CHARACTERISTICS OF SELECTED SUMATERAN TERTIARY COALS REGARDING THEIR PETROGRAPHIC ANALYSES

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ABSTRACT

Type and rank variation of selected Sumateran (Ombilin and Bukit Asam) Tertiary coals were assessed by petrographic examination of 170 samples. The coals are dominated by vitrinite, common liptinite and rare inertinite and mineral matter. Vitrinite macerals are dominated by detrovitrinite and telovitrinite. Resinite, cutinite and suberinite are the dominant liptinite macerals in the coals. Inertinite macerals in the coals consist of semifusinite, sclerotinite and inertodetrinite. The higher vitrinite reflectance of some coals is a result of the local and variable effects of igneous intrusions in both areas. Similarities in the type and rank characteristics in the coals reflect their geological setting, climatic influence and peat conditions.

Keywords: Ombilin, Bukit Asam, Tertiary coal, petrographic characteristics

1. INTRODUCTION

Tertiary coal deposits are widespread in many localities in the Indonesian archipelago, particularly in Sumatera and Kalimantan (Sigit, 1980; Hadiyanto, 2006). Coal resource estimate for the most significant Sumateran deposits is approximately 29 billion tons with the reserve of 3 billion tons.

Coal petrography can contribute to an understanding of the nature and aids in determining its utilisation potential. Publication of petrographic composition of Indonesian Tertiary coals, especially Sumateran coals, is rare. However, data on the chemistry of some of the Indonesian coals have been published (Roeslan, 1984; Soekarsono, 1984).

The aims of the study are to obtain an understanding of the following aspects:

- determining the type and rank characteristics of the coals by making maceral analyses and reflectance measurements.
- establishing the broad patterns of variations of type and rank.
- examining relation of type and rank to geological setting.
- contributing the data of maceral composition to the coal references.

In order to achieve the aims, analyses of two major coalfields in Ombilin (West Sumatera) and Bukit Asam (South Sumatera) are included in this study.

2. ANALYTICAL METHODS

The samples studied were collected from Tertiary coalfields of Ombilin and Bukit Asam (Figure 1). Thirty-six samples were obtained from Ombilin and one hundred and thirty-four samples from Bukit Asam. Sampling conducted was according to the procedure of the Standards Association of Australia (1964). The sample type have been collected from core, cutting and spot samples. The method of preparation of polished particulate coal mounts for microscopic analysis included impregnation, evacuation, setting, grinding, polishing, mounting and examination. All samples were examined in both reflected white light and reflected ultraviolet light excitation. Polarised light was essential for the examination of thermally altered samples. The liptinite group of macerals was studied using ultraviolet light excitation at a magnification of x500. An orthoplan microscope fitted with a Leitz vario-orthomat camera was used for photography. Reflectance measurements were made using incident light of 546 nm wavelength and oil immersion of refractive index 1.518 at a room temperature (Cook, 1982).

Normal point count techniques were used for maceral analysis. Approximately 500 points were counted for each maceral analysis. After completion of the analysis, the number of points counted for each individual maceral, maceral group or mineral was expressed as a percentage of the total points recorded. Each point could be examined in reflected white light and fluorescence mode.

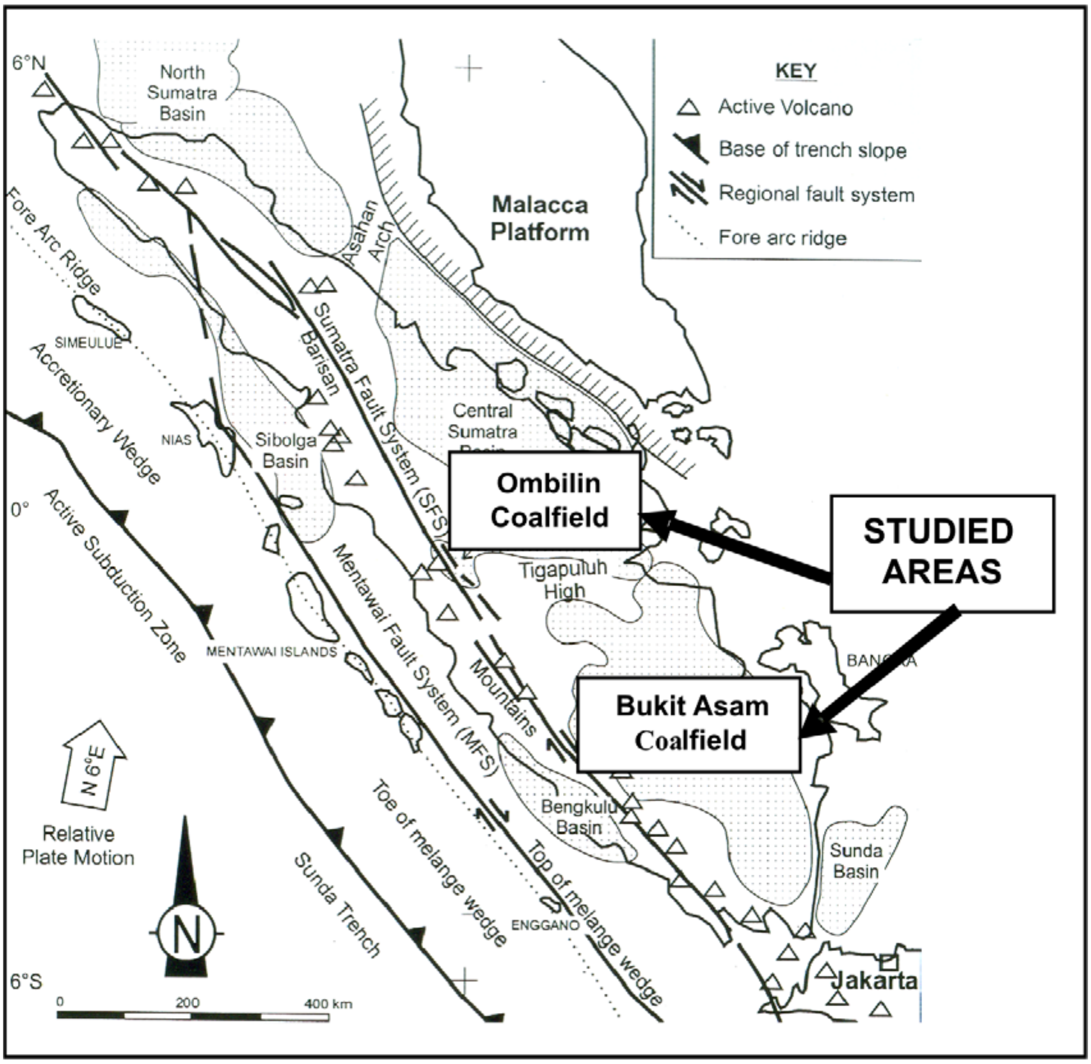

Figure 1. The studied areas at the Ombilin and Bukit Asam Coalfields (modified from Darman and Sidi, 2000).

3. GEOLOGICAL SETTING

The structural development of Sumatera is commonly attributed to the interaction of two major crustal plates, namely the Southeast Asian plate (Sunda Shield) and the Indian Ocean plate (Hamilton 1979; Darman and Sidi, 2000). This interaction caused strong deformation of the Mesozoic and Palaeozoic complexes of the Barisan Range. East of the Barisan Range, along the western edge of the Sunda Shield, a series of Tertiary foreland basins were developed, one of these being the South Sumatera Basin (Bukit Asam coalfield). The intermontane Ombilin Basin is developed in the western part of the island. In relation to coal deposition, the most important sedimentary basins are Palaeogene intermontane basins, Neogene back-arc basin and Neogene deltaic basin (Koesoemadinata, 1978).

Tertiary transgression was commonly preceded by Palaeogene intermontane basin development. Block faulting played an important role, and sediments are typically non-marine, although some marine incursions occurred in the Early Eocene. Coal seams deposited within these basins are interbedded with lacustrine, fluviatile, alluvial plain and near shore deposits (Koesoemadinata, 1978; Eubank and Makki, 1981). The coal seams tend to be limited in lateral extent, but numerous seams are present within the coal measure sequence.

A Neogene back-arc basin developed where marine clastic sedimentation occurred immediately above the Palaeogene sediments, forming some local basal unconformities. This marine sedimentation cycle terminated with a regressive sequence where vast swampy areas developed, resulting in extensive coal deposits such as in South Sumatera basinal area. The deposition of coal occurred in a paralic to limnic and brackish environment.

3.1. Ombilin Coalfield

The Ombilin Coalfield places on the northwest margin of the Eocene Ombilin Basin in the West Sumatera Province. The basin is structurally controlled by wrench faulting that is related to the Sumatera Fault Zone (Harsa, 1975).

The Palaeogene cycle of sedimentation in the Ombilin Basin expresses the initial terrestrial phase of the Tertiary sequence (Eubank and Makki, 1981). This sequence was formed in an intermontane basin that developed at the beginning of the Tertiary when the pre-Tertiary landmass was block-faulted into grabens. The graben-like basin was filled from all sides by alluvial fans, while some lakes existed in the central basin. Then, the basin became an alluvial fan with meandering rivers followed by a braided river system, before it was folded and uplifted in Early Miocene (Koesoemadinata, 1978). Folds (anticlines and synclines) are found in the Ombilin Basin, generally bounded by major faults that trend particularly east-west, northeast-southwest and northwest-southeast. Coal seams occur in two Stratigraphic units, namely: the Sawahlunto Formation and the Poro Member of the Sawahtambang Formation. Three coal seams (A, B and C) occur in the Sawahlunto Formation (Marubeni-Kaiser, 1971), as shown in Figure 2. The coal seams of the Poro Member of the Sawahtambang Formation crop out on the southeast part of the Ombilin Basin. The coals are very thin ranging from 15 to 18 cm thick.

3.2. Bukit Asam Coalfield

The Bukit Asam area contains Tertiary sediments that were deposited in the South Sumatera Basin. The basin constitutes part of the Muara Enim Anticlinorium. Shell Mijnbouw (1978) describes the regional stratigraphy of the South Sumatera coal. Transgressive and regressive phases occurred in two periods of sedimentation. The Telisa Group was deposited during the transgressive phase, whilst the Palembang Group in the regressive phase.

The mineable coal deposits in the South Sumatera Basin are developed in the Muara Enim Formation occurring in the middle of the Palembang Group (Roeslan, 1984; Soekarsono, 1984). The thickness of the Muara Enim Formation ranges from 450 to 750 metres. This formation was interpreted as Late Miocene to Pliocene. Roeslan (1984) and Soekarsono (1984) assumed that six major coal seams and several thin coal layers are present in the Bukit Asam Area. The thicknesses and nomenclatures of the seams and interseams can be seen in Figure 3. The Bukit Asam coals are autochthonous in origin.

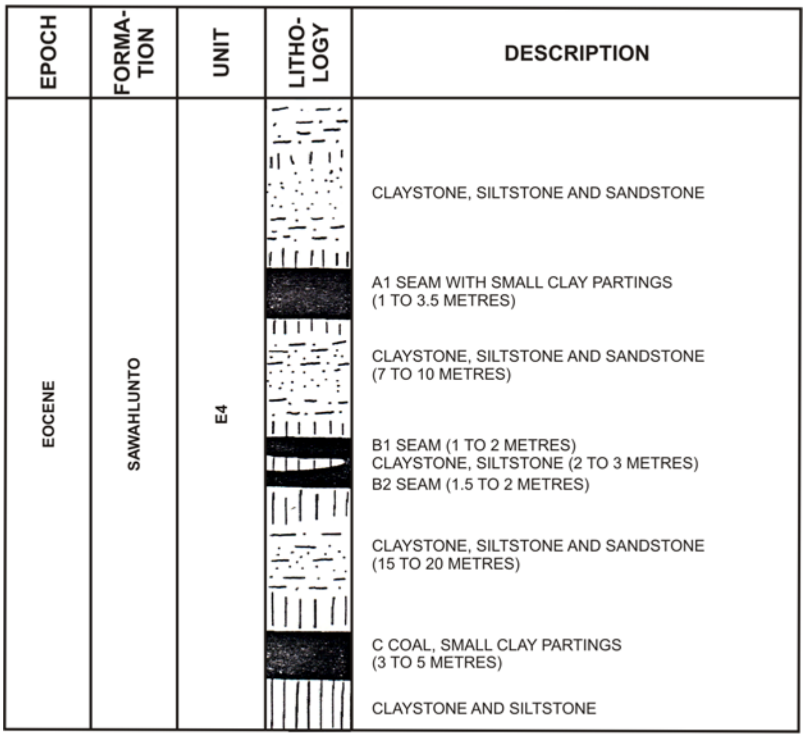

Figure 2. Stratigraphic sequence of the Ombilin coal measures (Marubeni-Kaiser, 1971).

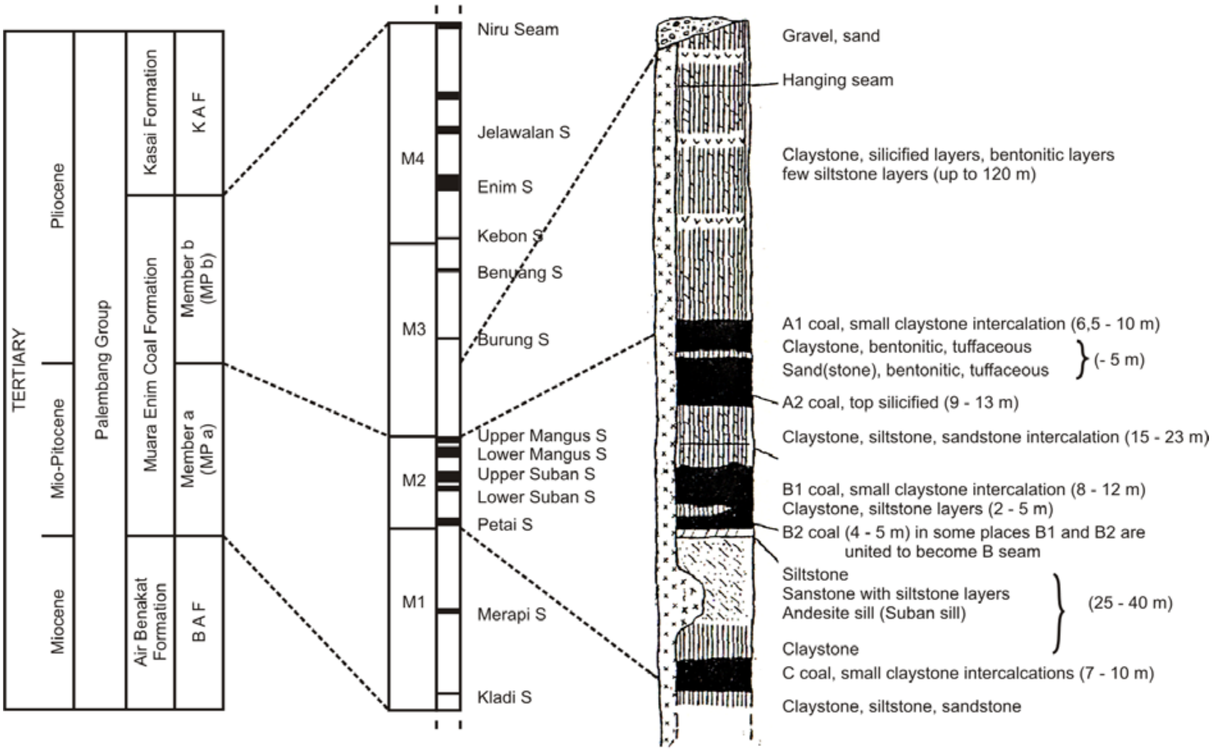

Figure 3. Stratigraphy of the Bukit Asam area (Soekarsono, 1984).

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4. TYPE AND RANK OF THE COALS

The Sumateran coals comprise essentially vitrinite and liptinite groups of macerals. Vitrinite consists particularly of interbedded detrovitrinite matrix and telovitrinite bands. Gelovitrinite, corpovitrinite and porigelinite take place throughout the coals. Liptinite includes resinite, cutinite, suberinite, sporinite, liptodetrinite, fluorinite and exsudatinite. Alginite is present in the Ombilin coals. Inertinite is poorly present in the Sumateran coals. Approximately 50% of the inertinite fraction is semifusinite and the rest is fungal sclerotinite, inertodetrinite and rare fusinite. Mineral matter content is low that is less than 5% including mainly pyrite and clay. Pyrite occurs as fine grains throughout the coals. Clay takes place mostly as fine-grained inclusions dispersed throughout the coals. Clay infills plant cell cavities in generally vitrinite.

Reflectance study of the Sumateran Tertiary coals shows that the coals vary from brown coal to anthracite stages. Normally, rank increases with depth of burial and geothermal gradient in the Sumateran coal-bearing basins. However, some coal seams in the Ombilin and Bukit Asam Coalfields exhibit abnormally high vitrinite reflectances due to proximity of andesitic intrusions. The Ombilin coals not affected by contact alteration are high volatile bituminous rank, whereas thermally altered coals are anthracite. The Bukit Asam coals not affected by contact alteration, range from brown coal to sub-bituminous coal rank. The Bukit Asam thermally altered coals vary from high volatile bituminous to semi-anthracite and anthracite. The higher rank of the Ombilin coals compared to the Bukit Asam coals is due to their different thermal history with higher temperatures acting over longer period at Ombilin.

4.1. Type

4.1.1 Ombilin

Microscopic study of thirty-six coal samples from four coal seams (A, B1, B2 and C) in the Ombilin Coalfield shows that all the seams are composed largely of vitrinite and liptinite with inertinite being rare (Table 1). Slightly different maceral compositions exist between coal seams. For instance, vitrinite content increases slightly from seam A through seam C. Thermally affected coals commonly contain vitrinite and rare inertinite, but no recognisable liptinite.

Vitrinite content of the Ombilin coals varies between 80% and 96% with average of 90%. Detrovitrinite forms a matrix for isolated thin bands of telovitrinite and for liptinite. The detrovitrinite matrix includes more than 50% of the total vitrinite in most of the coal samples. Gelovitrinite, mainly corpovitrinite and porigelinite, takes place throughout the coals, and are usually associated with suberinite.

Liptinite content is between 2% and 14% with average of 6%. Cutinite (Figures 4a and 4b), resinite and liptodetrinite are the dominant liptinite macerals. However, suberinite and sporinite are dominant in some occurrences. Fluorinite, exsudatinite and alginite occur in a few samples and are rare. Cutinite forms over 5% of some samples and occurs mostly as thin-walled cutinite. The cutinite has weak-moderate intensity orange fluorescence. In some cases, it does not fluoresce.

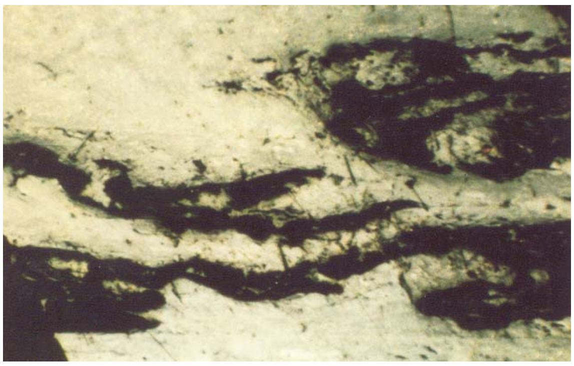

Figure 4a. Cutinite (black) in vitrinite (grey), seam B1, Rvmax = 0.65%, field width = 0.28 mm.

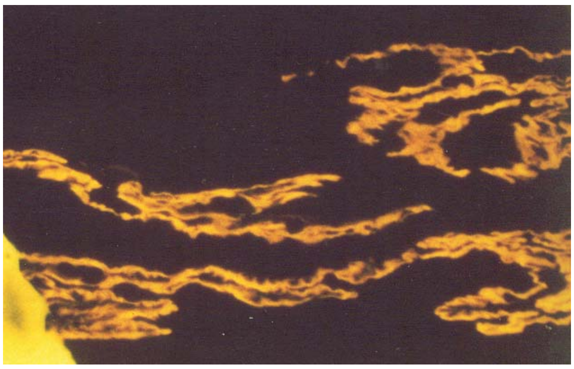

Figure 4b. As for Figure 4a, but in fluorescence mode.

Table 1. Maceral composition of the Ombilin coals

LOCATION	SEAM	VITRINITE (%)				INERTINITE (%)				LIPTINITE (%)				MM (%)
		Tv	Dv	Gv	Tot	Sf	Scl	Inert	Tot	Res	Cut	Sub	Tot	
Tanah Hitam	A	47	33	5	85	-	tr	tr	tr	-	6	3	9	1
o/c		21	57	10	88	-	-	-	-	-	1	tr	1	tr
Sawah Rasau	A	23	51	8	82	tr	tr	tr	tr	1	5	2	8	3
u/g		23	50	13	86	tr	tr	tr	tr	tr	4	4	8	1
		29	56	10	95	tr	tr	1	1	tr	1	tr	1	tr
		19	58	10	87	-	tr	tr	tr	tr	5	1	6	1
		37	49	10	96	-	1	1	2	tr	1	tr	1	-
		38	48	5	91	tr	2	1	3	1	2	tr	3	1
Tanah Hitam	B1	24	51	9	84	tr	tr	1	1	1	1	1	3	3
o/c		24	49	16	89	1	1	1	3	1	tr	tr	1	2
		19	58	13	90	tr	2	1	3	1	1	tr	2	1
Sawah Rasau	B1	14	65	5	84	tr	1	tr	1	tr	4	tr	4	6
u/g		23	60	9	92	tr	1	1	2	1	2	tr	3	1
Tanah Hitam	B2	19	65	9	93	1	2	1	4	1	tr	tr	1	tr
o/c		28	51	11	90	tr	1	1	2	tr	4	1	5	1
Sawah Rasau	B2	17	68	7	92	1	1	1	3	1	4	tr	5	tr
u/g		66	25	5	96	-	tr	tr	tr	1	1	tr	2	1
		19	61	5	85	tr	1	-	1	tr	3	-	3	3
BH7	B	41	47	7	95	tr	-	1	1	1	1	1	3	tr
Parambahan		42	49	1	92	tr	1	1	2	-	3	1	4	tr
		39	42	14	95	-	tr	-	tr	tr	3	tr	3	-
		23	57	8	88	1	2	1	4	1	2	-	3	3
		26	54	6	86	1	2	1	4	tr	5	tr	5	3
		40	41	9	90	tr	2	1	3	1	2	1	4	2
		36	36	8	80	2	1	-	3	tr	3	2	5	11
Tanah Hitam	C	19	54	13	86	tr	3	3	6	1	1	1	3	1
o/c		35	53	6	94	-	tr	tr	tr	-	tr	2	2	tr
		33	50	8	91	-	1	2	3	-	1	3	4	-
		99	-	tr	99	1	tr	-	1	-	-	-	-	tr
		99	-	-	99	tr	1	-	1	-	-	-	-	tr
		20	62	6	88	1	1	tr	2	tr	1	tr	1	7
Sawah Rasau	C	33	55	5	93	tr	1	tr	1	1	2	1	4	-
u/g		26	48	18	92	tr	tr	tr	tr	tr	4	2	6	tr
		32	50	12	94	tr	tr	-	tr	1	3	1	5	tr
BH7	C	33	48	8	89	1	2	tr	3	1	3	tr	4	2
Parambahan		38	45	8	91	tr	1	1	2	1	1	tr	2	4

Notes: Tv : telovitrinite, Dv : detrovitrinite, Gv : gelovitrinite, Sf : semifusinite, Scl : sclerotinite, Inert : inertodetrinite, Res : resinite, Cut : cutinite, Sub : suberinite, MM : mineral matter, Tot : total
o/c : open cut, u/g : underground, tr :trace

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Liptodetrinite constitutes up to 6% of some samples in the coals. The liptodetrinite has low reflectance and yellow-orange fluorescence. Resinite is present in most of the samples with trace to 1% content. The resinite occurs as discrete small bodies that are less than 0.06 mm. It has greenish yellow-yellow fluorescence. Suberinite constitutes more than 2% of some coal samples, with typically weak orange fluorescence, but in some cases does not fluoresce. Sporinite is a dominant liptinite maceral in some samples and occurs mostly as miospores and pollen and is disseminated throughout the coals. The sporinite has yellow-orange fluorescence. Fluorinite is rare in the coals and has a greenish yellow fluorescence. Alginite is present in some samples with varying contents ranging from trace to 2%. It has yellow-orange fluorescence.

Inertinite is a minor constituent in the samples. Its content is between a trace and 6% with average of 2%. Sclerotinite is the dominant inertinite group maceral and consists of sclerotia, single and twin-celled teleutospores and teleutospores with three and four cells. Semifusinite occurs as thin layers and poorly as isolated lenses in a detrovitrinite matrix. Inertodetrinite constitutes average of 1% of the coals and occurs as angular and irregular forms disseminated throughout the coals.

Mineral matter consists mainly of clay and pyrite, but is rare in the coals. It usually constitutes a trace to 1%, although some samples contain more than 3%. Most of the mineral matter occurs as pods disseminated throughout the coals. Framboidal pyrite is common in the thinner seam.

In summary, liptinite and inertinite contents of the Ombilin coals are systematically related to vitrinite content. The liptinite and inertinite contents decrease with increase in the vitrinite content. The liptinite content does not relate to the inertinite content.

4.1.2 Bukit Asam

The Bukit Asam coals are divided into unaffected and heat affected coals due to the thermal effects from an intrusion, as shown in Figures 5, 6 and 7. These figures show textural features of vitrinite, starting from coals unaffected by contact alteration to the most strongly thermally affected coals. The thermally unaffected coal is blackish grey; otherwise, the thermally affected coal is light grey. They have different maceral compositions as shown in Appendix 1.

Vitrinite content of the Bukit Asam coals unaffected by contact alteration is between 76% and 96% with average of 87%. This vitrinite typically occurs as a matrix of detrovitrinite, thin layers or small lenses of telovitrinite associated with liptinite and inertinite. Some of the telovitrinite cell lumens are infilled with fluorinite or resinite, and in some cases being filled by clay. Gelovitrinite, mainly corpovitrinite and porigelinite are scattered throughout the coals. In some places, porigelinite occurs as thin bands. Gelification of telovitrinite progressively increases with rank. The thermally affected coals have vitrinite coals ranging from 90% to 98% with average of 95%. Telovitrinite is the main type of vitrinite and is mostly structureless, although

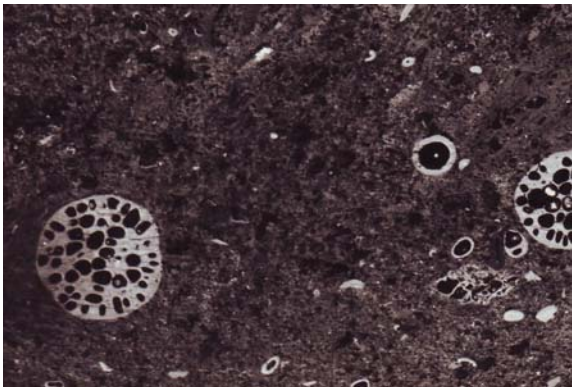

Figure 5. Detrovitrinite matrix (blackish grey) and sclerotinite (white) in coal not affected by contact alteration. Seam C, Rvmax = 0.41%, field width = 0.36 mm, reflected white light

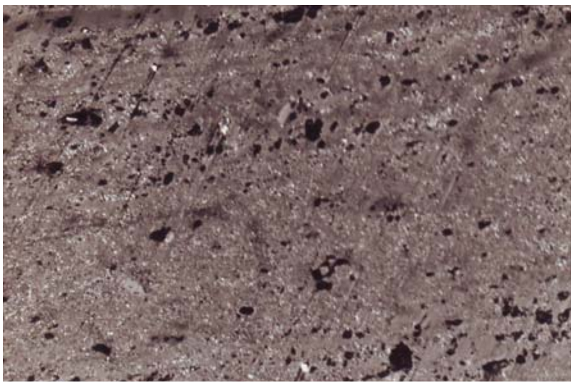

Figure 6. Vitrinite (grey) in thermally affected coal. Seam C, Rvmax = 0.89%, field width = 0.28 mm, reflected white light

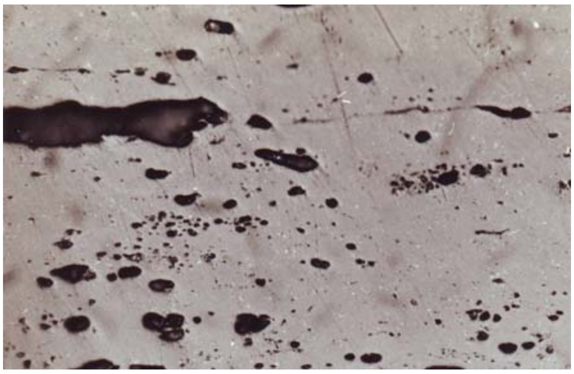

Figure 7. Vitrinite of thermally affected coal (light grey). Seam C, Rvmax = 2.28%, field width = 0.22 mm, reflected white light

some have cell structure. In some cases, vitrinite is layered and has a lower reflectance than the more massive one. Pores are present in some samples.

As shown in Appendix 1, the liptinite group constitutes a higher percentage in coals unaffected by contact alteration than in thermally affected coals. Liptinite content of the coals unaffected by contact alteration ranges between 2% and 15% with average of 7%. Thermally affected coals have trace amounts of liptinite. The liptinite mainly includes resinite (Figures 8a and 8b), cutinite, liptodetrinite and suberinite with minor sporinite and fluorinite and rare exsudatinite. The resinite mostly occurs as small discrete bodies of about 0.06 mm, which are commonly globular. It has a low reflectance and yellow-orange fluorescence. Some resinite is concentrated in distinct layers. Suberinite comprises the dominant liptinite maceral that is up to 5% in some coals. It occurs in distinct layers. It usually has strong green-yellow fluorescence. Liptodetrinite is a significant component of the coals and occurs as a fine degradation product of other liptinite. It has a bright yellow-orange fluorescence. Cutinite is common (1% to 3%) and present as tenuicutinite. It has yellowish orange fluorescence. Fluorinite is also common in some of the coals. It has low reflectance and green fluorescence. It commonly infills cell lumens and discrete small bodies. Sporinite is rare in the coals that are mostly less than 1%. It has a yellow fluorescence. Exsudatinite occurs in few samples. It has a very bright yellow-orange fluorescence.

Inertinite is commonly rare in the coals in which few samples contain more than 5%. Semifusinite is generally dominant over sclerotinite and inertodetrinite. Micrinite and macrinite occur in some coals. Sclerotinite includes single and twin-celled teleutospores and sclerotia. Some cell of fungal sclerotinite is filled by resinite and mineral matter. Inertinite contents of the coals unaffected by contact alteration vary from 1% to 8% with average of 3%. Seam A2 has the highest inertinite content (average 5%) among the five coal seams due to the existence of aerobic conditions for that seam. Inertinite contents of all coal seams in the thermally affected coal suite are similar with average of 3%. Fusinite and semifusinite of the coals occur as layers or lenses. Sclerotinite and inertodetrinite are scattered throughout the coals. Micrinite is commonly present as small (less than 0.01 mm) and irregularly-shaped grains.

Mineral matter is rare in the coals that is from trace to 5% with average of 2%. It is represented by clay occurring as pods and infilling cell lumens. Traces of pyrite are disseminated throughout the

Figure 8a. Resinite (black, rounded) infilling cells in sclerotinite (white), seam A1, Rvmax = 0.38%, field Width = 0.28 mm.

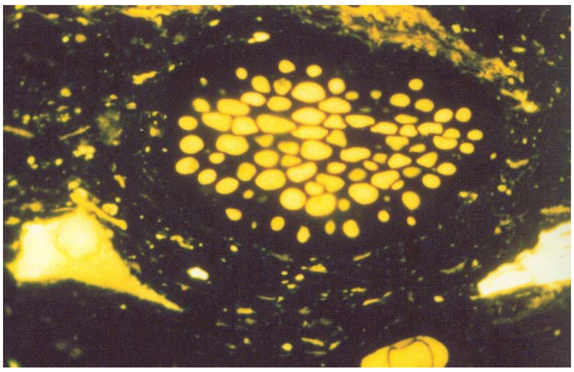

Figure 8b. As for Figure 8a, but in fluorescence mode.

coals. Mineral matter content of thermally affected coals is slightly higher than that of coals unaffected by contact alteration.

In summary, the liptinite and inertinite contents of the Bukit Asam coals are systematically related to the vitrinite content. The liptinite and inertinite contents decrease with increase in vitrinite content. The liptinite content does not relate to the inertinite content.

4.2. Rank

4.2.1 Ombilin

Vitrinite reflectance (Rvmax) values were measured from the coal samples of the Ombilin Coalfield. The result is shown in Table 2. Most of the samples are high volatile bituminous (Rvmax of 0.62% to 0.77%), although one sample is sub-bituminous (Rvmax of 0.55%). The low vitrinite reflectance

Table 2. Vitrinite reflectance of the Ombilin coals (Australian Standard, 1964)

LOCATION	SEAM	Rvmax (%)	RANGE	RANK
Tanah Hitam o/c	A	0.63 0.64	0.57-0.69 0.59-0.70	High volatile bituminous High volatile bituminous
Sawah Rasau u/g	A	0.62 0.68 0.71 0.64 0.67 0.68	0.54-0.70 0.62-0.74 0.60-0.72 0.58-0.70 0.60-0.74 0.60-0.82	High volatile bituminous High volatile bituminous High volatile bituminous High volatile bituminous High volatile bituminous High volatile bituminous
Tanah Hitam o/c	B1	0.62 0.64 0.64	0.57-0.69 0.57-0.69 0.56-0.70	High volatile bituminous High volatile bituminous High volatile bituminous
Sawah Rasau u/g	B1	0.55 0.65	0.46-0.63 0.59-0.71	Sub-bituminous High volatile bituminous
Tanah Hitam o/c	B2	0.68 0.64	0.61-0.75 0.59-0.71	High volatile bituminous High volatile bituminous
Sawah Rasau u/g	B2	0.71 0.71 0.62	0.66-0.80 0.61-0.80 0.54-0.71	High volatile bituminous High volatile bituminous High volatile bituminous
BH7 Parambahan	B	0.71 0.70 0.72 0.75 0.76 0.77 0.77	0.65-0.78 0.64-0.78 0.67-0.78 0.70-0.81 0.72-0.87 0.69-0.83 0.72-0.82	High volatile bituminous High volatile bituminous High volatile bituminous High volatile bituminous High volatile bituminous High volatile bituminous High volatile bituminous
Tanah Hitam o/c	C	0.6 0.63 0.62 **4.69** **3.39** 0.68	0.56-0.73 0.57-0.67 0.57-0.66 4.59-4.77 3.30-3.51 0.60-0.79	High volatile bituminous High volatile bituminous High volatile bituminous **Anthracite** **Anthracite** High volatile bituminous
Sawah Rasau u/g	C	0.64 0.70 0.68	0.59-0.75 0.65-0.77 0.61-0.75	High volatile bituminous High volatile bituminous High volatile bituminous
BH7 Parambahan	C	0.75 0.77	0.69-0.84 0.73-0.81	High volatile bituminous High volatile bituminous

Notes: o/c-open cut, u/g: underground

value of some samples is caused by the presence of alginite (Hutton and Cook, 1980). The rank of some coals increases sharply into anthracite stage. This change is predicted in association with heating from a local intrusion.

Vitrinite reflectance in some places increases from top to bottom of the seam. For instance, seam A shows an increase in vitrinite reflectance from 0.62% at the top through to 0.71% at the base.

4.2.2. Bukit Asam

Vitrinite reflectance measurements were made from the coal samples of the Bukit Asam Coalfield. Vitrinite reflectance is between 0.30% and 2.60% (Appendix 2). This wide range is caused by the intrusion of the Pliocene-Pleistocene andesitic body in the area.

Vitrinite reflectance of coal unaffected by contact alteration ranges from 0.30% to 0.53%, but the Rvmax of thermally altered coals varies from 0.69% to 2.60%. Vitrinite reflectances are between 0.40% and 0.50%, and are dominant at the coalfield.

Vitrinite reflectance also reveals a marked difference between the upper and lower seams. This difference may be due to the differences in stratigraphic position and the effect of heating from the andesitic intrusion.

5. DISCUSSION

The maceral composition of the Ombilin and Bukit Asam Tertiary coal samples is slightly different from each other. There are two factors accounting the variations, namely intrusion effect and age. In the thermally affected coals from both Ombilin and Bukit Asam Coalfields, liptinite generally cannot be distinguished from vitrinite. Therefore, it appears to contain high proportions of vitrinite that range from 90% to 99%. On the other hand, thermally unaffected coals from both coalfields contain 75% to 90% of vitrinite. Liptinite maceral is common in coals unaffected by contact alteration with some sample containing up to 15% of liptinite. In contrast, thermally affected coals have trace amounts of liptinite. Fluorinite and exsudatinite are prominent in some of the coals occurring in association with vitrinite.

Both thermally affected and unaffected coals contain rare inertinite (up to 5%). In some cases, coals with high inertinite content have a relatively high amount of mineral matter. This may be as a result of peat ablation in relatively oxidising environment providing an unfavourable balance between the rate of accumulation of organic material and mineral matter (Cook and Johnson, 1975).

The most obvious trend for both coals is the decrease in the proportion of liptinite and the increase in the proportion of vitrinite. Vitrinite in the coals unaffected by contact alteration consists of thick detrovitrinite matrix (up to 50%) interbedded with thin bands of telovitrinite. Vitrinite of thermally affected coals is mostly structureless, massive and few contain pores.

The dominance of vitrinite in the coals is indicative of forest type vegetation in humid tropical zone, without significant dry events throughout. Cook (1975) noted that many seams deposited in areas of rapid subsidence have both high vitrinite content and a high mineral content present as discrete dirt bands.

The coals exhibit variable vitrinite reflectances, significantly due to igneous intrusion factor, regardless their short geological history. In general, vitrinite reflectance of the thermally-unaffected Bukit Asam coal is between 0.30% and 0.53%; thermally-altered coals is greater than 0.83% and vitrinite content exceeds 85%. In the Ombilin and Bukit Asam Coalfields, a more rapid and thorough alteration has occurred where bodies of igneous rock have intruded the Tertiary sequences. Consequently, coal of lower rank coal has been metamorphosed to bituminous or anthracitic ranks. The extent of rank increase depends mainly on distance from the intruded igneous rocks, but may also be related to the size and temperature of the intrusion. The extent of gas or liquid streaming away from intrusion may also be significant. Table 3 shows vitrinite reflectances of heat-affected coals of the Ombilin and Bukit Asam Coalfields.

Table 3. Vitrinite reflectance of the coals

COALFIELD	% Rvmax	
	Unaffected Coal	Thermally-affected coal
Ombilin	0.55-0.77	3.39-4.69
Bukit Asam	0.30-0.53	0.69-2.63

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6. CONCLUSION

The Ombilin coals were deposited in intermontane basin continental margin basin, and are interbedded with lacustrine and fluviatile deposits; whereas the Bukit Asam coals in back-arc basin and continental margin basin associated with limnic to deltaic and paralic deposits. The palaeoclimate of Sumatera throughout the Tertiary was humid and tropical associated with tropical forests.

Vitrinite comprises the dominant maceral in both Sumateran coals, particularly in the thermally-affected coals surrounding the andesitic intrusions. Both contain commonly detrovitrinite and telovitrinite with minor gelovitrinite. Liptinite is common in the coals. Resinite is the dominant liptinite maceral in the coals. However, cutinite and suberinite are dominant in some occurrences. The coals are characterised by the presence of other liptinite macerals like exsudatinite and alginite as well. Inertinite is rare in the coals including semifusinite, sclerotinite, fusinite and inertodetrinite. Mineral matter consisting mainly of clay and pyrite is rare in the coals.

The type characteristics of the Ombilin and Bukit Asam coals more closely resemble. This suggests that the similarities are due to the basin setting in both areas. High proportion of vitrinite in the coals indicates that the original plant material consists essentially of woody plant tissue and the peatification occurred under relatively wet reducing condition.

The average vitrinite reflectance of the Ombilin coals is higher than that of the Bukit Asam coals. The Ombilin coals not affected by contact alteration have vitrinite reflectances between 0.53% and 0.83%, whilst the Bukit Asam coals not affected by contact alteration range from 0.30% to 0.57%. In the Ombilin and Bukit Asam Coalfields, the coal seams are locally altered by igneous activity that has resulted in a wide range of higher rank coals. In the proximity of the intrusions, very high lateral and vertical rank gradients are present.

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Appendix 1. Maceral composition of the Bukit Asam coals

LOCATION	SEAM	VITRINITE (%)				INERTINITE (%)				LIPTINITE (%)				MM
		Tv	Dv	Gv	Tot	Sf	Scl	Inert	Tot	Res	Cut	Sub	Tot	(%)
Tapuan	hanging	66	15	5	86	1	tr	-	1	3	1	1	5	
		26	47	14	87	3	tr	1	4	1	tr	3	4	
Banko	hanging	31	52	5	88	2	tr	tr	2	2	tr	3	5	2
		47	38	6	91	1	tr	-	1	1	tr	2	3	3
		58	26	8	92	1	tr	1	2	tr	-	3	3	1
Air Laya o/c	A1	48	32	5	85	2	-	tr	2	1	6	2	3	tr
		54	35	5	94	tr	tr	tr	tr	1	1	1	1	-
		50	19	17	86	1	tr	tr	1	1	8	tr	2	1
SE Balong Hijau o/c	A1	31	42	22	95	1	tr	-	1	1	1	tr	2	1
		27	49	17	93	3	tr	tr	3	tr	1	1	2	1
		33	33	19	85	2	tr	1	3	5	2	-	7	1
SW Balong Hijau o/c	A1	97	-	tr	97	1	1	-	2	-	-	-	-	1
		97	-	1	98	1	tr	-	1	-	-	-	-	1
Muara Tiga o/c	A1	17	40	34	91	1	1	-	2	1	5	tr	6	1
		97	-	1	98	1	tr	-	1	-	-	-	-	1
		56	33	7	96	-	tr	-	tr	-	-	tr	tr	-
Air Laway	A1	43	35	7	85	1	tr	-	1	1	1	6	8	4
		52	26	10	88	2	tr	-	tr	2	-	3	5	3
		57	19	10	86	2	1	tr	3	1	1	3	5	2
Tapuan	A1	57	22	12	91	1	-	-	1	1	1	3	5	1
Air Laway	A1	55	26	9	90	3	1	-	4	1	1	1	3	1
		52	27	9	88	1	1	tr	2	3	1	3	7	1
		77	10	5	92	4	tr	-	4	2	tr	2	4	1
Tapuan	A1	37	31	18	86	4	tr	tr	4	1	-	2	3	2
Air Laway	A1	34	36	11	81	5	1	1	7	1	-	3	4	2
		63	22	6	91	1	tr	-	2	1	tr	2	3	2
		36	39	9	84	2	tr	1	3	2	tr	2	4	2
		36	43	10	89	3	tr	1	4	1	tr	2	3	1
Suban o/c	A1	97	-	-	97	-	-	-	-	-	-	-	-	2
		96	-	-	96	2	tr	-	2	-	-	-	-	1
Air Laya o/c	A1	22	60	8	90	3	1	1	5	2	tr	tr	2	1
Air Laya	A1	46	24	15	85	4	1	1	6	2	tr	2	4	2
		84	5	2	91	3	1	1	5	-	-	-	-	5
		57	22	11	90	1	tr	-	1	1	tr	3	4	2
Suban	A1	33	48	12	92	5	tr	tr	5	-	-	-	-	1
Bukit Asam	A1, A2	96	-	1	96	tr	tr	-	tr	-	-	-	-	2
Air Laya	A1	26	56	10	92	2	tr	1	3	1	-	1	2	1
Tapuan	A1	49	22	19	90	7	tr	tr	7	-	-	-	-	1
Air Laya	A1	38	40	8	86	2	tr	1	3	1	tr	2	3	4
		36	43	11	90	2	tr	1	3	1	-	1	2	1
Banko	A1	51	36	7	94	1	tr	tr	1	1	-	2	3	1
		66	21	8	95	tr	tr	-	tr	tr	tr	1	1	2
		65	14	12	91	-	tr	tr	tr	1	tr	3	4	2
		58	25	9	92	tr	tr	-	Tr	2	1	2	5	2
		50	35	7	92	tr	1	-	1	tr	-	5	5	2

Continous Appendix 1 ...

LOCATION	SEAM	VITRINITE (%)				INERTINITE (%)				LIPTINITE (%)				MM
		Tv	Dv	Gv	Tot	Sf	Scl	Inert	Tot	Res	Cut	Sub	Tot	(%)
		57	24	5	86	tr	tr	-	tr	5	tr	3	8	1
		45	26	6	77	tr	tr	-	tr	4	4	7	15	1
SW Balong Hijau o/c	A2	96	tr	2	98	tr	1	-	1	tr	-	-	tr	tr
		96	-	1	97	1	1	-	2	-	-	-	-	1
Muara Tiga o/c	A2	31	44	10	85	10	1	-	11	tr	1	tr	1	tr
		30	37	11	78	11	1	-	12	4	2	1	7	1
		44	34	16	94	1	tr	1	2	1	2	1	4	tr
		38	27	23	88	5	tr	tr	5	1	2	-	3	1
Air Laway	A2	52	25	12	89	1	tr	-	1	1	-	4	5	3
		34	43	8	85	1	1	-	2	1	tr	6	7	4
		59	21	8	88	4	1	-	5	1	1	2	4	1
Tapuan	A2	44	33	11	88	2	tr	tr	2	2	tr	2	4	1
Air Laway	A2	55	20	12	87	3	1	tr	4	tr	2	2	4	tr
		62	20	8	90	1	1	tr	2	tr	-	2	2	2
		49	28	10	87	2	tr	-	2	3	tr	2	5	5
Tapuan	A2	59	21	9	89	1	1	-	2	2	tr	3	5	3
Air Laway	A2	27	43	16	86	5	1	1	7	1	-	2	3	1
		51	29	6	86	2	1	-	3	2	1	4	7	1
		25	55	11	91	3	1	tr	4	1	-	2	3	1
		39	39	11	89	3	1	tr	4	tr	tr	3	3	1
Suban o/c	A2	98	-	-	98	1	tr	-	1	-	-	-	-	1
		97	-	-	97	1	1	-	2	-	-	-	-	1
Air Laya	A2	44	25	16	85	3	1	1	5	2	-	3	5	2
		92	-	2	94	3	tr	-	3	-	-	-	-	2
Suban	A2	87	-	3	90	5	1	1	7	-	-	tr	tr	2
Air Laya	A2	62	12	13	87	5	tr	1	6	1	-	1	2	2
Tapuan	A2	50	34	9	93	2	-	1	3	tr	1	tr	1	1
Air Laya	A2	35	42	8	85	4	tr	1	5	2	1	2	5	2
Muara Tiga o/c	B	31	46	9	96	3	tr	1	4	1	-	4	5	3
		38	32	18	88	1	-	tr	1	2	tr	3	5	2
		40	35	15	90	1	-	tr	1	2	tr	3	5	2
Air Laway	B	48	31	8	87	2	1	-	3	1	3	tr	4	2
		37	40	9	86	1	1	tr	2	3	tr	3	6	1
		54	26	4	84	1	-	-	1	6	3	-	9	1
Tapuan	B	59	23	8	90	1	tr	tr	1	1	tr	2	3	2
Air Laway	B	58	21	6	85	1	1	-	2	3	tr	3	6	3
		26	43	15	84	5	1	1	7	1	-	2	3	2
		21	59	6	86	2	1	1	4	2	tr	2	4	1
		46	25	15	86	2	1	tr	3	1	tr	3	4	2
		18	64	8	90	2	1	-	3	2	tr	1	3	1
		27	48	15	90	3	tr	1	4	1	-	1	2	1
Air Laway	B1	53	22	10	85	2	1	tr	3	3	2	1	6	2
Suban o/c	B1	96	-	-	96	2	1	-	3	-	-	-	-	tr
		94	tr	2	96	tr	tr	-	tr	-	-	-	-	3
		94	1	tr	95	2	1	-	3	-	-	-	-	1

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Continous Appendix 1 ...

LOCATION	SEAM	VITRINITE (%)				INERTINITE (%)				LIPTINITE (%)				MM
		Tv	Dv	Gv	Tot	Sf	Scl	Inert	Tot	Res	Cut	Sub	Tot	(%)
Air Laya	B1	47	26	13	86	4	tr	tr	4	2	-	2	4	2
		89	-	1	90	4	1	-	5	-	-	-	-	3
		54	29	6	89	1	tr	-	tr	2	tr	2	4	2
Suban	B1	82	7	7	96	1	tr	tr	1	-	-	-	-	3
Bukit Asam	B1	95	-	2	97	1	tr	-	1	-	-	-	-	2
Air Laya	B1	49	29	8	86	1	-	tr	1	1	1	4	6	4
Tapuan	B1	72	20	7	99	tr	-	-	tr	-	-	-	-	1
Air Laya	B1	35	49	7	91	2	tr	1	3	1	-	1	2	1
Banko	B1	59	5	30	94	1	tr	-	1	1	-	2	3	1
		41	34	10	85	2	1	-	3	2	tr	5	7	2
Air Laway	B1	49	27	11	87	3	1	tr	4	2	1	1	4	2
Air Laya	B2	40	40	7	87	2	1	tr	3	3	1	2	6	2
		75	13	4	92	3	tr	-	3	-	-	-	-	4
		52	22	14	88	2	tr	tr	2	2	tr	2	4	2
Suban	B2	95	-	tr	95	1	1	tr	-	-	-	-	-	2
Bukit Asam	B2	95	-	1	96	tr	1	-	-	-	-	-	-	3
Air Laya	B2	20	65	6	91	2	1	tr	3	1	1	1	3	1
Tapuan	B2	97	-	-	97	tr	tr	-	tr	-	-	-	-	2
Air Laya	B2	30	48	10	88	4	tr	tr	4	2	1	2	5	1
		45	25	17	87	2	tr	1	3	1	tr	3	4	1
Muara Tiga o/c	C	97	-	-	97	1	1	-	2	-	-	-	-	1
		97	-	-	97	tr	1	-	1	-	-	-	-	1
Air Laway	C	54	26	6	86	2	tr	1	3	1	2	tr	3	1
		40	41	5	86	3	tr	tr	3	1	tr	3	4	2
		63	19	5	87	2	1	-	3	2	1	3	5	1
		62	18	8	88	3	1	tr	4	3	tr	2	5	tr
		51	33	7	91	1	tr	tr	1	2	tr	2	4	3
		69	19	5	93	1	1	-	2	-	-	1	1	4
		30	39	14	83	4	1	1	6	2	tr	2	4	2
		40	33	9	82	4	1	1	6	2	tr	2	4	2
		47	33	9	89	1	1	-	2	3	tr	3	6	1
		8	72	9	89	1	tr	1	2	1	1	2	3	2
Air Laya	C	47	27	13	87	2	-	1	3	2	tr	2	4	2
		86	-	4	90	3	tr	-	3	-	-	-	-	6
		20	59	9	86	1	tr	1	2	1	1	3	5	2
Bukit Asam	C	95	-	1	96	1	tr	-	-	-	-	-	-	2
Air Laya	C	39	37	14	90	2	1	-	3	1	tr	2	3	2
		49	32	10	91	1	1	1	2	tr	-	3	3	2
		36	36	9	81	5	tr	tr	tr	1	3	2	6	3
Banko	C	53	29	8	90	tr	1	-	1	2	-	2	4	2
		51	32	5	88	1	1	-	2	2	-	3	5	2
		47	28	7	82	1	tr	-	1	3	tr	8	11	2

Notes: Tv : telovitrinite, Dv : detrovitrinite, Gv : gelovitrinite, Sf : semifusinite, Scl : sclerotinite, Inert : inertodetrinite, Res: : resinite, Cut : cutinite, Sub : suberinite, MM : mineral matter, Tot : total
o/c : open cut, u/g : underground, tr: trace

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Appendix 2. Vitrinite reflectance of the Bukit Asam coals (Australian standard)

LOCATION	SEAM	Rvmax (%)	RANGE	RANK
Tapuan	Hanging	0.38 0.42	0.35-0.45 0.38-0.48	Brown coal Sub-bituminous
Banko	Hanging	0.41 0.36 0.38	0.37-0.46 0.30-0.41 0.34-0.43	Sub-bituminous Brown coal Brown coal
Air Laya o/c	A1	0.49 0.47 0.46	0.43-0.54 0.40-0.52 0.40-0.51	Sub-bituminous Sub-bituminous Sub-bituminous
SE Balong Hijau o/c	A1	0.41 0.41 0.40	0.36-0.47 0.36-0.52 0.36-0.45	Sub-bituminous Sub-bituminous Sub-bituminous
SW Balong Hijau o/c	A1	1.73 1.61	1.67-1.77 1.52-1.66	Low-volatile bituminous Low-volatile bituminous
Muara Tiga o/c	A1	0.42 0.38 0.40	0.37-0.49 0.35-0.42 0.36-0.44	Sub-bituminous Brown coal Sub-bituminous
Air Laway	A1	0.37 0.37 0.42	0.33-0.41 0.33-0.43 0.38-0.46	Brown coal Brown coal Sub-bituminous
Tapuan	A1	0.45	0.41-0.51	Sub-bituminous
Air Laway	A1	0.41 0.43 0.43	0.38-0.47 0.39-0.47 0.39-0.47	Sub-bituminous Sub-bituminous Sub-bituminous
Tapuan	A1	0.43	0.39-0.48	Sub-bituminous
Air Laway	A1	0.39 0.35 0.36 0.40	0.35-0.42 0.31-0.40 0.32-0.39 0.36-0.44	Brown coal Brown coal Brown coal Sub-bituminous
Suban o/c	A1	2.34 2.32	2.29-2.44 2.21-2.42	**Semi-anthracite** **Semi-anthracite**
Air Laya o/c	A1	0.41	0.37-0.47	Sub-bituminous
Air Laya	A1	0.44 1.44 0.43	0.39-0.50 1.39-1.49 0.39-0.47	Sub-bituminous Medium-volatile bituminous Sub-bituminous
Suban	A1	0.84	0.77-0.91	High-volatile bituminous
Bukit Asam	A1+A2	1.99	1.85-2.06	Low-volatile bituminous
Air Laya	A1	0.45	0.40-0.52	Sub-bituminous
Tapuan	A1	0.77	0.70-0.87	High-volatile bituminous
Air Laya	A1	0.42 0.42	0.38-0.46 0.37-0.50	Sub-bituminous Sub-bituminous
Banko	A1	0.44 0.40 0.37 0.42 0.41 0.43	0.41-0.49 0.36-0.44 0.33-0.42 0.37-0.48 0.35-0.47 0.38-0.47	Sub-bituminous Sub-bituminous Brown coal Sub-bituminous Sub-bituminous Sub-bituminous

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Continous Appendix 2 ...

LOCATION	SEAM	Rvmax (%)	RANGE	RANK
		0.45	0.39-0.52	Sub-bituminous
SW Balong Hijau o/c	A2	1.00 0.98	0.93-1.04 0.93-1.03	High-volatile bituminous High-volatile bituminous
Muara Tiga	A2	0.41 0.40 0.40 0.40	0.36-0.45 0.37-0.44 0.36-0.45 0.36-0.47	Sub-bituminous Sub-bituminous Sub-bituminous Sub-bituminous
Air Laway	A2	0.42 0.38 0.44	0.37-0.47 0.35-0.41 0.39-0.48	Sub-bituminous Brown coal Sub-bituminous
Tapuan	A2	0.46	0.39-0.51	Sub-bituminous
Air Laway	A2	0.43 0.41 0.45	0.38-0.48 0.38-0.45 0.40-0.48	Sub-bituminous Sub-bituminous Sub-bituminous
Tapuan	A2	0.42	0.38-0.47	Sub-bituminous
Air Laway	A2	0.39 0.39 0.41 0.40	0.36-0.42 0.36-0.42 0.35-0.44 0.36-0.44	Brown coal Brown coal Sub-bituminous Sub-bituminous
Suban o/c	A2	2.32 2.18	2.24-2.45 2.10-2.23	**Semi-anthracite** **Semi-anthracite**
Air Laya	A2	0.44 1.26 0.43	0.37-0.50 1.12-1.32 0.38-0.49	Sub-bituminous Medium-volatile bituminous Sub-bituminous
Suban	A2	0.89	0.80-0.95	High-volatile bituminous
Air Laya	A2	0.48	0.43-0.55	Sub-bituminous
Tapuan	A2	0.69	0.61-0.75	High-volatile bituminous
Air Laya	A2	0.44	0.40-0.49	Sub-bituminous
Muara Tiga o/c	B	0.43 0.44 0.40	0.38-0.47 0.39-0.49 0.36-0.45	Sub-bituminous Sub-bituminous Sub-bituminous
Air Laway	B	0.39 0.43 0.42	0.36-0.42 0.38-0.47 0.38-0.49	Brown coal Sub-bituminous Sub-bituminous
Tapuan	B	0.44	0.39-0.51	Sub-bituminous
Air Laway	B	0.41 0.40 0.40 0.39 0.41 0.41 0.43	0.38-0.46 0.37-0.44 0.37-0.45 0.31-0.40 0.37-0.45 0.37-0.47 0.39-0.48	Sub-bituminous Sub-bituminous Sub-bituminous Brown coal Sub-bituminous Sub-bituminous Sub-bituminous
Suban o/c	B1	2.60 2.41 2.55	2.50-2.70 2.30-2.53 2.47-2.63	**Anthracite** **Semi-anthracite** **Anthracite**
Air Laya	B1	0.43	0.39-0.49	Sub-bituminous

Continous Appendix 2 ...

LOCATION	SEAM	Rvmax (%)	RANGE	RANK
		1.70 0.43	1.64-1.75 0.39-0.49	Low-volatile bituminous Sub-bituminous
Suban	B1	1.07	1.01-1.13	High-volatile bituminous
Bukit Asam	B1	2.19	2.09-2.29	**Semi-anthracite**
Air Laya	B1	0.48	0.41-0.59	Sub-bituminous
Tapuan	B1	1.40	1.34-1.52	Medium-volatile bituminous
Air Laya	B1	0.44	0.40-0.49	Sub-bituminous
Banko	B1	0.42 0.53	0.38-0.49 0.43-0.64	Sub-bituminous Sub-bituminous
Air Laway	B2	0.43	0.39-0.49	Sub-bituminous
Air Laya	B2	0.49 1.72 0.44	0.42-0.56 1.66-1.78 0.39-0.51	Sub-bituminous Low-volatile bituminous Sub-bituminous
Suban	B2	1.25	1.20-1.33	Medium-volatile bituminous
Bukit Asam	B2	2.25	2.17-2.35	**Semi-anthracite**
Air Laya	B2	0.51	0.44-0.57	Sub-bituminous
Tapuan	B2	2.05	1.97-2.12	**Semi-anthracite**
Air Laya	B2	0.45 0.42	0.40-0.52 0.38-0.47	Sub-bituminous Sub-bituminous
Muara Tiga o/c	C	1.46	1.40-1.54	Medium-volatile bituminous
Muara Tiga	C	1.55 1.53	1.46-1.62 1.48-1.58	Low-volatile bituminous Low-volatile bituminous
Air Laway	C	0.42 0.43 0.44 0.47 0.45 0.89 0.42 0.41 0.45 0.42 0.45	0.37-0.48 0.38-0.47 0.39-0.48 0.41-0.54 0.40-0.50 0.81-0.97 0.38-0.47 0.35-0.48 0.39-0.50 0.39-0.47 0.40-0.51	Sub-bituminous Sub-bituminous Sub-bituminous Sub-bituminous Sub-bituminous High-volatile bituminous Sub-bituminous Sub-bituminous Sub-bituminous Sub-bituminous Sub-bituminous
Air Laya	C	1.78 0.45	1.66-1.85 0.39-0.50	Low-volatile bituminous Sub-bituminous
Bukit Asam	C	2.28	2.19-2.36	**Semi-anthracite**
Air Laya	C	0.51 0.47 0.43	0.46-0.58 0.40-0.54 0.38-0.50	Sub-bituminous Sub-bituminous Sub-bituminous
Banko	C	0.41 0.41 0.41	0.36-0.50 0.37-0.47 0.37-0.45	Sub-bituminous Sub-bituminous Sub-bituminous

Note: o/c – open cut