GEOLOGIC AND PETROGRAPHIC ASPECTS FOR COAL EXPLORATION IN SANGATTA-EAST KALIMANTAN

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ABSTRACT

The Miocene Sangatta coals indicate similarities and differences in type and rank characteristics. The phenomena express the geological setting that includes the stratigraphic aspect and the presence of intrusive body. The stratigraphic aspect relates to geologic age and cover thickness; the lower coal seam having a thicker cover has a higher rank than the upper coal seam. The intrusive body changes the rank of the coal up to semi-anthracite. The coals that are not affected by the intrusion have rank of brown coal to subbituminous. The rank of the coals increases from east to west toward the Meratus Range due to the cover thickness, where the western part has a thicker cover than the eastern part. These geological phenomena could be an exploratory target for the prospective coals.

Keywords: geology, petrography, exploration, type and rank of coal

1. INTRODUCTION

Coal resource in Indonesia is approximately 104.76 billion tons with reserve of 18.71 billion tons (Agency for Geology, 2009). Exploitation of the coal in Kalimantan is bigger than that of in Sumatera, which is 170.59 million tons and 10.16 million tons, respectively. Exploratory works of discovering the coal deposits have been carried out by applying conventionally geological surveys in Indonesia, without involving the coal petrographic studies, particularly in Sumatera and Kalimantan. The application of the petrographic studies can accurately be used to solve problems in determining the type and rank of the coals associated with the geological setting. Coal deposits in Sangatta-East Kalimantan have been chosen for the study (Figure 1) due to its abundant deposit and complicated geological problems. The laboratory-based study was initiated to collect petrographic data on coals from this area. The study has the potential to make a significant contribution to the knowledge and the future exploration of the prospective coal deposits.

The aims of the study are as follows:

a. To examine coal type and rank variations.
b. To determine types and abundances of mineral matter.
c. To interpret relationship between coal type and rank variations and geological setting.
d. To apply petrographic and geologic aspects for coal exploration.

2. GEOLOGIC SETTING

The Tertiary sedimentary basins in Kalimantan, particularly those along the east coast have been discussed by authors like Katili (1989) and Darman and Sidi (2000). The tectonic activities indicate that four main Tertiary sedimentary basins and associated coal deposits are recognised along the east coast of Kalimantan. From north to south respectively, they are the Tarakan, Kutai, Barito and Asem-Asem Basins (Figure 1). These basins initially developed as a single large depocentre during Early Tertiary, and then becoming separated by uplift zones in the later stages of basin development during the Late Miocene orogenic activity.

The basins are cratonic and back-arc basins that developed in the eastern part of Kalimantan and the adjacent Makassar Strait. Sedimentation was fairly continuous throughout the Tertiary and still occurs offshore today. The sediment was generally deposited in the basins as regressive sequences with the locus of thickest sedimentation moving eastwards. The Tertiary sequences of the basins overlie strongly-deformed Cretaceous rocks consisting of an ophiolite complex, metamorphic and volcanic rocks. Marine sedimentary rocks underlie the Tertiary coal deposits and probably form the basement of the Tertiary basins over most of eastern Kalimantan (Sikumbang, 1986). The four basins have a related depositional history ranging in age from Eocene to Middle Miocene.

In order to focus the topic, the explanation of this paper is only emphasised to the Kutai Basin where the Sangatta coal deposit was formed. The Kutai Basin is partly onshore in the eastern part of the island, and offshore in the adjacent Makassar Strait. The basin is the largest (165,000 km^2) and the deepest (12,000-14,000 m) Tertiary sedimentary basin in Indonesia (Darman and Sidi, 2000). It is bounded to the north by the Mangkalihat High; to the south by the Adang Fault; to the west by the Kuching High; and to the east by the Makassar Strait (Figure 2).

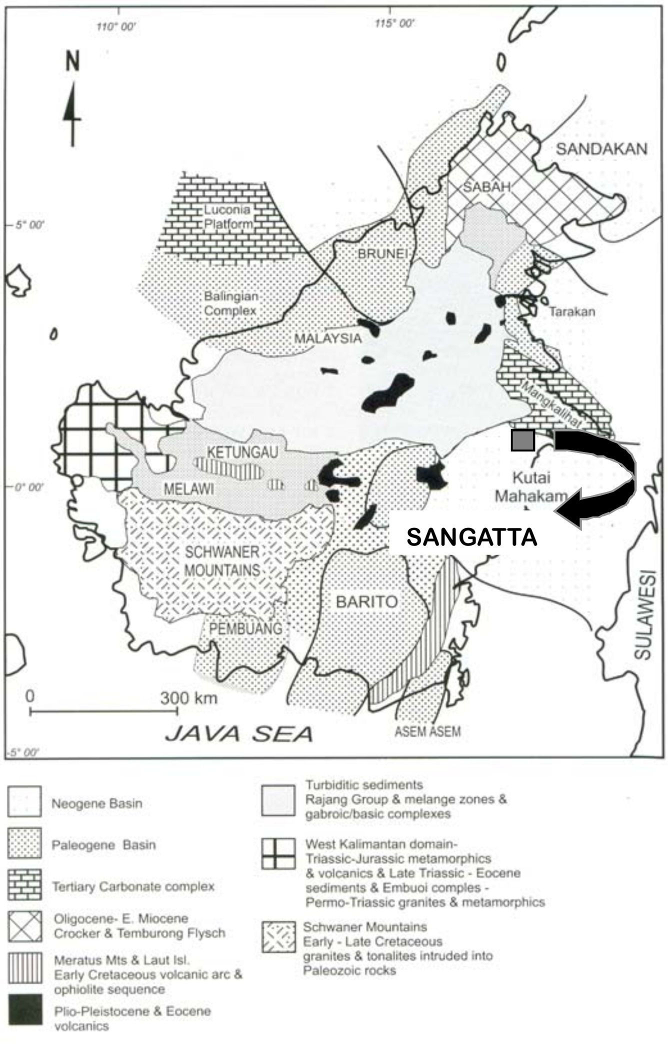

Figure 1. The Sangatta region, Kutai Basin, East Kalimantan (after Darman and Sidi, 2000)

The Early Tertiary rocks of the basin consist of basal coal-bearing, quartzose sandstone and mudstone units, which grade into marine mudstone and limestone. Oligocene rocks are widely distributed over the basin. The units are commonly composed of limestone and calcareous sediment of the Tuyu and Berai Formations. Miocene rocks comprise three formations, which from oldest to youngest, respectively, are the Pamaluan, Pulubalang and Balikpapan Formations. The most prospective coal-bearing unit is the Balikpapan Formation, particularly in the vicinity of the Mahakam River and the Pinang Dome (Sangatta area) in northern part of the basin. The Balikpapan coal measures are mainly deltaic and floodplain environments. Other Miocene rocks also contain coal seams, but these are very thin and few in number. The Pliocene Kampungbaru Formation has similar lithotypes to the Balikpapan Formation, but normally does not occur inland that indicates younger than the Balikpapan Formation. The Kampungbaru Formation also contains coal measures, but the coals are predominantly thin and of very low rank.

Coal seams in the Kutai Basin occur in the Early Miocene Pamaluan and Pulubalang Formations and the Miocene-Pliocene Balikpapan and Kampungbaru Formations. These coal-bearing sequences have been folded into north-northeast trending anticlines and synclines. In the Sangatta area, there are four main seams, namely the Prima, Sangatta, Pinang and Kedapat seams (Figure 3). They show lateral variations in thickness with the Sangatta seam being the most persistent and recognisable seam. The thicknesses of the seams vary from 2.5 m to 9.4 m (average of 5.5 m) with dips of 5-16º. Slumping appears to have affected the seams locally, as shown by brecciation of the seam and incorporation of the enclosing sediment. In some places, thinner seams (<3m) commonly thin laterally and grade into carbonaceous mudstone or shaly coal equivalents. Local tectonic activity may have affected the coal rank. Additionally, the prospective seams are concentrated in the Pinang Dome area that has been postulated as diapiric mudstone origin.

3. ANALYTICAL METHODS

Eighty coal samples from the Sangatta area of the Kutai Basin were analysed for the study. The sampling was according to the Australian Standard AS 1676 (Standards Association of Australia, 1975). The samples were prepared as polished particulate coal mounts and analysed using incident white light and fluorescence mode microscopy. The coal petrographic terms used follow the

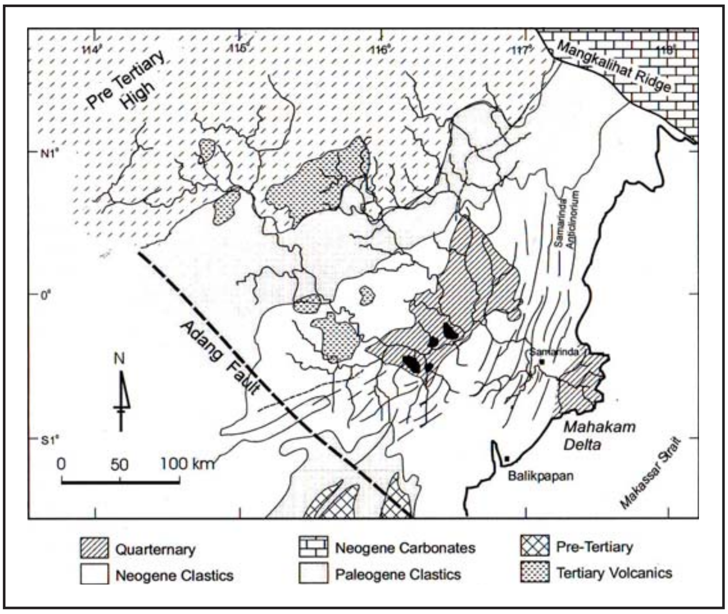

Figure 2. Geologic map of Kutai Basin, East Kalimantan (simplified from Darman and Sidi, 2000)

Standards Association of Australia (1986). The classification is based on the maceral nomenclature described by the International Committee for Coal Petrology Handbook modified by Smith (1981).

The point-counts of approximately 500 points for each block were obtained. Traverses were made perpendicular to the gravitational settling direction during mounting of the polished blocks. Normal point count techniques were applied for maceral analysis. The maceral data were calculated as follows:

- *mineral matter counted : vitrinite + liptinite + inertinite + mineral matter = 100%*
- *mineral matter free basis : vitrinite + liptinite + inertinite = 100%*

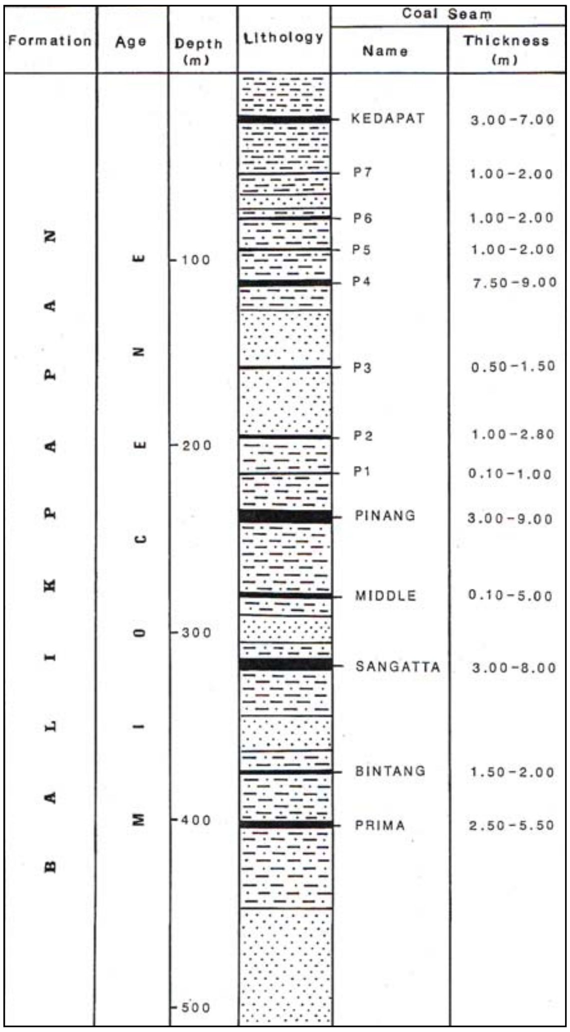

Figure 3. Stratigraphic column of Sangatta coals (Robertson Research, 1984)

The measurement of maximum reflectance of vitrinite follows the Standards Association of Australia (1989). The stage of the microscope was rotated to obtain the first maximum reading and then rotated through approximately 180° for the second maximum reading. Each pair of readings was averaged and the mean calculated to provide mean maximum vitrinite reflectance in oil immersion (Rvmax). The measurements were made on telo-, detro- and gelovitrinite maceral subgroups with number of measurements on each vitrinite subgroup based on the proportion of each subgroup in the sample as determined by point counting.

4. RESULTS

4.1. Coal Type

Examination of hand specimens indicates that the Sangatta coals are composed mainly of clarain and vitrain bands. Thick vitrain bands are normally interbedded with finely-striated bands of clarain (<5 mm). Fusain bands are only found in several samples of the coals.

Petrographically, the Miocene Sangatta coals are composed mainly of vitrinite (Figures 4a and 4b) with substantial liptinite (Figures 5a and 5b) and inertinite (Appendix 1). Mineral matter comprising clay minerals, quartz, pyrite (Figure 6) and carbonate (Figures 7a and 7b) is sparse to major in the coals.

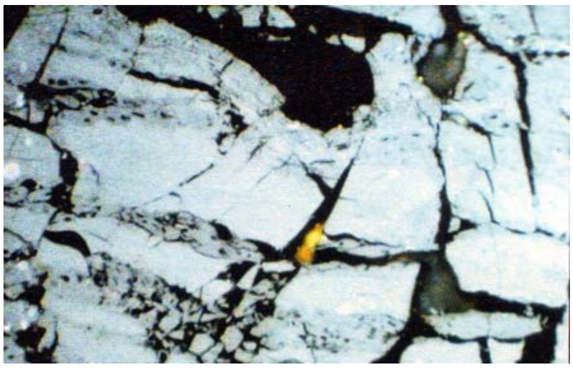

Figure 4a. Detrovitrinite (grey) and exsudatinite (black). Rvmax=0.64%, field width 0.36 mm, reflected white light

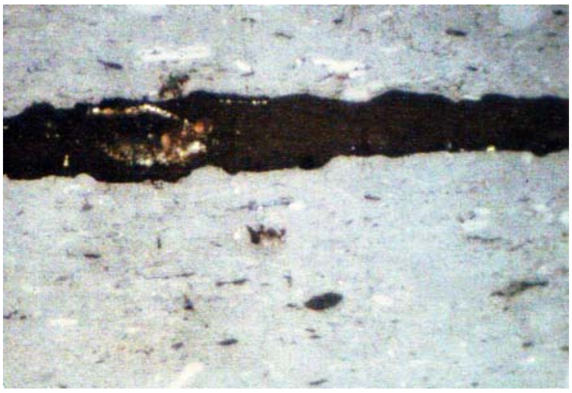

Figure 4b. Telovitrinite (grey) and vein of exsudatinite (black); vein are commonly parallel to bedding. Rvmax=0.66%, field width 0.23 mm, reflected white light

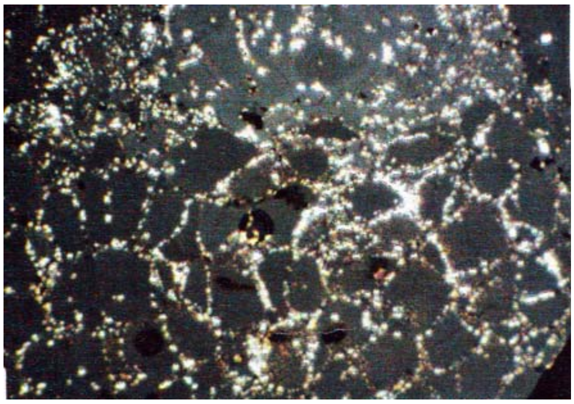

Figure 6. Dendritic pyrite (white) associated with vitrinite (grey). Rvmax=0.63%, field width 0.23 mm, reflected white light

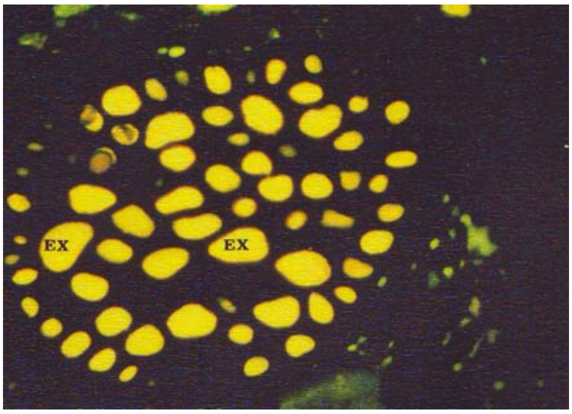

Figure 5a. Exsudatinite (EX, yellow) infilling cell lumens of sclerotinite. Rvmax=0.61%, field width 0.15 mm, fluorescence mode

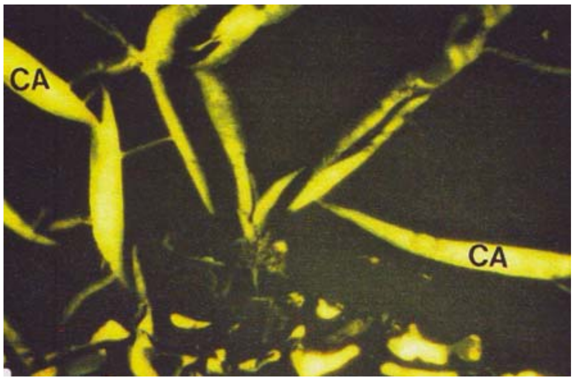

Figure 7a. Carbonate (CA, yellow) infilling fractures in vitrinite (black). Rvmax=0.64%, field width 0.26 mm, fluorescence mode

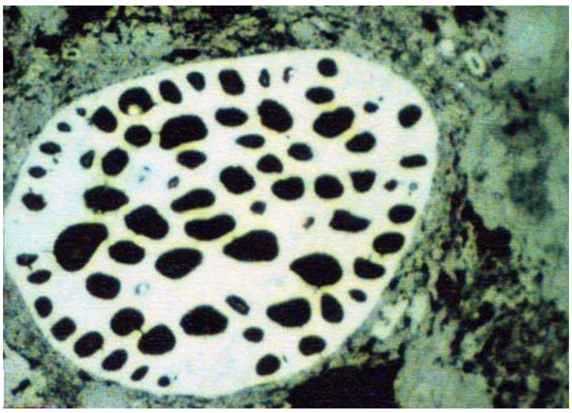

Figure 5b. As for Figure 5a, but in reflected white light

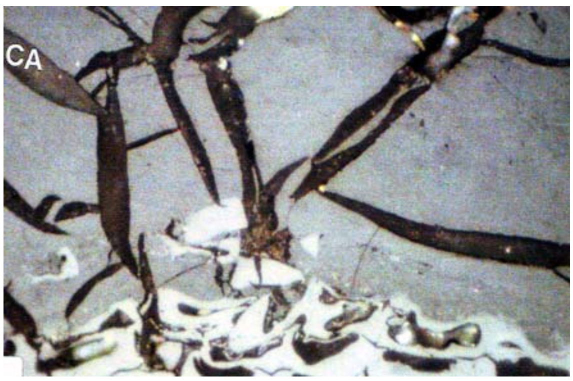

Figure 7b. As for Figure 7a, but in reflected white light

Vitrinite is dominant in all the coals, ranging from 63.5% to 98.0% with average of 82.9%. The exception to this is several thermally-altered coals with the average content of 95.0% (93.9% to 95.8%). Vitrinite mostly occurs as telovitrinite and detrovitrinite with gelovitrinite as a minor component. Telovitrinite, ranging from 0.04 mm to 0.20 mm in thickness, is major to dominant (16.6% to 85.6%, average of 42.4%), and consists predominantly of textinite, texto-ulminite, eu-ulminite and lesser telocollinite. Thin layers of telovitrinite are generally surrounded by a thick detrovitrinite groundmass, but some telovitrinite bands are interbedded with detrovitrinite. Detrovitrinite is major to dominant (10.2% to 60.3%, average of 36.1%) in all the coals, and is commonly associated with liptinite. Attrinite and densinite are the most common detrovitrinite macerals with desmocollinite as a minor component. Sparse to abundant gelovitrinite (0.1% to 9.9%, average of 4.4%) is disseminated throughout the telovitrinite and detrovitrinite with porigelinite occurring as thin bands within telovitrinite.

Inertinite is rare to major (<0.1% to 31.3%, average of 4.2%) in the coals, and comprises predominantly semifusinite, inertodetrinite and sclerotinite. Rare to abundant semifusinite (<0.1% to 9.9%, average of 2.2%) is dominant over other inertinite macerals, and commonly occurs as layers (up to 1 mm in length), lenses or isolated fragments. Semifusinite is generally associated with vitrinite (mainly telovitrinite). In some cases, cell lumen of semifusinite is filled with either resinite and fluorinite or mineral matter. Inertodetrinite is rare to abundant (0.1% to 7.4%, average of 0.9%), and is commonly associated with vitrinite and semifusinite. Sclerotinite consisting of unilocular and bilocular teleutospores and sclerotia, is rare to abundant (<0.1% to 2.7%, average of 0.7%), and is generally scattered throughout the sample with local concentrations. Fusinite, micrinite and macrinite are present in several samples, but commonly account for less than 1.0% of the bulk coal. These macerals are commonly disseminated throughout the coals with the exception of some micrinite that forms distinct layers within telovitrinite.

Liptinite averages 9% (0.2% to 30.9%), and comprises predominantly resinite, suberinite, liptodetrinite and cutinite with minor sporinite, fluorinite, exsudatinite and telalginite. Resinite is rare to major (<0.1% to 13.5%, average of 2.8%, and has bright greenish-yellow to dull orange fluorescence. It occurs as discrete bodies and lenses with some occurring as diffuse cell fillings in telovitrinite, semifusinite and sclerotinite. Suberinite is rare to major (<0.1% to 13.0%, average of 3.1%) and commonly occurs as distinct layers (0.05 mm to 0.40 mm thick) with very weak brown fluorescence or absent. It commonly occurs in association with corpogelinite, rarely with resinite and exsudatinite. Liptodetrinite is rare to abundant (<0.1% to 5.2%, average of 0.8%) in most samples and mainly occurs in clarite, where it has greenish-yellow to orange fluorescence. Rare to abundant cutinite (<0.1% to 3.8%, average of 0.8%) commonly occurs in association with vitrinite and resinite. However, in some cases, it is associated with suberinite and exsudatinite. It generally has greenish-yellow to orange fluorescence, although some have very weak brown or no fluorescence. Sporinite is rare to common (<0.1% to 1.8%, average of 0.5%), and has greenish-yellow to orange fluorescence. It commonly occurs in association with detrovitrinite, resinite and suberinite. The distinction between pieces of thick suberinite and sporinite within a simple sample is difficult in some cases, although the sporinite generally has yellow to orange fluorescence, whereas suberinite fluoresces greenish-yellow to yellow. Rare to abundant exsudatinite (<0.1% to 9.9%, average of 0.8%) occurs in most coals and commonly has bright greenish-yellow to orange fluorescence. It has various shapes and occurrences including infillings in fractures, bedding plane cavities and cell lumens. Fluorinite is rare to abundant (<0.1% to 2.6%, average of 0.2%) in some coals, and typically occurs as isolated bodies and lenses with bright green to greenish-yellow fluorescence of very strong intensity. Rare to sparse alginate with bright yellow to orange fluorescence is present in a few samples of the coal.

Mineral matter in the coals ranges from 0.2% to 27.9% with average of 3.7%. The coals that contain up to 27.9% of mineral matter, are commonly associated with clay partings, and are generally from the top or the bottom plies of the seam. Most of the coals have less than 2.0% of mineral matter. The mineral matter includes clay minerals, quartz, pyrite and calcite. These minerals usually occur in partings and nodules of different sizes or are disseminated throughout the coal seams.

4.2. Coal Rank

Mean maximum vitrinite reflectance values (Rvmax) for the Miocene Sangatta coals vary from

0.48% to 0.71% with average of 0.63% (Appendix 2). In this region, the strata have been strongly folded. A marked difference between vitrinite reflectance values for coal in the lowest seam, compared to those of the uppermost seam, is evident even though the difference in stratigraphic level is less than 50 metres. Reflectance values for the lower coal range from 0.58% to 0.71% with average of 0.64%, whereas for the upper seam, Rvmax varies between 0.48% and 0.52% with average of 0.49%. The significant difference in vitrinite reflectance is probably related to high geothermal gradients in this region as reported to be approximately 40ºC/km (Thamrin, 1987). A comparison of these coals does not show any unusual or different maceral types and abundances, thus eliminating any influence of type and rank.

Herudiyanto (Centre for Geological Resources, personal communication) also observed a high vitrinite reflectance gradient in a deep well in the region. The high rank gradients are presumably associated with high palaeogeothermal gradients, and therefore high heat flow is related to the igneous activity in this region.

The coals affected by local thermal metamorphism are also found in this region. The coal rank spans the low volatile bituminous to semi-anthracite range with Rvmax of 1.60% to 2.03% (average of 1.87%). The range in vitrinite reflectance for any single sample is very wide compared to the range in samples from the same seam away from the intrusion. Therefore, it is only exposed to normal coalification. The intrusion is hidden and has not been identified in outcrop or borehole intersections that were drilled adjacent to the coal seams. Miocene coals also have been affected by igneous intrusions in the Bukit Asam area of South Sumatera Basin, and span semi-anthracite to anthracite ranks (Santoso and Daulay, 2006b; Daulay and Santoso, 2008).

5. DISCUSSION

Coal petrographic composition is related to palaeoclimate, geological age and tectonic setting. The tectonic setting also plays an important role in any subsequent burial metamorphism. Consequently, spatial and temporal variations in palaeoclimate, geological age and tectonic setting cause coal type provincialism (Cook, 1975). Accordingly, some coals have properties that are different to the properties of other coals in different parts of the same seams, in different part of the same basins or coals in other basins.

The maceral composition of the Miocene Sangatta coals is remarkably is consistent with those for Tertiary coals from other localities in Indonesia (Santoso and Daulay, 2005, 2006a, 2006b, 2007; Daulay and Santoso, 2008).

The Sangatta coals are characterised by the dominance of vitrinite with subordinate liptinite, relatively low inertinite and mineral matter. The dominance of vitrinite in the coals is indicative of forest type vegetation in a humid tropical zone, which does not have a significant dry season (Stach *et al.*, 1982; Bustin *et al.*, 1983). Vitrinite-rich coal in some cases has a very low mineral content as shown by low ash yields. Low ash is a characteristic of many Tertiary coals, and has been interpreted as indicating a high-moor origin. This indicates that the coals have been deposited in areas of rapid subsidence.

The coal rank ranges from brown coal to high volatile bituminous with a few from the area in semi-anthracite. The higher vitrinite reflectance for the coals is probably related to regional geology, which is characterised by strongly folded units and a relatively higher geothermal gradient. In addition, the differences in the vitrinite reflectance values largely reflect the stratigraphic aspect, which is the thickness of cover at the time of coalification, although some influence from variations in vertical rank gradients may also have had a minor effect. The vitrinite reflectance of the coals in the Kutai Basin generally increases from east to west toward the Meratus Range and Kuching Highs. This variation in rank probably reflects an increase in depth of burial during coalification. However, the higher vitrinite reflectance values are complicated in the Sangatta area due to the local intrusions. Elsewhere, the coals do not appear to have been affected by any known igneous body. Regionally, the gradually increasing vitrinite reflectance values from east to west in the basin, not including the Sangatta area, support this hypothesis. The low vitrinite reflectance in some coals is caused by the maceral association, mineral matter and type differences within the vitrinite. For instance, extremely fine-grained liptinite like resinite or exsudatinite and mineral matter infilling the lumens in vitrinite would give an apparent vitrinite reflectance rather than the true reflectance.

Geologic and petrographic aspects of the Miocene

Sangatta coals could be focused for the exploratory purposes. Geologic aspects in the area mainly include intrusive body and stratigraphic sequence. The intrusive body has changed the rank of the coals to be semi-anthracite with Rvmax value of 1.60% to 2.03% (average of 1.87%). Outside this intrusive body, the rank of the coals is between 0.48% and 0.71% with average of 0.63%. These vitrinite reflectance values are influenced by stratigraphic aspect that is cover of burial of sediments; the lower seams are 0.58% to 0.71% with average of 0.64%, and the upper ones are 0.48% and 0.52% with average of 0.49%. The rank of the coals in the basin increases from east to west toward the Meratus Range due to the thicker overburden in the west. Therefore, according to these phenomena, the prospective area for coal exploration in the region is suggested in the area of the intrusive body and the area of adjacent the Meratus Range. In addition, the area around strongly folded sediments is also suggested to explore because of higher rank of the coals.

6. CONCLUSIONS

Small variations in the coal type are present in the samples studied. Differences in the type can be caused by interaction of tectonic, sedimentary, climatic factors and floral composition. Because of the relatively short period of the peat accumulation and the probable similarity in climates during the peat formation, slight differences in tectonic and sedimentary settings during the Miocene period have also to be considered.

Regionally, vitrinite reflectance values of the coals increase from east to west toward the Meratus Range. Due to the presence of intrusive bodies in the Sangatta area, the rank of the coals increases from brown coal to semi-anthracite.

The coal petrographic and geologic phenomena could be considered as significant factors for the future exploratory works of discovering prospective coals in the Sangatta area.

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Appendix 1. Petrographic data of the Sangatta coals

No	VITRINITE (%)				INERTINITE (%)				LIPTINITE (%)							MINERAL MATTER (%)			
	TV	DV	GV	total	SF	SCL	INE	total	SPO	CUT	RES	LIP	SUB	EXS	total	C,Q	CA	PY	total
1	40.3	26.3	2	68.6	1.8	0.6	1.1	3.5	-	-	1.3	0.2	1.1	0.2	2.8	24.8	0.2	0.1	25.1
2	44.2	40.4	3.2	87.8	4.7	-	0.9	5.6	-	2	1.5	-	1.3	0.4	5.2	1.4	-	-	1.4
3	58.8	29	2.3	90.1	3.1	0.4	1	4.5	0.2	1.9	1	0.2	1	-	4.1	1.3	-	-	1.3
4	57	24.5	4.2	85.7	6.8	0.6	1.4	8.8	-	1	0.6	-	1.7	-	3.3	1.8	0.2	0.2	2.2
5	60.4	24.8	1.3	86.5	2.6	0.6	1.1	4.3	0.4	0.2	0.6	0.2	2	0.2	3.6	4.6	0.8	0.2	5.6
6	48.8	35.3	3.6	87.7	5	0.8	0.8	6.8	-	-	2.2	0.2	0.8	0.8	4	1.3	-	0.2	1.5
7	56.8	29.9	3	89.7	4	0.6	1	5.6	-	-	1.6	-	1.4	0.4	3.4	1.6	-	-	1.6
8	57.9	31.7	3.3	92.9	0.8	0.6	0.4	1.8	-	0.4	2.2	0.2	1.1	0.6	4.5	0.8	-	-	0.8
9	53.1	34.2	2.3	89.6	2.3	0.2	0.9	4.4	-	0.2	2.1	0.2	2.3	-	4.8	1.2	-	-	1.2
10	58.8	27.2	2.3	88.3	1.6	0.6	0.2	2.6	0.6	0.9	2.8	0.2	2.2	1.2	7.9	1.2	-	-	1.2
11	52	30	2.7	84.7	4.7	0.6	1.1	6.6	0.9	0.5	3.2	0.9	0.8	1	7.3	1.4	-	-	1.4
12	62.1	21.6	2.3	86	2.2	1.1	0.2	3.5	1.6	0.2	0.8	0.2	2.4	0.2	5.4	5.1	-	-	5.1
13	32.6	37.8	-	70.4	0.5	-	-	0.5	-	-	0.5	0.5	0.2	-	1.2	17.4	0.6	9.9	27.9
14	45.7	38.7	2.6	87	3.4	0.9	0.7	5.4	-	1.6	2.1	-	2.6	-	6.5	1.1	-	-	1.1
15	56	26.6	1	83.6	4.8	1	1.7	7.7	0.3	0.8	2.4	0.3	1.9	1.6	7.5	1.2	-	-	1.2
16	47.9	33.2	2	83.1	6.4	0.6	1.1	8.5	0.2	0.4	1.6	-	0.5	0.9	3.6	2.1	0.3	2.4	4.8
17	48.4	36.6	3	88	3	0.6	0.6	4.2	-	0.6	3.2	-	1.7	1	6.5	1.3	-	-	1.3
18	42.8	36.8	1.2	80.8	5.1	1	0.4	6.9	0.4	1.4	1.6	0.2	1	0.4	5	6.3	0.6	0.4	7.3
19	47.5	39.8	2.6	89.9	2.4	0.2	0.4	3.2	0.4	0.7	2.1	-	2.2	0.2	5.6	1.3	-	-	1.3
20	45.9	38.9	3.3	88.1	2.8	0.4	-	3.4	0.7	0.7	1.6	-	1.5	0.6	5.1	3.4	-	-	3.4
21	52.8	31.7	2.7	87.2	4.8	0.6	1	6.6	0.4	0.2	1.4	0.2	1.2	0.6	4	2.2	-	-	2.2
22	49.8	33.3	1.3	84.4	5	0.2	0.8	6	0.2	0.4	2.8	0.2	2.9	1.4	7.9	1.7	-	-	1.7
23	60.2	26.6	1.3	88.1	1.7	0.4	0.8	2.9	-	0.4	2.8	0.2	3	1.2	7.6	1.2	-	0.2	1.4
24	43.8	38.6	5.1	87.5	1.7	0.2	0.7	2.6	-	0.7	2.9	-	2.4	0.2	6.2	3.4	0.1	0.2	3.7
25	50.4	33.8	1.1	85.3	2.4	0.6	0.6	3.8	0.2	0.4	4.1	0.4	1.4	1.6	8.1	0.9	1.5	0.4	2.8
26	56	33	1.2	90.2	0.9	0.2	0.4	1.5	-	1.2	2.4	0.2	2.4	0.4	6.6	1.2	0.3	0.2	1.7
27	42.5	30	2.5	75	0.7	0.5	0.5	1.7	-	0.2	1.8	-	0.6	0.4	3	18.1	0.6	1.6	20.3
28	45.8	35	3.4	84.2	3.9	0.6	2.5	7.2	-	0.8	2.8	0.8	1.9	-	6.3	2.1	0.2	-	2.3
29	48.2	35.9	5.1	89.2	2.9	0.4	0.4	3.7	0.2	1.1	1.7	0.2	2.2	-	5.4	1.7	-	-	1.7
30	50	36	4.3	90.3	0.7	0.2	0.7	1.6	-	0.9	3.1	-	1.6	1.4	7	1.1	-	-	1.1
31	37.3	42.6	4.7	84.6	3.8	0.9	1.8	6.7	0.2	0.6	2.9	0.5	1	1.8	7	1.7	-	-	1.7
32	44.4	34.3	4.9	83.6	6.1	-	1.5	8.2	0.2	0.4	3.1	0.4	1	1.2	6.3	1.9	-	-	1.9

Appendix 1. Petrographic data of the Sangatta coals (continued)

No	VITRINITE (%)				INERTINITE (%)				LIPTINITE (%)							MINERAL MATTER (%)			
	TV	DV	GV	total	SF	SCL	INE	total	SPO	CUT	RES	LIP	SUB	EXS	total	C,Q	CA	PY	total
33	49.6	32.1	5.3	87	3.3	1.4	2.1	6.8	-	0.2	2.4	-	1.1	0.8	4.5	1.7	-	-	1.7
34	57.5	28.7	1.8	88	3.1	0.2	0.4	4.1	-	2	2.8	0.4	0.6	0.2	6	1.9	-	-	1.9
35	54.5	17.1	0.6	72.2	1.7	0.4	0.2	2.3	0.6	2.3	4	-	0.4	0.4	7.9	17.2	0.2	0.2	17.6
36	42.2	34.5	2.9	79.6	1.8	0.4	0.4	2.8	0.2	0.4	2.2	0.4	0.8	1.8	6	9.6	1.2	0.8	11.6
37	55.2	27.4	2.5	85.1	2.3	0.2	0.4	2.9	0.2	-	1.4	-	1.2	0.6	3.4	8.2	0.2	0.2	8.6
38	50.4	37.6	4.6	92.6	1.3	0.2	0.8	2.3	-	0.4	1.3	-	1.5	-	3.2	1.9	-	-	1.9
39	44.9	39.2	2.6	86.7	1.7	0.6	1.1	3.4	0.4	0.6	4.4	0.6	1.8	0.6	8.4	1.5	-	-	1.5
40	44.6	36.5	4.8	85.9	3.2	1	0.6	5.2	0.4	1.6	2.2	-	2.4	0.4	7	1.9	-	-	1.9
41	45.2	37.2	4	86.4	1.7	1.2	1.2	4.1	0.8	0.4	3.8	0.2	1.7	0.2	7.1	2.2	-	0.2	2.4
42	46.2	36.8	3.6	86.6	4.9	0.2	0.9	6.6	-	1.2	2.6	-	0.7	0.2	4.7	2.1	-	-	2.1
43	52.4	34.5	2.4	89.3	3.7	0.4	0.2	4.7	0.2	-	1.6	-	1.4	0.2	3.4	2.6	-	-	2.6
44	55	33.3	0.9	89.2	2.3	0.6	0.2	3.3	0.4	0.4	1.3	-	2.3	0.4	4.8	2.7	-	-	2.7
45	47.9	36.2	2.9	87	2.5	1.7	1.2	5.6	0.7	1.2	2.4	-	1.4	-	5.7	1.7	-	-	1.7
46	61.7	24.1	2.4	88.2	1.4	1.9	0.7	3	-	0.9	3.4	-	2	0.4	6.9	1.9	-	-	1.9
47	63.6	25.7	2.1	91.4	2.3	0.7	0.2	3.2	-	0.2	1	0.2	0.2	0.2	1.8	3.6	-	-	3.6
48	79	16.4	-	95.4	0.2	0.2	0.4	0.8	-	-	-	-	-	-	-	3.8	-	-	3.8
49	75.8	18.1	-	93.9	-	-	1.5	1.5	-	-	-	-	-	-	-	4.4	-	0.2	4.6
50	57.4	33.1	3.3	93.8	0.2	0.9	-	1.1	0.4	0.2	1.4	0.4	0.9	0.2	3.5	1.6	-	-	1.6
51	60.4	25.1	2.9	88.4	2.7	0.7	0.7	4.1	-	0.9	1.9	0.4	2.2	0.2	5.6	1.9	-	-	1.9
52	53.2	28.9	5.1	87.2	4.2	0.4	1	6.2	0.4	0.9	1.4	0.4	0.4	0.8	4.7	1.9	-	-	1.9
53	64.5	17.7	3.9	86.1	2	0.2	0.4	2.6	-	1.8	4.1	0.4	3	-	9.5	1.8	-	-	1.8
54	58.8	22.3	7.8	88.9	4.2	0.6	-	5.6	0.2	-	0.6	-	-	-	0.8	3.9	0.2	0.6	4.7
55	61.3	20.6	4.4	86.3	1	0.4	0.4	1.8	0.2	1.6	6.5	0.4	2.1	-	11.2	0.7	-	-	0.7
56	85.6	10.2	-	95.8	1.2	0.2	0.4	2.2	-	-	-	-	0.2	-	0.2	1.8	-	-	1.8
57	57.8	21.9	8.1	87.8	5	0.4	1.3	7.7	0.4	0.2	1.7	-	0.6	-	2.9	1.6	-	-	1.6
58	50.9	30.6	4	85.5	0.5	0.6	-	1.1	-	3.2	5.4	-	0.9	-	10.1	2.3	0.6	0.4	3.3
59	59.9	28.1	4	92	0.2	0.4	0.4	1	-	2	0.4	-	2.4	-	4.8	1.8	0.2	0.2	2.2
60	39.4	39.6	5.3	84.3	7.1	0.4	0.4	9.3	-	0.6	1.5	0.2	2.4	-	4.7	1.5	-	0.2	1.7
61	48	34.9	3.4	86.3	3.4	1.4	0.6	5.8	-	0.2	2.9	0.4	2.7	-	6.2	1.7	-	-	1.7
62	45.4	28.6	3.6	77.6	2.3	0.4	1.3	4.6	0.6	0.4	0.9	-	0.4	0.7	3	9.2	0.2	5.4	14.8
63	30.3	43.8	6.5	80.6	8.9	1.3	1.1	12.1	0.9	0.4	3.6	-	-	0.4	5.3	1.4	-	0.6	2
64	41.9	41.6	1.5	85	4.5	0.8	2	8.1	0.2	0.4	1.7	-	1.1	0.6	4	2.1	0.2	0.6	2.9

Appendix 1. Petrographic data of the Sangatta coals (continued)

No	VITRINITE (%)				INERTINITE (%)				LIPTINITE (%)							MINERAL MATTER (%)			
	TV	DV	GV	total	SF	SCL	INE	total	SPO	CUT	RES	LIP	SUB	EXS	total	C,Q	CA	PY	total
65	26	35.5	2.2	63.7	3.1	0.4	0.7	4.2	-	-	1.9	0.2	0.4	-	2.5	29.6	-	-	29.6
66	36.5	45.1	2.5	84.1	4.6	1	0.4	6.6	-	1.8	2.9	0.6	1.2	-	6.5	2.4	-	-	2.8
67	28.8	50	0.9	79.7	5.2	2.4	1.5	11.1	0.2	0.5	2.8	0.4	2.2	0.8	7.1	2.1	-	-	2.1
68	44.4	39.2	4.7	88.3	2	-	0.4	2.4	-	0.9	4	-	1.5	1.2	7.6	1.7	-	-	1.7
69	49.1	38.8	1.4	89.3	3.4	0.2	0.6	5	0.4	-	2.9	0.2	0.4	-	3.9	1.8	-	-	1.8
70	36.2	44.5	0.8	81.5	5.7	1.5	0.8	8.8	0.2	0.6	4.7	0.4	1.3	0.6	7.8	1.9	-	-	1.9
71	54.9	33.4	3.9	92.2	0.4	0.2	-	0.6	0.2	1.3	1.7	0.4	-	1.5	5.3	1.9	-	-	1.9
72	45	44.7	0.8	90.5	1.8	0.2	0.4	2.8	0.4	1.2	2.2	0.7	0.8	0.4	5.7	0.8	0.2	-	1
73	36.9	49.5	0.8	87.2	5	0.2	0.6	7.4	-	0.4	1.3	0.4	1.3	0.4	3.8	1.6	-	-	1.6
74	39.5	47.2	1.9	88.6	4.8	1.7	0.9	7.8	0.1	0.3	0.9	0.1	0.9	0.2	2.5	1.1	-	-	1.1
75	52.4	34.9	3.2	90.5	0.7	0.3	1.5	2.5	0.2	0.5	2.4	0.1	1.8	0.2	5.6	0.8	0.2	0.4	1.4
76	37.6	40.3	3.7	81.6	2.4	0.6	0.6	4	-	1.3	2.1	-	2.1	0.4	5.9	7.5	0.8	0.2	8.5
77	25.2	23.2	1.1	49.5	0.9	0.1	0.3	1.3	-	-	0.9	-	0.3	0.7	1.9	47.3	-	-	47.3
78	40.7	41	2.4	84.1	2	0.8	0.8	4	0.1	1.1	1.3	0.2	2.8	1.4	8.1	3.8	-	-	3.8
79	42.8	39	3.5	85.3	0.2	-	-	0.2	0.2	0.7	2.3	0.9	1.2	1.4	6.7	6.4	0.5	0.9	7.8
80	42.8	37.5	2.1	82.4	3.1	0.4	-	4.1	-	1.4	3.7	-	1	2.5	8.6	4.1	0.6	0.2	4.9

Notes: TV : telovitrinite; DV : detrovitrinite; GV : gelovitrinite; SF : semifusinite; SCL : sclerotinite; INE : inertodetrinite; SPO : sporinite; CUT : cutinite; RES : resinite; LIP : liptodetrinite; SUB : suberinite; EXS : exsudatinite; C,Q : clay, quartz; CA : calcite; PY : pyrite

Appendix 2. Vitrinite reflectance (Rvmax%) data of the Sangatta coals

No	TV (%)	DV (%)	VIT (%)	RANGE-Rvmax (%)
1	0.69	0.66	0.67	0.61-0.74
2	0.7	0.69	0.69	0.63-0.74
3	0.71	0.67	0.7	0.63-0.78
4	0.71	0.68	0.7	0.64-0.75
5	0.64	0.61	0.63	0.58-0.68
6	0.67	0.64	0.66	0.61-0.72
7	0.68	0.64	0.67	0.61-0.74
8	0.66	0.64	0.66	0.60-0.74
9	0.66	0.63	0.65	0.59-0.73
10	0.68	0.65	0.67	0.61-0.73
11	0.69	0.65	0.35	0.32-0.42
12	0.59	0.59	0.59	0.55-0.65
13	0.64	0.6	0.62	0.54-0.68
14	0.63	0.63	0.63	0.60-0.67
15	0.62	0.62	0.62	0.59-0.68
16	0.65	0.62	0.64	0.58-0.68
17	0.65	0.62	0.64	0.57-0.71
18	0.65	0.62	0.64	0.55-0.71
19	0.67	0.64	0.66	0.60-0.72
20	0.66	0.63	0.65	0.57-0.70
21	0.65	0.63	0.64	0.59-0.70
22	0.66	0.62	0.65	0.59-0.71
23	0.65	0.63	0.64	0.60-0.70
24	0.66	0.63	0.65	0.60-0.72
25	0.65	0.62	0.63	0.54-0.71
26	0.64	0.62	0.64	0.56-0.70
27	0.64	0.61	0.63	0.55-0.68
28	0.63	0.61	0.62	0.57-0.68
29	0.63	0.62	0.63	0.56-0.68
30	0.63	0.62	0.63	0.56-0.68
31	0.61	0.61	0.61	0.55-0.66
32	0.63	0.61	0.62	0.55-0.69
33	0.64	0.61	0.63	0.56-0.69
34	0.64	0.63	0.64	0.58-0.70
35	0.63	0.61	0.63	0.56-0.68
36	0.62	0.6	0.61	0.55-0.66
37	0.64	0.62	0.63	0.57-0.70
38	0.65	0.64	0.65	0.61-0.70
39	0.65	0.64	0.64	0.59-0.70
40	0.65	0.63	0.64	0.60-0.71

No	TV (%)	DV (%)	VIT (%)	RANGE-Rvmax (%)
41	0.66	0.63	0.64	0.56-0.72
42	0.65	0.64	0.65	0.60-0.71
43	0.65	0.63	0.64	0.57-0.71
44	0.65	0.63	0.64	0.59-0.70
45	0.64	0.62	0.63	0.58-0.72
46	0.61	0.6	0.61	0.57-0.66
47	0.62	0.61	0.62	0.53-0.69
48	**2.03**	**2.06**	**2.03**	**1.96-2.22**
49	**2**	**1.82**	**1.97**	**1.58-2.25**
50	0.68	0.66	0.67	0.61-0.73
51	0.69	0.67	0.69	0.62-0.75
52	0.7	0.66	0.68	0.62-0.75
53	0.66	0.63	0.65	0.59-0.71
54	0.68	0.66	0.67	0.62-0.73
55	0.67	0.66	0.67	0.61-0.73
56	**1.61**	**1.55**	**1.6**	**1.49-1.81**
57	0.72	0.69	0.71	0.64-0.77
58	0.65	0.62	0.64	0.58-0.69
59	0.64	0.62	0.63	0.59-0.71
60	0.66	0.65	0.65	0.60-0.71
61	0.65	0.63	0.64	0.59-0.72
62	0.65	0.63	0.64	0.58-0.70
63	0.64	0.61	0.63	0.56-0.68
64	0.65	0.63	0.64	0.59-0.70
65	0.64	0.62	0.63	0.56-0.69
66	0.51	0.48	0.5	0.44-0.54
67	0.49	0.49	0.49	0.44-0.54
68	0.49	0.48	0.48	0.44-0.51
69	0.51	0.48	0.49	0.43-0.57
70	0.5	0.47	0.48	0.43-0.55
71	0.53	0.51	0.52	0.48-0.58
72	0.63	0.62	0.63	0.57-0.68
73	0.64	0.62	0.63	0.55-0.68
74	0.64	0.62	0.63	0.58-0.69
75	0.62	0.61	0.62	0.58-0.68
76	0.64	0.63	0.64	0.60-0.70
77	-	-	0.65	0.58-0.72
78	0.63	0.61	0.62	0.51-0.68
79	0.67	0.64	0.65	0.60-0.72
80	0.6	0.58	0.59	0.53-0.63