



Depositional Cycles of Muara Wahau Coals, Kutai Basin, East Kalimantan

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Abstract - Fifteen samples were taken ply by ply from a 33 m thick drill core of Muara Wahau coal seams for interpretation of depositional environments. Generally, lithotype variation in the bottom part of the coal seams has a lower frequency than in the upper part. Petrographical analysis was performed to determine the maceral composition, groundwater index (GWI), and gelification index (GI). The samples from lower sections show much higher GWI-GI values and lower variation frequency than from the upper section. This characteristic is interpreted as the result of development of mesotrophic to ombrotrophic peats during the deposition of lower to upper parts of the section, respectively. During the development of the mesotrophic peat, water was more abundant and relatively stable in budget. However, during the development of ombrotrophic peat, water was less abundant and relatively not stable in budget. The latter is related to the water supply depending only on rain, resulted in the more sensitive water table in the ombrotrophic peat. The unstable water table is thought as the reason of higher variation frequency of lithotype, GWI, GI, as well as maceral composition in the upper part of the core. Unstable water table would lead to moist condition in the uppermost layer of the ombrotrophic peat, favoring fungi to grow. This is confirmed by the higher abundance of sclerotinite maceral in samples from the upper part of the coal core.

Keywords: coal seam facies, Muara Wahau, Kutai Basin

INTRODUCTION

Muara Wahau coals are part of Early Miocene Wahau Formation, Kutai Basin, East Kalimantan, consisting of several thick coal seams. The thickness of each seam is up to 60 m. The coal has not been disturbed by exploitation, as the site is located in a very remote area.

Peat accumulation is controlled by at least two key factors: subsidence rate creating accommodation space and organic matter (trees) supply rate (Taylor *et al.*, 1998). The interplay between the two factors in equilibrium state brings through peat accumulation. The longer equilibrium state time is reached, the thicker peat would be accumulated. Another important aspect is the presence of water which takes a role as media of nutrient

supply and deposited-organic matter preservation. Peat water may originate from groundwater, rain water, and intrusion of sea water. The peat water table is fluctuative and sensitive to season or climate changes. The hydrological condition in peats determined the vegetation and peat type accumulated in a basin.

In the present case, the Muara Wahau coals are interesting to investigate. The thick coal seams can provide more detailed indications of chemical and physical changes during peatification. With respect to hydrological condition, the succession of early development of Muara Wahau coals will be reconstructed and discussed in detail. Petrographical analysis was carried out to characterize the maceral composition of the Muara Wahau coals.

GEOLOGICAL SETTINGS

The studied area is located in Muara Wahau Sub-regency, East Kutai Regency, East Kalimantan, Indonesia (Figure 1). The area is mostly composed of Early Miocene Wahau Formation according to Supriatna and Abidin (1995) (Figure 2). The formation was deposited in Upper Kutai Basin (Calvert, 1999). The lower part of the formation consists of interbedded coralline and algal limestones. The upper part of Wahau Formation comprises interbedded tuff, claystones, quartz sandstones, sandy claystones, and coal layers. There are two major coal seams in the area (Figure 3), showing variation in the thickness from 15 to 62 m, with gentle dips that range from 8° to 12°. The cropline distribution is controlled by the presence of syncline in the area. Generally, the coals are blackish brown, hard, brittle, dull in luster, and contain resin and fossilized wood in some parts.

METHODS

The study was commenced by collecting representative samples from the coal field. Drilling programme, which was conducted, penetrated Seam 1 and Seam 2 in the coal field (Figure 4). The selected coal samples were then taken directly ply-by-ply/ply sampling (Thomas, 2002) from Seam 1 core. The samples were separated based on the lithotype observed along the core, then they were crushed and split for further laboratory analysis.

For maceral composition, fifteen samples were investigated using Zeiss Axio Imager A2m polarized microscope in the Laboratory of Earth Resources Exploration, Faculty of Mining and Petroleum Engineering, ITB. During the maceral analysis, five hundred points with a minimum distance of 0.2 mm between each point were counted from the polished sections. The maceral composition is stated as percent (%-volume).

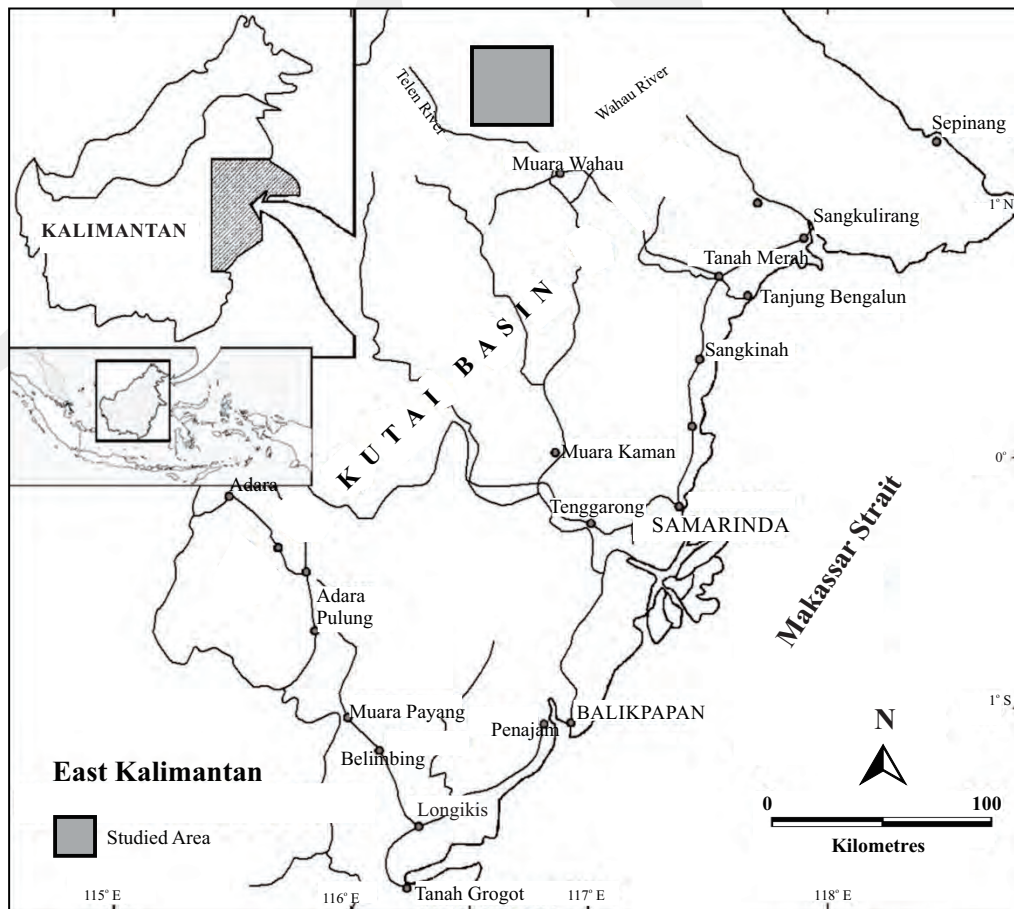


Figure 1. Location map of the studied area.

PERIOD	AGE	SURFACE DEPOSITS	VOLCANIC ROCK	FORMATION	INTRUSION	DESCRIPTION	
QUATERNARY	HOLOCENE	[Pattern]				Alluvium: pebble, cobble, sand, mud and plant remain	
	PLEISTOCENE	[Pattern]					
TERTIARY	PLIOCENE		[Pattern]			Metulang Volcanic: andesite, basalt, lava, tuff, aglomerat breccia and laharc	
	MIOCENE	LATE	[Pattern]				
		MIDDLE	[Pattern]		[Pattern]	[Pattern]	Sintang intrusion: stock and dyke of andesite and diorite Upper Wahau Formation: intercalation of tuff, clastone, quartz sandstone, clayish sandstone, sandy claystone, and lignite Lower Wahau Formation: interbedded coral and algae limestone
		EARLY	[Pattern]		[Pattern]		
	OLIGOCENE			[Pattern]			
	EOCENE	LATE			[Pattern]		Marah Formation: intercalation of marl, claytone, conglomrate, and limestone
EARLY				[Pattern]			
PALEOCENE				[Pattern]		Metaphorphic rock and ultra basic rock	

Figure 2. Regional stratigraphy of Upper Kutai Basin (Supriatna and Abidin, 1995).

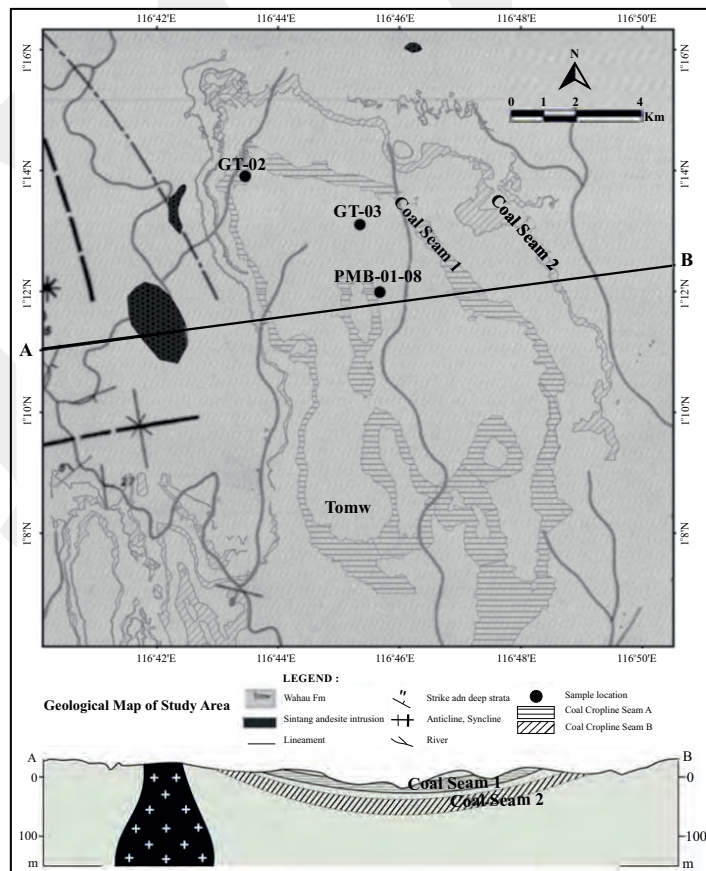


Figure 3. Geological map and cropline of Muara Wahau coals (modified from Supriatna and Abidin, 1995).

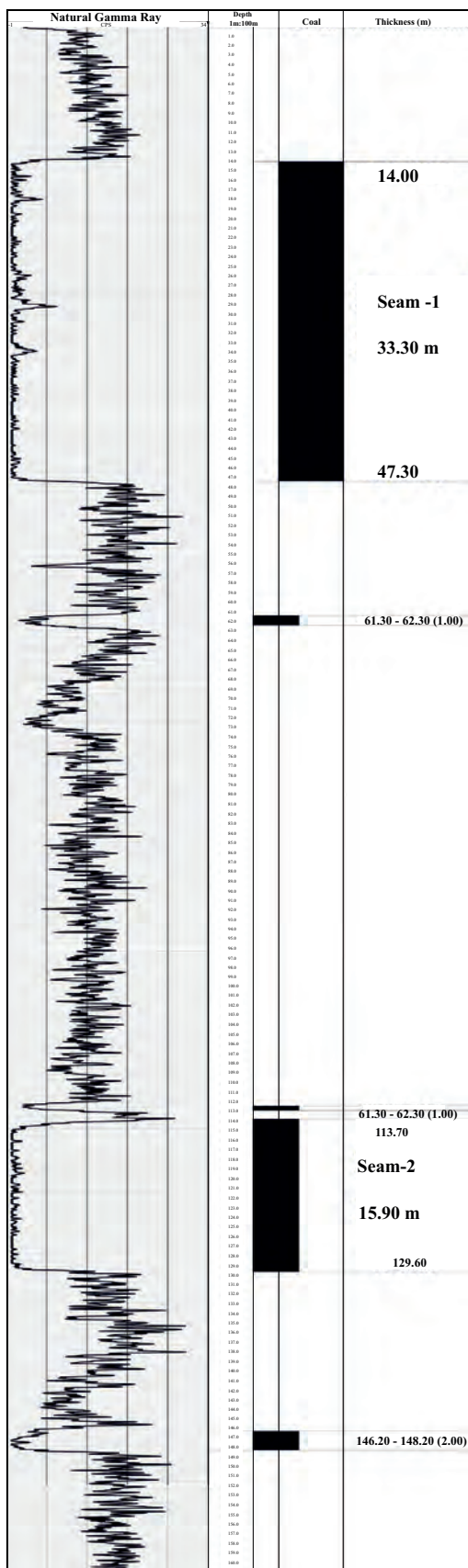


Figure 4. Coal seam profiles (Seam 1 and Seam 2) from density log interpretations of Borehole GT-02.

Vitrinite (huminite) reflectance measurement was also carried out in the Centre of Geological Resources, Geological Agency, Ministry of Energy and Mineral Resources. Mean random vitrinite reflectance measurements were performed on the surface of vitrinite particles under oil immersion. Fifty points of vitrinite reflectance were taken on each sample. The identification and classification of macerals in this study are based on ICCP System 1994 (ICCP, 1998, 2001, 2011), Suarez-Ruiz and Crelling (2008), and Sykorova *et al.* (2011).

In order to investigate the hydrological regime of the ancient peat, two indices were determined. Groundwater index (GWI) based on Calder *et al.* (1991) was used to indicate the ratio of strongly gelified macerals (humocollinite), as well as the mineral matter, to weakly gelified ones (humotelinitite, humodetrinite). Mineral matter is considered to be related to water carrying detrital material to the former peat during flood (Crosdale, 1995).

$$GWI = \frac{\text{Humocollinite} + \text{Minerals}}{\text{Humocollinite} + \text{Humodetrinite}} \dots\dots\dots(1)$$

The second indicator used in this study is gelification index (GI) based on Diessel (1986). GI is a tool to contrast gelified macerals to nongelified ones as the indicator of peat wetness. When the peat is flooded by water, vitrinite and geloinertinite tend to form. On the other hand, when the water table is lower and the peat surface becomes dryer or moist, teloinertinite and detroinertinite will form in the peat surface due to oxidation (Lamberson *et al.*, 1991)

$$GWI = \frac{\text{Huminite} + \text{Macrinite}}{\text{Fusinite} + \text{Semifusinite} + \text{Sclerotinite} + \text{Inertedotrinite}} \dots\dots\dots(2)$$

GWI and GI have different concepts. GWI changes reflect the fluctuation of water table which could happen in both high and low moor peat types. In high moor, the water table would typically raise, following the development of rising peat surface. GI assumes that gelification process takes place in reduced water where the water table is static regardless of peat surface development.

The GWI could be correlated with GI on the development of peat as follows:

1. $GWI < 0.5$ and weak gelification ($GI < 1$) reflect lower water table of a marsh (Diessel,

- 1986) and ombrotrophic peat type (Calder *et al.*, 1991).
2. GWI 0.5 - 1 and moderate gelification (GI ~ 1) reflect higher water table of a fen? (Diessel, 1986) and mesotrophic peat type (Calder *et al.*, 1991).
 3. GWI > 1 and strong gelification (GI > 1) reflect higher water table of a wet forest swamp (Diessel, 1986) and rheotrophic peat type (Calder *et al.*, 1991). GI > 1 is characterized by limited influx of clastics.

RESULT AND DISCUSSIONS

Coal Lithotype

Lithotype classification used in this study is based on Stopes (1919) and Diessel (1965). Coal from the Seam 1 of the Muara Wahau Formation could be classified into three lithotypes, those are banded coal (clarain), dull banded coal (clarain), and dull coal (durain). Coal lithotype profile shows cycle changes in the vertical section as presented in Figure 5. Lithotype variation may indicate changes of vegetation type composing coals (Bustin *et al.*, 1983) or changes in sedimentary facies, especially related to water table conditions during peat depositional process. Facies changes in both vertical and lateral trends could control the variation of maceral composition.

Coal Petrology

Microscopic analysis shows that huminite reflectance of the Muara Wahau coals is 0.44 % on the average, suggesting brown coal maceral nomenclature based on ICCP System 1994. The coals predominantly consist of huminite macerals, with minor liptinite and inertinite (Figure 6). Huminite maceral of the coals comprises humotelinite, humodetrinite, densinite, and humocollinite. Liptinite maceral consists of cutinite, resinite, suberinite, and sporinite. Inertinite maceral is dominated by fusinite, semifusinite, and sclerotinite.

Humotelinite (Figure 6a) is mostly found as thick layers in association with humodetrinite and cutinite, grey to dark in colour, sometimes forming lighter layers. This maceral may originate from the lignin of high plants.

Humodetrinite (Figure 6b) shows fragmented materials associated with inertinite, liptinite, or minerals. Densinite appears as a mixture of fine fragments of vitrinite. It is more homogenous than attrinite. Humocollinite (Figure 6c) was found as homogenous, rounded to oval bodies, and often isolated one within desmocollinite.

Cutinite (Figure 6d) is mainly present as thin continuous bands in association with vitrinite maceral. Suberinite (Figure 6d) looks as cell walls filled by other macerals, typically humocollinite. Resinite (Figure 6e) appears as rounded, oval, and unstructured material. Sporinite (Figure 6e) is present only in a minor amount. It appears as individual body with distinct cell walls and a higher relief.

Sclerotinite shows rounded to oval forms and has high reflectance (Figure 6f). This maceral is present in all coal samples.

Mineralogical analysis shows that the coal seam from the Seam 1 contains pyrite which is present mostly as fine crystals within the dense macerals (Figure 6f). The coal seam profiles

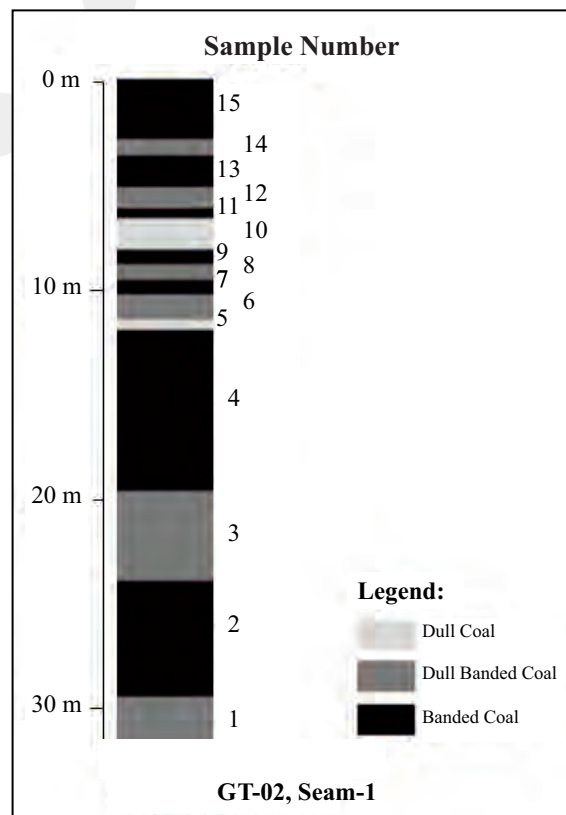


Figure 5. Coal lithotype profile of seam 1 from Drillhole GT-02.

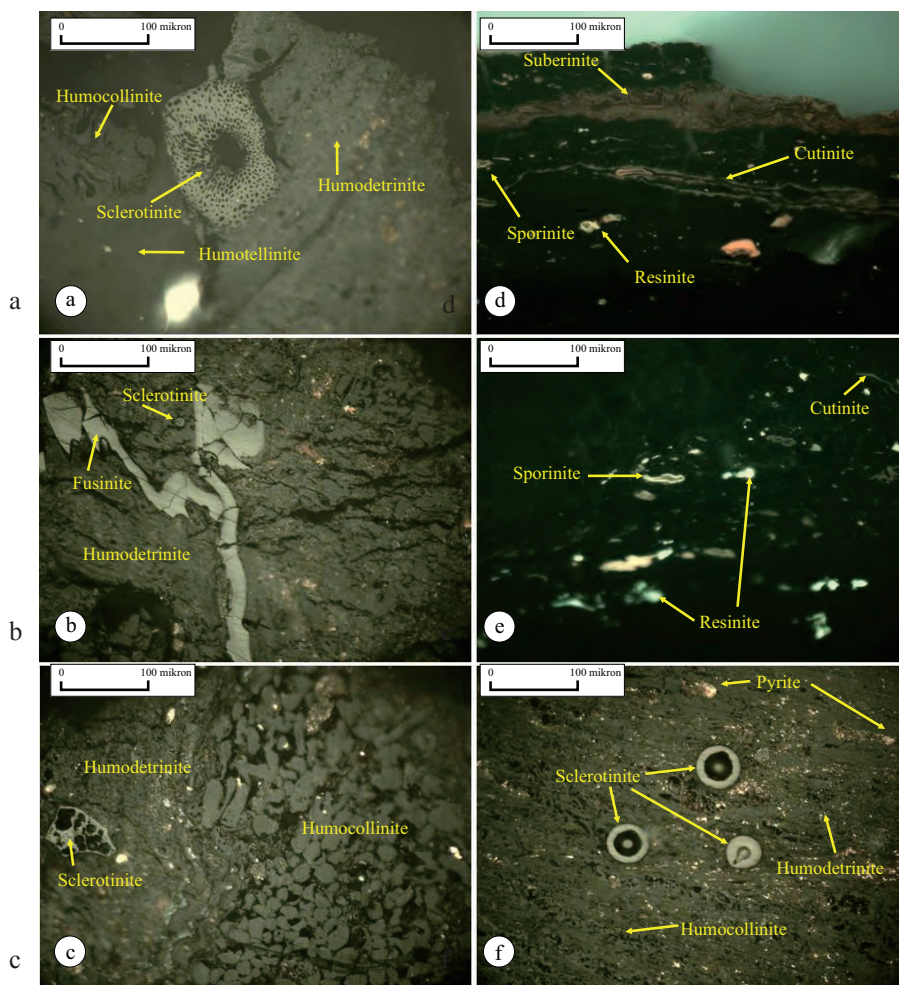


Figure 6. Photomicrographs of macerals in the Muara Wahau coals (Seam 1). a. Sclerotinite associated with huminite; b. Sclerotinite and fusinite associated with humodetrinite; c. Humodetrinite in association with round bodies of sclerotinite and humocollinite; d. Suberinite, sporinite, resinite, and cutinite as individual bodies with distinct cell walls; e. Sporinite, resinite, and cutinite as individual bodies with distinct cell walls; f. Huminite macerals in association with round bodies of sclerotinite and pyrite mineral. a, b, c, and f in reflected light mode, while d and e in fluorescence mode.

obtain the mineralogical distribution and variation in vertical sequence.

Coal Facies/Coal Deposition

Based on the maceral quantification, the Muara Wahau coals consist of higher amount of huminite (73.4 to 88%), lower proportion of liptinite (0.6%-6.8%), and inertinite (5.8%-18%) macerals (Table 1). The abundance of the macerals and minerals along the vertical coal profile are shown in Figures 7a - d.

Figure 7a shows the variation of huminite macerals along the coal profile. Humotellinite and attrinite amount to about 9% and 8% on the average, respectively, and exhibit no vertical variation. Humodetrinite and humocollinite average

at 47% and 18%, respectively. Generally, humodetrinite abundance exhibits a decrease in depth, the opposite condition with that of humocollinite. In segment 1 (sample 1 - 4), the variation is low, while in segment 2 (sample 5 - 15) the variation is higher. The higher variation of humodetrinite - humocollinite in segment 2 may reflect that the groundwater in the ancient peat fluctuated more intensively.

Figure 7b indicates that the abundance of liptinite macerals generally decrease in depth. Sporinite and cutinite only appear in some of segment 2 samples. Resinite is consistently present in all samples, averaging 1.3%. Alginite is present only in some samples of segment 2. Suberinite appears in sample 3 - 15 with varying amounts.

Table 1. Maceral Composition of Seam 1 the Muara Wahau Coal

Sample Number			1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	
Maceral group	Maceral subgroup	Maceral	% Volume of each sample															
HUMINITE	Humotelinite		83.6	81.4	78.6	82.6	86.6	88.0	80.4	73.4	87.8	83.2	75.0	77.4	86.0	81.4	86.8	
			12.6	11.0	10.6	10.0	10.6	12.2	8.6	5.0	12.6	10.0	2.8	6.0	8.6	7.4	7.6	
	Humodetrinite	Telocollinite	12.6	11.0	10.6	10.0	10.6	12.2	8.6	5.0	12.6	10.0	2.8	6.0	8.6	7.4	7.6	
		Attrinite	52.2	45.0	51.8	49.0	39.4	52.4	53.4	57.6	48.4	56.2	67.4	64.4	63.6	61.2	64.2	
	Humocollinite	Densinite	8.6	6.0	6.6	7.6	5.2	8.4	8.8	9.2	6.6	11.4	5.0	3.4	8.8	7.2	13.8	
		Corpogelinite	43.6	39.0	45.2	41.4	34.2	44.0	44.6	48.4	41.8	44.8	62.4	61.0	54.8	54.0	50.4	
	LIPTINITE	Humocollinite		18.8	25.4	16.2	23.6	36.6	23.4	18.4	10.8	26.8	17.0	4.8	7.0	13.8	12.8	15.0
				18.8	25.4	16.2	23.6	36.6	23.4	18.4	10.8	26.8	17.0	4.8	7.0	13.8	12.8	15.0
Sporinite		0.8	0.6	2.0	3.2	1.0	1.6	1.6	4.8	1.8	4.0	6.8	5.6	3.0	2.4	1.4		
Cutinite		0.0	0.0	0.0	0.0	0.0	0.0	0.2	0.0	0.0	0.6	0.2	0.6	0.2	0.2	0.2	0.2	
Resinite		0.0	0.0	0.0	0.0	0.2	0.0	0.0	0.8	0.2	0.4	0.4	1.0				0.2	
Alginate		0.8	0.6	0.6	1.2	0.8	1.0	0.6	2.4	0.6	2.4	3.4	1.4	1.4	1.6	0.4		
Suberinite		0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.2	0.0	0.0	0.2	
INERTINITE	Fusinite		8.8	12.0	15.0	7.6	6.4	5.8	13.6	18.4	6.4	9.6	11.8	13.6	8.6	12.0	9.4	
			0.4	0.2	1.2	0.8	0.4	0.0	1.2	1.2	0.4	0.6	0.4	0.6	1.4	0.6	0.0	
	Semifusinite	0.8	1.8	3.0	2.8	0.8	0.2	2.8	2.6	0.2	1.4	1.6	1.6	0.4	1.2	2.0		
	Sclerotinite	5.8	7.6	7.4	3.4	3.8	4.8	5.6	9.8	5.6	6.0	7.2	8.8	5.8	7.6	5.2		
	Inertodetrinite	1.8	2.4	3.4	0.6	1.4	0.8	4.0	4.8	0.2	1.6	2.4	2.6	1.0	2.6	2.2		
	Macrinite	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.2	0.0	0.0	0.0	0.0		
MINERAL MATTER	Oxide		6.8	6.0	4.4	6.6	6.0	4.6	4.4	3.4	4.0	3.2	6.4	3.4	2.4	4.2	2.4	
			0.6			4.6	2.0				0.6					0.0	0.0	
	Pyrite	1.8	0.4	2.0	1.6	3.6	1.6	1.8	1.0	1.2	0.6	2.8	2.4	0.6	1.6	1.2		
	Clay	4.4	5.6	2.4	0.4	2.0	1.6	1.8	1.0	1.2	0.6	2.8	2.4	0.6	1.6	1.2		
TOTAL (%)			100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0		
Rv. mean (%)			0.45	0.46	0.45	0.45	0.45	0.43	0.45	0.43	0.43	0.42	0.44	0.45	0.45	0.45	0.44	

Resinite may originate from various plants. Thus, this maceral is not a paleoenvironmental-indicative in the present case. Suberinite originates from cork tissues, plant components which are similar to cuticles deriving cutin. The suberinite source is easier to be destructed during coalification, consequently, suberinite is rare and infrequently found in some coals (Taylor *et al.*, 1998). In the Muara Wahau coal, suberinite occurs in almost entire vertical coal seam profiles, except in the lower part (sample 1 and sample 2). This may indicate that during the deposition of sample 1 - 2, trees were firstly not present in the peat. After that, the peat was starting to develop trees, forming ombrogenous peat.

In Tertiary coals, sporinite originates generally from pollen of angiospermae. Thus, the mechanism transport of pollen to the peat swamp might be dominated by wind (Esterle and Ferm, 1994). The preservation of spore and pollen is generally/mainly controlled by depositional environments. Taylor *et al.* (1998) for

example, revealed that the marine and brackish environments would be more effective for spore and pollen preservation than freshwater environments. In addition, the preservation of spore and pollen would be less efficient when exposed to atmosphere. In the Muara Wahau coal, sporinite is present only in segment 2 which might not be related to a specific environment. The absence of sporinite in segment 1 may suggest that during the development of the segment, there were very limited spore/pollen producing plants as the peat was still mesotrophic and dominated by aquatic plants.

Inertinite macerals of the Muara Wahau coals mainly consist of sclerotinite maceral. In vertical sequence, sclerotinite is the most abundant maceral in the top and bottom parts of the seam (Figure 7c). Sclerotinite was derived from fungi dwelling in moist environments. The presence of sclerotinite in all investigated samples suggests that moist conditions intermittently occurred during the development of the peat.

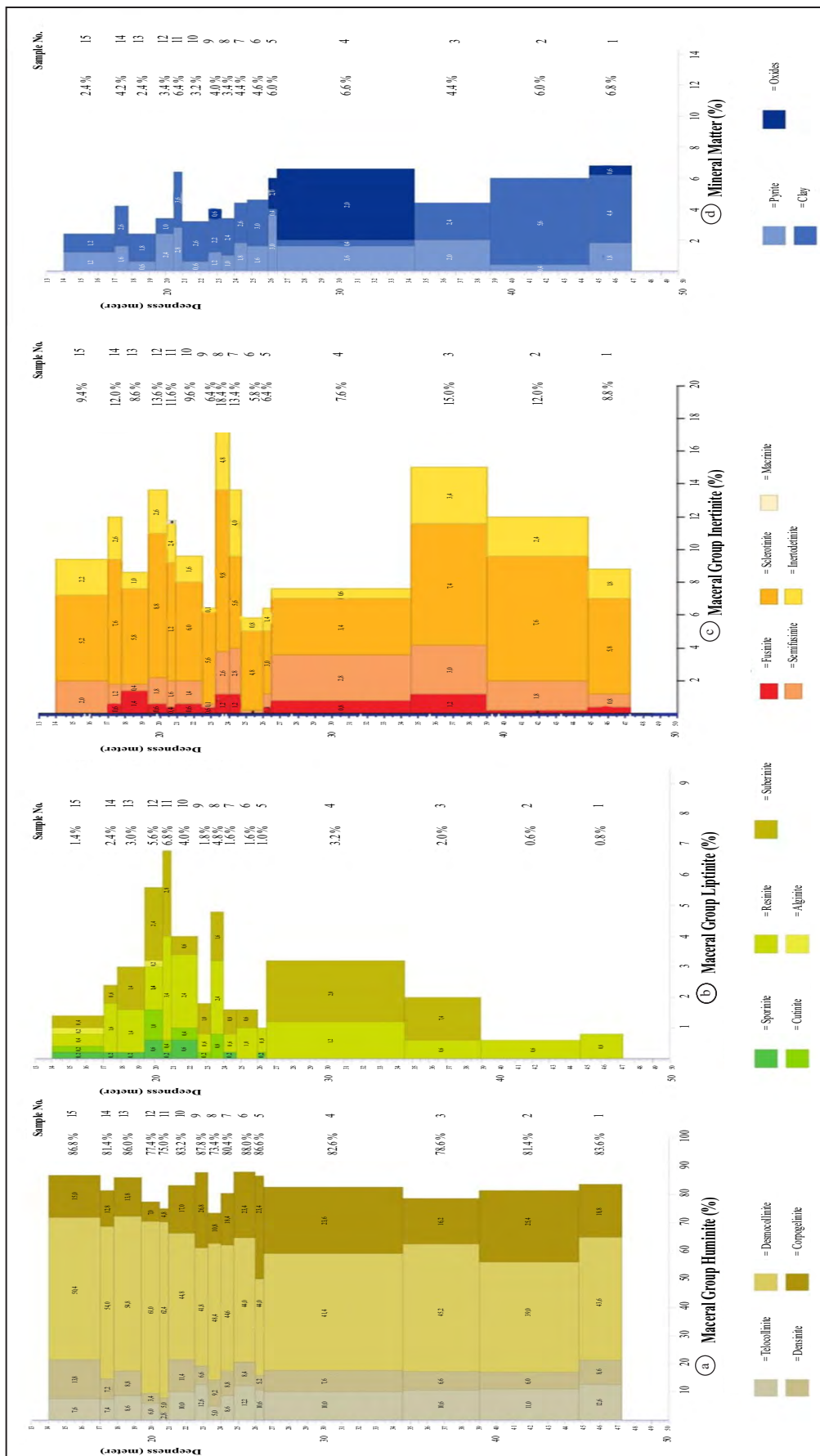


Figure 7. Comparison of maceral distribution in vertical section of the Seam-1, Muara Wahau coals a. huminites; b. lipinites; c. inertinites; d. minerals.

Maceral variation and distribution in vertical section of the coal profile, as mentioned above clearly reveal that the peat developed under the mesotrophic to ombrotrophic conditions. Mesotrophic peat was mainly developed in segment 1 of the coal profile indicated by the presence of aquatic plants. On the other hand, the ombrotrophic peat might occur during the deposition of segment 2 dominated by trees with less water influence.

Figure 8 shows the vertical variation of GWI, GI, humocollinite, inertinite, sclerotinite, and mineral matter profiles. Segment 1 (sample 1 - 4) shows lower fluctuation profiles, while segment 2 (sample 5 - 15) indicates high fluctuation profiles. The change of the fluctuation pattern in the vertical coal profiles matches with that of coal lithotype.

Segment 1 represents the development of the mesotrophic peat type. In the peat, the

hydrological regime was influenced by both groundwater and rain water. Such condition would lead to the relatively more stable water table. Segment 2 represents the development of the ombrotrophic peat type. The hydrological regime in the ombrotrophic peat relied only on rain water. This condition would promote less stable water table, as rain water is very sensitive to season and climate changes. Water table fluctuation might occur faster resulting in a more frequent moist condition in the peat surface. This could allow fungi to grow. Thus, consequently the coal in segment 2 contains relatively more sclerotinite.

In order to investigate the relation between the above parameters, some correlation plots were made. Some of the plots are shown in Figure 9, while the complete coefficients of determination are listed in Table 2. The parameters are

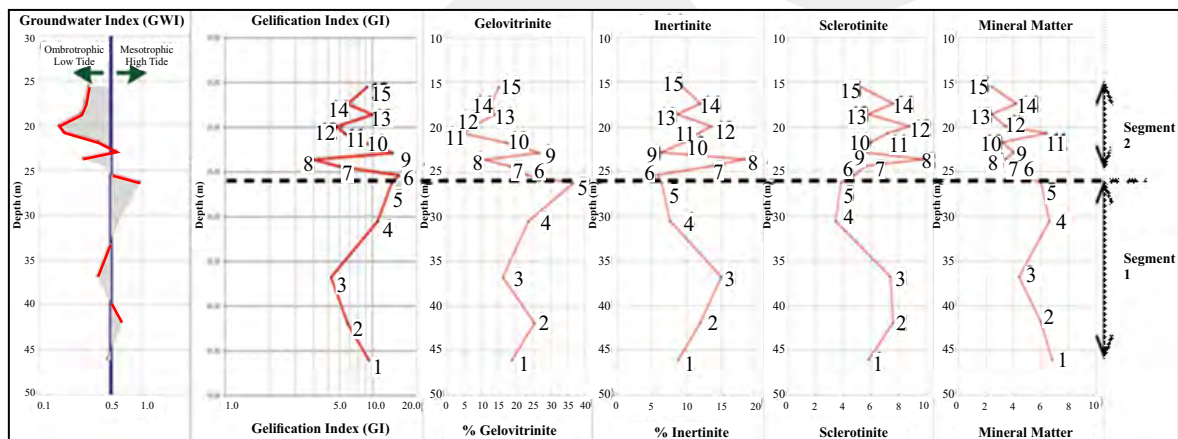


Figure 8. Vertical variation of GWI, GI, humocollinite, inertinite, sclerotinite, and minerals.

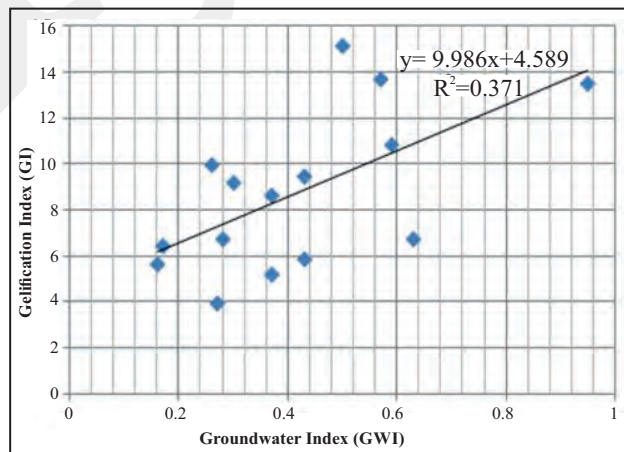


Figure 9. GWI versus GI correlation.

Table 2. Correlation of GWI, GI, Macerals, and Minerals

No	Parameter	Correlation	Coefficient of determination (R ²)
1	GWI vs. GI	+	0,37
2	GWI vs. humocollinite	+	0,96
3	GWI vs. inertinite	-	0,29
4	GWI vs. sclerotinite	-	0,39
5	GWI vs. minerals	+	0,24
6	GI vs. humocollinite	+	0,49
7	GI vs. inertinite	-	0,89
8	GI vs. sclerotinite	-	0,62
9	GI vs. minerals	+	0,02
10	Humocollinite vs. minerals	+	0,13

typically positively correlated. GWI is positively correlated with GI, as both indices are sensitive to groundwater influence. Both indices are also positively correlated with mineral and some macerals which are well preserved in a wet condition under water table. Several parameters show negative correlation as shown by inertinite and sclerotinite vs. GWI and GI. These macerals developed under a moist condition, in parts where sometimes covered by water.

A strong negative correlation occurs in parameters GI vs. inertinite. It is normal, as the two parameters require opposite depositional environments. Gelification can only occur below water table (reduction) condition, while inertinite could only be derived in moist or oxidation condition. The correlation between GI and mineral matter is very weak. It is confirmed that the mineral might be epigenetic, rather than related to groundwater flow in the peat. This also confirms that the peat development was not initiated by eutrophic peat type, but it was directly commenced by mesotrophic and then ombrotrophic peats. Eutrophic peat generally depends on groundwater flow for nutrient supply. Coal which was deposited in such peatland should have well correlation with mineral matter content.

CONCLUSIONS

The thick Muara coal seam has been investigated and is considered representative to indicate

variation in depositional cycles. The variation of lithotype and maceral composition reveals two segments showing different patterns along the vertical profile. Segmen 1 (lower part of the coal profile) shows depositional cycles related to relatively stable water table, as interpreted by the less frequent changes of sclerotinite, GWI, and GI. Segmen 2 (upper part of the coal profile) shows depositional cycles related to less stable water table, as it shows more frequent changes of the latter parameters. Based on the relatively low GWI, GI, and the absence of correlation between the two parameters and mineral matter content, the Muara Wahau coal is interpreted to be deposited in mesotrophic peat (segment 1) which subsequently developed to ombrotrophic peat (segmen 2).

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