yield the classifications for organic soil (KS.TP.02) and peat (KS.TP.07) (Table 4.5.3). However, the peats were initially field tested (von Post classification) to be classified as fibric (KS.TP.02) and fibric to hemic (KS.TP.07) peats. These observations show that field classifications (e.g. von Post Classification) may not necessarily support laboratory or ASTM test method classifications or vice-versa. However, the determination of organic content is necessary to classify whether the peats are actually organic soils or peats according to the Malaysian Soil Classification System for Engineering Purposes (from BS5930:1981, after Jarret 1995; Bujang 2004; Minerals and Geoscience Department, 2007). In addition, the determination of organic content is also relevant to further determine the ash content which generally represents the mineral soils (or ‘natural’ mineral soil filler content) present in the organic soil or peat tested. The natural msf content of the peats or organic soil is relevant in terms of peat (or organic soil) cement-filler stabilization because relatively high msf content in the peat may help to enhance peat stabilization strength as was discussed in the earlier sections.

CHAPTER 6

6.0 CONCLUSIONS

This chapter focuses on the various conclusions and findings from the different types of analyses carried out in this study.

6.1 Effects of vegetation lateral variation and basin 'dome' shape on tropical lowland peat stabilization

Generally, the conclusive remarks derived from the results and discussion in Chapter 4 and Chapter 5 regarding the effects of vegetation lateral variation and basin 'dome' shape on tropical lowland peat stabilization are:

1) Mapping, field identification and classification (von Post) of the tropical lowland peat studied indicates that there is a lateral variation of peat humification levels (von Post) in the form or range of dominantly occurring fibric, fibric to hemic, sapric and hemic to sapric peat (KS.TP.02, KS.TP.07, KS.TP.08, KS.TP.09 and KS.TP.10) occurring, respectively, from margin/periphery to midsection and further towards the centre of the tropical lowland peat dome or basin.

2) After stabilization of 28 air-curing days, test results indicate that there is a lateral variation in unconfined compressive strengths of the stabilized cement-mineral soil filler-peat mix. The average strength values yielded varies from a relative maximum of

203.67 kPa and 169.8 kPa to an intermediate value of 61.03 kPa and is followed by 122.57 kPa and 152.33 kPa, from basin margin to mid-section and further towards the centre of the peat dome, respectively. All the stabilized cement-filler-peat mix specimens with added mineral soil (silt, clay and fine sands) fillers tested, exhibited brittle or shear failures with no barrelling except for the specimen with peat obtained from location KS.TP.08 which exhibited dominantly more shear failure than barrelling failure. Besides this observation, test specimens with peat from the midsection location KS.TP.08 also exhibited relatively medium to higher shrinkage; relatively more bending and a not so uniform cylindrical shape due to some deformation; and relatively more indentations and discontinuities in the form of small holes and cracks at some layer planes when compared to peat samples augered from the other locations as mentioned above.

3) In conclusion, topogenous, clayey, high-ash, shallow transitional peats (with more naturally occurring in-situ mineral soil filler content) occurring near or at the periphery (usually occurring at or before PC I (Mixed Peat Swamp Forest)) of the peat dome/basin have relatively higher unconfined compressive stabilized peat strength when compared to the deeper, intermediate topogenous to ombrogenous, low-ash peats (with relatively lesser or no natural filler content) occurring at midsection or towards the basin centre, when stabilized with a fixed composition of ordinary Portland cement and mineral soil fillers. Furthermore, stabilized peat specimens from topogenous, marginal, shallow, transitional peat areas (e.g. at locations KS.TP.0 and KS.TP.02) also exhibited relatively better, uniform and consistant cylindrical shape, with less deformation, are denser, are harder, has lesser cracks, less holes, less indentations or lesser joints/discontinuities at the tamped layer planes. These observations may actually reflect the enhanced field conditions of the stabilized peat columns if added mineral soil

fillers were applied in cement-peat stabilization and targetted at the marginal/fringe, topogenous peat areas of the peat dome.

4) After stabilization of 28 air-curing days, specimens mixed with increasing quantities of 5 g, 15 g, 25 g to 50 g of mineral soil filler (from auger sample KS.TS.06 at 0 to 0.5 m sampling depth) showed an increment of unconfined compressive strengths from 42.5 kPa, 67.0 kPa, 77.0 kPa to 106.6 kPa, respectively. This strength increment indicates that cement-peat stabilization depends on the amount of solid natural/insitu or added mineral soil filler contained within the peat. Strength enhancement by improved densification of the stabilized peat-cement-mineral soil filler mix can be achieved by supplying increasingly more and more solid particles in the form of mineral soil fillers (clay, silt or fine sand) available for the cement binder to unite to form a more stabilized, load sustainable structure. This, also supports and explains why cement stabilized marginal, shallow, topogenous, clayey peats (or high ash peats) with relatively more natural mineral soil filler content yielded strength values, relatively greater than cement stabilized, low ash, topogenous to ombrogenous peats located near or towards the peat dome centre (with a relatively lesser natural msf content).

5) If there is an association between variations of unconfined compressive strengths of cement-mineral soil filler stabilized tropical lowland peats occurring with varying distance from periphery towards the centre of peat dome/basin in the current scope of this study, it is probably caused by a combination of factors, which are:

a) The relatively higher quantity of *in situ* or natural mineral soil fillers (or related ash content) present in the topogenic, marginal or transitional mangrove to shallow peats (which occurs before or with PC I (Mixed Peat Swamp Forest)) may enhance the strength of the stabilized peat-cement mix probably because more solid particles in the form of naturally deposited mineral soil fillers (clay, silt or fine sand) are available for the cement binder to unite to form a more stabilized, load sustainable structure in the cement-peat stabilization process. Thus, this supports and explains why cement stabilized shallow, marginal, topogenous, clayey peats with relatively more natural mineral soil filler content show relatively greater stabilized strength values than cement stabilized peats with low ash, topogenous to ombrogenous peats which are located at midsection area and near or towards the peat dome centre.

b) Horizontal zonation and lateral variation of dominant species of plant assemblages may occur with varying distance from periphery towards the near-centre of the tropical lowland peat dome. Woody material (tree logs, broken branches, bark and roots) contributed by dominant hardwood species (e.g. *Shorea* type) which usually begins to occur in successive vegetation zones of phasic communities II (Alan or 'Alan Batu' Swamp Forest) away from the peat basin periphery and near or towards the basin centre may decompose to produce sapric or hemic to sapric peats with relatively higher unconfined compressive strength when stabilized, hardened and dried (in the air-curing stabilization process) with use of ordinary portland cement and added mineral soil fillers (clay, silt and fine sands).

6) Generally speaking, from this study, there is a mix or a combination of varying unconfined compressive strengths of cement-mineral soil filler stabilized peats occurring on the tropical lowland peat basin surface and these lateral variations in stabilized peat strength may support the lateral variation vegetation concept (Anderson 1961; 1963; 1983 and Paramanathan, 2011). Hence, lateral vegetation succession, phasic community zonation and variations of unconfined compressive strengths of

cement-mineral soil filler stabilized peats are probably associated, to a certain degree in tropical lowland peat domes. However, the effect of the insitu, natural, mineral soil filler content of cement stabilized peats is more pronounced in topogenous, clayey, marginal and shallow or transitional mangrove to shallow peats (which occurs at or before PC I). Furthermore, this study indicates that these unconfined compressive stabilized strength variations are probably at the maximum near the dome or basin margin/periphery, followed by a decrease to a low (intermediate) at the mid section area, and progressively increases back again further towards basin centre (or wherever hardwood plant species are or were dominant) in the peat dome.

6.2. Macerals and organic matter (kerogen) type variations and trend due to vegetation lateral variation and peat humification levels

From field identification and von Post classification, petrographic studies and source rock analyses (SRA) of the five augered peat samples (KS.TP.02 to KS.TP.10) at the western Plaie peat forest of the study area, the conclusive remarks derived from the test results and discussion in Chapter 4 and Chapter 5 are:

1) Field identification and classification (von Post) of the tropical lowland peat shows that there is a lateral or horizontal variation of peat humification levels and trend in the form of dominantly occurring fibric, fibric to hemic, sapric and hemic to sapric peat, occurring progressively, from margin towards the centre of the tropical lowland peat dome or basin.

2) Petrographic studies show that humification or decomposition levels of peat are related to the dominantly occurring peat macerals in the form of yellow fresh or unaltered plant cells, red textinite, gray textinite, texto-ulminite, eu-ulminite and humodetrinite or humocollinite. The observed relationships and trend from margin to basin centre are:

a) Dominantly fibric peats (margin area) consists of mainly fresh, yellow to orange cells and red textinite macerals.

b) A range of fibric to hemic peats (from margin to midsection) consists of mainly fresh, yellow to orange cells, red textinite and dark humodetrinite and humocollinite macerals.

c) Dominantly sapric peats (midsection) consist of mainly red textinite with dark humodetrinite and humocollinite or just mainly dark humodetrinite and humocollinite macerals.

d) Dominantly sapric peats (midsection towards centre) consist of mainly red textinite with dark humodetrinite and humocollinite or just mainly dark humodetrinite and humocollinite macerals.

e) A range of hemic to sapric peats (towards centre) consists of mainly dark humodetrinite and humocollinite macerals.

3) Variations of dominant peat maceral types observed in this study are probably related to different levels of diagenesis in the humification or peatification process of the

tropical lowland peats. The respective progressive stages (and the associated dominant maceral types) that are observed to occur 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) Source Rock Analyses (SRA) results show that there is a lateral variation of organic matter (kerogen) types occurring within the top 0 to 0.5 metres layer, from margin towards the centre, of the tropical lowland peat dome studied. The organic matter types and trend within the peat dome vary from dominantly Type II to Type III to again Type II (kerogen), from margin to mid-section and near or towards the peat dome centre, respectively.

5) If there is an association between variations of organic matter type (kerogen) of tropical lowland peats occurring with varying distance from periphery towards the centre of peat dome in the current scope of this study, it is probably caused by a combination of factors, which are:

a) Horizontal zonation and lateral variation of dominant species of plant assemblages occurring with varying distance from periphery towards centre of the tropical lowland peat dome supported by the field observations of this study and SRA analyses indicates that woody material (tree logs, broken branches, bark and roots) contributed by dominant tree species (e.g. *Shorea* type) may likely produce peat with relatively more or dominantly Type III organic matter (kerogen). However, waxy leafy material and palynomorphs contributed from dominant species of trees, shrubs and ferns may produce peat that constitutes relatively more or dominantly organic matter of Type II (kerogen). Thus, the peat organic matter of types II and III (kerogen) may be related to and occur in association with certain successive phasic community vegetation zonations on the tropical lowland peat dome.

b) Lateral variations of peat humification levels (von Post Humification levels of H1 to H10) and its related dominant diagenesis peatification stages (Phase I, II, III, IV, V and post phase V) is observed to occur from periphery towards the centre of the tropical lowland peat dome in the study area. The designated von Post classifications of peats used in this study 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 and moat area of the dome, with relatively lower levels of decomposition) and hemic to sapric peats (near the centre or thicker area of the dome, with relatively higher humification levels), seems to be associated also with organic matter Type II (kerogen) (?). These fibric and hemic von Post classified peats are similar in the sense that petrographically, they both have probably significant amounts of red to gray textinite (diagenesis phases II and III) macerals. Dominant phases of textinite occurring within these peats means that these types of peat consists of plant components that are relatively intact or with partially intact cell structure.

6) The observations in this study may support the concept of lateral variation and horizontal zonation. The proposed Phasic Communities inferred vegetation succession that were observed to occur laterally from margin to near-centre of the studied tropical lowland peat dome are probably transitional mangrove to shallow peats, PC I (Mixed Peat Swamp Forest) and PC II (Alan Swamp Forest) as was studied by Anderson (1961; 1963 and 1983) and Paramanathan (2011).

7) In general, there is a mixed or a combination of organic matter Types II and III (kerogen) occurring within the tropical lowland peat basin surface and that these lateral

variations in organic matter types may support the lateral vegetation variation concept (Anderson 1961; 1963; 1983 and Paramanathan, 2011). Hence, lateral vegetation succession, PC zonation and organic matter types II and III (kerogen) are probably associated in tropical lowland peat domes. And also, this study indicates that these organic matter types (based on SRA-HI) that occur from basin periphery to mid section and further towards basin centre are of organic matter type II to type III and again to type II (kerogen), respectively.

6.3 Biomarkers and depositional environment characteristics concluded from GCMS analyses of peat samples

The hopanes are the dominant pentacyclic (Waples and Machihara, 1991) triterpanes in the peat alkane fraction of samples KS.TP.02, KS.TP.08 and KS.TP.09 sampled from basin periphery to mid section and then further towards the centre of a tropical lowland peat basin (Plaie peat forest), in the Kota Samarahan-Asajaya area. The peats with biomarker hopane compounds have 13 to 33 carbon atoms that may extend up to 39 carbon atoms and these all show odd over even predominance. Hopane peaks in the peats maximize at n-C_{29} (near basin margin), n-C_{31} (mid-section) and n-C_{27} (near to the basin centre).

Pr/Ph ratios for the peats located from margin (moat area) to midsection and further towards the centre of the peat basin/dome varies slightly from 0.97 to 1.0 and again 1.0, respectively, corresponding to probably anoxic (margin) to suboxic (midsection) and again suboxic (near basin centre) depositional environmental conditions. Near the relatively 'wetter' margin area or the 'moat area' of the peat dome, the Pr/Ph ratio is slightly <1 and indicates a relatively more anoxic environment of deposition for the peats due to relatively higher groundwater tables, and relatively more aquatic/subaquoes conditions with relatively lower elevations near the margin/periphery of the peat dome. From the midsection towards the peat basin centre, the pristane/phytane ratios (=1) are both in the range of 1 to 3 and are indicative of a relatively more suboxic environment of deposition and relatively less aquatic/subaqueous conditions with relatively deeper/lower groundwater tables due to the relatively slightly increasing, elevations from midsection and further towards the peat dome centre.

The Pr/n-C_{17} and Ph/n-C_{18} ratios for the peat samples from periphery to midsection and further towards the dome centre are relatively low and this indicates and supports the anoxic to suboxic, still reducing depositional environmental conditions for the wet, tropical lowland peats.

The S/(S+R) ratios for the peat samples from periphery to midsection and further towards the dome centre are relatively low, indicating and supporting the immaturity of the peats in terms of hydrocarbon production. In addition, the presence of ββ hopanes also supports and indicates immaturity.

All the samples have hopanes containing ββ C30 hopane (17 β, 21β (H)-Hopane) and ββ C31 hopane (17β, 21β (H)-Homohopane) with the 17β (H), 21β (H) configuration (ββ hopanes) which are usually present in very immature samples. The other common hopanes present in all the samples are C29 hopane (Norhopane), 22Sαβ C31 hopane (17α, 21β (H)-Homohopane, S-configuration) and 22Rαβ C31 hopane (17α, 21β (H)-Homohopane, R-configuration).

6.4 Inferred vegetation succession (peat phasic communities) and related depositional environments concluded from pollen analyses

From field identification and von Post classification as well as pollen analyses of the augered peat samples (KS.TP.09 to KS.TP.10) at the western peat forest of the study area, the findings could be summarized as follows:

1) Field identification and classification (von Post) of the vertical, top to the bottom peat layer on the tropical lowland peat dome in the western part of the study area shows that there is a vertical variation of peat humification levels (von Post) for every 0.5 m interval, in the form of dominantly occurring decomposition levels of hemic to sapric (H6 to H7), hemic (H5 to H6), hemic (H4 to H6) and fibric to hemic (H3 to H5), respectively, at KS.TP.10; and sapric (H7 to H8), hemic to sapric (H6 to H7) and hemic (H5 to H6), respectively, at location KS.TP.09, with both profiles generally indicating a vertical decrease of humification levels with peat depth.

2) The proposed Phasic Communities inferred vegetational zonation that was observed to occur vertically, from the top to the bottom of the studied auger peat profiles near the centre of the tropical lowland peat dome are Phasic Community II (Alan or Alan Batu Swamp Forest), Phasic Community I (Mixed Peat Swamp Forest) followed by the underlying transitional mangrove to shallow peat swamp, respectively.

3) Based on pollen analyses and field observations, it can be concluded that most of the studied peat profiles from locations KS.TP.10 and KS.TP.09 were part of a progradational deltaic succession whereby a mangrove swamp environment was progressively replaced by a floodplain or floodbasin depositional environment followed by a peat swamp environment. The peat swamp phasic communities inferred vegetation succession ranges from a transitional mangrove to shallow peat swamp environment (or shallow/marginal peats) to a normal open swamp phasic community I (Mixed Peat Swamp Forest) that may extend up to phasic community II (Alan Swamp Forest). In addition, field observations and the presence of large, hollow, scattered *Shorea* type trees, supports that the surface, vegetational zonation of the studied tropical lowland peat dome may have reached Phasic Community II, at the least. In addition, there are pollen types that are found to occur that are also abundant in PC III and PC IV or successively higher, from pollen evidence and analyses, as was previously reported by Anderson and Muller (1975).

4) It is interpreted that the depositional environment at the location of the profile seems to commence on a mangrove swamp environment which, due to a continued regression of sea levels, gave rise to a more inland mangrove swamp environment with an increased riparian influence. Peat then starts to develop in a transitional mangrove to floodplain (or floodbasin) depositional environment, and was followed by a shallow, topogenic peat depositional environment at approximately 2420 ± 30 years B.P. This shallow/marginal topogenic peat swamp assemblage with a riparian influence then started to develop with an inferred peat vegetational succession (Anderson and Muller, 1975) reaching phasic community I (at approximately 2380 ± 30 years B.P.) and phasic community II (approximately 1780 ± 30 years ago till present time), towards the upper part of the present ombrogenic peat profile.

5) It is concluded from pollen analyses of the auger core profiles of both KS.TP.10 and KS.TP.09, that estuarine and deltaic, brackish to saline water influence may have gradually ceased at approximately 0.5 metres below the lithological boundary between peat and soil. This is supported and indicated from field and sample observations of yellow coloured jarosite minerals that also cease to occur above this level. As a result, this approximately 0.5 m thick soil (or slightly organic to organic soil) layer (above the mentioned lithological boundary) consisting of floodplain or floodbasin deposits (and laying between the peat and estuarine/deltaic deposits), was increasingly deposited by flooding river waters after or with the gradual decline of mangrove or estuarine influence due to receding sea levels, and was later followed or overlain by peat deposition, usually in low-lying back-levee depressions/basins. In these basins, vegetation plant succession occurred together with the deposition and accumulation of topogenous peats followed sometimes by thicker, ombrogenous peats (in some basins) to form the present, domed deposits with elevated centres.

6) From the initial age of deposition of 2420 ± 30 years B.P (for transitional peats) to 1780 ± 30 years B.P (for the upper peat layer of Alan Batu Swamp Forest/PC II), the possible approximate average rate of peat deposition in the Kota Samarahan-Asajaya study area for the period stated above would be probably 1 metre (100 cm) of peat accumulated over a period of 320 ± 30 years (B.P).

6.5 Proposed Soil Family and Soil Series Names by the key classification method of tropical lowland peats

From this study, 2 new Soil Family and 5 new Soil Series names or classifications were assigned and proposed for tropical lowland peats occurring in the

Kota Samarahan-Asajaya study area by adapting the Key classification method proposed by Paramananthan (2011). The proposed Soil Family classification names are MUARA TUANG and SAMARAHAN. The proposed Soil Series names are Muara Tuang, Meretuang, Samarahan, Samarahan 2 and Samarahan 3.

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APPENDICES

APPENDIX A: KEY TO THE IDENTIFICATION OF HIGHLAND AND LOWLAND SOILS (SEE FIGURE A1 AND TABLE A1) (Paramananthan, 2011)

According to Paramananthan (2011), areas with an elevation of >750 m or 2,250 feet are considered to have Highland Soils as they have isothermic or cooler soil temperature regime and perudic soil moisture regime. The areas designated as Highland Soils (elevation >750 m) are not necessarily all considered steepland (slopes >25° or 50%). Similarly some areas with Lowland Soils (<750 m) can also contain steepland.

HIGHLAND SOILS

This Key (Table A1) is tentative and is not fully developed as very little soil mapping has been done in these areas. Most of these areas are steepland. In the identification of these soils, a broad grouping of the soils using climatic regimes and seven parent material groups is initially made. Then the dominant soil order in each climatic regime over the parent material group is identified. Only the soil series identified to-date are named in this table.

Table A1. Key to the identification of Highland soils of Malaysia (Paramananthan, 2011).

Climatic Regime	Isomesic/Perudic (>1,750 metres asl.)				Isothermic/Perudic (1,500-1,750 metres asl.)		Isothermic/Perudic (750-1,500 metres asl.)			
Soil Order	**Histosols (Folists/Gambists)**		**Lithosols**	**Spodosols**	**Spodosols**	**Andisols**	**Ultisols**		**Inceptisols**	**Entisols**
Other Properties / Parent Material/Rock	**Ombro (>150 cm)**	**Topo (<150 cm)**			**Histic epipedon Episaturation**		**Deep humus rich kandic/ argillic horizon**	**Moderately deep humus rich kandic/ argillic horizon**	**Umbric**	
Acid Igneous Rocks		Brinchang (sa) Ulu Kali (te)(placic)	Kinabalu	Gunong Padang (placic) Mesilau (placic)	Tanah Rata		Ringlet Nibong Selio (imp)		Mantaki	
Basic/Intermediate Igneous Rocks										
Ultrabasic Igneous Rocks										
Sedimentary (s) Metasediment (m) Tuffs (tu)	s Bareo (fi)	s Kaintano (te) s Umor (fi)			s Pa Sia m Tiang tu Bamun		tu Temenggor	s Gunung Alab/imp s Kiau m Manggar	tu Mujan	
Calcareous Rocks		Mulu (moss)								
Volcanic Ash						Apau				
Colluvium/Accreting Alluvium										Tumau (histic)

Paramananthan, Jan 2011

KEY:

Climatic regimes
- isomesic = mean annual soil temperature 8-15°C with seasonal variation <5°C
- isothermic = mean annual soil temperature 15-22°C with seasonal variation <5°C
- isohyperthermic = mean annual soil temperature >22°C with seasonal variation <5°C
- perudic = soil moist throughout year
- udic = soil is moist for > 9 months in 6 years out of ten

Organic soil materials
- sa = sapric
- fi = fibric
- te = terric
- moss = moss

Diagnostic horizon
- placic = placic

Variants
- imp = imperfectly drained

Table A2. Key to the identification of Lowland organic soils of Malaysia (Paramananthan, 2011).

Depth of Organic Soil Materials	Soil Moisture Regime	Poorly Drained (Aquic) — GAMBIST								
	Dominant Material in sub-surface Tier / Nature of Under-lying Substratum / Mineral Materials	Sapric			Hemic			Fibric		
		Non Woody	Wood Decom -posed	Wood Unde-compos-ed	Non Woody	Wood Decom-posed	Wood Unde-compos-ed	Non Woody	Wood Decom-posed	Wood Unde-compos-ed
Shallow (50-100 cm) and Moderately Deep (100-150 cm) TOPOGAMBISTS	Marine Clay Sulfidic (> 15% clay)	PENOR			BAKRI			MERAPOK		
		Penor			Nipis	Bakri			Merapok *Mahat*	
	Marine Clay (> 15% clay)	LINGGI			EPAI			MUKAH		
		Linggi		Trus			Epai		Mukah	Bino
	Marine Sand Calcareous (< 15% clay)	MENGALUM								
		Mengalum								
	Marine Sand Sulfidic (<15% clay)	LONG PUTAT								
		Long Putat								
	Marine Sand (< 15% clay)	BARAM						IGAN		
		Baram	Kabala	Simalau					Igan	
	Riverine/Colluvial Clay (> 15% clay)	ERONG			GALI			CHANGKAT LOBAK		
		Erong				Gali		Changkat Lobak		
	Riverine/Colluvial Sand (< 15% clay)				PAK BONG					
					Pak Bong					
Deep (150-300) and Very Deep (>300 cm) OMBROGAMBISTS	Marine Clay Sulfidic (> 15% clay)	PRIMALUCK			PONTIAN			KLIAS		
		Primaluck		Teraja		Pontian		Arang	Klias *Luk*	
	Marine Clay (> 15% clay)	NAMAN			BAYAS			ANDERSON		
		Naman	Retus	Kenyana		Bayas	Gedong			Anderson
	Marine Sand Calcareous (< 15% clay)									
	Marine Sand Sulfidic (<15% clay)									

	Marine Sand (< 15% clay)	TELONG			ADONG					
			Telong	Suai		Adong	Alan			
	Riverine/Colluvial Clay (> 15% clay)	LIKU			GONDANG			SALLEH		
		Liku		Karap		Gondang	Taniku		Salleh	Tinjar
	Riverine/Colluvial Sand (< 15% clay)	KABOK								
			Kabok							

KEY: BAYAS Soil Family; Bayas Soil Series; *Luk* = allochthonous

LOWLAND SOILS

The subdivisions of lowland soils are as provided below.

- Organic soils
  - Soils in which the thickness of organic soil layers make up more than half the soil to 100 cm or shallower if rocks or parent materials occur at less than 100 cm.
  - These soils are sub-divided based on their thickness.
- *In situ* soils
  - These soils are developed over *in situ* parent materials/rocks. However, soils with iron-coated parent material or lateritic gravels/stones and quartz gravels are excluded from this group.
  - Sub-divided according to the origin of the underlying parent rock–igneous rocks/sedimentary, metamorphic calcareous rocks and tuffs.
- Skeletal Soils
  - These soils are with more than 35% by volume of coarse fragments (> 2 mm diameter), forming a horizon >25 cm thick with its upper boundary within the 100 cm depth.

- The coarse fragments can consist of quartz, iron-coated parent materials or ironstone (lateritic) in origin.

- Alluvial Soils
  - These are soils usually developed over alluvial deposits.
  - **Older alluvium**: Normally occurs on gently rolling hills or at elevations of 100 feet (>30 m). Valleys between these low hills are ‘U’ shaped and broad. Colours in these soils get paler with depth and rounded water-worn pebbles (parent material) occur at different depths. These soils can also be confused with soils over conglomerate but in these soils colour becomes redder with depth and the valleys are ‘V’-shaped.
  - **Sub-recent non-accreting alluvium and colluvium**: These soils normally occur on gently undulating to level terrain at elevations of 50-100 feet (15-30 m). Termite mounds are common on such terrain. These terraces are usually associated with old rivers and mostly occur away from large rivers. Red mottles are common in these soils due to a fluctuating watertable. Drainage classes and textural classes are used to separate these soils.
  - **Recent accreting alluvium**: These are soils formed on recent floodplains of the larger rivers, occur on level terrain and are widely used for wetland rice cultivation. Depending on the type of the surrounding hills, mica flakes may be present. Manganese nodules or specks are common in these soils. Lithologic discontinuities are common below 50 cm of depth.
  - **Beach deposits**: These are deposits often referred to as Bris Soils – Beach ridges interspersed with swales. The sandy deposits often form ridges while the swales are variable ranging from sand, clay and even organic.

– **Sulfidic materials/Sulfuric horizon**: These soils are marine or brackish water sediments (clays or sands rich in iron sulfides (Fe_2S) characterized by their hydrogen sulfide (rotten eggs) smell. When these soils are drained the sulfides are oxidized to sulfuric acid and yellow jarosite mottles appear and the soil pH drops to <3.5 (sulfuric horizon). To be considered significant the sulfidic materials or the sulfuric horizon must occur within 100 cm of the soil surface.

– **Marine alluvium, estuarine and brackish water deposits**: These are soils usually formed near the coast or adjacent to peat swamps. Like the sulfidic materials they were waterlogged but are now drained for cultivation.

LOWLAND ORGANIC SOILS

The Key to the identification of lowland organic soils is given in Table A2. The criteria used to separate these soils is outlined in the control section (Figure A1) and explained below. The thickness, material in the subsurface tier/underlying substratum and reaction class are used as criteria at the different categoric levels and are as summarised in Table A3. Table A4 presents the proposed names (highlighted) of soil series and soil families of peats characterized in this study with their related classification criteria by using the Key method mentioned.

Thickness of Organic Soil Materials

- Thick > 150 cm – Ombro
- Thin 50-150 cm – Topo

Dominant materials in Subsurface Tier

- **Sulfuric:** presence of yellow jarosite mottles and pH <3.5

- **Sulfidic materials:** rich in sulfides, smell of rotten eggs
- **Terric:** mineral soil materials
- **Sapric:** highly decomposed organic soil materials
- **Hemic:** partly decomposed organic soil materials
- **Typic (fibric):** undecomposed organic soil materials
- **Lithic:** rock

Nature of Underlying Substratum	–	self explanatory
Reaction Class	–	self explanatory
Wood	–	presence of >10% of logs and stage of decomposition
Mode of origin	–	allochtohonous: organic deposits which have been transported and redeposited.

Table A3: Criteria used at different categoric levels.

CATEGORIC LEVEL	CRITERIA USED	EXAMPLE
ORDER	• Minimum cumulative thickness of 50 cm within 100 cm or more than half to lithic/paralithic or terric layer	HISTOSOLS
SUB-ORDER	• Drainage Class – poor, well	GAMBIST – poorly drained FOLIST – well drained
GREAT GROUP	• Thickness of organic layer – Ombro: >150 – Ombro – Topo: 50-150 – Topo	Ombrogambist Topogambist
SUB-GROUPS	• Dominant in sub-surface (50-100 cm) tier – Terric, Sapric, Hemic, Typic (Fibric)	Hemic Topogambist Sapric Ombrogambist
FAMILY	• Nature of substratum – marine clay/sand – riverine clay/sand • Soil temperature regime – isohyperthermic/isomesic	BARAM FAMILY ADONG FAMILY
SOIL SERIES	• Presence and nature of wood – no wood – wood decomposed – wood undecomposed • Mode of origin autochthonour/allochthonous	**Baram Series:** Sapric Topogambist, marine-sandy, isohyperthernic, non-woody, autochthonous. **Adong Series:** Hemic Ombrogambist, marine-sandy, isohyperthermic, decomposed wood, autochthonous.
PHASE	• Depth – shallow: 50-100 cm – moderately deep: 100-150	Baram/shallow Baram/moderately deep Adong/deep

CATEGORIC LEVEL	CRITERIA USED	EXAMPLE
	cm – deep: 150-300 cm – very deep: 300+ cm	Adong/very deep

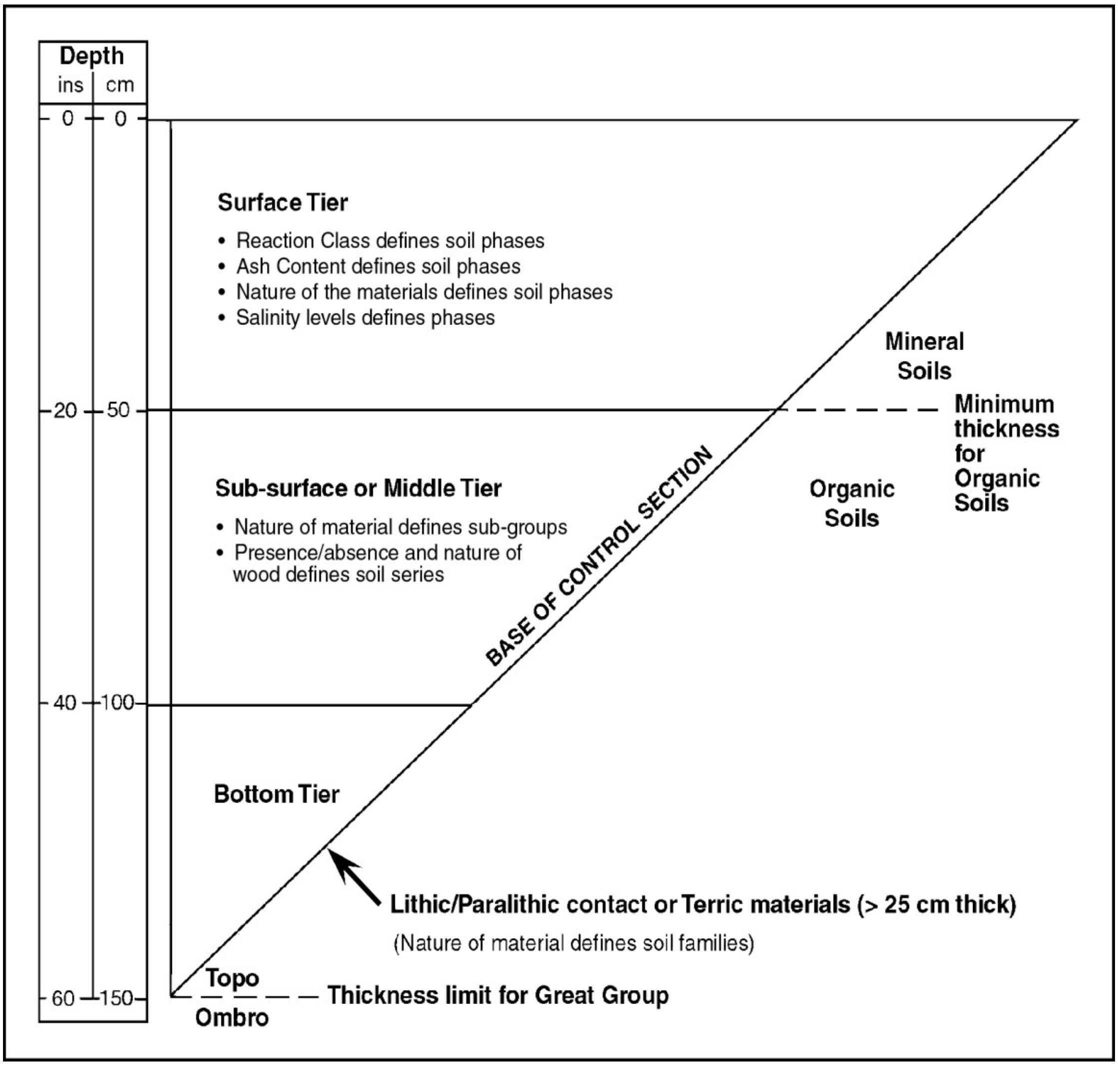


Figure A1: Control section for organic soils of Malaysia (after Paramananthan *et al.*, 1984).

Table A4: Keys to the identification of Lowland Peats (Gambists) (Paramananthan, 2011) and proposed classification for peats in the Kota Samarahan-Asajaya study area.

Depth of Organic Soil Materials	Soil Moisture Regime	Poorly Drained (Aquic) — GAMBIST								
	Dominant Material in Subsurface (50–100 cm) / Nature of Underlying Tier Substratum/ Mineral Materials	Sapric			Hemic			Fibric		
		Non Woody	Wood Decomp-osed	Wood Undeco-mposed	Non Woody	Wood Decomp-osed	Wood Undeco-mposed	Non Woody	Wood Decomp-osed	Wood Undeco-mposed
Shallow (50-100 cm) and Moderately Deep (100-150 cm) TOPOGAMBISTS	Marine Clay Sulfidic (> 15% clay)	PENOR			BAKRI			MERAPOK		
		Penor			Nipis	Bakri			Merapok *Mahat*	
	Marine Clay (> 15% clay)	LINGGI			EPAI			MUKAH		
		Linggi		Trus			Epai		Mukah	Bino
	Marine Sand Calcareous (< 15% clay)	MENGALUM								
		Mengalum								
	Marine Sand Sulfidic (<15% clay)	LONG PUTAT								
		Long Putat								
	Marine Sand (< 15% clay)	BARAM						IGAN		
		Baram	Kabala	Simalau					Igan	
	Riverine/Colluvi-al Clay (> 15% clay)	ERONG			GALI			CHANGKAT LOBAK		
		Erong	Muara Tuang			Gali		Changkat Lobak		
	Riverine/Colluvi-al Sand (< 15% clay)	MUARA TUANG			PAK BONG					
			Meretuang		Pak Bong	Samarahan 2				
Deep (150-300) and Very Deep (>300 cm) OMBROGAMBISTS	Marine Clay Sulfidic (> 15% clay)	PRIMALUCK			PONTIAN			KLIAS		
		Primaluck		Teraja		Pontian		Arang	Klias *Luk*	
	Marine Clay (> 15% clay)	NAMAN			BAYAS			ANDERSON		
		Naman	Retus	Kenyana		Bayas	Gedong			Anderson
	Marine Sand Calcareous (< 15% clay)									
	Marine Sand Sulfidic (<15% clay)									
	Marine Sand (< 15% clay)	TELONG			ADONG					
			Telong	Suai		Adong	Alan			
	Riverine/Colluvi-al Clay (> 15% clay)	LIKU			GONDANG			SALLEH		
		Liku	Samarahan 3	Karap		Gondang	Taniku		Salleh	Tinjar
	Riverine/Colluvi-al Sand (< 15% clay)	KABOK			SAMARAHAN					
			Kabok			Samarahan				

KEY: BAYAS Soil Family; Bayas Soil Series; *Luk* = allochthonous

From this study, 2 new Soil Family and 5 new Soil Series classifications were proposed and assigned as are shown and highlighted in Table A4 above.

APPENDIX B: DETAILED SAMPLE, AUGER HOLE AND TEST TYPE LOCATION MAPS

This section will provide detailed location maps for samples, augerholes, sample test types along with peat isopach and peat thickness data for this study. The maps presented are in figures:

Figure B1: Detailed geological, peat thickness (range) and auger sample location map.

Figure B2: Sample number according to test type location map

Figure B3: Map with symbol legend showing type of tests done according to sample location.

Figure B4: Sample location with proposed peat isopach map

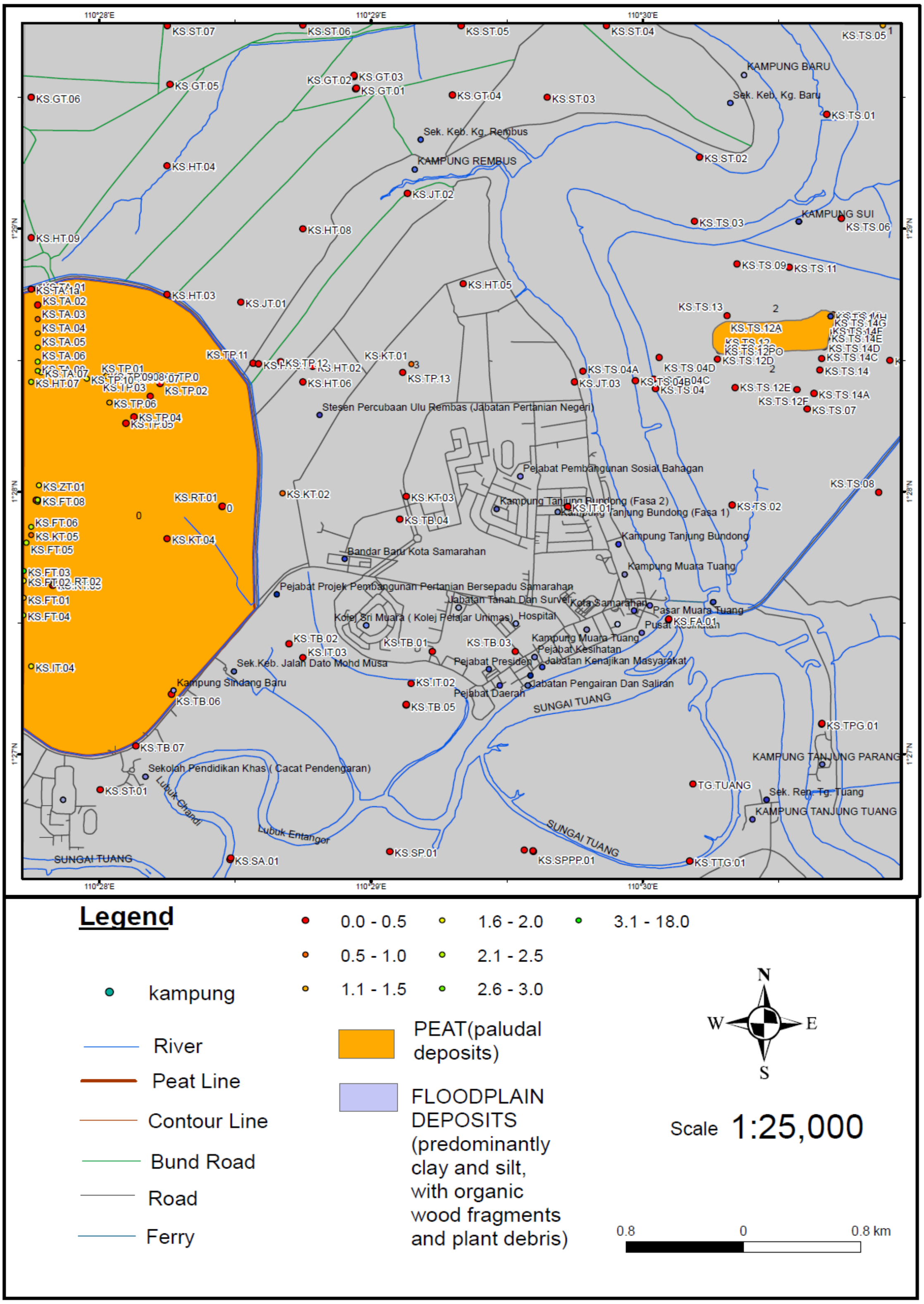
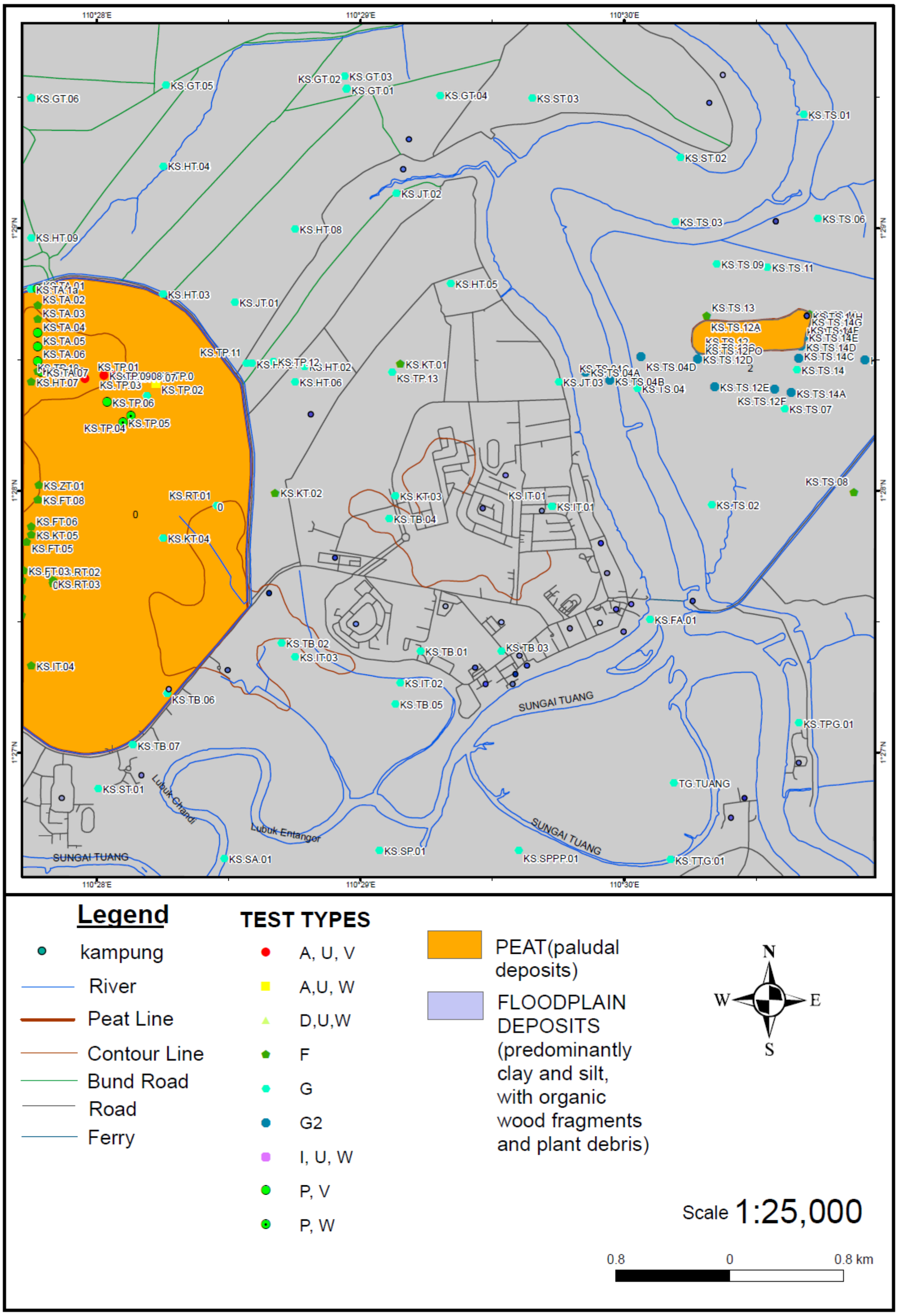


Figure B1: Detailed geological, peat thickness (range in metres) and auger sample location map.



SYMBOL LEGEND FOR TEST TYPES (FIGURE B2):

A	LOGGING	VON POST CLASSIFICATION	STABILIZATION TESTS (UCS)	SRA	GCMS	POLLEN ANALYSES	
D	LOGGING	VON POST CLASSIFICATION	STABILIZATION TESTS (UCS)				
F, G	LOGGING	VON POST CLASSIFICATION					

		(for peats/organic soils only)					
I	LOGGING	VON POST CLASSIFICATION		SRA			
P	LOGGING	VON POST CLASSIFICATION	ORGANIC MATTER	NMC	ASH CONTENT		
U			ORGANIC MATTER	NMC	ASH CONTENT		
V						SOIL CLASSIF.	
W						ENG. CLASSIF.	
G2							AUGER CHECK

NOTES:

UCS=Unconfined Compression Test

SRA=Source Rock Analyses

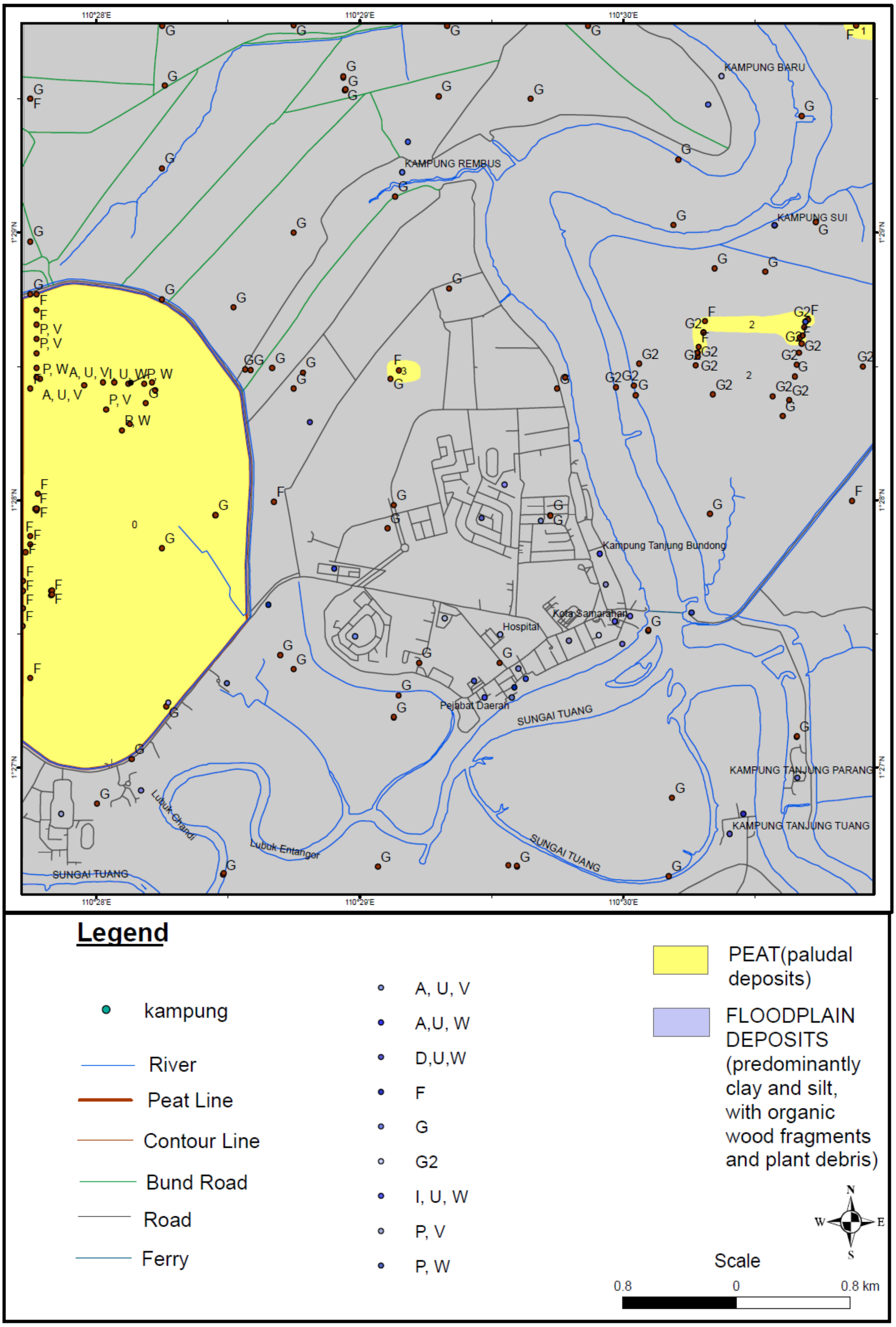
GCMS=Gas Chromatography Mass Spectrometry

SOIL CLASSIF.=Soil Science Classification (Paramananthan, 2011)

ENG CLASSIF.=conventional Geotechnical/ Civil Engineering Classification

SOIL & ENG. CLASSIF.= Soil Science Classification (Paramananthan, 2011) and conventional Geotechnical/ Civil Engineering Classification

Figure B2: Sample number according to test type and location map



SYMBOL LEGEND FOR TEST TYPES (FIGURE B3):

A	LOGGING	VON POST CLASSIFICATION	STABILIZATION TESTS (UCS)	SRA	GCMS	POLLEN ANALYSES	
D	LOGGING	VON POST CLASSIFICATION	STABILIZATION TESTS (UCS)				

F, G	LOGGING	VON POST CLASSIFICATION (for peats/organic soils only)					
I	LOGGING	VON POST CLASSIFICATION		SRA			
P	LOGGING	VON POST CLASSIFICATION	ORGANIC MATTER	NMC	ASH CONTENT		
U			ORGANIC MATTER	NMC	ASH CONTENT		
V						SOIL CLASSIF.	
W						ENG. CLASSIF.	
G2							AUGER CHECK

NOTES:

UCS=Unconfined Compression Test

SRA=Source Rock Analyses

GCMS=Gas Chromatography Mass Spectrometry

SOIL CLASSIF.=Soil Science Classification (Paramananthan, 2011)

ENG CLASSIF.=conventional Geotechnical/ Civil Engineering Classification

SOIL & ENG. CLASSIF.= Soil Science Classification (Paramananthan, 2011) and conventional Geotechnical/ Civil Engineering Classification

Figure B3: Map with symbol legend showing type of tests done according to sample location.

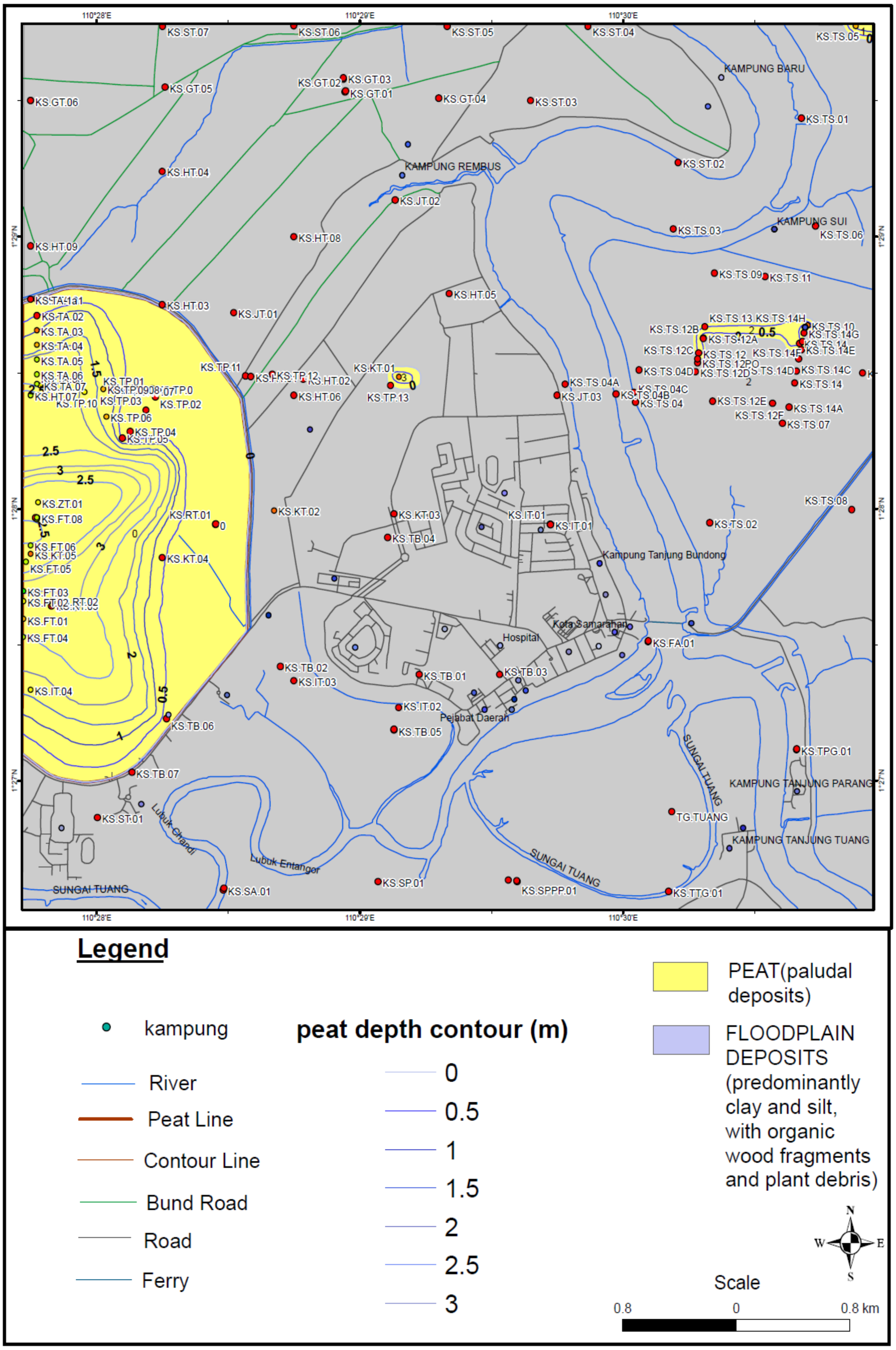


Figure B4: Sample location with proposed peat isopach map

APPENDIX C

C.1 Carbon dating laboratory particulars and quotation for ^{14}C analyses:

SUERC Radiocarbon Lab

Prices 1,473.11 MYR

Commercial Analysis Costs

AMS ^{14}C ANALYSIS - £290 + VAT per sample

This price is fixed for all sample types and batch sizes and includes correction for isotopic fractionation (delta ^{13}C measurement) of the sample and calibration of the conventional ^{14}C age to the calendar time-scale. The turnaround time for the analysis varies between 4 and 10 weeks. A more precise estimate is given when we are acknowledging receipt of samples.

FAST TURNAROUND AMS ^{14}C ANALYSIS - £490 + VAT per sample.

The turnaround time for this service is two weeks.

We can also provide δ ^{15}N, δ ^{18}O, ^{210}Pb and ^{87}Sr/ ^{86}Sr analyses. Prices are given upon enquiry.

SUERC Consortium Universities

Reduced rates are available to staff in the SUERC Consortium Universities who are undertaking research.

For further information, e-mail Professor Gordon Cook or Philip Naysmith.

Alternatively, telephone or write to Professor G Cook (details below).

Scottish Universities Environmental Research Centre
Rankine Avenue, Scottish Enterprise Technology Park
East Kilbride, G75 0QF, Scotland, UK
Telephone: 01355 223332
Direct Dial: 01355 270136
Fax: 01355 229898

C.2 Sent AMS ^{14}C Sample particulars

Table C1: Sample particulars

Name	Institute	Address	Area	Sample Code	Sample Type	Samples accepted/rejected
Mohamad Tarmizi Mohamad Zulkifley	Geology Department, Faculty of Science, University of Malaya.	Geology Department, Faculty of Science, University of Malaya, Lembah Pantai Road, 59100, Kuala Lumpur , Malaysia.	Kota Samarahan-Asajaya, West Sarawak, Malaysia	KS.TP.10 (0-0.5m)	Peat	accepted
Mohamad Tarmizi Mohamad Zulkifley	Geology Department, Faculty of Science, University of Malaya.	Geology Department, Faculty of Science, University of Malaya, Lembah Pantai Road, 59100, Kuala Lumpur , Malaysia.	Kota Samarahan-Asajaya, West Sarawak, Malaysia	KS.TP.10 (0.5-1.0m)	Peat	accepted
Mohamad Tarmizi Mohamad Zulkifley	Geology Department, Faculty of Science, University of Malaya.	Geology Department, Faculty of Science, University of Malaya, Lembah Pantai Road, 59100, Kuala Lumpur , Malaysia.	Kota Samarahan-Asajaya, West Sarawak, Malaysia	KS.TP.10 (1.5-2.0m)	Peat	accepted
Mohamad Tarmizi Mohamad Zulkifley	Geology Department, Faculty of Science, University of Malaya.	Geology Department, Faculty of Science, University of Malaya, Lembah Pantai Road, 59100, Kuala Lumpur , Malaysia.	Kota Samarahan-Asajaya, West Sarawak, Malaysia	KS.TP.10 (3.0-3.5m)	Silt	Rejected (insufficient organic carbon)
Mohamad Tarmizi Mohamad Zulkifley	Geology Department, Faculty of Science, University of Malaya.	Geology Department, Faculty of Science, University of Malaya, Lembah Pantai Road, 59100, Kuala Lumpur , Malaysia.	Kota Samarahan-Asajaya, West Sarawak, Malaysia	KS.TP.10 (5.5-6.0m)	Silt	Rejected (insufficient organic carbon)
Mohamad Tarmizi Mohamad Zulkifley	Geology Department, Faculty of Science, University of Malaya.	Geology Department, Faculty of Science, University of Malaya, Lembah Pantai Road, 59100, Kuala Lumpur , Malaysia.	Kota Samarahan-Asajaya, West Sarawak, Malaysia	KS.TP.02 (0.2-0.5m)	Organic Soil	Rejected (insufficient organic carbon)
Mohamad Tarmizi Mohamad Zulkifley	Geology Department, Faculty of Science, University of Malaya.	Geology Department, Faculty of Science, University of Malaya, Lembah Pantai Road, 59100, Kuala Lumpur , Malaysia.	Kota Samarahan-Asajaya, West Sarawak, Malaysia	KS.TP.02 (1.0-1.5m)	Silt	Rejected (insufficient organic carbon)

Mohamad Tarmizi Mohamad Zulkifley	Geology Department, Faculty of Science, University of Malaya.	Geology Department, Faculty of Science, University of Malaya, Lembah Pantai Road, 59100, Kuala Lumpur , Malaysia.	Kota Samarahan-Asajaya, West Sarawak, Malaysia	KS.TP.02 (5.5-6.0m)	Silt	Rejected (insufficient organic carbon)

C.3 Results and certificate details of accepted samples that were analysed or radiocarbon dated

Scottish Universities
Environmental Research Centre

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RADIOCARBON DATING CERTIFICATE

19 December 2011

Laboratory Code	SUERC-37423 (GU25688)
Submitter	Mohamad Tarmizi Mohamad Zulkifley Geology Department, Faculty of Science University of Malaya lembah Pantai Road, 59100 Kuala Lumpur, Malaysia
Site Reference	Kota Samarahan-Asjaya, West Sarawak, Malaysia
Context Reference	n/a
Sample Reference	KS.TP.10 (0-0.5m)
Material	Peat : n/a
$\delta^{13}C$ relative to VPDB	-29.5 ‰

Radiocarbon Age BP 1780 ± 30

N.B. The above ^{14}C age is quoted in conventional years BP (before 1950 AD). The error, which is expressed at the one sigma level of confidence, includes components from the counting statistics on the sample, modern reference standard and blank and the random machine error.

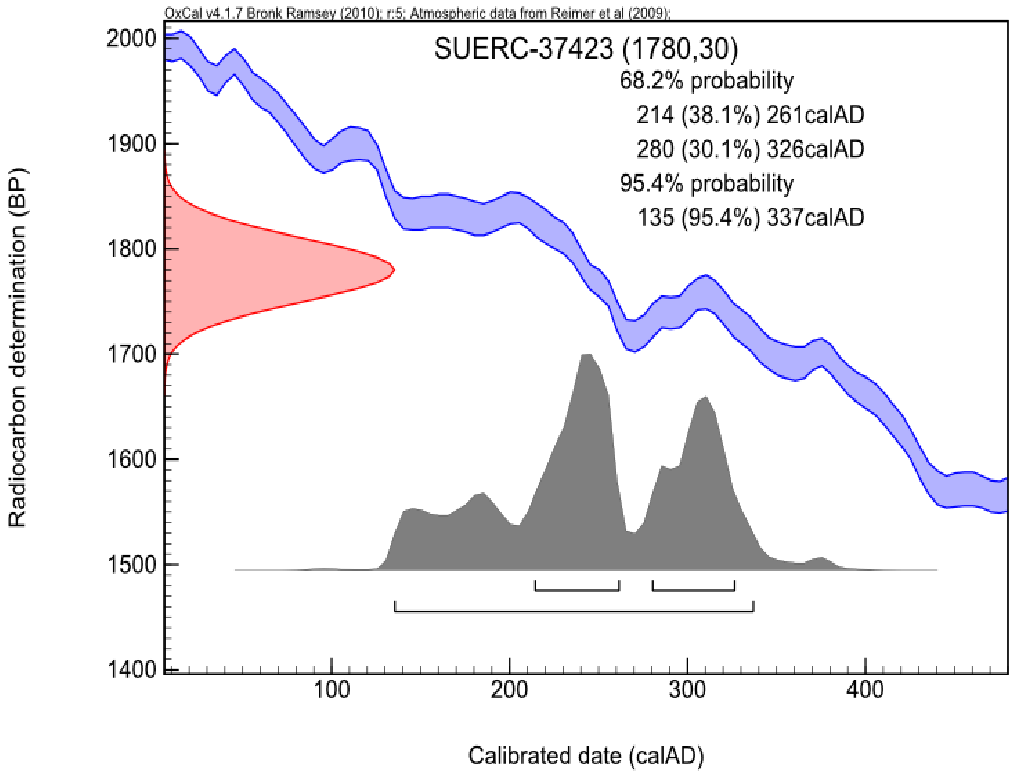
The calibrated age ranges are determined from the University of Oxford Radiocarbon Accelerator Unit calibration program (OxCal4).

Samples with a SUERC coding are measured at the Scottish Universities Environmental Research Centre AMS Facility and should be quoted as such in any reports within the scientific literature. Any questions directed to the Radiocarbon Laboratory should also quote the GU coding given in parentheses after the SUERC code. The contact details for the laboratory are email g.cook@suerc.gla.ac.uk or Telephone 01355 270136 direct line.

Conventional age and calibration age ranges calculated by :- Date :-

Checked and signed off by :- Date :-

Calibration Plot



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RADIOCARBON DATING CERTIFICATE

19 December 2011

Laboratory Code	SUERC-37424 (GU25689)
Submitter	Mohamad Tarmizi Mohamad Zulkifley Geology Department, Faculty of Science, University of Malaya, Lembah Pantai Road, 59100, Kuala Lumpur, Malaysia.
Site Reference	Kota Samarahan-Asjaya, West Sarawak, Malaysia
Context Reference	n/a
Sample Reference	KS.TP.10 (0.5- 1.0m)
Material	Peat : n/a

$\delta^{13}C$ relative to VPDB -29.2 ‰

Radiocarbon Age BP 2380 ± 30

N.B. The above ^{14}C age is quoted in conventional years BP (before 1950 AD). The error, which is expressed at the one sigma level of confidence, includes components from the counting statistics on the sample, modern reference standard and blank and the random machine error.

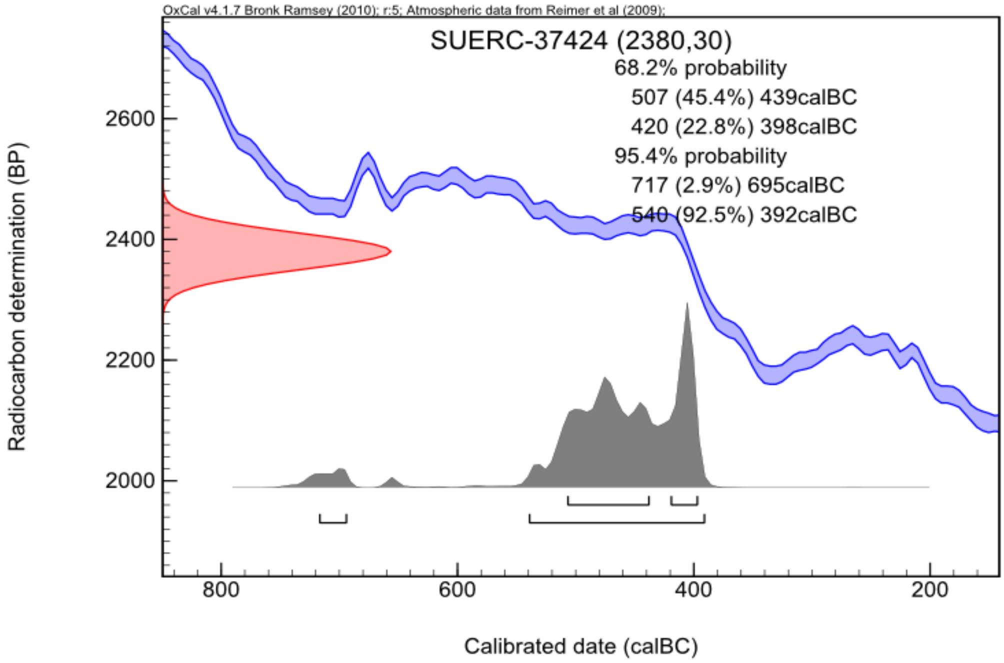
The calibrated age ranges are determined from the University of Oxford Radiocarbon Accelerator Unit calibration program (OxCal4).

Samples with a SUERC coding are measured at the Scottish Universities Environmental Research Centre AMS Facility and should be quoted as such in any reports within the scientific literature. Any questions directed to the Radiocarbon Laboratory should also quote the GU coding given in parentheses after the SUERC code. The contact details for the laboratory are email g.cook@suerc.gla.ac.uk or Telephone 01355 270136 direct line.

Conventional age and calibration age ranges calculated by :- Date :-

Checked and signed off by :- Date :-

Calibration Plot



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RADIOCARBON DATING CERTIFICATE

19 December 2011

Laboratory Code	SUERC-37426 (GU25691)
Submitter	Mohamad Tarmizi Mohamad Zulkifley, Geology Department, Faculty of Science, University of Malaya, Lembah Pantai Road, 59100, Kuala Lumpur, Malaysia.
Site Reference	Kota Samarahan-Asjaya, West Sarawak, Malaysia
Context Reference	n/a
Sample Reference	KS.TP.10 (1.5- 2.0m)
Material	Peat : n/a
$\delta^{13}C$ relative to VPDB	-27.9 ‰
Radiocarbon Age BP	2420 ± 30

N.B. The above ^{14}C age is quoted in conventional years BP (before 1950 AD). The error, which is expressed at the one sigma level of confidence, includes components from the counting statistics on the sample, modern reference standard and blank and the random machine error.

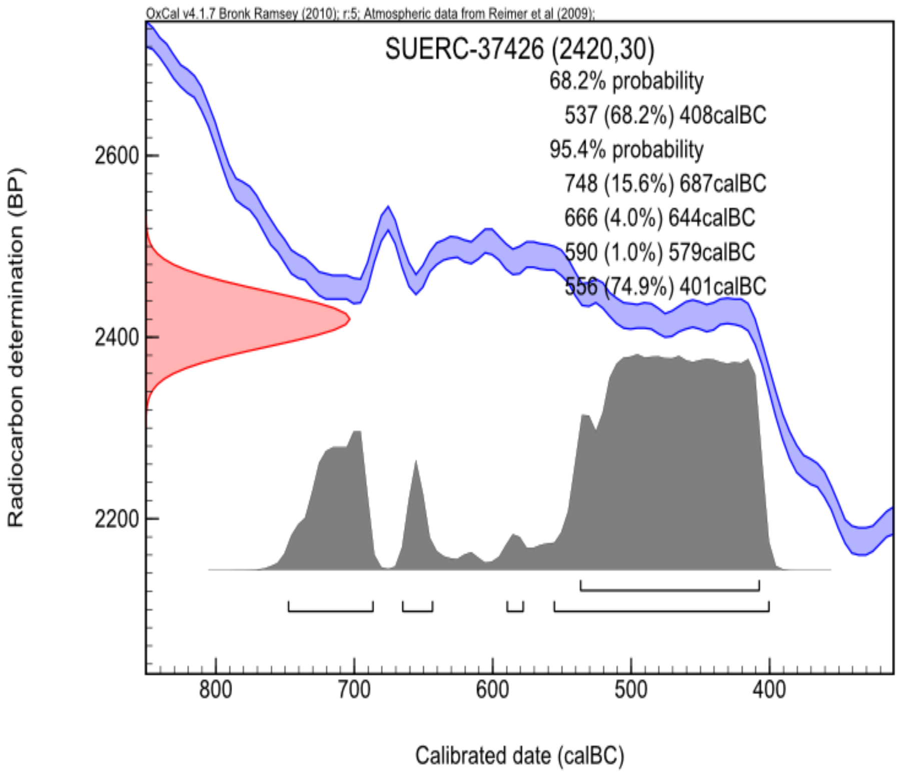
The calibrated age ranges are determined from the University of Oxford Radiocarbon Accelerator Unit calibration program (OxCal4).

Samples with a SUERC coding are measured at the Scottish Universities Environmental Research Centre AMS Facility and should be quoted as such in any reports within the scientific literature. Any questions directed to the Radiocarbon Laboratory should also quote the GU coding given in parentheses after the SUERC code. The contact details for the laboratory are email g.cook@suerc.gla.ac.uk or Telephone 01355 270136 direct line.

Conventional age and calibration age ranges calculated by :- Date :-

Checked and signed off by :- Date :-

Calibration Plot



APPENDIX D

MOISTURE CONTENT -BS1377: 1990, Test 1 (A)

The natural moisture content of peats sampled in the study area were tested and calculated according to the BS1377: 1990, Test 1 (A) British Standard method.

PEAT AND ORGANIC SOILS (GAMBUT DAN TANAH LEMBUT)

TESTS ON THE BASIC PROPERTIES OF PEAT (UJIAN SIFAT FIZIKAL ASAS GAMBUT)

MOISTURE CONTENT-BS1377: 1990, Test 1 (A) (BORANG MAKMAL UJIAN KANDUNGAN AIR)

Sample No (No Sampel):…………………………………Agency (Agensi) :…… …………………….. Sample Location (Lokasi Sampel): ………(Soil/Peat) (Tanah/Gambut)

Sample Depth (Kedalaman Sampel) (m) : …………… Name of tester (Nama Penguji):.................…………………………

Date Tested (Tarikh Diuji):………………..

Sample Code				
Can No (Nombor Bekas/Acuan)				
M1=Mass of Empty Can (Jisim Bekas Kosong) (g)				
M2=Mass of can and wet soil/peat (Jisim Bekas dan Tanah Basah/ gambut) (g)				
M3= Mass of can and dried soil/peat (Jisim Bekas dan Tanah Kering) (g)				
M4=M3-M1=Mass of dried soil/peat (Jisim Tanah Kering) (g)				
M*w*, Moisture Content (Kandungan Air)=M2-M3				
NMC, 'Natural Moisture Content'= (Mw/ M4) x 100%				
Average NMC=Total NMC /4 x 100%				

CALCULATION (KIRAAN):

Mass of dried soil/peat (oven-dried at 105^0C for 1 day for soils or oven-dried at 55^0C for 3 days for peats/organic soils=M4=M3-M1

M*w*, Moisture Content (Kandungan Air)=M2-M3

Average NMC=Total NMC /4 x 100%= ------------------------- = $\boxed{}$

APPENDIX E

TESTS ON THE BASIC PROPERTIES OF PEAT (UJIAN SIFAT FIZIKAL ASAS GAMBUT)

ORGANIC MATTER DETERMINATION LABORATORY FORM (BORANG MAKMAL UJIAN KANDUNGAN ORGANIK)

(ASTM D2974-'Standard Test Methods for Moisture, Ash and Organic Matter of Peat and Organic Soils)

Sample No (No Sampel):……………Agency (Agensi) :…… …………………..

Sample Location (Lokasi Sampel): …………………….....................………

Sample Depth (Kedalaman Sampel) (m) : ……………...........................………

Name of Tester (Nama Penguji) :…………………...…

Date Tested (Tarikh Diuji)………………...

Sample Code (Kod Sampel)				
Can No (Nombor Bekas/Acuan)				
MP=Mass of empty can (Jisim Bekas Kosong) (g)				
MPDS=Mass of can and oven-dried peat/organic soil (Jisim Bekas dan Tanah Kering) (g)				
MPA= Mass of can and ash (burnt peat/organic soil) (Jisim Bekas dan Tanah Dibakar 'Ash') (g)				
MD=Mass of oven-dried peat/organic soil (Jisim Tanah Kering) (g)				
MA=Mass of ash (Jisim Tanah Dibakar 'Ash') (g)				
MO=Mass of organic content (Jisim Kandungan Organik) (g)				
OM= Organic content (Kandungan Organik)				
Average (Purata) OM				

CALCULATION (KIRAAN):

Mass of oven-dried peat/organic soil (Jisim Tanah Kering), MD = MPDS-MP (oven-dried at 55^0C for 3 days)

Mass of ash (Jisim Tanah Dibakar 'Ash'), MA= MPA-MP (furnaced at 440 ^{0}C for 4 hours

MO, Mass of organic content (Jisim Kandungan Organik) = MD-MA

OM, Organic content
(Kandungan Organik)=(MD- MA)/ MD x 100% =

APPENDIX F: Augerlogs

Figure F1. Augerlog for KS.TA.01

KS.TA.01 (AR)	AUGER LOG FOR PEAT OCCURRENCE STUDY (Ph.D PROJECT) IN THE KOTA SAMARAHAN-ASAJAYA AREA, WEST SARAWAK.		
PROJECT	THE GEOLOGICAL OCCURRENCE OF PEAT IN THE KOTA SAMARAHAN-ASAJAYA AREA		
LOCATION	N 01⁰ 28' 46.3" E 110⁰ 27' 45.0"		
AUGERHOLE NO.	KS.TA.01AR	20/10/2011	10.25 am
GROUND WATER LEVEL	0.5m	TOP OF AUGERHOLE [(Above m.s.l)]	8.1m
RECORD BY	MOHAMAD TARMIZI BIN MOHAMAD ZULKIFLEY	CHECKED BY	MOHAMAD TARMIZI BIN MOHAMAD ZULKIFLEY

CLASSIFICATION SYMBOL		DEPTH (M)	SOIL DESCRIPTION	REMARKS
SYMBOL	GRAPHIC LOG			
Mo		0	Pale brown, soft to firm SLIGHTLY ORGANIC CLAYEY SILT Roots2-3cm long. Wood fragments 10%. Moist to wet.	10 YR 6/3.
M		0.5	Pale brown, soft to firm SLIGHTLY ORGANIC CLAYEY SILT Roots2-3cm long. Wood fragments 10%. Wet.	10 YR 6/3.
M		1	Bluish gray, soft to firm CLAYEY SILT. Wood fragments 5-10% Wet. Plastic	GLEY 2, 5/1
M		1.5	Bluish gray, soft to firm CLAYEY SILT. Wood fragments 5% Wet. Plastic	GLEY 2, 5/1
M		2	Bluish gray, soft to firm CLAYEY SILT. Wood fragments <5% Wet. Plasticity high.	GLEY 2, 5/1
M		2.5	Dark Bluish gray, soft CLAYEY SILT. Wood fragments 5-10% Very Wet. Plasticity high	GLEY 2, 4/1
M		3	Dark bluish gray, very soft CLAYEY SILT. Wood fragments 5-10% Wood fragments length <1cm. Wet	GLEY 2, 4/1
M		3.5	Dark bluish gray, soft to firm CLAYEY SILT. Wood fragments <5% Wood fragments length <1cm. Wet	GLEY 2, 4/1
M		4	Dark bluish gray, soft to firm CLAYEY SILT. Wood fragments 5-10%, length <1cm. Wet	GLEY 2, 4/1

LEGEND: Paludal Deposits/Peat; Slightly Organic Soil; Floodplain Deposits; Estuarine/Deltaic Deposits

KS.TA.01(AR)	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	N 01⁰ 28' 46.3" E 110⁰ 27' 45.0"		
AUGERHOLE NO.	KS.TA.01AR	20/10/2011	10.25 am
GROUND WATER LEVEL	0.5m	TOP OF AUGERHOLE [(Above m.s.l)]	8.1m
RECORD BY	MOHAMAD TARMIZI BIN MOHAMAD ZULKIFLEY	CHECKED BY	MOHAMAD TARMIZI BIN MOHAMAD ZULKIFLEY

CLASSIFICATION SYMBOL		DEPTH (M)	SOIL DESCRIPTION	REMARKS
SYMBOL	GRAPHIC LOG			
M		4.5	Dark bluish gray, soft to firm CLAYEY SILT. Wood fragments <5% Wood fragments, length<1cm. Wet. Plasticity High	GLEY 2, 4/1
		5	(Augering stopped at 5.0m due to consistant soil type returns)	

LEGEND: Paludal Deposits/Peat; Slightly Organic Soil; Floodplain Deposits; Estuarine/Deltaic Deposits

Figure F2. Augerlog for KS.TA.02

KS.TA.02	**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	N 01^0 28.716' E 110^0 27.777"		
AUGERHOLE NO.	KS.TA.02	15/10/2011	9.31 am
GROUND WATER LEVEL	0.5m	**TOP OF AUGERHOLE [(Above m.s.l)]**	21.0m
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	Dark brown FIBRIC to HEMIC PEAT. Brown,muddy water extruded. Slightly amorphous material present. Plant struct still identifiable. High moisture content. Some paste. Wood fragment 2 - 3cm long.	7.5 YR 3/4 H3B4F3W2 to H4B4F3W2
(M)		0.5	Light yellowish brown, very soft SLIGHTLY ORGANIC SILT. No Wood fragment. Wet. Sticky, plastic.	10 YR 6/4 to
M		1	Dark bluish gray, very soft CLAYEY SILT.No wood fragments Wet	GLEY 2, 4/1
M		1.5	Dark bluish gray, very soft CLAYEY SILT.No wood fragments Wet	GLEY 2, 4/1
M		2	Dark bluish gray, very soft CLAYEY SILT.No wood fragments Wet	GLEY 2, 4/1
M		2.5	Dark bluish gray, very soft CLAYEY SILT.No wood fragments Wet	GLEY 2, 4/1
M		3	Dark bluish gray, very soft CLAYEY SILT.No wood fragments Wet	GLEY 2, 4/1
M		3.5	Dark bluish gray, very soft CLAYEY SILT.No wood fragments Wet	GLEY 2, 4/1
(M)		4	Dark bluish gray, very soft CLAYEY SILT.No wood fragments wet	GLEY 2, 4/1

LEGEND: Paludal Deposits/Peat; Slightly Organic Soil; Floodplain Deposits; Estuarine/Deltaic Deposits(marine?)

KS.TA.02	**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	N 01^0 28.716' E 110^0 27.777"		
AUGERHOLE NO.	KS.TA.02	15/10/2011	9.31 am
GROUND WATER LEVEL	0.5m	**TOP OF AUGERHOLE [(Above m.s.l)]**	21.0m
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)		4.5	Dark bluish gray, soft CLAYEY SILT.No wood fragments Wet	GLEY 2, 4/1
(M)		5	Dark bluish gray, soft to firm CLAYEY SILT.No wood fragments Wood fragments 1%, 1 cm long. Wet	GLEY 2, 4/1
		5.5	(Augering stopped due to difficulty in auger rod extrection)	

LEGEND: Paludal Deposits/Peat; Slightly Organic Soil; Floodplain Deposits; Estuarine/Deltaic Deposits

Figure F3. Augerlog for KS.TA.03

KS.TA.03	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	N 01^{0} 28.661' E 110^{0} 27.778"		
AUGERHOLE NO.	KS.TA.03	15/10/2011	10.39 am
GROUND WATER LEVEL	0.5m	TOP OF AUGERHOLE [(Above m.s.l)]	24.0m
RECORD BY	MOHAMAD TARMIZI BIN MOHAMAD ZULKIFLEY	CHECKED BY	MOHAMAD TARMIZI BIN MOHAMAD ZULKIFLEY

CLASSIFICATION SYMBOL		DEPTH (M)	SOIL DESCRIPTION	REMARKS
SYMBOL	GRAPHIC LOG			
(Pth-Pta))		0	Dark brown HEMIC to SAPRIC PEAT. Wood fragment <2 cm long.	7.5 YR 3/4 H6B3F2W1 to H7B3F2W1
(Pth)		0.5	Dark brown HEMIC PEAT. Wood fragment <2 cm long.	7.5 YR 3/4 H5B3F2W1 to H6B3F2W1
(M)		1	Light yellowish gray, very soft SLIGHTLY ORGANIC CLAYEY SILT. Wet. Wood fragments 5-10%, 1cm long	10 YR 5/2
(M)		1.5	Light yellowish gray, very soft CLAYEY SILT.No wood fragments Wet. Wood fragments 5%, 1cm long.	10 YR 5/2
(M)		2	Dark bluish gray, soft CLAYEY SILT. Wet. Wood fragments 5%, 1cm long	GLEY 2, 4/1
(M)		2.5	Dark bluish gray, soft CLAYEY SILT. Wet. Wood fragments 5%, 1cm long	GLEY 2, 4/1
(M)		3	Dark bluish gray, soft CLAYEY SILT. Wet. Wood fragments 5%, 1cm long	GLEY 2, 4/1
(M)		3.5	Dark bluish gray, soft CLAYEY SILT. Moderately wet. Wood fragments 5%, 1cm long	GLEY 2, 4/1
(M)		4	Dark bluish gray, firm CLAYEY SILT. Moist. Wood fragments 5%, 1cm long	GLEY 2, 4/1

LEGEND: Paludal Deposits/Peat; Slightly Organic Soil; Floodplain Deposits; Estuarine/Deltaic Deposits

KS.TA.03	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	N 01^{0} 28.661' E 110^{0} 27.778"		
AUGERHOLE NO.	KS.TA.03	15/10/2011	10.39 am
GROUND WATER LEVEL	0.5m	TOP OF AUGERHOLE [(Above m.s.l)]	24.0m
RECORD BY	MOHAMAD TARMIZI BIN MOHAMAD ZULKIFLEY	CHECKED BY	MOHAMAD TARMIZI BIN MOHAMAD ZULKIFLEY

CLASSIFICATION SYMBOL		DEPTH (M)	SOIL DESCRIPTION	REMARKS
SYMBOL	GRAPHIC LOG			
(M)		4.5	Dark bluish gray, firm CLAYEY SILT. Moist. Wood fragments 5%, 1cm long	GLEY 2, 4/1
(M)		5	Dark bluish gray, firm CLAYEY SILT. Moist. Wood fragments 5%, 1cm long	GLEY 2, 4/1
		5.5	(Augering stopped due to difficulty in auger rod extraction)	

LEGEND: Paludal Deposits/Peat; Slightly Organic Soil; Floodplain Deposits; Estuarine/Deltaic Deposits

Figure F4. Augerlog for KS.TA.04

KS.TA.04	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	N 01° 28.605' E 110° 27.778"		
AUGERHOLE NO.	KS.TA.04	16/10/2011	10.22 am
GROUND WATER LEVEL	0.5m	TOP OF AUGERHOLE [(Above m.s.l)]	37.0m
RECORD BY	MOHAMAD TARMIZI BIN MOHAMAD ZULKIFLEY	CHECKED BY	MOHAMAD TARMIZI BIN MOHAMAD ZULKIFLEY

CLASSIFICATION SYMBOL		DEPTH (M)	SOIL DESCRIPTION	REMARKS
SYMBOL	GRAPHIC LOG			
(Pth-Pta))		0	Dark brown HEMIC to SAPRIC PEAT. Wood fragments 30-40%, >2 cm(2-30cm) long. Wet(morning rain)	7.5 YR 3/2 H6B3F3W2 to H7B3F3W2
(Pth)		0.5	Dark brown HEMIC PEAT. Wood fragments 30-40%, >2 cm(2-20cm) long. Wet(morning rain and groundwater table 0.5m)	7.5 YR 3/2 H5B4F2W2 to H6B4F2W2
(Pth)		1	Dark brown HEMIC PEAT. Wood fragments 10-20%, >2 cm(2-10cm) long. Wet(morning rain and groundwater table 0.5m)	7.5 YR 3/2 H5B4F1W2 to H6B4F1W2
		1.3	Light yellowish gray, very soft SLIGHTLY ORGANIC . CLAYEY SILT. 5%, 2-5cm wood fragments	
(M)		1.5	Light yellowish gray, very soft SLIGHTLY ORGANIC CLAYEY SILT. 5%, 2-5cm wood fragments. Wet	10 YR 5/2
M		2	Light yellowish gray, very soft SLIGHTLY ORGANIC CLAYEY SILT. 5%, 2-5cm wood fragments. Wet	10 YR 5/2
M		2.5	Dark bluish gray, soft-firm CLAYEY SILT. Moist to wet. Wood fragments 5%, 1-2 cm long. Plastic	GLEY 2, 4/1
M		3	Dark bluish gray, soft-firm CLAYEY SILT. Moist to wet. Wood fragments 5%, 1-2 cm long. Plastic	GLEY 2, 4/1
M		3.5	Dark bluish gray, soft-firm CLAYEY SILT. Moist to wet. Wood fragments 5%, 1-2 cm long. Plastic	GLEY 2, 4/1
M		4	Dark bluish gray, soft-firm CLAYEY SILT. Moist to wet. Wood fragments 5-10%, 1-2 cm long	GLEY 2, 4/1

LEGEND: Paludal Deposits/Peat; Slightly Organic Soil; Floodplain Deposits; Estuarine/Deltaic Deposits

KS.TA.04	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° 28.605' E 110° 27.778"		
AUGERHOLE NO.	KS.TA.04	16/10/2011	10.22 am
GROUND WATER LEVEL	0.5m	TOP OF AUGERHOLE [(Above m.s.l)]	37.0m
RECORD BY	MOHAMAD TARMIZI BIN MOHAMAD ZULKIFLEY	CHECKED BY	MOHAMAD TARMIZI BIN MOHAMAD ZULKIFLEY

CLASSIFICATION SYMBOL		DEPTH (M)	SOIL DESCRIPTION	REMARKS
SYMBOL	GRAPHIC LOG			
M		4.5	Dark bluish gray, soft-firm CLAYEY SILT. Moist to wet. Wood fragments 5%, 1-2 cm long	GLEY 2, 4/1
(M)		5	Dark bluish gray, soft-firm CLAYEY SILT. Moist to wet. Wood fragments 5%, 1-2 cm long	GLEY 2, 4/1
		5.5	(Augering stopped due to difficulty in auger rod extraction)	

LEGEND: Paludal Deposits/Peat; Slightly Organic Soil; Floodplain Deposits; Estuarine/Deltaic Deposits

Figure F5. Augerlog for KS.TA.05

KS.TA.05	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	N 01° 28.550' E 110° 27.778'		
AUGERHOLE NO.	KS.TA.05	17/10/2011	9.51 am
GROUND WATER LEVEL	0.5m	**TOP OF AUGERHOLE [(Above m.s.l)]**	35.0m
RECORD BY	MOHAMAD TARMIZI BIN MOHAMAD ZULKIFLEY	**CHECKED BY**	MOHAMAD TARMIZI BIN MOHAMAD ZULKIFLEY

CLASSIFICATION SYMBOL: SYMBOL	GRAPHIC LOG	DEPTH (M)	SOIL DESCRIPTION	REMARKS
(Pta)		0	Dark brown to black SAPRIC PEAT. Wood fragments 10-20%, >2 cm(2-10cm) long. Wet	7.5YR 3/2 to 2.5/2 H7B3F3W2 to H8B3F3W2
(Pth-Pta)		0.5	Dark brown to black HEMIC to SAPRIC PEAT. Wood fragments 10-20%, >2 cm(3cm) long. Wet. (groundwater table 0.5m)	7.5YR 3/2 to 2.5/2 H6B4F2W2 to H7B4F2W2
(Pth)		1	Dark brown to black HEMIC PEAT. Wood fragments 10-20%, >2 cm(2-3cm) long. Wet	7.5YR 3/2 to 2.5/2 H5B4F1W2 to H6B4F1W2
(Pth)		1.5	Dark brown to black HEMIC PEAT. Wood fragments 10-20%, >2 cm(2-3cm) long. Wet	7.5YR 3/2 to 2.5/2 H5B4F1W2 to H6B4F1W2
(Pth)		2	Dark brown to black HEMIC PEAT. Wood fragments 40-50%, >2 cm(2-3cm) long. Wet	7.5YR 3/2 to 2.5/2 H5B4F1W2 to H6B4F1W2
		2.3	Light yellowish gray, very soft SLIGHTLY ORGANIC . CLAYEY SILT. 10-20%, 2-3cm wood fragments. Wet.	10 YR 5/2
Mo		2.5	Light yellowish gray, very soft SLIGHTLY ORGANIC . CLAYEY SILT. 10-20%, 2-3cm wood fragments. Wet.	10 YR 5/2
Mo		3	Light yellowish gray, very soft SLIGHTLY ORGANIC . CLAYEY SILT. 30-40%, 2-3cm wood fragments.Moist to wet.	10 YR 5/2
M		3.5	Dark bluish gray, very soft CLAYEY SILT. Moist to wet. Wood fragments 1-10%, 2-3cm long. Plastic	GLEY 2, 4/1
M		4	Dark bluish gray, very soft CLAYEY SILT. Wet. Wood fragments 1-10%, 2-3 cm long. Plastic	GLEY 2, 4/1

LEGEND: Paludal Deposits/Peat; Slightly Organic Soil; Floodplain Deposits; Estuarine/Deltaic Deposits

KS.TA.05	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	N 01° 28.550' E 110° 27.778'		
AUGERHOLE NO.	KS.TA.05	17/10/2011	9.51 am
GROUND WATER LEVEL	0.5m	**TOP OF AUGERHOLE [(Above m.s.l)]**	35.0m
RECORD BY	MOHAMAD TARMIZI BIN MOHAMAD ZULKIFLEY	**CHECKED BY**	MOHAMAD TARMIZI BIN MOHAMAD ZULKIFLEY

CLASSIFICATION SYMBOL: SYMBOL	GRAPHIC LOG	DEPTH (M)	SOIL DESCRIPTION	REMARKS
M		4.5	Dark bluish gray, very soft CLAYEY SILT. Wet. Wood fragments 1-5%, 2-3 cm long. Plastic	GLEY 2, 4/1
		4.8	Dark bluish gray, soft CLAYEY SILT. Wet. Wood fragments 1-5%, 2-3 cm long. Plastic	GLEY 2, 4/1
M		5	Dark bluish gray, soft SILT. Saturated/Wet. No wood fragments. Intermediate plasticity	GLEY 2, 4/1
M		5.5	Dark bluish gray, soft SILT. Saturated/Wet. No wood fragments. Intermediate plasticity	GLEY 2, 4/1
M		6	Dark bluish gray, soft SILT. Saturated/Wet. No wood fragments. Intermediate plasticity	GLEY 2, 4/1
M		6.5	Dark bluish gray, soft SILT. Saturated/Wet. No wood fragments. Intermediate plasticity	GLEY 2, 4/1
		7	(Augering stopped due to consistant soil type return)	

LEGEND: Paludal Deposits/Peat; Slightly Organic Soil; Floodplain Deposits; Estuarine/Deltaic Deposits

Figure F6. Augerlog for KS.TP.01

KS.TP.01	**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	N 01^0 28' 26.0" E 110^0 28' 11.0"		
AUGERHOLE NO.	KS.TP.01	21/10/2011	9.30 am
GROUND WATER LEVEL	0.2 m	**TOP OF AUGERHOLE (Above m.s.l)**	9 m
RECORD BY	MOHAMAD TARMIZI BIN MOHAMAD ZULKIFLEY	**CHECKED BY**	MOHAMAD TARMIZI BIN MOHAMAD ZULKIFLEY

CLASSIFICATION SYMBOL		**DEPTH (M)**	**SOIL DESCRIPTION**	**REMARKS**
SYMBOL	**GRAPHIC LOG**			
(Pta)		0 (Pt=0.2 m)	Very dark brown SAPRIC PEAT. Wet. Wood fragments 20-30%, 3-4 cm. Rootlets 3 to 4 cm long, 2-3 mm thick.	10 YR 5/3 H8B4F3W3,
(Mo)		0.2	Grayish brown, banded, very soft SLIGHTLY ORGANIC CLAYEY SILT. Wood fragments 10-20%, 2-3 cm. Very wet. (Groundwater table 0.2 m)	10 YR 5/2
(Mo)		0.5	Grayish brown, banded, very soft SLIGHTLY ORGANIC CLAYEY SILT. Wood fragments 10-20%, 2-3 cm. Very wet.	10 YR 5/2
(M)		1	Dark grayish brown, very soft CLAYEY SILT. Wood fragments 5-10%,1-2 cm. Wet. Plastic.	10 YR 4/2
(M)		1.5	Dark grayish brown, very soft CLAYEY SILT. Wood fragments <5%, 1-2 cm. Wet. Plastic.	10 YR 4/2
(M)		2	Dark gray, soft CLAYEY SILT. Wood fragments <5%, 1-2 cm. Wet. Plastic.	10 YR 4/1
(M)		2.5	Dark gray, soft CLAYEY SILT. Wood fragments <5%, 1-2 cm. Wet. Plastic.	10 YR 4/1
(M)		3	Dark gray, soft CLAYEY SILT. Wood fragments 20-30%, 1-2cm. Wet. Plastic.	10 YR 4/1
(M)		3.5	Dark gray, soft CLAYEY SILT. Wood fragments <5%, 1-2 cm. Wet. Plastic.	10 YR 4/1
(M)		4	Dark gray, soft to firm CLAYEY SILT. Wood fragments <5%, 1-2 cm. Moist to wet. Plastic.	10 YR 4/1

LEGEND: Paludal Deposits/Peat; Slightly Organic Soil; Floodplain Deposits; Estuarine/Deltaic Deposits

KS.TP.01	**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	N 01^0 28' 26.0" E 110^0 28' 11.0"		
AUGERHOLE NO.	KS.TP.01	21/10/2011	9.30 am
GROUND WATER LEVEL	0.2 m	**TOP OF AUGERHOLE (Above m.s.l)**	9 m
RECORD BY	MOHAMAD TARMIZI BIN MOHAMAD ZULKIFLEY	**CHECKED BY**	MOHAMAD TARMIZI BIN MOHAMAD ZULKIFLEY

CLASSIFICATION SYMBOL		**DEPTH (M)**	**SOIL DESCRIPTION**	**REMARKS**
SYMBOL	**GRAPHIC LOG**			
(M)		4.5	(Augering stopped at 4.5 m due to consistant soil type return and rain)	

LEGEND: Paludal Deposits/Peat; Slightly Organic Soil; Floodplain Deposits; Estuarine/Deltaic Deposits

Figure F7. Augerlog for KS.TP.03

KS.TP.03	**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	N 01^0 28' 21.9" E 110^0 28' 11.3"		
AUGERHOLE NO.	KS.TP.03	23/10/2011	10.41 am
GROUND WATER LEVEL	0.5 m	**TOP OF AUGERHOLE (Above m.s.l)**	4.9 m
RECORD BY	MOHAMAD TARMIZI BIN MOHAMAD ZULKIFLEY	**CHECKED BY**	MOHAMAD TARMIZI BIN MOHAMAD ZULKIFLEY

CLASSIFICATION SYMBOL		DEPTH (M)	SOIL DESCRIPTION	REMARKS
SYMBOL	GRAPHIC LOG			
(Mo)		0	Grayish brown to gray, soft SLIGHTLY ORGANIC CLAYEY SILT. Wood fragments 10-20 %,1-1.5 cm. Wet. Intermediate plasticity, sandy/ 'gritty feel'. (Site waterlogged due to rain)	10 YR 5/2 to 10 YR 5/1 (Raining last night)
(Mo)		0.5	Grayish browny, soft SLIGHTLY ORGANIC CLAYEY SILT. Wood fragments 10-20%,1-1.5 cm. Wet. Intermediate plasticity, sandy/ 'gritty feel'. (g/water level 0.5m)	10 YR 5/2
(M)		1	Banded, Gray to dark gray, soft CLAYEY SILT. Wood fragments 10-20%, 2-3 cm. Wet. Intermediate plasticity, sandy/ 'gritty feel'.	10 YR 6/1 to 10 YR 4/1 to
(M)		1.5	Banded, Gray to dark gray, soft CLAYEY SILT. Wood fragments 10-20%, 2-3 cm. Wet. Intermediate plasticity, sandy/ 'gritty feel'.	10 YR 6/1 to 10 YR 4/1 to
(M)		2	Gray, soft CLAYEY SILT. Wood fragments 10%, 2-3 cm. Wet. Intermediate plasticity, sandy/ 'gritty feel'.	10 YR 6/1
(M)		2.5	Gray, soft CLAYEY SILT. Wood fragments 10%, 2-3 cm. Wet. Intermediate plasticity, sandy/ 'gritty feel'.	10 YR 6/1
(M)		3	Gray, soft CLAYEY SILT. Wood fragments 5-10%, 2-3 cm. Wet. Intermediate plasticity, sandy/ 'gritty feel'.	10 YR 6/1
(M)		3.5	Gray, soft to firm CLAYEY SILT. Wood fragments 5-10%, 2-3 cm. Moist to wet. Intermediate plasticity, sandy/ 'gritty feel'.	10 YR 5/1
(M)		4	Gray, soft CLAYEY SILT. Wood fragments < 5%, 2-3 cm. Wet. Intermediate plasticity, sandy/ 'gritty feel'.	10 YR 5/1

LEGEND: Paludal Deposits/Peat; Slightly Organic Soil; Floodplain Deposits; M-silt; vy'-very; Estuarine/Deltaic Deposits

KS.TP.03	**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	N 01^0 28' 21.9" E 110^0 28' 11.3"		
AUGERHOLE NO.	KS.TP.03	23/10/2011	10.41 am
GROUND WATER LEVEL	0.5 m	**TOP OF AUGERHOLE (Above m.s.l)**	4.9 m
RECORD BY	MOHAMAD TARMIZI BIN MOHAMAD ZULKIFLEY	**CHECKED BY**	MOHAMAD TARMIZI BIN MOHAMAD ZULKIFLEY

CLASSIFICATION SYMBOL		DEPTH (M)	SOIL DESCRIPTION	REMARKS
SYMBOL	GRAPHIC LOG			
(M)		4.5	Gray, soft CLAYEY SILT. Wood fragments 5-10%, 1 cm length. Wet/Saturated. Plastic. Shell fragments, black, 5-10%, 1-2 cm.	10 YR 5/1
(M)		5	Gray, soft CLAYEY SILT. Wood fragments <5%, 1 cm. Saturated/Wet. Plastic.	10 YR 5/1
(M)		5.5	Gray, soft CLAYEY SILT. Wood fragments <5%, 1 cm. Saturated/Wet. Plastic.	10 YR 5/1
		6	(Augering stopped at 6.0 m due to consistant soil type return and raining)	

LEGEND: Paludal Deposits/Peat; Slightly Organic Soil; Floodplain Deposits; M-silt; 'vy' -very; Estuarine/Deltaic Deposits

Figure F8. Augerlog for KS.TP.04

KS.TP.04	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	N 01° 28' 17.4" E 110° 28' 07.9"		
AUGERHOLE NO.	KS.TP.04	23/10/2011	12.26 am
GROUND WATER LEVEL	0.2-0.3m(raining-flooded/waterlogged)	TOP OF AUGERHOLE (Above m.s.l)	7.6 m
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
Pta		0 (Pt=0.2 m)	Dark yellowish brown SAPRIC PEAT. Very wet. Pasty. Wood fragments 20-30%, 3-4 cm. Rootlets 1-5 cm long, 1-2 mm thick.	H7B5F3W3 to H8B5F3W3
Mo		0.2	Light gray, soft SLIGHTLY ORGANIC CLAYEY SILT. Wood fragments 10-20%, 2-3 cm. Very wet. (Groundwater table 0.2 m, raining, mostly waterlogged)	(10 YR 3/4-peat) 10 YR 7/2-silt
Mo		0.5	Dark gray to light gray, banded, soft SLIGHTLY ORGANIC CLAYEY SILT. Wood fragments10-20%, 2-3 cm. Very wet.	10 YR 4/1 to 10 YR 7/2
M		1	Dark gray, soft to firm CLAYEY SILT. Wood fragments 10-20%, 1-2 cm. Wet. Plastic.	10 YR 4/1
M		1.5	Dark gray, soft CLAYEY SILT. Wood fragments 10-20%,1-2 cm. Wet. Plastic.	10 YR 4/1
M		2	Dark gray, soft to firm CLAYEY SILT. Wood fragments 10-20%, 1-2 cm. Moist to wet. Plastic.	10 YR 4/1
M		2.5	Dark gray, soft CLAYEY SILT. Wood fragments 10-20%, 1-2 cm. Wet. Plastic.	10 YR 4/1
M		3	Dark gray, soft to firm CLAYEY SILT. Wood fragments 10-20%, 1-2 cm. Moist to wet. Plastic.	10 YR 4/1
M		3.5	Dark gray, soft to firm CLAYEY SILT. Wood fragments 10-20%, 1-2 cm. Moist to wet. Plastic.	10 YR 4/1
M		4	Dark gray, soft to firm CLAYEY SILT. Wood fragments 10-20%, 1-2 cm. Wet. Plastic.	10 YR 4/1

LEGEND: Paludal Deposits/Peat; Slightly Organic Soil; Floodplain Deposits; M-silt; 'vy' -very; Estuarine/Deltaic Deposits

KS.TP.04	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	N 01° 28' 17.4" E 110° 28' 07.9"		
AUGERHOLE NO.	KS.TP.04	23/10/2011	12.26 am
GROUND WATER LEVEL	0.2-0.3 m (raining-flooded/waterlogged)	TOP OF AUGERHOLE (Above m.s.l)	7.6 m
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		4.5	Dark gray, soft to firm CLAYEY SILT. No wood fragment. Wet/saturated. Intermediate plasticity.	10 YR 4/1
M		5	Dark gray, soft to firm CLAYEY SILT. No wood fragment. Wet/saturated. Intermediate plasticity.	10 YR 4/1
		5.5	(Augering stopped at 5.5 m due to consistant soil type return and raining)	

LEGEND: Paludal Deposits/Peat; Slightly Organic Soil; Floodplain Deposits; M-silt; 'vy' -very; Estuarine/Deltaic Deposits

Figure F9. Augerlog for KS.TP.05

KS.TP.05	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	N 01° 28' 15.8" E 110° 28' 06.1"		
AUGERHOLE NO.	KS.TP.05	24/10/2011	10.35 am
GROUND WATER LEVEL	0.3 m (raining-flooded/waterlogged)	TOP OF AUGERHOLE (Above m.s.l)	10.7 m
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	Very dark brown FIBRIC PEAT. Very wet. Not pasty. Wood fragments 20-30%, 4-5 cm. Rootlets 2-3 cm long, 1 mm thick.	H3B4F3W2 to 7.5 YR 2.5/2
		(Pt=0.5 m)		
Mo		0.5	Light brownish gray, very soft SLIGHTLY ORGANIC CLAYEY SILT. Wood fragments<3%, 2-3 cm. Very wet. (Groundwater table 0.3 m, raining night to morning, waterlogged)	10 YR 6/2
M		1	Gray-grayish brown, banded, very soft CLAYEY SILT. Wood fragments <3%, 1-2 cm. Wet. Plastic.	10 YR 5/1-to 10 YR 5/2
M		1.5	Dark gray, soft CLAYEY SILT. Wood fragments <5%, 1-2 cm. Wet. Plastic.	10 YR 4/1
M		2	Dark gray, soft CLAYEY SILT. Wood fragments <3%, 1-2 cm. Wet. Plastic.	10 YR 4/1
M		2.5	Dark gray, soft CLAYEY SILT. Wood fragments 5%, 1-2 cm. Wet. Plastic.	10 YR 4/1
M		3	Dark gray, soft CLAYEY SILT. Wood fragments 5%, 1-2 cm. Wet. Plastic.	10 YR 4/1
M		3.5	Dark gray, soft CLAYEY SILT. Wood fragments 5%, 1-2 cm. Wet. Plastic.	10 YR 4/1
M		4	Gray, soft CLAYEY SILT. No wood fragments . Saturated/wet. Intermediate plasticity. Shell fragments 1-2 cm	10 YR 5/1

LEGEND: Paludal Deposits/Peat; Slightly Organic Soil; Floodplain Deposits; M-silt; 'vy' -very; Estuarine/Deltaic Deposits

KS.TP.05	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	N 01° 28' 15.8" E 110° 28' 06.1"		
AUGERHOLE NO.	KS.TP.05	24/10/2011	10.35 am
GROUND WATER LEVEL	0.3 m(raining-flooded/waterlogged)	TOP OF AUGERHOLE (Above m.s.l)	10.7 m
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
		4.5	White to very pale brown, soft to firm CLAYEY SILT. No wood fragments. Moist to wet. Intermediate plasticity.	10 YR 8/1 10 YR 8/2
M		5	White to very pale brown, soft to firm CLAYEY SILT. No wood fragments. Moist to wet. Plastic.	10 YR 8/1 10 YR 8/2
		5.5	White to very pale brown, soft to firm CLAYEY SILT. No wood fragments. Moist to wet. Intermediate plasticity.	10 YR 8/1 10 YR 8/2
		6	(Augering stopped at 6.0 m due to consistant soil type return and rain)	

LEGEND: Paludal Deposits/Peat; Slightly Organic Soil; Floodplain Deposits; M-silt; 'vy' -very; Estuarine/Deltaic Deposits

Figure F10. Augerlog for KS.TP.06

KS.TP.06	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	N 01°28' 20.4" E 110°28' 02.3"		
AUGERHOLE NO.	KS.TP.06	27/10/2011	9.56 am
GROUND WATER LEVEL	0.5 m	**TOP OF AUGERHOLE (Above m.s.l)**	7 m
RECORD BY	MOHAMAD TARMIZI BIN MOHAMAD ZULKIFLEY	**CHECKED BY**	MOHAMAD TARMIZI BIN MOHAMAD ZULKIFLEY

CLASSIFICATION SYMBOL: SYMBOL	GRAPHIC LOG	DEPTH (m)	SOIL DESCRIPTION	REMARKS
Pth-Pta		0	Dark yellowish brown HEMIC TO SAPRIC PEAT. Very wet. Pasty. Wood fragments 20-30%, 2-10 cm. Rootlets 4-6 cm long, 1-5 mm thick.	H6B3F2W2 to H7B3F2W2 7.5 YR 3/4
Pth		0.5	Dark brown HEMIC PEAT. Very wet. Pasty. Wood fragments 10-20%, 2-10 cm. (Groundwater table 0.5 m)	H5B4F2W2 to H6B4F2W2 to 7.5 YR 3/2
Pth		1 Pt=1.2m	Dark brown HEMIC PEAT. Very wet. Pasty. Wood fragments 10-20%, 2-10 cm.	H5B4F2W2 to 7.5 YR 3/2
M		1.2	Banded, brown to dark gray, soft SLIGHTLY ORGANIC CLAYEY SILT. Wood fragments 5-10%, 2-5 cm.	10 YR 5/3 to 10 YR 4/1
M		1.5	Dark gray, soft CLAYEY SILT. Wood fragments 20-30%, 2-5 cm. Wet. Plastic.	10 YR 4/1
M		2	Dark gray, soft to firm CLAYEY SILT. Wood fragments 40-50%, 2-3 cm. Moist to wet. Plastic.	10 YR 4/1
M		2.5	Dark gray, soft to firm CLAYEY SILT. Wood fragments 20-30%, 4-5 cm. Moist to wet. Plastic.	10 YR 4/1
M		3	Dark gray, soft to firm CLAYEY SILT. Wood fragments 30-40%, 4-5 cm. Moist to wet. Plastic.	10 YR 4/1
M		3.5	Dark gray, soft to firm CLAYEY SILT. Wood fragments 30-40%, 4-5 cm. Moist to wet. Plastic.	10 YR 4/1
M		4	Banded, dark gray to light gray, soft to firm CLAYEY SILT. Wood fragments <10%, 4-5 cm. Saturated/wet. Intermediate plasticity.	10 YR 4/1 to 10 YR 7/2

LEGEND: Paludal Deposits/Peat; Slightly Organic Soil; Floodplain Deposits; M-silt 'vy' -very; Estuarine/Deltaic Deposits

KS.TP.06	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	N 01°28' 20.4" E 110°28' 02.3"		
AUGERHOLE NO.	KS.TP.06	27/10/2011	9.56 am
GROUND WATER LEVEL	0.5 m	**TOP OF AUGERHOLE [(Above m.s.l)]**	7 m
RECORD BY	MOHAMAD TARMIZI BIN MOHAMAD ZULKIFLEY	**CHECKED BY**	MOHAMAD TARMIZI BIN MOHAMAD ZULKIFLEY

CLASSIFICATION SYMBOL: SYMBOL	GRAPHIC LOG	DEPTH (M)	SOIL DESCRIPTION	REMARKS
M		4.5	Banded, light gray to very pale brown, soft to firm CLAYEY SILT. Wood fragments <10%, 4-5 cm. Moist to wet. Intermediate plasticity.	10 YR 7/1 10 YR 8/2
MG		5	Very pale brown, soft GRAVELLY/ SANDY SILT. Gravel 20%, size 0.3-2.0 cm, Sandy/'gritty'feel. No wood fragments. Saturated/wet. Low plasticity.	10 YR 8/2
MG		5.5	Light gray, soft GRAVELLY/ SANDY SILT. Gravel 20-30%, size 3-4 mm. Sandy/'gritty'feel. No wood fragments. Saturated/wet. Low plasticity.	10 YR 7/1
MG		6	Light greenish gray, soft to firm GRAVELLY/ SANDY SILT. Gravel 10-20%, size 2-3 mm. Sandy/'gritty'feel. No wood fragments. Saturated/wet. Low plasticity.	GLEY 8/1
MG		6.5	Light greenish gray, soft to firm GRAVELLY/SANDY SILT. Gravel 10-20%, size 2-3 mm. Sandy/'gritty'feel. No wood fragments. Saturated/wet. Low plasticity.	GLEY 8/1
		7	(Augering stopped at 7.0 m due to consistant soil type return)	

LEGEND: Paludal Deposits/Peat; Slightly Organic Soil; Floodplain Deposits; M-silt 'vy' -very; Estuarine/Deltaic Deposits

Figure F11. Augerlog for KS.TS.05

KS.TS.05	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 29' 50.7" E110^0 30' 53.1" (Jln.Sui 16/Jln Tambey 2)		
AUGERHOLE NO.	KS.TS.05	28/04/2011	11.06 am
GROUND WATER LEVEL	1.0 m	TOP OF AUGERHOLE (Above m.s.l)	5 to 7.0 m
RECORD BY	MOHAMAD TARMIZI MOHD ZULKIFLEY	CHECKED BY	MOHAMAD TARMIZI BIN MOHAMAD ZULKIFLEY

CLASSIFICATION SYMBOL: SYMBOL	CLASSIFICATION SYMBOL: GRAPHIC LOG	DEPTH (M)	SOIL DESCRIPTION	REMARKS
(Pth-Pta)		0	Brown to dark brown HEMIC to SAPRIC PEAT. Wood fragments 20-30%, 2 to 20 cm long, 2 to 20 cm wide. Rootlets 2 to 3 cm long, 2 to 3 mm wide. Moderately wet	7.5YR 4/2 to 7.5YR 3/3 H6 to H7B3F2W2
(Pth-Pta)		0.5	Dark brown HEMIC to SAPRIC PEAT. Wood fragments 20-30%, 3 to 4 cm. Rootlets 2 to 3cm long, 2 to 3 mm wide. Very wet.	7.5YR 4/2 to 7.5YR 3/3 H6 to H7B3F1W2
(Pth)		1	Brown HEMIC PEAT. Wood fragments 20-30%, 5 to 10cm long. Very wet (ground water table 1.0 m)	7.5YR 4/3 H4 to H5B4F2W2
(Mo)		1.4 1.5 1.6	Brown, very soft SLIGHTLY ORGANIC SILT Brown, very soft SLIGHTLY ORGANIC SILT Bluish gray, very soft SILT. No wood fragment.	7.5YR 5/2 7.5YR 5/2 GLEY 2, 5/1
(M)		2	Bluish gray, very soft SILT. No wood fragment. Wet.	GLEY 2, 5/1
(M)		2.5	Bluish gray, very soft SILT. No wood fragment. No wood fragments. Wet/saturated.	GLEY 2, 5/1
(M)		3	Bluish gray, very soft SILT. No wood fragment. No wood fragments. Wet/saturated.	GLEY 2, 5/1
(M)		3.5	Bluish gray, very soft SILT. No wood fragment. No wood fragments. Wet/saturated.	GLEY 2, 5/1
(M)		4	Bluish gray, very soft SILT. No wood fragment. No wood fragments. Wet/saturated.	GLEY 2, 5/1

LEGEND: Paludal Deposits/Peat; Slightly Organic Silt; Floodplain Deposits; Estuarine/Deltaic Deposits

KS.TS.05	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 29' 50.7" E110^0 30' 53.1"(Jln.Sui 16/Jln Tambey 2)		
AUGERHOLE NO.	KS.TS.05	28/04/2011	11.06 am
GROUND WATER LEVEL	1.0m	TOP OF AUGERHOLE (Above m.s.l)	5 to 7.0 m
RECORD BY	MOHAMAD TARMIZI MOHD ZULKIFLEY	CHECKED BY	MOHAMAD TARMIZI BIN MOHAMAD ZULKIFLEY

CLASSIFICATION SYMBOL: SYMBOL	CLASSIFICATION SYMBOL: GRAPHIC LOG	DEPTH (M)	SOIL DESCRIPTION	REMARKS
(M)		4.5	Bluish gray, very soft SILT. No wood fragment. No wood fragments. Wet/saturated. Shell fragments, 5%, 2 to 5 mm wide.	GLEY 2, 5/1
(M)		5	Bluish gray, very soft SILT. No wood fragment. No wood fragments. Wet/saturated. Shell fragments, 10%, 2 to 5 mm wide.	GLEY 2, 5/1
(M)		5.5	Bluish gray, very soft SILT. No wood fragment. No wood fragments. Wet/saturated.	GLEY 2, 5/1
		6	(Augering stopped at 6.0 m due to consistant soil type return)	

LEGEND: Paludal Deposits/Peat; Slightly Organic Silt; Floodplain Deposits; Estuarine/Deltaic Deposits

Figure F12. Augerlog for KS.TS.10

KS.TS.10	AUGERLOG 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' 40.5" E110^{0} 30' 42.3", (Jln Sui 6)		
AUGERHOLE NO.	KS.TS.10	12/5/2011	9.30 am
GROUND WATER LEVEL	0.3 m	TOP OF AUGERHOLE (Above m.s.l)	8 to 10 m
RECORD BY	MOHAMAD TARMIZI MOHD. ZULKIFLEY	CHECKED BY	MOHAMAD TARMIZI MOHD. ZULKIFLEY

CLASSIFICATION SYMBOL: SYMBOL	CLASSIFICATION SYMBOL: GRAPHIC LOG	DEPTH (M)	SOIL DESCRIPTION	REMARKS
Pth		0	Dark brown, HEMIC PEAT. 2/3 to 1/3 left in hand, dark brown water extruded. Wet.Wood fragments 30 to 40%, 4 to 5 cm Rootlets 2 to 3 cm long, 2.0 to 3.0 mm thick ,	10 YR 2/2 H5B3F2W1
Ptf to Pth		0.5	Dark brown, FIBRIC to HEMIC PEAT. 2/3 left in hand,dark brown water extruded. Wet. Wood fragments 50%, 2 to 3 cm Rootlets 2 to 3 cm long, 2.0 to 3.0 mm thick,	10 YR 2/2 H3 to H4B4F2W1
(Mo)		0.8	Banded, dark bluish gray, soft SLIGHTLY ORGANIC SILT Wet. Wood fragments <5 %, black, 2.0 to 3.0cm long	GLEY 2, 4/1 to 10 YR 2/2
(M)		1	Dark bluish gray, soft SILT. Wet. Wood fragments <5 %, black, 2.0 to 3.0 cm long	GLEY 2, 4/1
(M)		1.5	Dark bluish gray, very soft SILT. Wet. No wood fragments.	GLEY 2, 4/1
(M)		2	Dark bluish gray, very soft SILT. Wet. No wood fragments.	GLEY 2, 4/1
(M)		2.5	Dark bluish gray, soft SILT. Moist to wet. No wood fragments.	GLEY 2, 4/1
(M)		3	Dark bluish gray, soft SILT Wet. No wood fragments.	GLEY 2, 4/1
(M)		3.5	Dark bluish gray, very soft SILT. Saturated/wet. No wood fragments.	GLEY 2, 4/1
(M)		4	Dark bluish gray, very soft SILT. Saturated/wet. No wood fragments.	GLEY 2, 4/1

LEGEND: Paludal Deposits/Peat; Slightly Organic Silt; Floodplain Deposits; Estuarine/Deltaic Deposits

KS.TS.10	AUGERLOG 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' 40.5" E110^{0} 30' 42.3" (Jln Sui 6).		
AUGERHOLE NO.	KS.TS.10	12/5/2011	9.30 am
GROUND WATER LEVEL	0.3 m	TOP OF AUGERHOLE (Above m.s.l)	8 to 10 m
RECORD BY	MOHAMAD TARMIZI MOHD. ZULKIFLEY	CHECKED BY	MOHAMAD TARMIZI MOHD. ZULKIFLEY

CLASSIFICATION SYMBOL: SYMBOL	CLASSIFICATION SYMBOL: GRAPHIC LOG	DEPTH (M)	SOIL DESCRIPTION	REMARKS
(M)		4.5	Dark bluish gray, very soft SILT. Saturated/wet. No wood fragments.	GLEY 2, 4/1
		5	(stopped augering due to consistant soil type return)	

LEGEND: Paludal Deposits/Peat; Slightly Organic Silt; Floodplain Deposits; Estuarine/Deltaic Deposits

Figure F13. Augerlog for KS.TS.12

KS.TS.12	**AUGERLOG 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' 34.6" E110^0 30' 17.4"		
AUGERHOLE NO.	KS.TS.12	13/5/2011	9.30 am
GROUND WATER LEVEL	0.2 m	**TOP OF AUGERHOLE (Above m.s.l)**	8 m
RECORD BY	MOHAMAD TARMIZI MOHD. ZULKIFLEY	**CHECKED BY**	MOHAMAD TARMIZI MOHD. ZULKIFLEY

CLASSIFICATION SYMBOL		**DEPTH (M)**	**SOIL DESCRIPTION**	**REMARKS**
SYMBOL	**GRAPHIC LOG**			
Ptf-Pth		0	Vy. dark brown, FIBRIC to HEMIC PEAT. 2/3 left in hand, brown muddy water extruded. Wet. Wood fragments 20 to 30%, 4 to 5cm. Rootlets 2 to 3cm long, 2.0 to 3.0 mm thick. (groundwater level 0.2 m)	10 YR 2/2 H3 to H4B4F2W1
(Mo)		0.5	Banded, dark bluish gray, very soft SLIGHTLY ORGANIC SILT Wet. Wood fragments 40 to 50 %, black, 2.0 to 3.0 cm long.	10 YR 4/1
(M)		1	Dark bluish gray, very soft SILT. Wet. Wood fragments 10 to 20 %, black, 2.0 to 3.0 cm long.	GLEY 2, 4/1
(M)		1.5	Dark bluish gray, soft SILT. Wet. Wood fragments <5 %, black, 2.0 to 3.0 cm long.	GLEY 2, 4/1
(M)		2	Dark bluish gray, very soft SILT. Saturated/ Wet. No wood fragments.	GLEY 2, 4/1
(M)		2.5	Dark bluish gray, very soft SILT. Saturated/wet. No wood fragments.	GLEY 2, 4/1
(M)		3	Dark bluish gray, soft SILT. Saturated/Wet. No wood fragments.	GLEY 2, 4/1
(M)		3.5	Dark bluish gray, very soft SILT. Saturated/wet. No wood fragments.	GLEY 2, 4/1
(M)		4	(Stopped augering at 4.0 m due to consistant soil type return)	

LEGEND:

	Paludal Deposits/Peat		Slightly Organic Silt
	Floodplain Deposits	'Vy.' - Very	
	Estuarine/Deltaic Deposits		

Figure F14. Augerlog for KS.TS.13

KS.TS.13	AUGERLOG 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' 40.3" E110° 30' 18.8"		
AUGERHOLE NO.	KS.TS.13	13/5/2011	11.36 am
GROUND WATER LEVEL	0.3 m	**TOP OF AUGERHOLE (Above m.s.l)**	6 to 7 m
RECORD BY	MOHAMAD TARMIZI MOHD. ZULKIFLEY	**CHECKED BY**	MOHAMAD TARMIZI MOHD. ZULKIFLEY

CLASSIFICATION SYMBOL: SYMBOL	CLASSIFICATION SYMBOL: GRAPHIC LOG	DEPTH (M)	SOIL DESCRIPTION	REMARKS
Ptf		0	Very dark brown, FIBRIC PEAT. More than 2/3 left in hand, light brownish water extruded. Wet. Wood fragments 40%, 2 to 3 cm Rootlets 20 to 30%, 2 to 3 cm long, 2.0 to 3.0 mm thick , (groundwater level 0.3 m)	10 YR 2/3 H3B4F2W1
(Mo)		0.5	Banded, dark bluish gray, very soft SLIGHTLY ORGANIC SILT. Wet. Wood fragments 40 to 50 %, black, 2.0 to 3.0 cm long	10 YR 4/1 to GLEY 2, 4/1
(M)		1	Dark bluish gray, very soft SILT. Wet. Wood fragments 10 to 20 %, black, 2.0 to 3.0 cm long.	GLEY 2, 4/1
(M)		1.5	Dark bluish gray, soft SILT. Wet. Wood fragments 10 to 20 %, black, 2.0 to 3.0 cm long.	GLEY 2, 4/1
(M)		2	Dark bluish gray, very soft SILT. Saturated/ Wet. No wood fragments.	GLEY 2, 4/1
(M)		2.5	Dark bluish gray, very soft SILT. Saturated/wet. No wood fragments.	GLEY 2, 4/1
(M)		3	Dark bluish gray, soft SILT. Saturated/Wet. No wood fragments.	GLEY 2, 4/1
(M)		3.5	Dark bluish gray, very soft SILT. Saturated/wet. No wood fragments.	GLEY 2, 4/1
		4	(Stopped augering at 4.0 m due to consistant soil type return)	

LEGEND:

Paludal Deposits/Peat

Slightly Organic Silt

Floodplain Deposits

Estuarine/Deltaic Deposits

Figure F15. Augerlog for KS.TS.14

KS.TS.14	AUGERLOG 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' 36.8" E110^0 30' 40.6"		
AUGERHOLE NO.	KS.TS.14	14/5/2011	12.05 am
GROUND WATER LEVEL	0.3 m	TOP OF AUGERHOLE (Above m.s.l)	6 m
RECORD BY	MOHAMAD TARMIZI MOHD. ZULKIFLEY	CHECKED BY	MOHAMAD TARMIZI MOHD. ZULKIFLEY

CLASSIFICATION SYMBOL: SYMBOL	CLASSIFICATION SYMBOL: GRAPHIC LOG	DEPTH (M)	SOIL DESCRIPTION	REMARKS
Ptf		0	Very dark brown, FIBRIC PEAT. More than 2/3 left in hand, light brownish water extruded. Wet. Wood fragments 40%, 2 to 3 cm Rootlets 40 to 50%, 2 to 3 cm long, 2.0 to 3.0 mm thick. (groundwater level 0.3 m)	7.5 YR 3/2 H3B4F2W1
(Mo)		0.5	Greenish gray, very soft SLIGHTLY ORGANIC SILT. Wet. Wood fragments <3 %, black, 2.0 to 3.0 cm long.	GLEY 2, 6/1
(M)		1	Bluish gray, very soft SILT. Wet. Wood fragments <5 %, black, 2.0 to 3.0 cm long.	GLEY 2, 5/1
(M)		1.5	Bluish gray, soft SILT. Wet. Wood fragments <5 %, black, 2.0 to 3.0 cm long.	GLEY 2, 5/1
(M)		2	Bluish gray, soft SILT. Wet. Wood fragments <5 %, black, 2.0 to 3.0 cm long.	GLEY 2, 5/1
(M)		2.5	Bluish gray, soft SILT. Wet. Wood fragments <5 %, black, 2.0 to 3.0 cm long.	GLEY 2, 5/1
		3	(Stopped augering at 3.0 m due to consistant soil type return)	

LEGEND: Paludal Deposits/Peat; Floodplain Deposits; Estuarine/Deltaic Deposits; Slightly Organic Silt