Limnic Condition in Ombrotrophic Peat Type as the Origin of Muara Wahau Coal, Kutei Basin, Indonesia

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Limnic Condition in Ombrotrophic Peat Type as the Origin of Muara Wahau Coal, Kutei Basin, Indonesia

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Abstract: Samples of early Miocene Muara Wahau coal from three drill cores were investigated with respect to maceral composition. Huminite macerals are dominant in the coal, ranging from 73.3 to 88.0% (vol.) with an average value of 77.4% (vol.). Liptinite macerals account for lower amount, from 0.7 to 6.7 with an average value of 1.8% (vol.). Inertinite macerals vary from 4.3 to 34.0% (vol.), averaging at 15.3% (vol.). Some paleoenvironmental indices based on the maceral composition were determined. Groundwater index (GWI) and vegetation index (VI) were considered as indicators for hydrological regime and type of peat vegetation. Tissue preservation index (TPI) and gelification index (GI) were determined to indicate the degree of preservation and relative wetness of the peat forming conditions. The VI-GWI diagram suggest that the coal was developed from herbaceous plants in ombrotrophic type of peat. TPI-GI diagram shows that the preservation was low and the peat was relatively wet or limnic. However, ombrotrophic peat type have commonly been related to relatively drier or telmatic environments. It is therefore, interpreted that the limnic condition could occur in ombrotrophic peat type, as the water level was rising up during the development of a high moor peat.

Keywords: Coal, Ombrotrophy, Peat, Paleoenvironment, Indonesia.

INTRODUCTION

Indonesia is located in low latitude and tropical climate region. There are dry and rainy seasons in a year. The latter season gives high rainfall, averaging at 2000 mm/yr. In the geological past, especially in Paleogene and Neogene, tropical climate with relatively warmer and higher humidity than today was present in the Indonesian region (e.g. Widayat, 2011; Widodo et al., 2009). Unlike in boreal peats of temperate regions, the warmer and higher humidity conditions favored great peat accumulations in Indonesia having tropical rainforests. Generally, peat accumulation in tropical climate occurs very intensively during the whole year (Dehmer, 1993; Grady et al., 1993; Esterle and Ferm, 1994; Hawke et al., 1999).

Climate, geology, vegetation and hydrological regime significantly determine the accumulation of peat and its associated facies including the composition of maceral. The latter can be used for reconstruction of the peat accumulation. Hydrological regime and vegetation type influencing the peat accumulation have commonly been indicated with groundwater index (GWI) and vegetation index (VI), respectively (Calder et al., 1991). GWI can be used to show the development of paleo-mires as well as their type varying from rheotrophic to ombrotrophic mires (e.g. Widodo, 2008; Amijaya and Littke, 2005). The degree of preservation of peat deposit has commonly been reconstructed by tissue preservation index (TPI), whereas, the relative dryness (telmatic) and wetness (limnic) of the peat-forming conditions by gelification index (GI) (e.g. Diesel, 1986; Lamberson et al., 1991).

In the present study, early Miocene Muara Wahau coal from Indonesia is investigated with respect to its maceral composition. The depositional environments relating to the degree of preservation, vegetation type, hydrological regime and wetness of the paleo-mire has been reconstructed.

GEOLOGICAL SETTING

One of the coal fields in Indonesia is located in Muara Wahau, East Kalimantan (Fig.1). The coal seams belong to Wahau Formation of Kutei basin, which was deposited during early Miocene(Fig.2) (Supriatna and Abidin, 1995).

Fig.1. Location map of Muara Wahau coal field in Kutei Basin, East Kalimantan.

Koesoemadinata (2002) has proposed three phases of tectono-stratigraphy related to coal deposition in Indonesia. Syn-rift phase occurred during rift development in Paleogene (Eocene – Oligocene). Coal deposition continued in the post-rift transgressive phase developed during Oligocene to early Miocene. The last coal deposition period extended from early Miocene to Quarternary (Syn-Orogenic Regressive phase). Deposition of Wahau Formation took place during the last phase in passive margin setting. The Wahau Formation is composed of carbonaceous claystones, tuffaceous claystones, sandstones and thick coal seams. Coals of the formation were deposited in deltaic floodplain environments of the prograding deltas. Generally, the Muara Wahau coal is characterized by its blackish brown colour, dull luster, moderately hard and brittle with resin and fossilized wood remains. The dip of the coal seam is about 10° with true-thickness ranging from 15 to 68 m. The geological map of Muara Wahau area is presented in Fig.3.

METHODS

Muara Wahau coal samples were collected from coal seams 1 and 2 from three drill cores (GT-02, GT-03, PMB-01-08) as shown in Figure 3. Correlation of the seams from the drill cores based on density logs is shown in Figure 4. Sampling was conducted ply-by-ply based on lithotypes along the coal cores. The samples were wrapped in aluminium foil, stored in plastic bags and transported to the laboratory within 45 days.

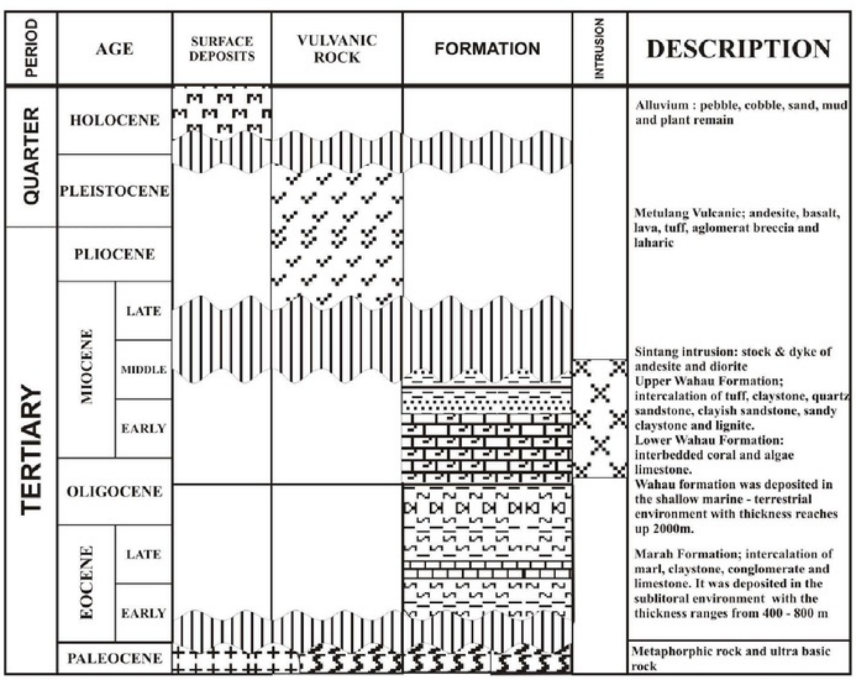

Fig.2. Regional stratigraphy of Muara Wahau area (Supriatna and Abidin, 1995).

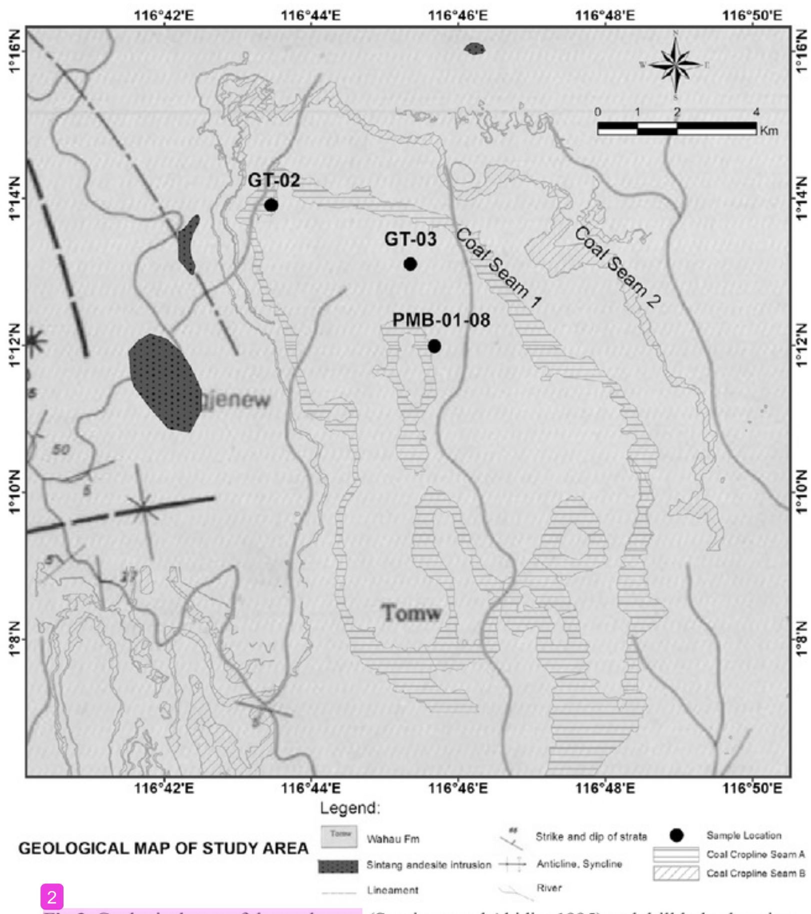

Fig.3. Geological map of the study area (Supriatna and Abidin, 1995) and drill holes location.

The coal samples were then crushed to a maximum size of 1 mm and placed in resin blocks. The sample blocks were polished with a specified polisher. Microscopic investigation was carried out with a Carl-Zeiss Axio Imager.A2m reflected-light microscope. During maceral analysis, 500 points with a minimum distance of 0.2 mm between each point were counted from the polished sections. The maceral composition is expressed as percent (% volume). Maceral classification used in this study refers to ICCP (2001). Mean random huminite reflectance measurements were performed on the surface of huminite particles under oil immersion. Fifty points of huminite reflectance were made on each sample.

Proximate analysis was performed, following the methods: ASTM D3173 for moisture content, ASTM D3174 for ash content, and ISO 5071-1 for volatile matter content. Ultimate analysis was conducted with reference methods: ASTM D3178 for carbon and hydrogen contents, and ASTM D3179 for nitrogen. Analysis procedures for total sulfur and calorific value was according to ASTM D4239 and ASTM D2015, respectively.

Depositional environments of the Muara Wahau coal were reconstructed based on the maceral composition. Some indices namely tissue preservation index (TPI) and gelification index (GI) according to Diessel (1986) and Lamberson et al. (1991) were determined. The indices were applied to investigate the degree of humification and the wetness of the paleo-mires. Vegetation index (VI) and groundwater index (GWI) based on Calder et al. (1991) were also calculated. The indices were used for the reconstruction of the type of paleo-mires developed in the deltaic basin. The indices were calculated by the following formulae.

$$TPI = \frac{Humotelinite + Teloinertinite}{Humodetrinite + Humocollinite + Inertodetrinite + Geloinertinite}$$

$$GI = \frac{Huminite + Geloinertinite}{Inertinite\ (except\ Macrinite)}$$

$$GWI = \frac{Humocollinite + Minerals}{Ulminite + Humodetrinite}$$

$$VI = \frac{Ulminite + Fusinite + Telogelinite + Semifusinite + Suberinite + Resinite}{(Humo+Inerto+Lipto)detrinite + Detrogelinite + Sporinite + Cutinite + Alginite}$$

RESULTS

The results of petrographic, calorific value, proximate and ultimate analyses are summarized in Table 1. Due to limited sample material, non-maceral analyses from PMB-01-08 were not performed. Maceral composition of the coal samples is dominated by huminite, ranging from 73.3 to 88.0% (vol.) with an average value of 77.4% (vol.). Liptinite and inertinite macerals are in lower amounts. Liptinite macerals range from 0.7 to 6.7% (vol.), with an average of 1.8% (vol.). Inertinite macerals vary between 4.3 and 34.0% (vol.), with an average value of 15.3% (vol.). Minerals are present in the coal samples, average of 5.4%. The huminite reflectance values are low (about 0.45%). The photomicrograph of the samples are shown in Figure 5. The calorific values are low as well (about 5.329 kcal/kg, ad). Proximate analysis result shows that moisture content of the coal samples is relatively high (46.83%). The elemental analysis exhibit the domination of carbon (68.17%, daf) with low total sulfur (0.19%, ad).

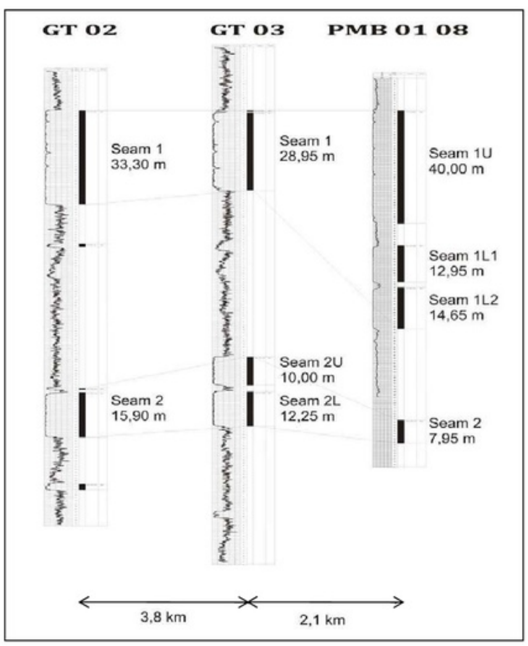

Fig.4. Correlation of coal seams 1 and 2 along the drill holes based on density logs.

Plot of TPI versus GI on the Diessel diagram (1986) and Lamberson diagram (1991) are shown in Figure 6 and Figure 7, respectively. Most of the coal samples have TPI values less than 1 and GI values more than 1. The TPI values indicate that the tissue preservation is relatively low, whereas the GI values show that the paleo-mires were relatively wet. On both the diagrams, the coal samples fall in limnic environments. The relation between VI and GWI is shown in the Calder diagram (1994, see Figure 8). Most of the coal samples have VI values less than 1 and GWI values less than 1. The VI values infer that the coal might originate mostly from herbaceous plants, while GWI values indicate ombrotrophic type of pelo-mires.

DISCUSSION

Some parameters such as huminite reflectance, calorific value, carbon content and moisture content have been widely used to infer the rank of coal (e.g. Taylor et al., 1998 and references therein). The huminite reflectance value (averaging at 0.45%), calorific value (averaging at 5,329 kcal/kg, ad) and carbon content (averaging at 68.17%, daf) suggest that the Muara Wahau coal can be classified as low rank or sub-bituminous, though the moisture content (averaging at 46.83%, ar) indicated less degree of coalification.

Although the Muara Wahau coal layers are older in age (early Miocene) relative to the other Indonesian coals, the geological setting (most probably the less intense burial history) is likely to be responsible for the low coal rank. This is reasonable, as the coal was developed in western border of the Kutei basin which underwent less intense of subsidence. The paleogeographic position of the Muara Wahau likely led to an inland depositional environments, which was far away from the ocean. This is supported by the lower amount of total sulfur content of the coals (averaging at 0.19%, ad).

Diessel (1986) suggested that 'limnic' on his diagram is a wet condition in inland swamp area with no or less of marine influence. According to the diagram of TPI versus

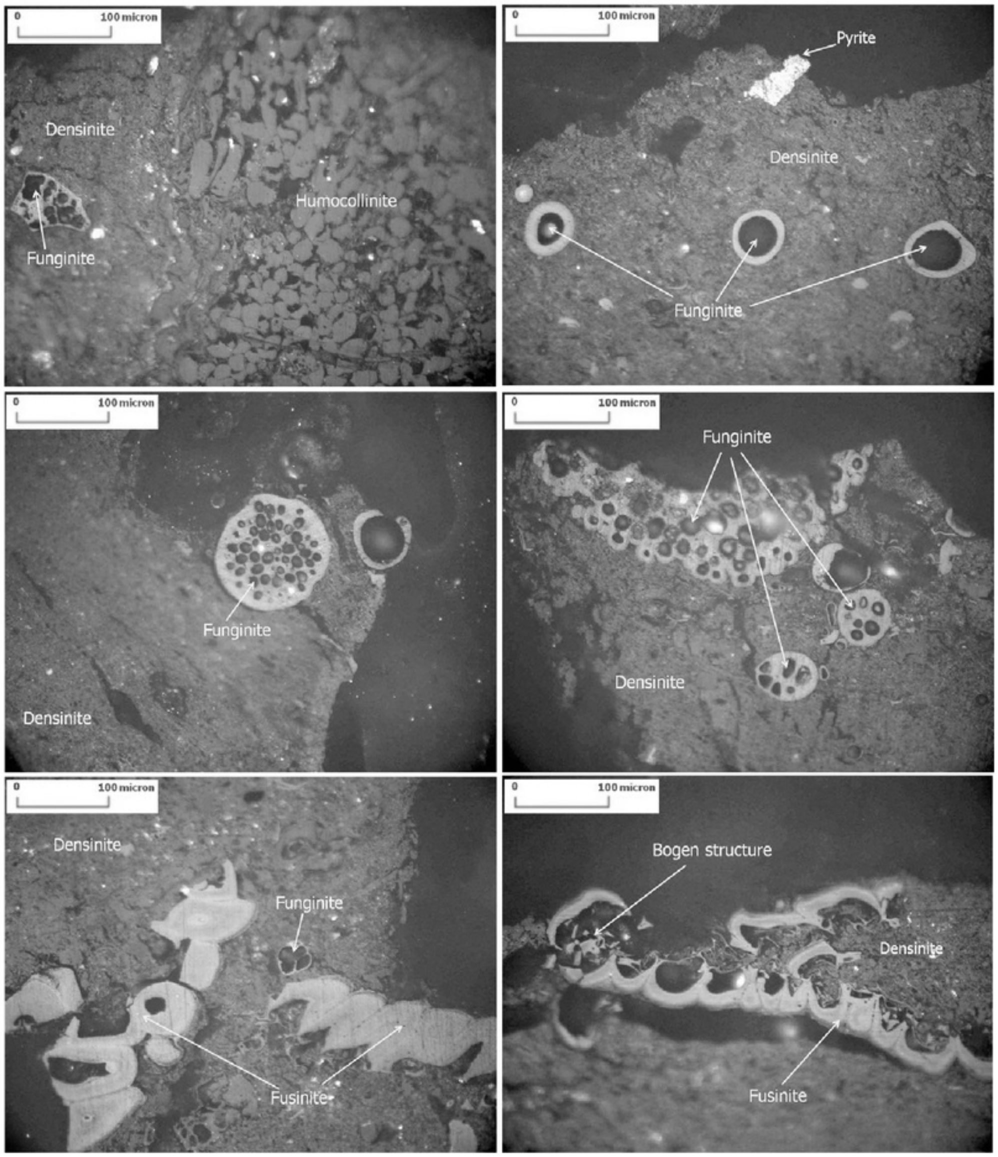

Fig.5. Photomicrograph showing macerals of the coal samples.

GI shown in Figure 6, generally the Muara Wahau coals might be deposited in wet or limnic condition of an inland swamp. The peat grew below the water level. However, relatively higher abundance of funginite in all coal samples might indicate humid condition of the peat surface, supporting thegrowth of fungi. Such condition was possible mostly when the water level was below the peat surface. The limnic and humid conditions of the peat surface was thus probably occurred cyclically. Dry and wet seasons likely were responsible for the cycles. In wet season, the peat was fully limnic and grew below the water level. In dry season, the water level was below the peat surface, enabling most of the fungi to grow on the surface. It is therefore likely that the hydrological regimes of the peat were depend mostly on the rainfall.

With respect to paleo-mire type, e.g. Calder et al. (1991)

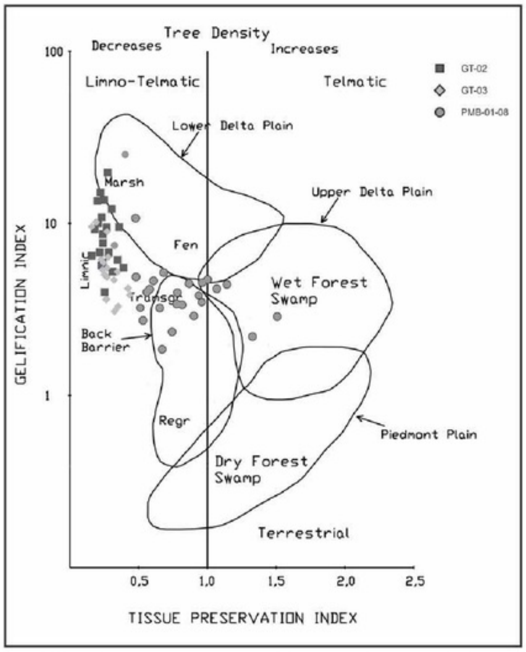

Fig.6. Plot of tissue preservation index (TPI) versus gelification index (GI) of the Muara Wahau coal on the Diessel diagram (1986).

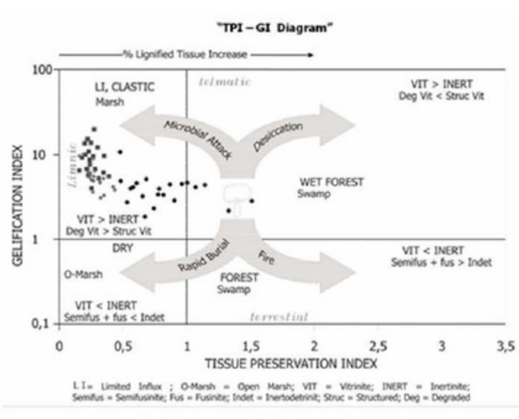

Fig.7. Plot of tissue preservation index (TPI) versus gelification index (GI) of the Muara Wahau coal on the Lamberson diagram (1991).

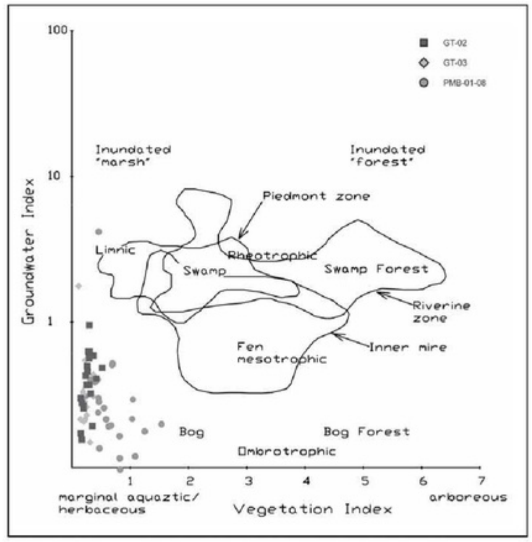

Fig.8. Plot of vegetation index (VI) versus groundwater index (GWI) of the Muara Wahau coal on the Calder diagram (1991).

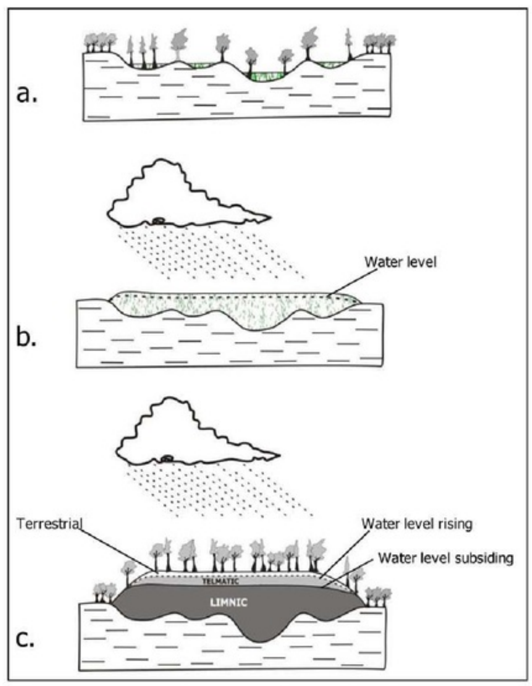

Fig.9. Reconstruction of ombrotrophic high moor peat development in Muara Wahau: **(a)** initial development of the peat, **(b)** limnic condition on the surface of high moor peat in wet season, **(c)** limno-telmatic condition on the surface of high moor peat in dry season.

Table 1. Results of petrographic, proximate, ultimate and calorific value analyses.

COAL PARAMETER			GT02			GT03			PMB0108			Average
			Min.	Max.	Average	Min.	Max.	Average	Min.	Max.	Average	(All)
Macerals (%, vol.)			n=21			n=17			n=26			
Huminite	Humotelinite	Ulminite	2.8	18.6	10.8	4.4	13.4	9.1	8.8	36.0	23.3	15.4
	Humodetrinite	Attrinite	3.4	13.8	7.3	2.0	17.4	7.6	2.0	45.4	27.1	15.4
		Densinite	34.2	62.4	46.1	23.6	59.6	47.5	2.2	46.0	17.9	35.0
	Humocollinite	Gelinite	4.8	36.6	18.2	4.4	21.0	12.4	1.0	14.0	5.7	11.6
	Total				**82.4**			**76.6**			**74.0**	**77.4**
Liptinite		Sporinite	-	0.6	0.1	-	-	-	-	1.0	0.1	0.1
		Cutinite	-	1.4	0.2	-	1.0	0.2	-	1.4	0.2	0.2
		Resinite	0.4	3.4	1.2	-	1.4	0.5	0.4	2.4	1.1	1.0
		Alginite	-	0.2	0.0	-	0.4	0.0	-	1.0	0.0	0.0
		Suberinite	-	2.8	0.9	0.4	2.4	1.0	-	-	-	0.6
	Total				**2.5**			**1.6**			**1.4**	**1.8**
Inertinite		Fusinite	0.2	2.8	0.7	0.4	3.4	0.9	0.4	7.8	2.2	1.3
		Semifusinite	0.2	3.6	1.7	0.4	5.4	2.3	0.4	13.6	5.6	3.4
		Funginite	3.4	9.8	5.7	2.6	13.4	8.3	2.6	23.6	9.0	7.7
		Inertodetrinite	0.2	4.8	2.2	1.6	7.4	3.8	0.4	6.0	2.6	2.8
		Macrinite	-	0.2	0.0	-	0.6	0.0	-	0.6	0.0	0.0
	Total				**10.4**			**15.2**			**19.3**	**15.3**
Minerals (%, vol.)			2.4	10.0	4.8	1.4	45.0	6.5	0.4	44.8	5.2	5.4
Huminite reflectance (%)					0.44			0.45			0.45	0.45
Non-Maceral			n=13			n=7						
Proximate analysis (%, wt.):												
Total moisture (ar)			44.01	50.03	47.52	42.62	47.45	45.54				46.83
Inherent moisture (ad)			13.50	16.99	15.47	12.95	15.29	14.35				15.08
Ash (ad)			2.02	10.64	4.39	1.88	7.28	4.00				4.25
Volatile matter (ad)			36.65	44.36	41.15	40.34	45.22	42.61				41.66
Fixed carbon (ad)			36.51	41.34	38.99	37.38	40.53	39.05				39.01
Calorific value (kcal/kg, ad)			4,750	5,717	5,276	5,087	5,660	5,429				5,329
Ultimate analysis (%, wt.):												
Carbon (daf)			63.71	70.81	68.41	66.09	70.91	67.71				68.17
Hydrogen (daf)			4.10	5.41	4.89	4.76	5.65	5.21				5.00
Nitrogen (daf)			0.67	1.06	0.85	0.73	0.87	0.80				0.84
Oxygen (daf)			22.96	30.50	25.63	22.76	27.53	25.37				25.54
Total sulfur (ad)			0.09	0.35	0.20	0.10	0.25	0.18				0.19
Abbreviations: ar=as received basis, ad=air dried basis, daf=dry ash free basis, vol=volume, wt=weight.												

and McCabe (1984) supposed that environments could determine the type of peat or mire. In limnic condition, water in the peat mostly comes from groundwater inflow in the surrounding area. Such condition leads to the development of low moor peat type with abundant of nutrients (rheotrophy). In telmatic condition, a peat develops under minimum water supply which depends only on rain. This environment would generally forms a high moor peat type with limited of nutrients (ombrotrophy).

Based on the interpretation of limnic condition from the TPI versus GI diagram, it is expected that the peat should be rheotrophic with abundant nutrients. However, plot of VI versus GWI of the Muara Wahau coals indicates an ombrotrophic peat type with dominance of herbaceous plants. Although the interpretations contradicts, both are likely for Indonesian peat. We suggest that the limnic or wet condition could also develop in the ombrotrophic peat type. As the high moor peat was formed, the water level would rise, following the peat surface (Figure 9b). This maintained the peat in a limnic condition during the entire peat development especially in the wet season. The peat hydrology was thus dependent only on the rain water supply, so that the environments was less of nutrients or ombrotrophic. Fungi could grow on the peat surface when the environments become limno-telmatic or moist as the water level falls in the dry season (Fig.9c).

Limnic condition in ombrotrophic peat type might be common in Indonesian geological history. Anggayana (1996), Amijaya (2005) and Widodo (2008) also reported generally similar maceral compositions from coal of Muara Enim Formation (South Sumatra basin), Pulaubalang and Balikpapan Formations (Kutei basin).

CONCLUSIONS

Maceral composition of Muara Wahau coals exhibit relatively low TPI and high GI, indicating a wet or limnic condition of the peat. The coal may originate from an ombrotrophic peat as interpreted from the VI and GWI diagram. The limnic condition was reached in the ombrotrophic peat with the rising of water level following the peat surface during the development of high moor peat.

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