INDONESIAN MINING JOURNAL Vol. 15, No. 1, February 2012 : 1 - 13

PETROGRAPHIC CHARACTERISTICS AND DEPOSITIONAL ENVIRONMENT OF COAL SEAMS D (MERAPI) AND E (KELADI), MUARA ENIM FORMATION, SOUTH SUMATERA BASIN

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ABSTRACT

Coal seams D and E belong to the Muara Enim Formation in South Sumatra Basin, which includes to the Middle Miocene to Late Miocene. The research is located at the Air Laya coal mines, PTBA, Tanjung Enim, South Sumatra. The purpose of this study was to investigate the characteristics of coal and coal depositional environments of Seam D (Merapi) and Seam E (Keladi). Observations were done on samples of coal from exploration drilling results from the Air Laya mining pit. The analysis is carried out by a petrographic analysis, which is supported by the results of coal vitrinite reflectance.

Petrographic characteristics indicate that both of seams D and E dominant macerals are vitrinite, the most dominant sub-group of vitrinite is telovitrinite. Inertinite in both seams consists of semifusinite, sclerotinite and inertodetrinite. Pyrite, clay mineral and carbonate are the main mineral in the seams. Vitrinite reflectance (Rv-max,%) value shows similar rank of sub-bituminous to high volatile bituminous. Based on the results of coal depositional environment reconstruction using four parameters, which are the degree of preservation of plant tissue (TPI), the degree of Gelification (GI), the degree of ground water influence (GWI) and vegetation aspects (VI), it is interpreted that seams D (Merapi) and E (Keladi) were deposited in upper delta plain depositional environment with ombrotrophic peat type.

Keywords: coal, petrography, depositional environment, South Sumatra Basin

INTRODUCTION

Coal deposits in South Sumatra Basin, especially in the Muara Enim Formation, include to the Miocene-Pliocene. Plio-Pleistocene orogenesis ended the sedimentation in this basin, followed by andesite intrusions, which affect the rank of coal, ranging from lignite to anthracite, the same as those in the Air Laya coal field, Suban, and the Mount of Kendi. Coal-forming process can be identified by petrographic study, which is aimed to find out the process of peat forming and coal forming especially for seams D (Merapi) and E (Keladi).

GEOLOGICAL SETTING

The island of Sumatra is part of the Sundaland continental shelf. Oceanic crust underlying the Indian Ocean includes the Indo-Pacific plate, tilt subduct along the Sunda trench, outer west coast of Sumatra. As a result of this subduction, magmatic arc formed the shape of Bukit Barisan Mountains. In connection with this magmatic arc, it was formed fore-arc basin and back-arc basin (Figure 1).

Received : 11 November 2011, first revision : 02 January 2012, second revision : 03 February 2012, accepted : February 2012

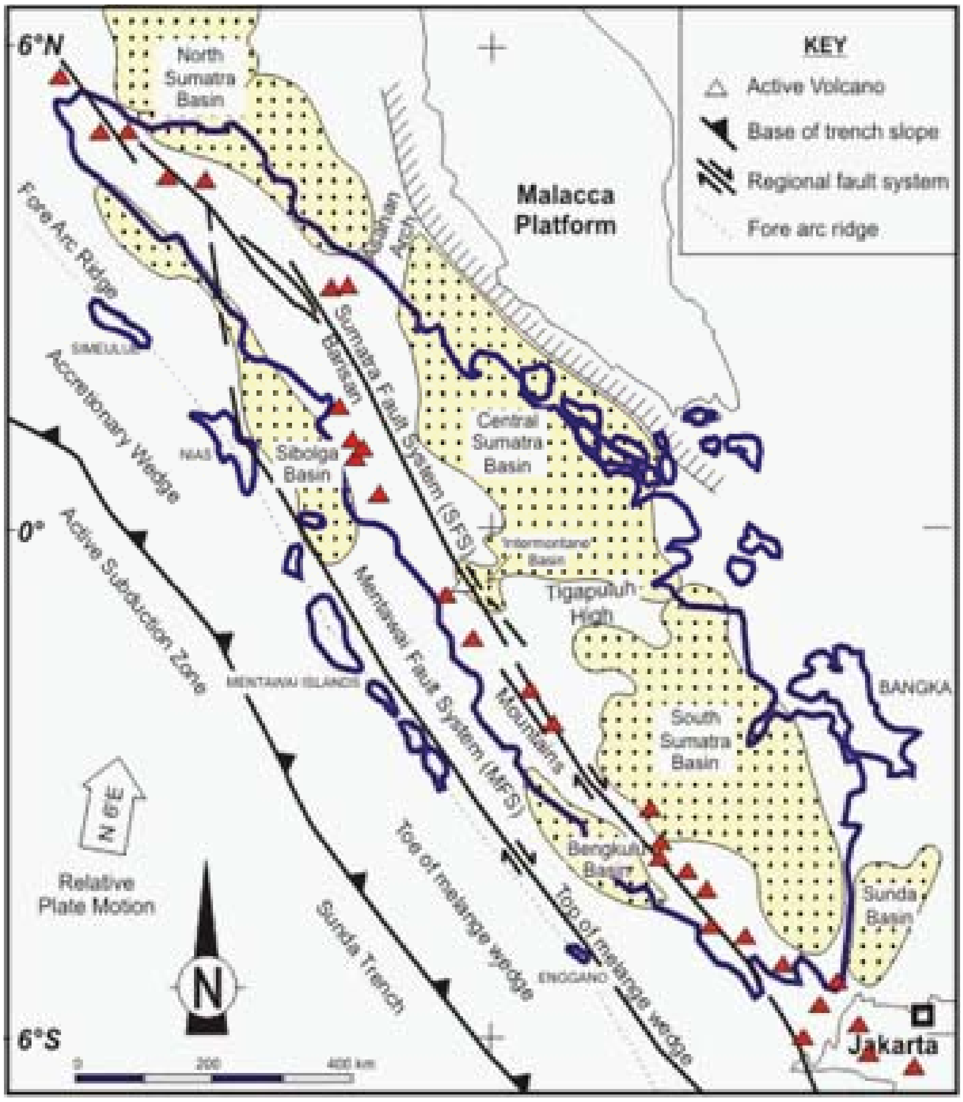

Figure 1. Sedimentary basins and coal distribution in Sumatra Island (Darman and Sidi, 2000)

It has been recognized two main basins deposited in the back arc zone, which are the target of exploration and production of coal in Sumatra; they are South Sumatra and the Central Sumatra Basins. The basins are separated by the Tinggian Tigapuluh, which is located between the provinces of Riau and Jambi. Meanwhile, coal basin, located near magmatic arc Sumatra Island is in the form of intramontana basin similar as Ombilin and Kiliran Jao. Coal deposit located (dispersed) in the Bengkulu area is part of the magmatic arc and fore arc, filled by sediments, which later formed Bengkulu Basin.

The South Sumatra Basin is one of the important basins as it contains oil and coal deposits. Various sources mentioned that the basin is donating one third of the coal resources in Indonesia. The basin has experienced orogenesis three times, either during the era of Middle Mesozoic, Late Cretaceous - Early Tertiary or Plio-Pleistocene.

In brief, it can be noted that in this basin there are two phases of deposition that are transgression and regression. Transgressive phase produces Telisa Group sediment consisting of formations such as: Lahat, Talang Akar, Batu Raja and Gumai; while the regressive one produces Air Benakat, Muara Enim and Kasai Formations.

Based on the research of Gafoer et al. (2007) about the depositional cycle in the South Sumatra

Basin, it was concluded that the rock and coal deposits which belong to the Muara Enim Formation has a regressive depositional cycles. Plio-Pleistocene orogenesis ended the sedimentation in this basin and produced angular unconformity between Tertiary and Quaternary sediments. This orogenesis was followed by andesitic intrusions that gave a very important influence to the rising of coal quality in Bukit Asam. The basin is located in an area that is tectonically active. Consequently, the coal-bearing layers in general were affected by folding, fracturing, and intrusive and extrusive activity. The effect of this intrusive resulted in lifting, folding and fracturing. As a result, coal rank ranges from lignite to anthracite, existing in several locations. In general, the basin produces coal deposit fairly wide spread, but has a relatively low rank coal, except in the intrusive area of igneous, such as those found in the coal field of Air Laya, Suban, and Bukit Kendi (Figure 2).

(Figure 3). Plio-Pleistocene orogenesis ended this sedimentation in the basin, followed by andesite intrusion affecting the increase of coal rank in the area. The coal consist of ± 21 seams whereas, Air Laya has 7 seams, with the direction of the coal seam trending northeast-southwest with dip of 80-20º to the southeast and northwest, with coal thickness ranging from 1.34 m to 13.04 m. The quality of the coal in the study area is divided into three categorie: steam coal (high volatile bituminous coal), low volatile bituminous coal and anthracite.

Megascopically, the coals are mainly composed of vitrain, which has a homogenous appearance, and a luster, which varies according to the coal rank, from dull and waxy in the hard lignites, to brilliant in the anthracites. The color varies from dark brown similarly to jet black (Shell Mijnbouw, 1978).

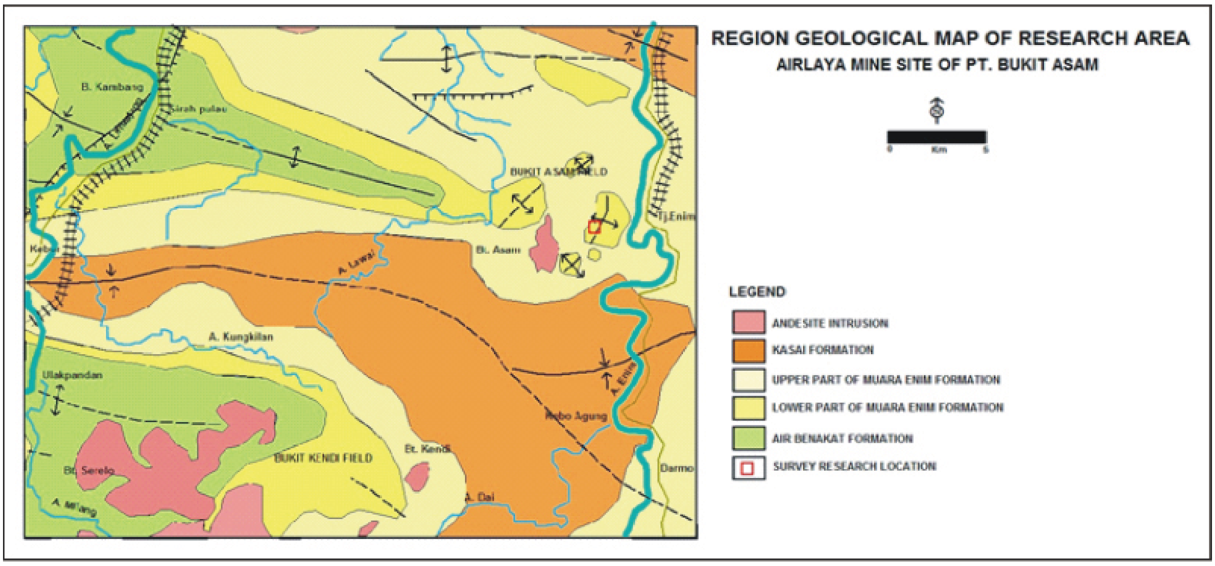

Figure 2. Regional geological map of the Regional Research (Gafoer et al., 2007)

Besides Muara Enim Formation, there are also thin layers of coal in the Talang Akar and Lahat Formations, which are relatively older than the Muara Enim Formation. Also it is estimated that the potential of coal in the form of thin layers belongs to Kasai Formation, which is younger than the Muara Enim Formation.

Coal in the Tanjung Enim mining units was deposited in the South Sumatra Basin, especially in the Muara Enim Formation of Miocene-Pliocene

Daulay et al. (2000) divided the coals of the South Sumatra Basin into normal coalification coal and heat affected coal. The normal coalification coal has a sub-bituminous rank with a range of Rvmax from 0.40% to 0.50% while the heat-affected coal shows a range from bituminous to anthracite rank with Rvmax of 0.60% to 2.60%.

Anggayana (1996) studied the A1, A2 and B1 seams of Tanjung Enim coal and found that the coals have a huminite and vitrinite content of

81.6–97.4 %, liptinite content of 0.2–5.2 % and inertinite content of 0.6–16.6 vol.%. Minerals normally occur only in trace amounts, but one sample had a mineral content of 4.4 %. The ash and sulphur content of the Tanjung Enim coal is very low. He reported that the mean ash contents of A1, A2 and B1 seams are only 2.9%, 2.1% and 1.3% (db), respectively. The sulphur content ranges between 0.1% and 2.1% (db). Other data, for example, generally confirm these results. The low rank coal from this area has a sulphur content of less than 1% (db). Sulphur content of coal from the area affected by igneous intrusion is slightly higher. The average ash content of the seams is 4.95–7.88% (ar). Kinhill-Otto Gold (1986) stated that the coal from the Banko Barat field in Tanjung Enim area generally has a low ash content (average 6.3% db for all seams) and a low to very low sulphur content (average 0.42% db for all seams).

METHODOLOGY

Samples were obtained from the results of drilling activity conducted on 13 units of mining pit (7 samples of seam D from drill core and 6 samples of seam E from cutting). Then, the samples were reduced in size and divided into two parts, namely for the documentation and analysis. Sample parts will be analyzed and then divided into two, for petrographic and proximate analyses.

Petrographic analysis is conducted quantitatively and qualitatively to determine organic and inorganic components in coal with the aid of a

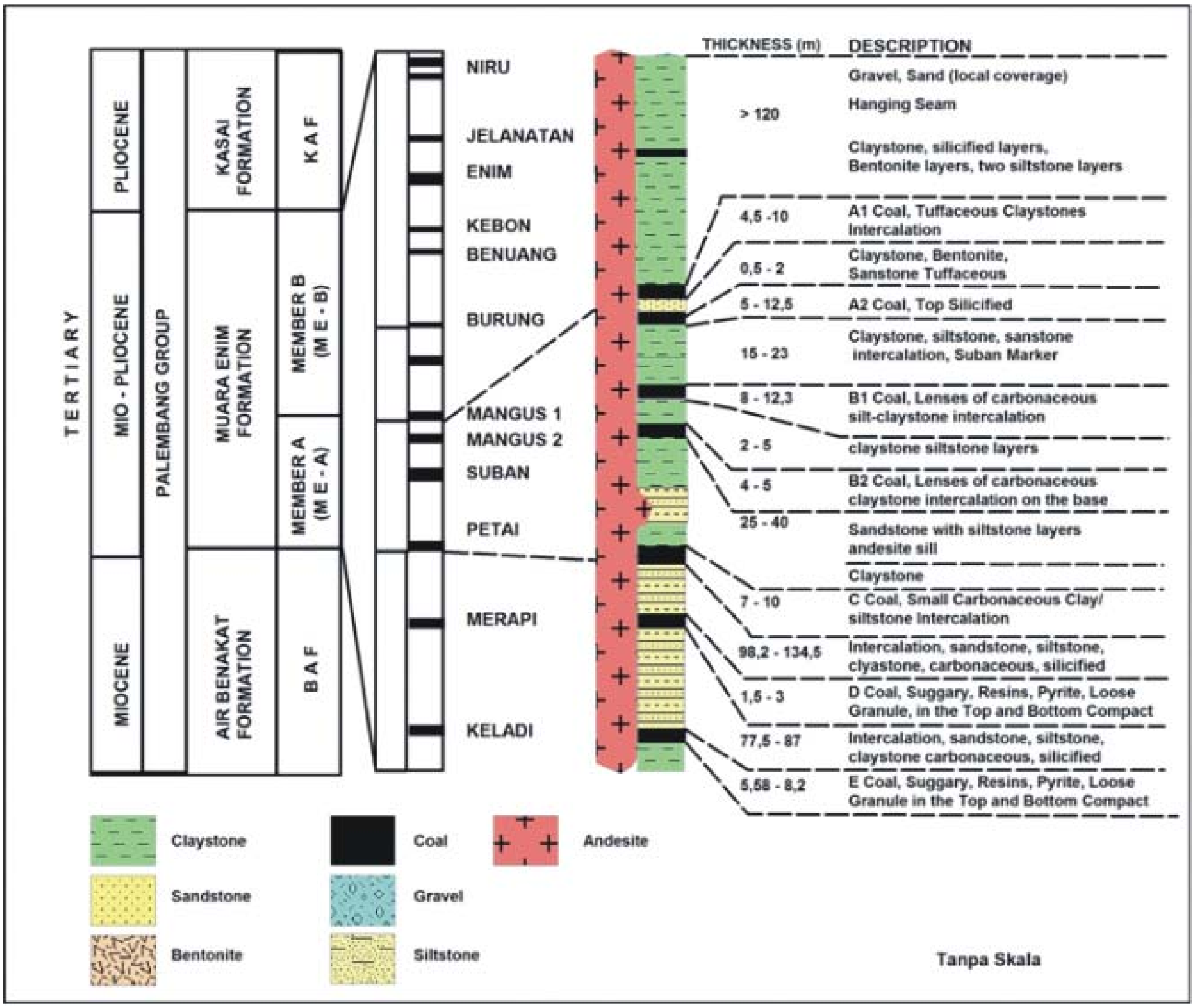

Figure 3. Stratigraphy of the studied area (Daranin,1995)

microscope. Organic component consists of 3 main ingredients, which are vitrinite, liptinite and inertinite. While the inorganic component is a mineral consisting of clay minerals, carbonates, sulfides, silica and other minerals.

Vitrinite reflectance measurement determines the intensity of light reflected back by the vitrinite maceral. Increased amount of this intensity is progressive with increasing coal forming, so it can be used as a level of maturity (rank) parameter of a coal seam. Vitrinite reflectance measurements are carried out under the immersion oil, which has a refractive index of 1.52 at a wavelength of 546 nm and temperature of 23ºC. To obtain accurate measurements, it is used a known reflectance standard. In this study, reflectance standard used is synthetic spinel with the reflectance amount of 0.586%. Reflectance standard measurements are performed prior to vitrinite reflectance measurements. Reflectance measured of maceral vitrinite is telocollinite, because this is a maceral most commonly found among other maceral. It is homogeneous, and its size is relatively large. Reflectance type measured is random reflectance. Reflectance values used to determine the rank of coal is the average maximum reflectance value of all measurements (ASTM, 2009).

RESULTS AND DISCUSSION

Composition of Maceral

The maceral composition of the seams D and E is dominant vitrinite with relatively low inertinite and liptinite. Belkin et. al (2009) have investigated that coals in eastern Kalimantan and South Sumatera have the same maceral composition. Maceral analysis results in 7 samples tested from the seam D show that maceral composition has some similarities, where the vitrinite is the dominant maceral group (between 75.6 to 91.3%, with an average of 84.87%), as seen in Figure 7, while the other maceral found in small amounts is inertinite (between 4.4 to 13%, 7.64% average) and liptinite (between 0 to 5.4%, 2.03% average). As for the maceral analysis of seam E tested 6 samples, show that the maceral composition of seam E is dominated by vitrinite group (between 79.8 to 93.6%, 86.63%), as seen in Figure 8, while other macerals found in small amounts are inertinite (between 5.2 to 8.2%, with the average of 6.6%) and liptinite (between 0 to 6.6%, with an average of 3%).

In seam D, the most dominant sub-group of vitrinite is telovitrinite (52% to 69.4% with an average of 60.35%), followed by detrovitrinite (19.4% to 28.4 % with an average of 24.08%) and gelovitrinite (0 to 1.6% with an average of 0.43%), as seen in Figure 4.

For seam E, the most dominant sub-group of vitrinite is telovitrinite (55.6% to 78.4% with an average of 66.03%), followed by detrovitrinite (12.2% to 25.6% with an average of 19.93%) and gelovitrinite (2.4% with an average of 0.67%), as illustrated in Figure 5.

Telovitrinite is dominated by telocollinite with an average of 60.35% (seam D) and 66.03% (seam E), while other macerals (textinite, eu-ulminite and texto-ulminite) were not observed. Telocol-

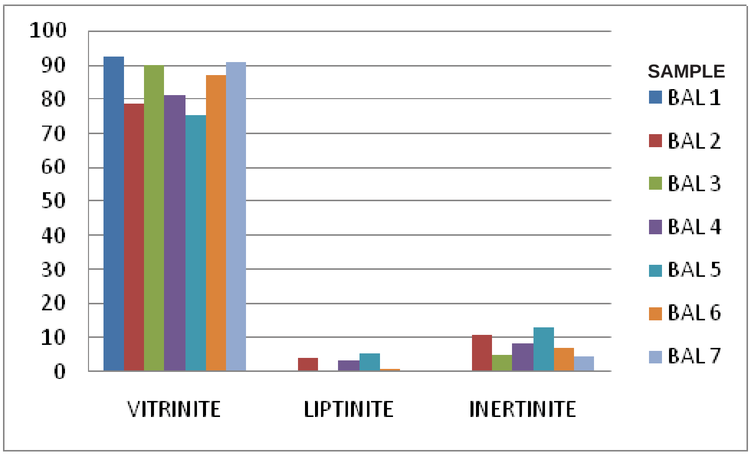

Figure 4. Composition of maceral group of seam D

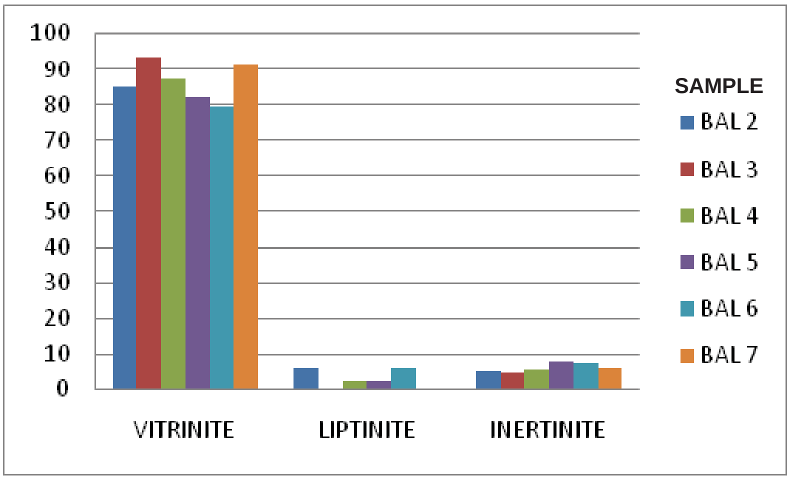

Figure 5. Composition coal maceral group of seam E

linite is the remains of plant tissue derived from stems, twigs, leaves and roots in the form of large fragments that weakly gelificated and immediately preserved as peat accumulation took place (Falcon and Snyman, 1986). The high content of telocollinite in almost all samples indicates that the seams D and E coal forming material have not been gelificated intensively (weak), thus preserved in the moist peat but not stagnated by water. This is caused by the fluctuating condition of water level in the peat bog.

Detrovitrinite is dominated by densinite with an average of 22.8% (seam D) and 19.63% (seam E), where there is also maceral desmocollinite with an average of 1.26% (seam D) and 0.3% (seam E). Densinite is the components that come from shrubs and timber plants that are easily decomposed with low gelification level (Teichmüller and Teichmüller, 1982), while desmocollinite derived from the composition of the remains of plants derived from plant tissues which broken down into fine granules, either insitu or during transport to the deposition place (Falcon and Snyman, 1986). Gelovitrinite is dominated by a corpogelinite with a relatively low average of 0.37% (seam D) and 0.6% (seam E), while the average of porigelinite is 0.03% (seam D) and 0.07 (seam E). Thus, it gives an indication that the gelification process of seams D and E is very low.

For seam D, liptinite is dominated by resinite (average 1.17%), alginite (average 0.34%), cutinite (average 0.31%), sporinite (average 0.17 %), and liptodetrinite (0.03%). Whilst fot the seam E, liptinite is dominated by resinite (average 2.2%) as seen in Figure 6a-b, alginite (average 0.1%), cutinite (average 0.30%), sporinite (average 0, 2%), suberinite (average 0.17%) and liptodetrinite (average 0.03%). The low content of liptinite proves that coal is formed from woody plants significantly.

For seam D, inertinite consists of semifusinite (average 4.54%), sclerotinite (average 1.67%), inertodetrinite (average 1.43%). Whilst, for seam E, inertinite consists of semifusinite (average 3.2%), sclerotinite (average 2.27%), inertodetrinite (average 1.13%), as seen in Figure 6c-d. Inertinite is a component, which was oxidized due to the reduced moisture peat. Inertinite content that is relatively low may indicate coal derived from depositional environment that is wet and have low levels of oxidation (Stach et al, 1982; Suarez-Ruiz and Crelling, 2008; Suwarna and Kusumahbrata, 2010).

Depositional condition influences both lithotype and mineral composition of the coals (Susilawati and Ward, 2006). Mineral matter content of seam D is pyrite and clay minerals and small amount of carbonates (Figure 6e-f). The largest component of the mineral content is pyrite (average 4.91%), followed by clay (average 0.4%) and carbonate in a very small amount (average 0.02%). While the mineral matter content of seam E is pyrite (average 2.8%), followed by clay (average 0.7%) and carbonate in a very small amount (average 0.27%), as seen in Figures 7 and 8. The variation of mineral matter content can be caused by the fluctuation of water level in peat bog in rotate, which is caused by instability condition of basin or flood caused by high rainfall.

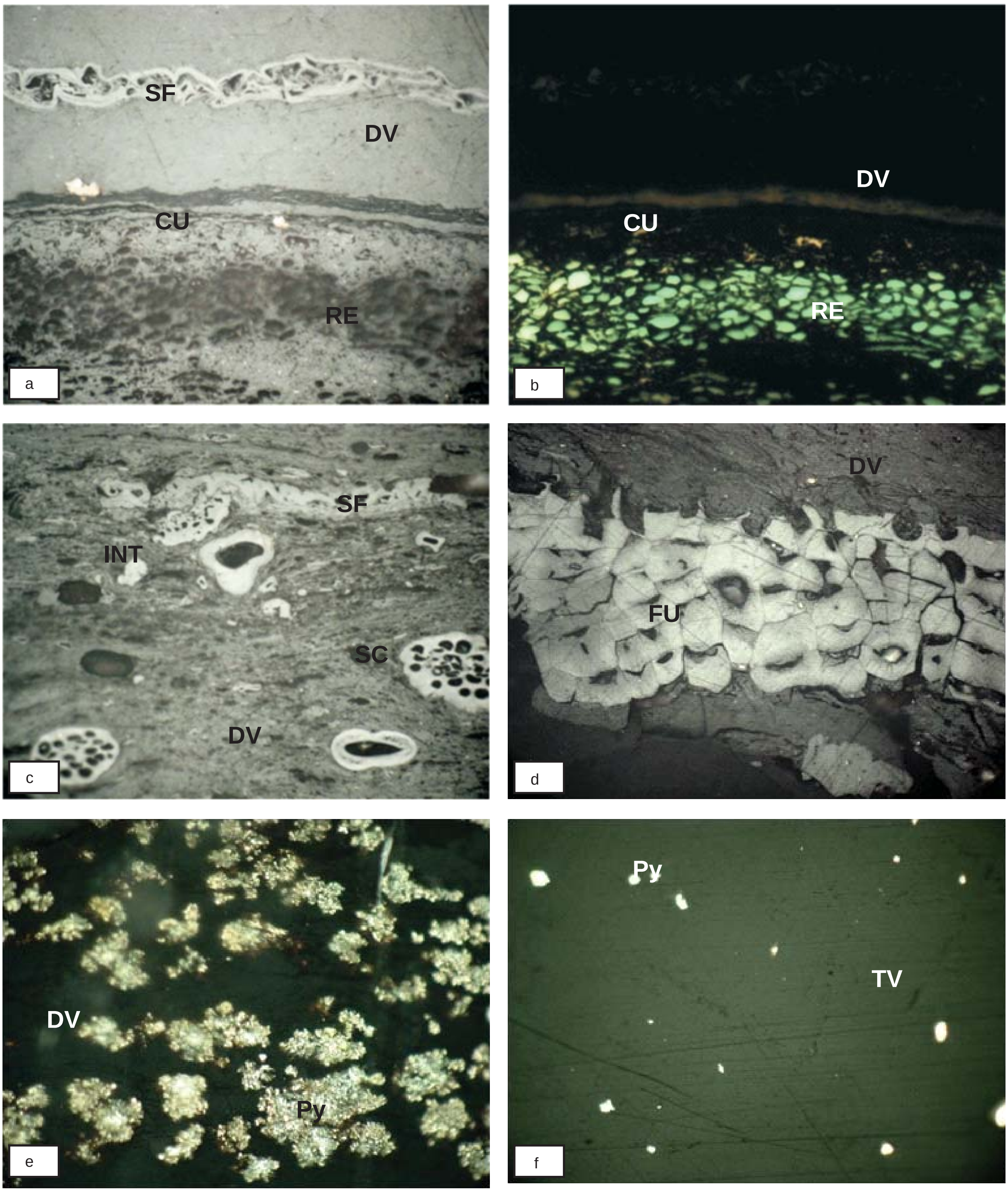

Figure 6. Maceral and mineral matter in seams D and E

a. Semifusinite (SF), cutinite (CU) and resinite (RE) associated with detrovitrinite (DV) in coal, reflected white light, 500x, seam E.
b. As for (a), but in flourescence mode.
c. Sclerotinite (SC), semifusinite (SF), inertodetrinite (INT) associated with detrovitrinite (DV) in coal, reflected white light, 500x, seam D.
d. Fusinite (FU) associated with detrovitrinite (DV) in coal, reflected white light, 500x, seam E.
e. Pyrite (Py) associated with detrovitrinite (DV) in coal, reflected white light, 500x, seam D.
f. Pyrite (Py) associated with telovitrinite (TV) in coal, reflected white light 500x, seam E.

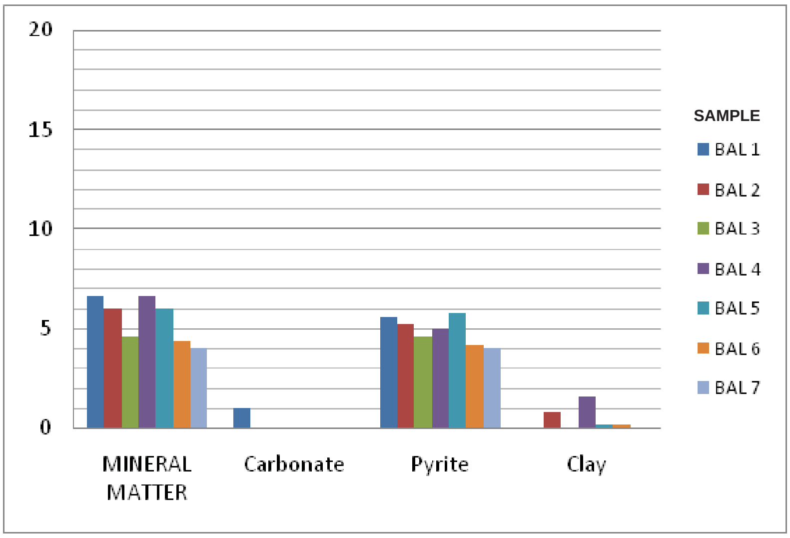

Figure 7. Mineral matter composition of seam D

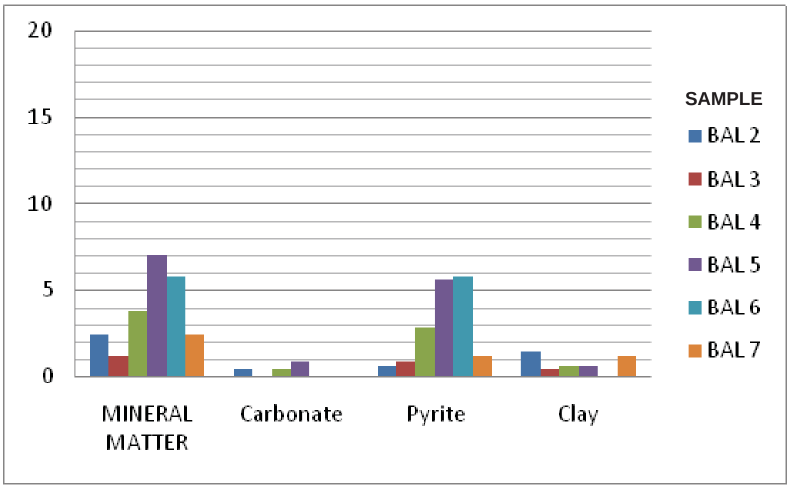

Figure 8. Mineral matter composition of seam E

Maceral composition may reflect the plant clump-forming peat bog. Maceral that is interpreted to derive from wood plants are telovitrinite, fusinite, semifusinite, telogelinite, suberinite and resinite. While macerals, that are interpreted to derive from shrubs are detrovitrinite, detrogelinite, inertodetrinite, sporinite, cutinite, liptodetrinite and alginite.

The maceral composition of seams D and E shows that maceral forming is more dominated by timber plants rather than shrub plants (Figures 9 and 10). This indicates that the peat swamp conditions may be in a oligotrophic state (poor food), because circulation relies only on rain water, while the variation of shrubs plants content is likely caused by the fluctuation of the ground water surface.

Vitrinite Reflectance and Rank

Based on the classification of coal rank (Table 1), the result of the average maximum vitrinite reflectance measurements (Rv max) of coal seam in the Pit Airlaya (Tables 2 and 3), seam D has a brown coal rank (BAL 04), subbituminous (BAL 02, BAL 05, BAL 06 and BAL 07) and high volatile bituminous (LAB 01 and LAB 03), while seam E has a rank of subbituminous (BAL 02, BAL 04, BAL BAL 05 and 06), high volatile bituminous (LAB 03 and LAB 07).

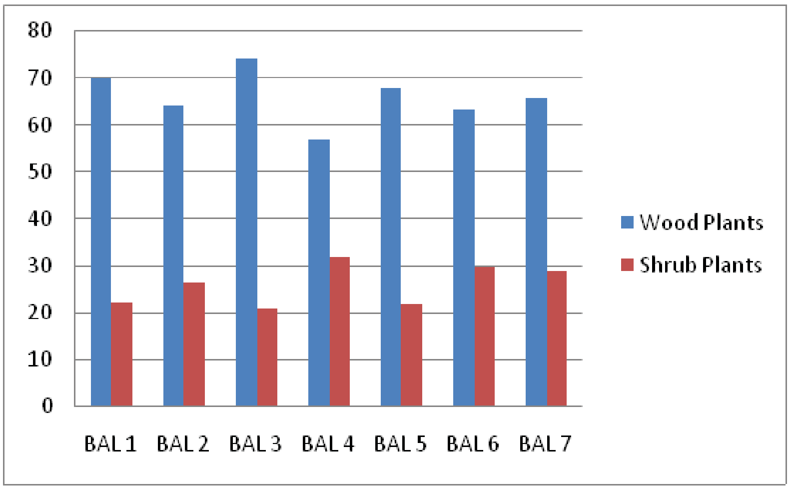

Figure 9. Comparison of maceral derived from wood plants and shrub plants on seam D

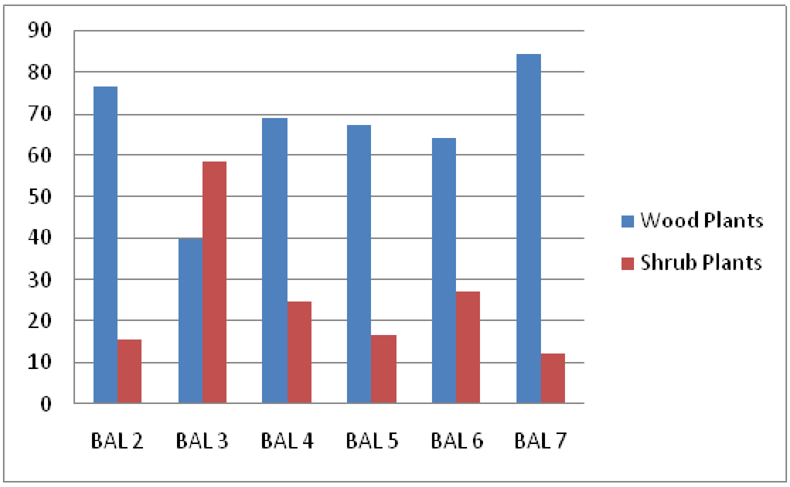

Figure 10. Comparison of maceral derived from wood plants and shrub plants on seam E

Table 1. Reflectance relations of vitrinite and coal rank (Bustin et al., 1983)

Rv max (%)	Coal Rank
< 0.47	Sub-bituminous
0.47 – 0.57	High volatile bituminous C
0.57 – 0.71	High volatile bituminous B
0.71 - 1.10	High volatile bituminous A
1.10 - 1.50	Medium volatile bituminous
1,50 - 2,05	Low volatile bituminous
2,05 – 3.00	Semi-anthracite
➢ 3	Anthracite

Table 2. Vitrinite reflectance measurements of seam D

Sample Number	Rv max (%)		Reading Amounts	Rank
	Range (%)	Average (%)		
BAL 01	0.64-0.72	0.68	30x	High Volatile Bituminous
BAL 02	0.38-0.46	0.42	30x	Subbituminous
BAL 03	0.58-0.68	0.63	30x	High Volatile Bituminous
BAL 04	0.36-0.40	0.38	30x	Brown Coal
BAL 05	0.38-0.46	0.42	30x	Subbituminous
BAL 06	0.42-0.46	0.44	30x	Subbituminous
BAL 07	0.42-0.52	0.47	30x	Subbituminous

Table 3. Vitrinite reflectance measurements of seam E

Sample Number	Rv max (%)		Reading Amounts	Rank
	Range (%)	Average (%)		
BAL 02	0.43-0.48	0.45	30x	Subbituminous
BAL 03	0.58-0.66	0.63	30x	High Volatile Bituminous
BAL 04	0.40-0.46	0.43	30x	Subbituminous
BAL 05	0.44-0.48	0.46	30x	Subbituminous
BAL 06	0.44-0.50	0.47	30x	Subbituminous
BAL 07	0.75-0.82	0.78	30x	High Volatile Bituminous

Environment of Coal Deposition

The parameters used in the interpretation of depositional environment of coal is the value (Tissue Preservation Index, TPI) and (Gelification Index, GI), which is then plotted TPI-GI network structure preservation diagram of Diessel (1992).

TPI shows the network structure is still maintained on the network structure that has been decomposed. GI is the ratio of gelificated components to fusinited components. TPI also can indicate the level of peat humification in the process coal forming. Meanwhile, GI is associated with peat conditions continuity below water.

Another parameter was introduced by Calder et al., (1991), namely the ground water influence (GWI) and vegetation index (VI) to determine the type of peat (rheotrophic, mesotrophic and ombrotrophic), which indirectly reflects the humidity factor, hydrogen ion concentration, food supply and activity of bacteria in a peat bog.

TPI calculation results of seams D and E can be seen in Table 4. Seam D has a relatively high TPI values with an average of 2.64 (between 1.87 to 3.54), whereas the TPI values for seam E has an average of 3.623 (between 2.39 to 6.62). A high TPI value (> 1), in addition to showing the high percentage of the presence of wood plants (in this case indicated the number of telocolinite maceral), also it may indicate that the plant tissue was well preserved.

The GI value for seam D is 13.14 in average (between 5.18 to 20.2), while the GI value of seam E coal is 13.56 in average (between 10.02 to 18). This indicates the level of oxidation did not take place dominantly, as indicated by the low content of inertinite and a preserved peat moisture. The GI value would inverse with the level of oxidation, the greater the price of the GI, the smaller the degree of oxidation.

TPI and GI values for the seam D and E after plotted into the diagram Diessel et.al. (1986), can be seen in Figure 11.

The diagram shows that the plot of seams D and E is formed in the upper delta plain environment. This depositional environment was relatively unaffected and interacted with sea water. While the plot of seam D coal was below the plot of seam E coal. It indicates that the depositional environment of seam D has a higher oxidation state compared with the depositional environment of seam E.

The calculation of VI value on seams D coal and E shows a high result (> 1). This indicates that the composition maceral derived from timber plants is larger than plant shrubs, while for the GWI values obtained also show that a low value (<1). This

Table 4. Calculation results of TPI-GI and VI-GWI value

No	Sample Code	TPI	GI	VI	GWI
1	Bal 1 Seam D	3.02	20.20	0.07	3.02
2	Bal 2 Seam D	2.58	7.30	0.08	2.40
3	Bal 3 Seam D	3.54	18.08	0.05	3.53
4	Bal 4 Seam D	1.87	9.71	0.10	1.80
5	Bal 5 Seam D	3.03	5.81	0.09	2.98
6	Bal 6 Seam D	2.15	12.14	0.05	2.10
7	Bal 7 Seam D	2.30	19.64	0.04	2.27
8	Bal 2 Seam E	4.30	14.72	0.05	4.86
9	Bal 3 Seam E	2.58	18.00	0.01	2.57
10	Bal 4 Seam E	2.78	14.13	0.05	2.79
11	Bal 5 Seam E	3.07	10.02	0.09	3.01
12	Bal 6 Seam E	2.39	10.23	0.07	2.35
13	Bal 7 Seam E	6.62	14.25	0.03	6.62

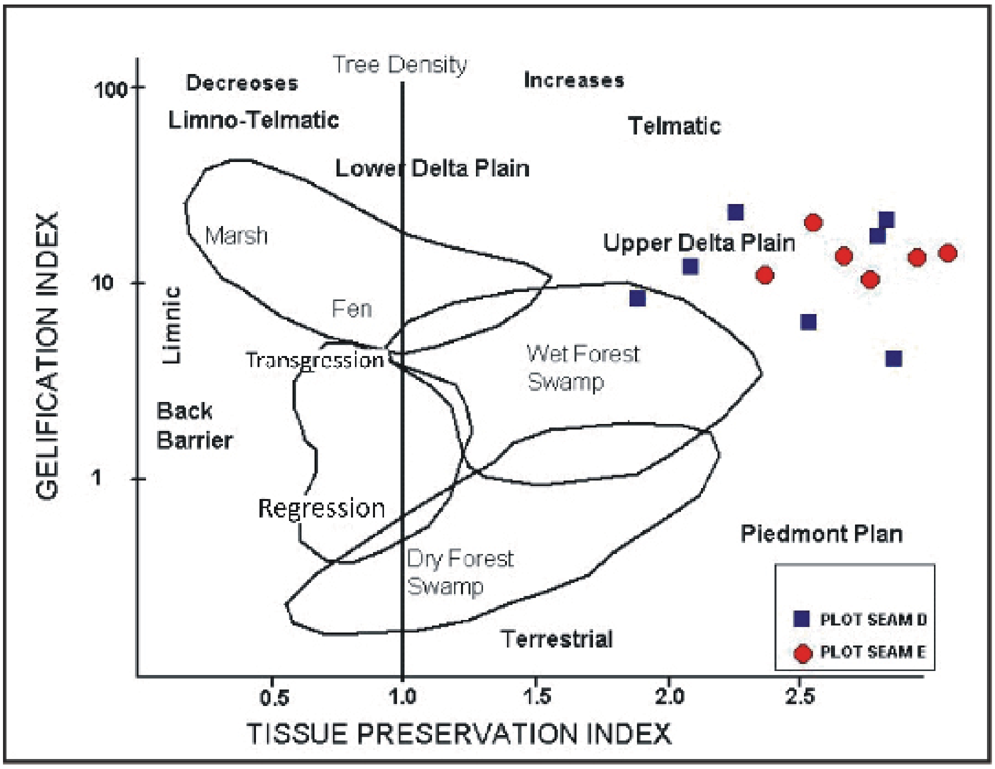

Figure 11. Plot of TPI-GI value of seams D and E in a Diessel diagram (1986)

indicates that the maceral was intensively gelificated due to the peat was formed under conditions which tend to be acidic (low pH). The type of peat for seams D and E after plotted on a Calder chart et al., (1991) shows that all samples tend to be on a bog -ombrotrophic zone (Figure 12), which describes the condition of the peat bog depends on rain water so it has small pH and poor oxygen. Therefore, it has small microorganism activity and inhibit the destruction of the remaining food.

CONCLUSION

The characteristics of seams D and E are indicated by the dominant vitrinite over inertinite and liptinite. The most dominant sub-group of vitrinite is telovitrinit which is indicated seams D and E forming material have been weak gelificated, preserved in the moist peat but not stagnated by water.

Inertinite in both seam consists of semifusinite, sclerotinite and inertodetrinite. Inertinite content which is relatively low may indicate coal derived from depositional environment that is wet and have low levels of oxidation.

Pyrite, clay mineral and carbonate are the main mineral in seams D and E. The variation of mineral content indicates the fluctuation of water level in peat bog caused by high rainfall.

Vitrinite reflectance (Rvmax %) value of seam D coal ranging between 0.38% and 0.68% show, the coal rank from lignite to high volatile bituminous.

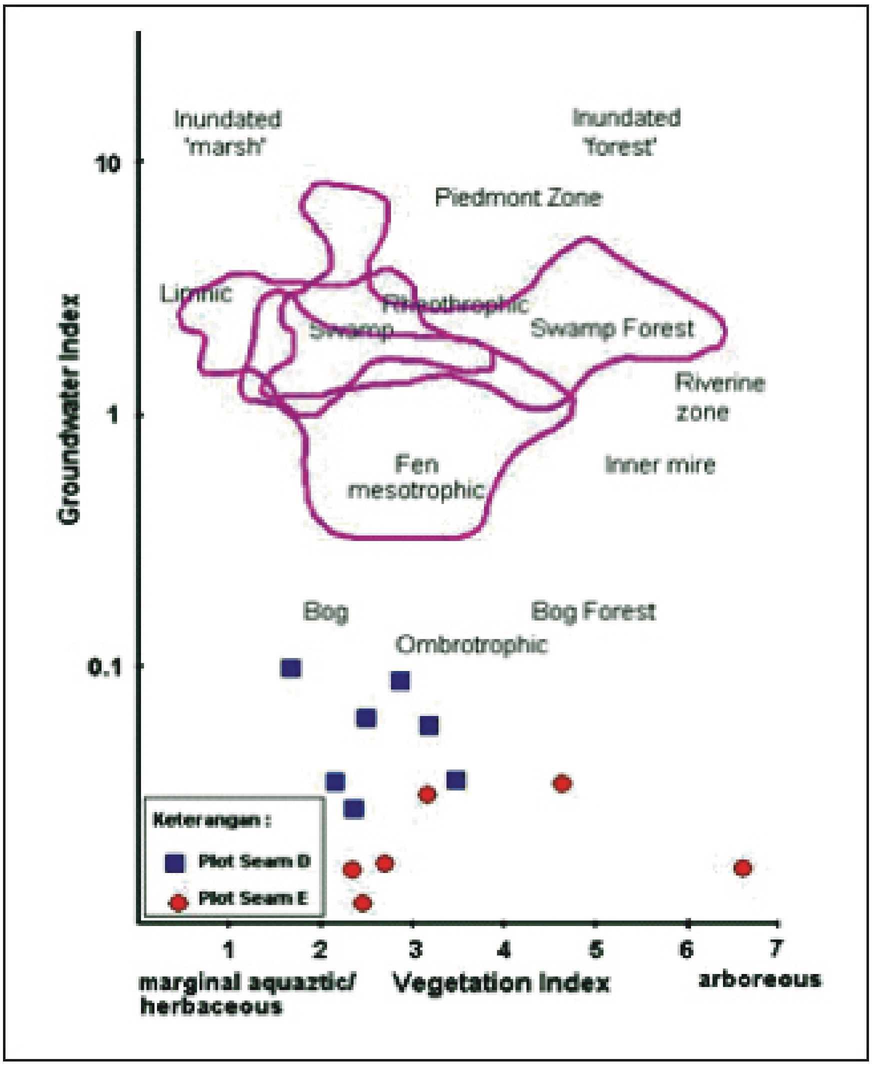

Figure 12. Plot of VI-GWI value of seams D and E in a Calder Diagram (1991)

Vitrinite reflectance (Rvmax %) value of seam E coal ranging between 0.43% and 0.78% show, the coal rank from sub-bituminous to high volatile bituminous.

Seams D and E are formed in the upper delta plain environment. The depositional environments of seam D has a higher oxidation state compare with depositional environment of seam E coal.

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