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Application of Ground Penetrating Radar for Spatial Mapping of Organic Contents in Potian Peat Soil, Johor Malaysia

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Abstract
Ground Penetrating Radar (GPR) is an electromagnetic probe instrument that has wide range of application in near surface non-invasive and non-destructive geophysical exploration. It is highly effective in precision agriculture where it can be used to map spatial variation in nutrient and organic contents of soil with good precision. In this work, GPR was used to map the spatial variation of organic nutrient content of peat soil, in Pontian, Johor, Malaysia. The work is aimed at categorizing the resource according to its nutrient content. Four profiles of equal lengths were scanned with the instrument and core samples of the peat were also collected and analyzed using Lost in Ignition method of organic content estimation. The results revealed that peat deposit of the study area is made up of three layers, high nutrient Fibric top layer overlaying low nutrient Hemic layer. The third layer, which is of medium nutrient, is considered a transition zone between peat and less fibric organic content. Based on radar signal velocity analysis, the top layer is also found to have the highest cation carrying capacity.

Keywords: Peatland, Ground Penetrating Radar, Organic soil, Humic soil, Fibric soil.

INTRODUCTION
Peat soil is produced as a result of partial and gradual decomposition of plant organic materials in marshy areas under waterlogged condition and is therefore characterized by extensively high proportion of organic materials. The formation process of peat is the consequences of the development of an ecosystem where the accumulation rate of organic matter exceeds its decomposition rate (Huat *et al*., 2011). Hence peat production is a continuous process with the continuous growth and deaths of bog plants.

Peat soil is classified on the bases of variation in its organic contents. This is a consequence of great variability in the decompositional resistance of various parts of plant materials. There is significant variation in the rate of decomposition of organic matter. Since degree of decomposition usually increases with depth, the variation, appears as stratigraphic layers within the peat core (Xuehui and Jinnming, 2009).The stratigraphic sequences show different decompositional state and hence represents distinctive physical and chemical properties within the formation. Thus based on degree of humification, peat is classified on a scale known as Von Post classification scale, into ten successive degrees of decomposition from H1(undecomposed) to H10 (completely decomposed) (Klavins *et al*., 2008). The American

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Society for Testing and Measurement (ASTM) however narrowed down the Von Post classification into three classes according to the following degree of humification (ASTM D4427-07, 2007):

- Fabric, least decomposed with more than 67 % fibre content,
- Hemic, moderately decomposed with fibre content between 33-67 %.
- Sapric, highly decomposed with less than 33 % fibre content.

In an attempt to study the above classifications with tropical peat, Wust *et al*. (2003) developed a classification scale uniquely for tropical peat soil based on organic content with reference to the work done at Tasek Bera Basin peatland in the central part of Peninsular Malaysia. They defined peat soil with reference to the work as any organic soil with organic content above 35 % and classified it into five: very high (95-100 %), high (85 – 95 %), medium (75-85 %), low (45-60 %) and very low (45- 35 %).

In view of the significance of peat soil to the socioeconomic development of the ecosystem and its impact to the environment, this study is aimed at mapping and estimating the organic content of the deposit within the study area. The goal of the work is two-fold: to assess the variation of the organic content of the deposit with depth which is the measure of its level of fertility and to appraise the applicability of radar imaging technique in near surface geophysical prospecting.

MATERIALS AND METHODS

Study Area

The study was carry out on a farmland of area 850 m^2 km located midway by the side of the main road linking Pontian and Pecan Nenas, Pontian District, in the state of Johor Bahru Malaysia. The centre of the study area is geographically located at longitude 103^{0}04'49.39"E and latitude 1^{0}35'14.03"N (Fig. 1). The area is a lowland with a relatively flat topographic terrain covered with thick vegetation. It is a portion of the coastal plain of southwestern Johor described by ASEAN (2008) as largely underlain with marine clay, silt and the paludal peat deposit of Holocene age. The land utilization of the area is mainly agriculture.

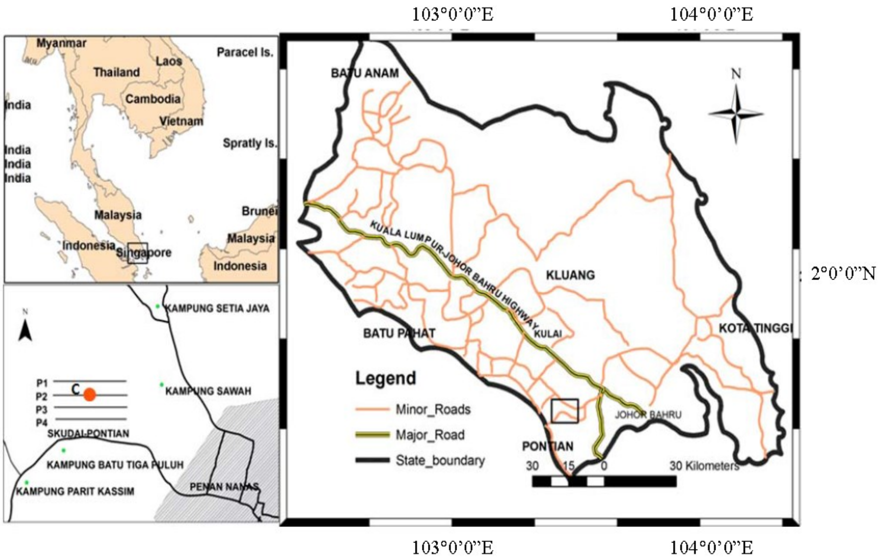

Fig. 1 study area. The four scanned profiles and the points of sample collection are shown on the lower left frame.

The area is a part of the largest peat deposit in southeast Asia, the Indonesia – Malaysia coastal axis. The state of Johor generally hosts the largest deposit of peat resources in peninsular Malaysia. (Wetland International, 2010). The peatland of western coast is described by ASEAN/US CPMP (1991) as highly extensive with a mean thickness of about 6 m .

Theoretical framework

Ground Penetrating Radar is a near-surface geophysical tool that works based on the application of electromagnetic method of geophysical prospecting. It is generally regarded as a near surface tool due to high attenuation rate of electromagnetic signal of the earth. The tool is made up of transmitting and receiving antennas housed in a single casing. GPR is a scanner which transmits, receives and records backscatter signals from the subsurface as it is dragged over the surface. The arrival time, phase changes and intensity of the backscattered signals are determined by the contrast in the electrical properties of the subsurface compositions. Thus the traces of the backscatter or reflected signals, known as the radargram, give the scanned image of the subsurface. GPR's capability of recording data fast and effectively with the speed of a vehicle give it added advantage as an effective tool for precision agriculture.

The suitability of GPR as a near-surface geophysical tool is influenced by the electrical and hydrogeological properties of the subsurface. Peat soil is associated with low electrical conductivity due to high concentration of inactive and strongly bound organic compounds (Jol, 2009). This translates into correspondingly higher penetration capability. The electrical and hydrogeological properties of peat are functions of various components of the aggregate deposit. According to Wetland International (2010), four main components of southeast Asian peat are water, air, minerals and organic content. Each of these exercise significant influence on the electrical properties of the soil and modify the backscatter. For instance radar signal velocity v through a soil medium is related to the dielectric permittivityε_0 of the medium by the equation

$$v = \frac{c}{\sqrt{\varepsilon_0}} \qquad 1$$

where c is the radar speed in free space. Dielectric permittivity is the measure of polarizability of the molecules of the medium in response to electromagnetic fields. Water molecules are polar with a dielectric permittivity of about 81 within GPR frequency range. Most soil materials on the other hand have dielectric permittivity of 4 to 7 within the same range of frequencies while air has a dielectric permittivity of 1 (Daniel, 2004). Thus the presence of water is a major factor influencing the speed of radar signals through subsurface medium. The presence of free-phase (biogenic) gas on the other hand reduces the overall magnitude of the dielectric permittivity and thus increases the radar signal velocity (Benedetto, 2010). Variation in signal velocity could therefore be used to detect the presence or absence of these two compositions.

Radar signal attenuation rate α through a medium is related to the electrical conductivity σ of the medium by the expression

$$\alpha = \frac{\sqrt{\omega\mu\sigma}}{2} \qquad 2$$

where ω is the radar angular frequency and μ is the magnetic permeability of the medium which is close to that of free space in most materials. Electrical conductivity of peat depends on its chemical composition, cation exchange capacity and acidity. These in turn depend on the degree of humification of the peat (McGlashan *et al.*, 2012). Thus, the presence of mineral ions enhances the electrical conductivity causing the radar signal to be more strongly attenuated.

Data acquisition and interpretation

A common offset reflection profiling was used to scan four equidistant profiles(Fig. 1) of length 20 m each across the study area with a Ground Penetrating Radar (GPR) scanner. The profiles were scanned with GPR model IDS DAD fast wave radar acquisition unit at a central frequency of 200 MHz. The scanner is equipped with a perpendicularly polarized in-built antenna. The output is a raw scanned images of the subsurface which need to be preprocess for meaningful interpretation. Core samples of undisturbed peat were collected about the centre of profile 2, at an interval of 0.5 m from the surface to a depth of 3 m using a cylindrical sampler of diameter 30 cm.

The radar image (radargram) obtained for the four profiles were processed using Reflex W radar processing packages. The preprocessed technique applied includes subtraction mean (dewow), static correction, amplitude gain and background removal (Sandmeier, 2010). The preprocessed radargram for the four profiles are shown in Fig. 2. Radar signal velocities were estimated using hyperbolic velocity analysis. Discernible reflection hyperbolas within the radargrams were fit with mathematical velocity models so that the velocity of the best fitting hyperbola is recorded as the velocity of the signal within the layer above the point as shown in Fig. 3 (Sandmeier, 2010).

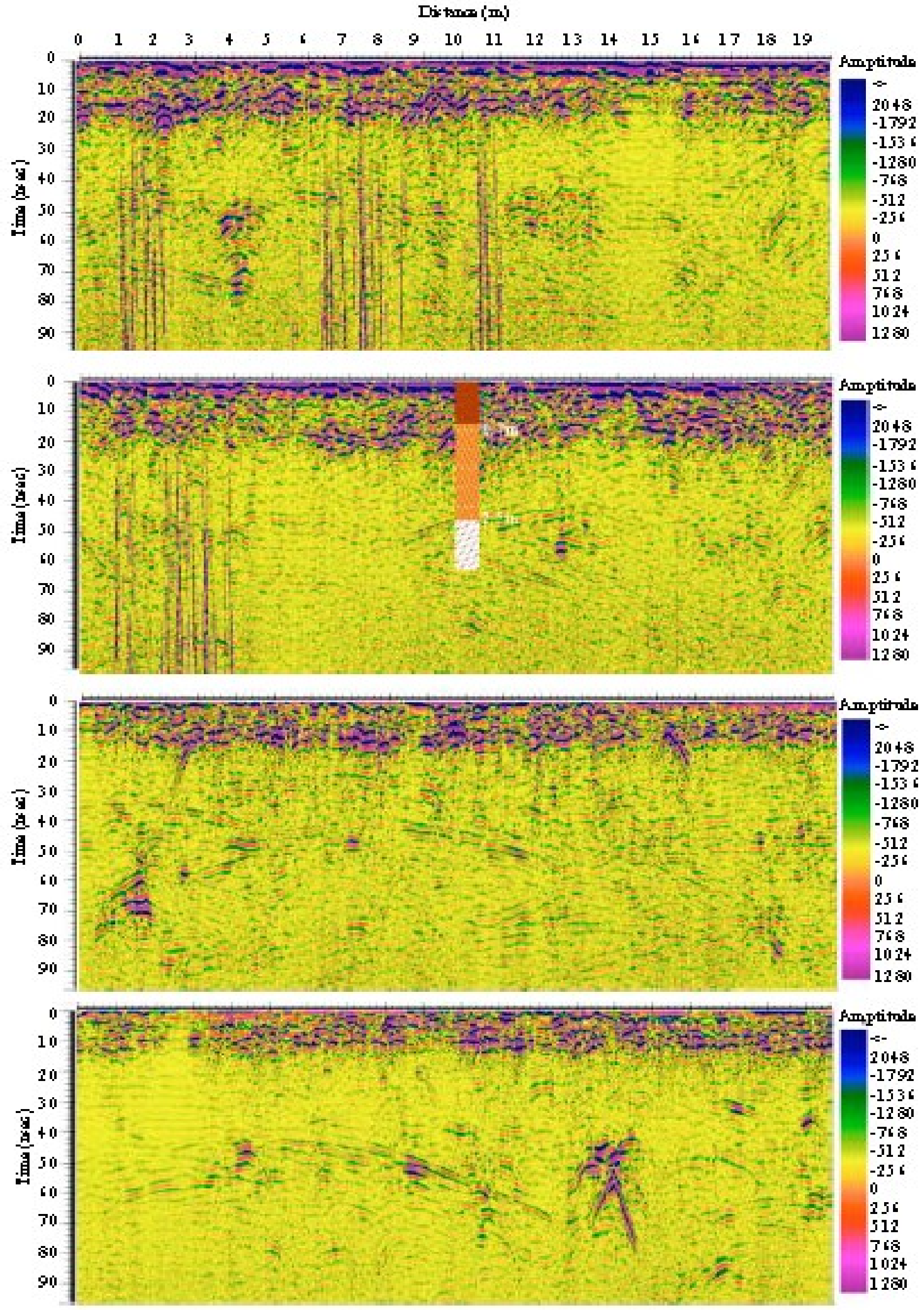

Fig. 2 Preprocessed radargrams of obtained with respect to the four profiles.

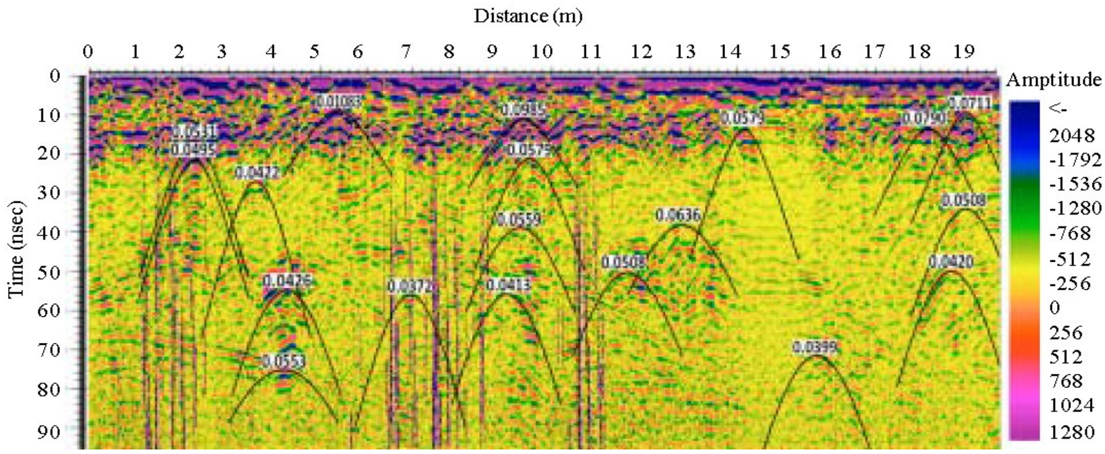

Fig. 3 Reflection velocity adaptation hyperbolas of profile p1

The organic contents of the collected samples were measured in a laboratory using Lost of Ignition (LOI) experiment where the ash content of the samples were determined and used to compute the organic content (ASTM D2974-07, 2007; Handayani *et al*., 2010; Gasim *et al*., 2011). The experiment involves oven drying and measurement of the mass of the oven-dried sample specimen. It is then followed by ashing the specimen to a constant mass in a furnace at a temperature of 440^0C. According to ASTM D2974-07 standard, the ash content AC of the sample is given by

$$AC = \frac{M_a}{M_d} \qquad 3$$

where M_a is the mass of ash remains after subjecting the sample to excessive heating and M_d is the mass of oven dried specimen. The organic content OC is then computed based on the expression given by the standard as

$$OC = 1 - AC \qquad 4$$

In this work, organic contents of two set of specimens representing successive depths from the surface at an interval of 0.5 m were determined based on the above procedure.

RESULTS AND DISCUSSION

The velocity values obtained were used to perform layer picking which is a process of obtaining horizontal stratigraphic regions with common velocities. Fig. 4 shows the detected layers picked with respect to profile 1. It has been observed that the layer velocities increase with depth in all the cross sections. This is due to the increase in water content with depth as explained earlier. Physical observation of the processed radargram in comparison with the core sample collected at the centre of profile 2 shows that the top layer is a water saturated region with high fibre content overlaying the water table. This top layer appears in the radargram as the region of strong signal activity. This implies that the signals encountered strong attenuation at the top layer – water table interface due to high conductivity of the soil – water mixture.

Table 1 gives the ash contents and the computed organic contents obtained. According to the results, top soil has the lowest organic content while the two underlyinglayers have nearly the same contents. The layers are therefore assumed to be similar in level of decomposition with slight difference in water content which obviously increase with depth. Underlying the second (merged) layers is a layer of lowest organic content which is correspondingly the highest velocity layer detected. The layer is detected at all the four regions from a minimum depth of 2.5 m and extents deeply beyond the depth limit of investigation.

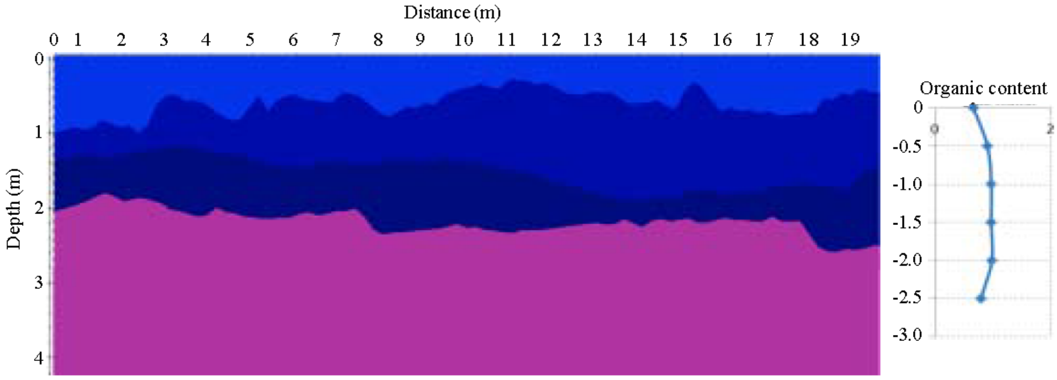

Fig. 4. Picked velocity layers of profile 1. The right frame is the plot of the variation of organic content with depth for same profile.

Table 1. Results of ash and organic contents experiment

Depth (m)	AC	OC
0.0	0.3334	0.6667
0.5	0.0903	0.9097
1.0	0.0228	0.9772
1.5	0.0244	0.9756
2.0	0.0122	0.9878
2.5	0.2027	0.7973

Comparison of the velocity –based stratigraphic layers with the plot of the organic content (Fig. 4) shows that the study area is made up of three major layers of varying organic content. The top layer with low organic content (high ash content), high organic (low ash) content and lower organic (higher ash) content that extends beyond the depth of coverage.

Comparative classification of the peatland of the study area on the bases of both ash content and ATSM technique revealed that the peatland of the study area is made up of three major classes:

(i) High ash (low organic) content with a mean ash content of 0.0333 which is the top soil and corresponds to the Fibric humification level in the ASTM scale. It exists to a mean depth of 0.5 m from the surface.

(ii) Low ash (high organic) content layer with a mean ash content of 0.0374 which exists to a mean depth of 2.5 m under waterlogged condition and corresponds to Hemic humification level in the ASTM scale.

(iii) High ash (low organic) content with mean ash content of about 0.2027which also corresponds to Fibric humification level. This layer is however interpreted as a transition zone between peat and a low fibre organic soil due to the abrupt loss of organic content with depth (Zainorabidin and Bakar, 2003).

Fig. 5 is a fence plot of the stratigraphic sequence of the peat deposit within the study area based on the organic content according to the findings of this work.

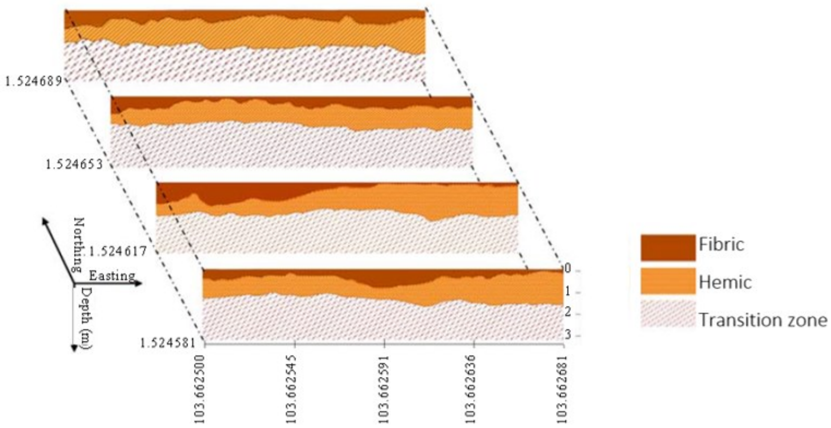

Fig. 5. Fence plot of peat classification based on organic content

Although the figure indicates undulating stratigraphic layers of peat according to organic (nutrient) content, it is however made up of horizontal beddings. This is one of the significant features of peat deposit accumulated under still water environment (Xuihui and Jinning, 2009).

CONCLUSION

In this work, GPR is utilized as a noninvasive technique of mapping the nutrient contents of peat soil and used to scan a portion of Pontian peatland with the goal identifying the spatial variability in organic contents of the deposit. Three layers of varying organic contents were identified and classified on the bases of available classification schemes. The peat deposit of the area was found to be of intermediate extent with organic contents that increases to a depth of 2.5 m. Abrupt drop in organic content beyond 2.5 m is a mark of transition from peat to fibric organic soil. The finding revealed that the top layerbeing richer in fibre content, has the highest cation exchange capacity and is therefore the richest in nutrient contents.

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