INDONESIAN MINING JOURNAL Vol. 16, No. 2, June 2013 : 71 - 81

COAL GEOCHEMISTRY OF THE UNCONVENTIONAL MUARAENIM COALBED RESERVOIR, SOUTH SUMATERA BASIN: A CASE STUDY FROM THE RAMBUTAN FIELD

GEOKIMIA RESERVOAR NON-KONVENSIONAL BATUBARA MUARAENIM, CEKUNGAN SUMATERA SELATAN: STUDI KASUS LAPANGAN RAMBUTAN

IMAM B. SOSROWIDJOJO
R & D Centre for Oil and Gas Technology, LEMIGAS
Jalan Ciledug Raya Kav. 109, Cipulir - Kebayoran Lama, Jakarta Selatan 12230
Ph. 021 7228614, Fax. 021 7228614
e-mail: ibs@lemigas.esdm.go.id

ABSTRACT

Muaraenim coalbeds in Rambutan Field have typically high vitrinitic coal geochemical features that indicates the main target for CBM development. The presence of vitrinite coals in South Sumatra Basin is indicated by high huminite concentration (up to 83 vol.%). The coalbeds are of sub-bituminous rank (Ro<0.5%). They are geochemically characterized by high moisture content (up to 21%) and less than 80 wt.% (daf) carbon content. Minerals are found only in small amounts (<5 vol.%), mostly iron sulfide. Cleat fillings are dominated by kaolinite. This behavior can either be related to the increase coal moisture content to the depth or significant variation in vitrinite content within the deeper seams.

Keywords: geochemistry, CBM, South Sumatra Basin, Muaraenim coal, low rank, unconventional reservoir, Rambutan Field

SARI

Kandungan vitrinit yang tinggi merupakan ciri utama geokimia lapisan batubara Muaraenim di Lapangan Rambutan pada cekungan Sumatra Selatan dan biasanya mengindikasikan adanya target utama pada pengembangan gas metana batubara (GMB). Kehadiran vitrinit ini ditunjukkan dengan tingginya konsentrasi huminit (hingga 83 vol.%). Peringkat batubara Muaraenim tersebut adalah subbituminus (Ro<0,5%), yang secara geokimia ditandai oleh kadar air tinggi (hingga 21%) dan kandungan karbon kurang dari 80 berat.% (daf). Mineral yang ditemukan hanya dalam jumlah kecil (<5% vol.), sebagian besar sebagai besi sulfida. Material pengisi rekahan (cleat) *didominasi oleh kaolinit. Perilaku ini dapat berhubungan dengan meningkatnya kadar air batubara terhadap kedalaman atau dengan variasi kandungan vitrinit yang signifikan pada lapisan batubara yang lebih dalam.*

Kata kunci: geokimia, GMB, Cekungan Sumatra Selatan, batubara Muaraenim, peringkat rendah, reservoar non-konvensional, Lapangan Rambutan

Received : 28 February 2013, first revision : 02 April 2013, second revision : 05 June 2013, accepted : June 2013

INTRODUCTION

Coal is one of the most complex and challenging natural materials to be analyzed. Each coal has a unique characters, due to different plant sources over geologic time. This diversity presents a challenge to construct a coherent picture of coal geochemistry and the processes that influence chemical composition of coal (Orem and Finkelman, 2003).

South Sumatra Basin is very interesting, contains some thick gassy coals at optimal depth in existing oil fields due to having the Indonesia's best combination of resource size and quality, data control, well services, and pipeline infrastructure. In the basin, the coals occur in the Lahat, Talangakar and Muaraenim Formations. The main sizable coal seams are concentrated into two horizons within the Muaraenim Formation.

The coal-bearing Muaraenim Formation was deposited during the Late Miocene-Early Pliocene. Through detailed outcrop study, integration of sedimentological observations and palaeontological information has led to the recognition of a number of sub-environments within the delta system. It has been interpreted as representing deposition in a humid tropical regressive deltaic system (Boyd and Peacock, 1986).

The main economically significant coal deposits for coalbed methane (CBM) target on the South Sumatra Basin occur in the Muaraenim coal (Stevens and Hadiyanto, 2004). Other important coal deposit in the basin is in the Talangakar coal, showing relatively thinner net thickness of single seams. The coal thickness is often below 2 m and total net thickness is usually less than 5 m. In the two areas evaluated in this study, the depth of the top of the coal sequence is deeper than the typical CBM depth window (deeper than 1,500m) (Sosrowidjojo, 2006). For these reasons, the Talangakar coal prospectivity for CBM must be rated lower than the Muaraenim coal.

Early published data on the gas storage capacity of Indonesian coals concluded that the Southern Sumatra coal mines are the most suitable for CBM exploration in Indonesia (Stevens et al., 2001; Kurnely et al., 2003; Stevens and Hadiyanto, 2004; Sosrowidjojo, 2006). Nowadays, as many as 54 CBM working areas have been signed in Indonesia. Some 19 working areas of them are in the South Sumatra Basin. A map showing all the working areas is presented in Figure 1. However, in spite of these indications showing the existence of economical CBM resources in the South Sumatra Basin, until recently, no systematic drilling and exploration of these resources had been undertaken. The purpose of this paper is to provide the coal geochemical characteristic of Muaraenim coal in the South Sumatra Basin with focus on the Muaraenim coalbed reservoir system in the Rambutan Field.

GEOLOGICAL SETTINGS

The geological setting, stratigraphy and tectonic evolution of the South Sumatra Basin have been described by numerous authors (e.g. Adiwidjaja and de Coster, 1973; Boyd and Peacock, 1986; Bishop, 2000; Pulunggono et al., 1992; Barber et al., 2005; Wibowo et al., 2008; Angraini and Yonatan, 2011). Only a brief summary is presented here.

The South Sumatra Basin is regarded as a foreland (back-arc) basin bounded by the Barisan Mountains to the southwest, and the pre-Tertiary Sunda Shelf to the northeast. The basin was formed by east-west extension during the Late Cretaceous to Early Tertiary. Orogenic activity during the Late Cretaceous-Eocene divided the basin into four sub-basins.

The structural features present in the basin are the result of the main tectonic events: Middle-Mesozoic orogeny, Late Cretaceous-Eocene tectonism and Plio-Pleistocene orogeny. The first two events provided the basement configuration including the formation of half grabens, horsts and fault blocks. The last event, the Plio-Pleistocene orogeny, resulted in the formation of the present northwest-southeast structural features and the depression to the northeast.

The sediments of the South Sumatra Basin (Figure 2A) comprise an economic basement of pre-Tertiary rocks that is overlain unconformably by a thick Tertiary sequence. The first Tertiary sedimentation occurred during the Middle Eocene and gave rise to the Lahat Formation consisting mainly of volcanic rocks, claystone and shale that was deposited locally in the graben areas. The Talangakar Formation of Late Oligocene and Early Miocene overlies the basement, where the Lahat Formation is missing. It is a transgressive sequence resulting from the Late Oligocene to

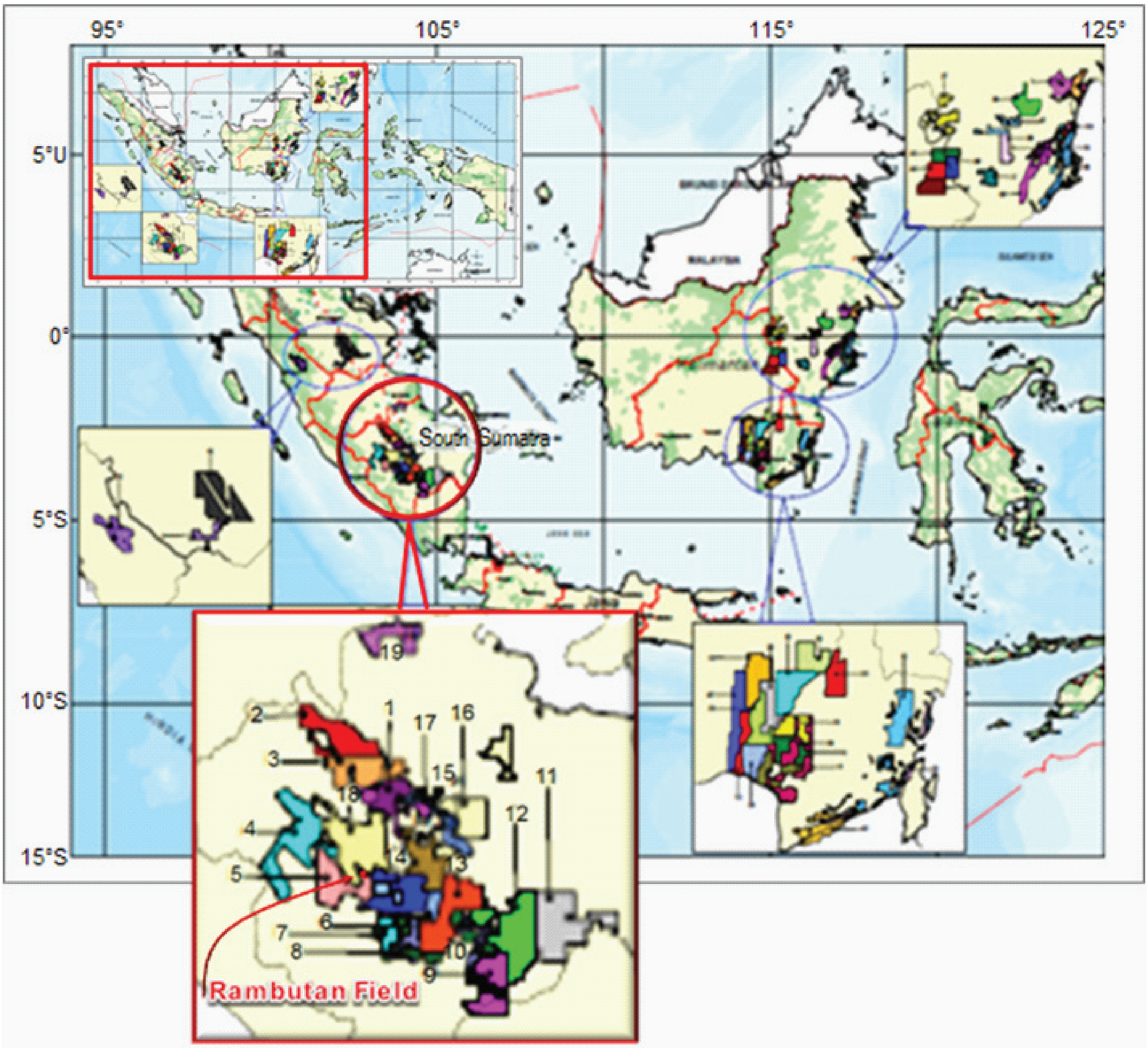

Figure 1. Map showing 54 CBM working areas in some prolific coal basins in Western Indonesia, 19 of them are in the South Sumatra Basin (modified from Sirait, 2013)

Middle Miocene subsidence. The later sedimentation during the Middle Miocene to present produced a regressive sequence including the Muaraenim Formation. The coal seams are found within the Muaraenim Formation and were formed during the Late Miocene and Early Pliocene. A generalized stratigraphy of the Palembang Group of the South Sumatra Basin is shown in Figure 2 where the coal seams of the Muaraenim Formation are shown.

The Muaraenim Formation (MEF) may be coal-bearing over its total thickness or only partially coal-bearing, depending on the area, with a total coal thickness ranging between 0 and 120 m. Coal seams typically account for 10% to 20% of MEF gross thickness. This is the formation, which contains the large brown coal or lignite resources of the South Sumatra region which were the principal target of Shell Coal Mining Exploration in the past. The thickness of the formation varies from 200 to over 800 m and generally decreases, together with the percentage of coal from south (South Palembang depression) to north (Jambi area) across the basin, reflecting a transition from delta plain to marine dominated environments. The formation is present throughout the Palembang sub-basins and along the west coast of Sumatra where the more marine facies (Eburna Marls) are thought to be equivalent to both the Muaraenim Coal member and the Kasai Tuff member (Steinhauser and van Delden, 1973).

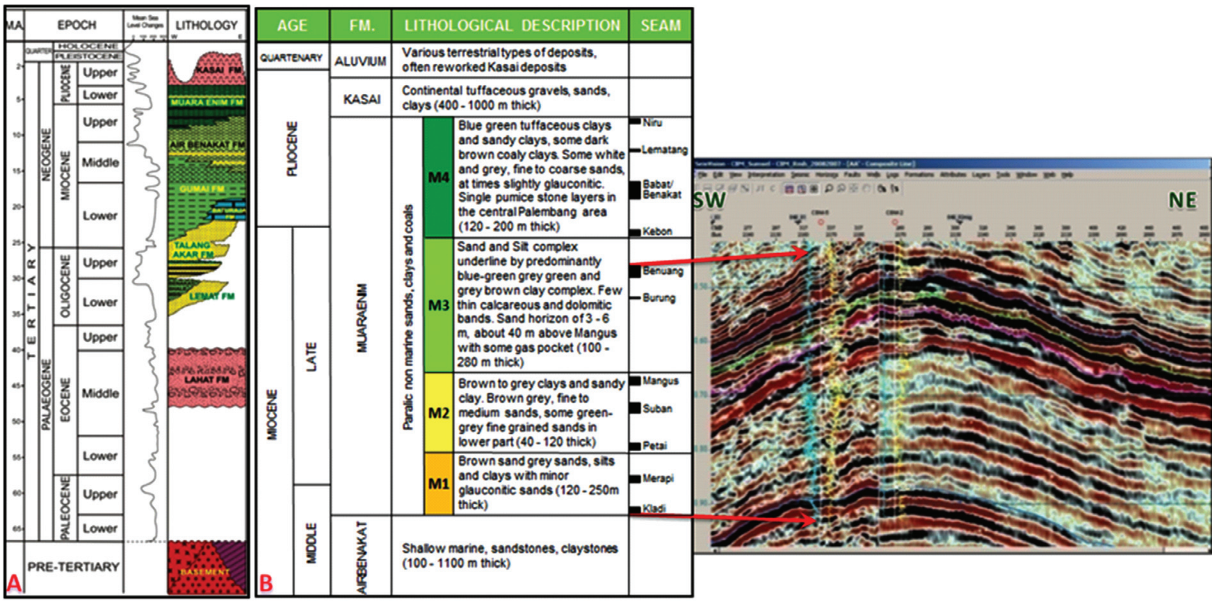

Figure 2. (A) Stratigraphy of the South Sumatra Basin (redrawn from van Gorsel, 1988);
(B) Stratigraphy of the Muaraenim Formation and its coal seam nomenclatures based on Shell Mijnbouw (Franks, 1978).

According to Amijaya (2005), the development of these thick coal deposits and its extremely low content of mineral matter are explained by the doming paleo-peat geomorphology of this deposit. By analogy to recent conditions, these morphological conditions limited the influx of suspended sediment from river water keeping any overbank deposits thin, so that the peat could not be enriched in mineral matter.

The andesitic intrusions in the Tanjungenim area, South Sumatra, which represents the late stage manifestation of post Miocene volcanic activity, is presumed to be of Pleistocene to Early Quaternary age, causing further uplift, faulting and folding as well as formation of some shallow domes (Darman and Sidi, 2000), but most importantly the local metamorphism of the strata in the Bukit Asam coal mine areas (Gafoer and Purbohadiwidjoyo, 1986). Moreover, Pujobroto and Hutton (2000) report the occurrence of three main intrusive bodies near the Bukit Asam coal mines (Air Laya and Suban). Those are Bukit Asam dyke, Suban sill and a vertical parasitic cone to the west of Air Laya Dome. The Bukit Asam dyke is the largest intrusive body and its outcrop forms a hill. The presence of the andesite intrusion in the Bukit Asam area has resulted in locally change rank of the coals (e.g. Santoso and Daulay, 2005). These coal seams can be classified into medium-volatile bituminous to anthracite coals up to 5.18% Ro (Amijaya and Littke, 2006). Coal seam with indirect contact with the andesitic intrusion may have been coalified by hydrothermal metamorphism (e.g. Hower and Gayer, 2002).

METHODOLOGY

The sample preparation, canister gas desorption, canister gas composition, adsorption isotherm, proximate and microscopic examination followed the procedures described elsewhere (Sosrowidjojo, 2006). Coal particles of about 1 mm in diameter were used for preparation of polished sections, which were embedded in a silicone mould using epoxy resin as an embedding medium. After hardening, the samples were ground flat and polished.

Five gas exploration boreholes, namely, CBM-1, CBM-2, CBM-3, CBM-4 and CBM-5 at a spacing of ~300 to 650 m, were drilled in the Rambutan Field (Figure 3). The boreholes were drilled to a maximum depth of 1,000 m and traversed five laterally extensive continuous coal seams and one thick but discontinuous coal seam (hanging seam). Coring jobs were using conventional coring equipment instead of a wireline-coring one, and the five continuous core-coal seams were

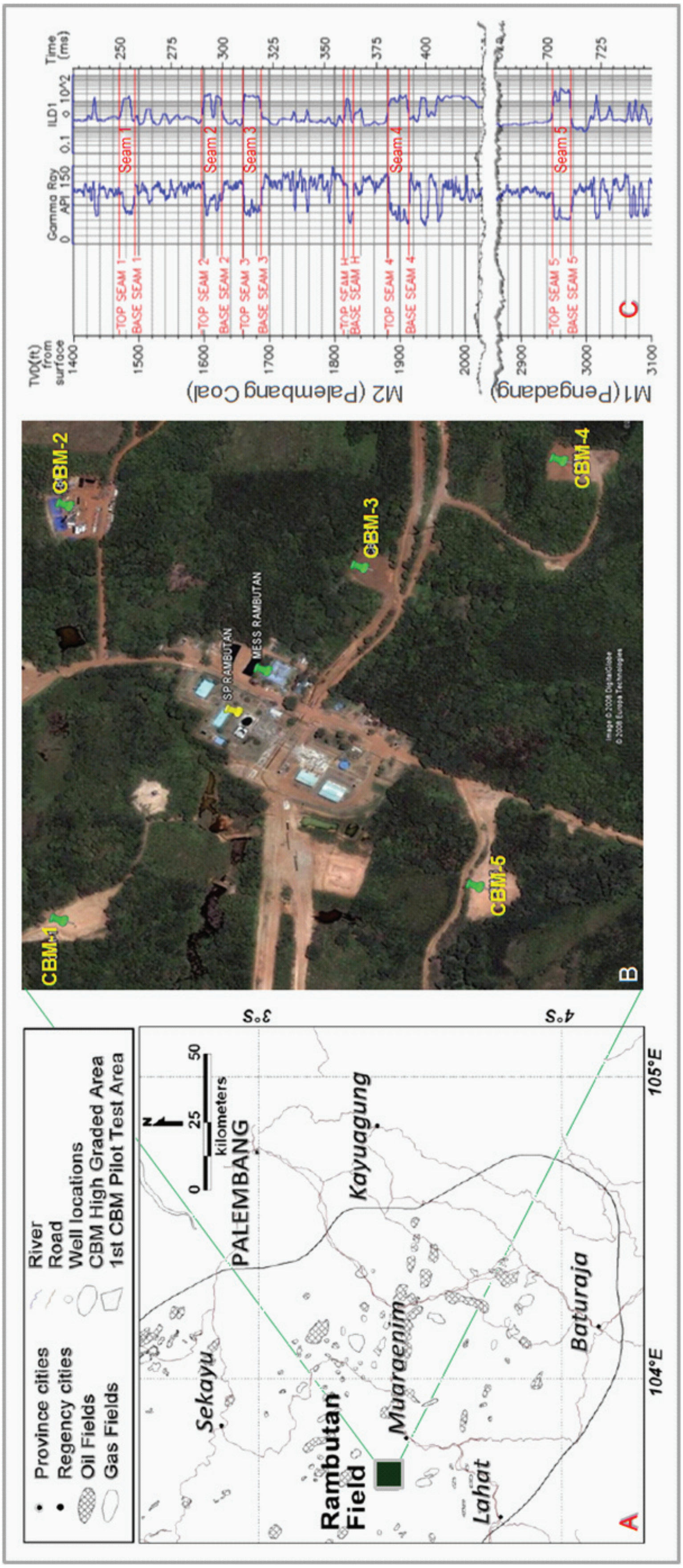

Figure 3. Map of South Palembang Sub-basin showing (A) the first CBM Pilot Test in Indonesia. (B) A set of five CBM wells (CBM-1 to CBM-5) were drilled and (C) CBM well log to illustrate Palembang coalbed (Seam-2 and Seam-3) and Pengadang coalbed reservoirs (Seam-5).

called Seam 1 to Seam 5. Measured gas composition from wells was selected for coalbed reservoir production only i.e. Seam 2, Seam 3 and Seam 5. The depths and thicknesses of the selected coalbed reservoirs are presented in Table 1. Moreover, the Seam 1 through the Seam 4 that is classified as M2 has nick name as Palembang coal while the Seam 5 (M1) is called Pengadang Coal. This study focused on the Seam 2, the Seam 3 and the Seam 5 only that are used pilot coalbed reservoir development test in the Rambutan Field.

RESULTS AND DISCUSSION

a. Muaraenim Coalbed Geochemical Properties

Proximate analysis from several surfaces and subsurface coal samples is presented on Table 2. The volatile matter of the seams are in the range of 29.3-45.8% with maximum fixed carbon is 46.54% and described as bright and lustrous. From those data, it can be seen that the coal in this area is classified as lignite-sub-bituminous. Ash contents are very low, except for one coal sample which is relatively as high as 19.8%. The coalbed is relatively high in volatile matter content. In short, these factors maybe promote good cleating and can enhance permeability.

Coalbed porosity in the Rambutan Field ranges from 5 to 10%, and classified as high porosity. High porosity means coalbed reservoir will produce more water compare to low porosity. Common coalbed reservoir porosity in the CBM well testing is less than 5%, lower than any result from the Rambutan Field. Permeability test in the Rambutan area shows low around <10 mD. Porosity, permeability and adsorption isotherm parameters from the Rambutan Field are presented in Table 2.

The petrographic composition of the coalbed has been studied in detail in order to classify favourable reservoir properties for gas storage and production. These coalbeds are rich in vitrinite ranging from 59 to 83% or vitrinite with in mineral free condition to be between 79 and 86%. The inertinite composition changes from 5.6 to 19%, except for the deepest coal for which the inertinite composition is 39.2%. The coals with high vitrinite and low mineral contents can have favourable reservoir properties for gas storage and production. The coalbed samples are characterized by low vitrinite (huminite) reflectance (Ro=0.31- 0.49%). Hence, coal rank for the coalbed samples is low, ranging from lignite to sub-bituminous. These low rank coals are dominated by huminite. Less abundance are liptinite and inertinite (see Mazumder and Sosrowidjojo, 2010). In addition, minerals are found only in small amounts; mostly as iron sulfide. Kaolinite occurs as cleat fillings at some places.

The rank and maceral composition of coal affect amongst other factors its gas generation potential. Most information on the subject of rank and maceral composition has been obtained around the existing Muaraenim Coal Mining Area near the Bukit Asam mine (Brom, 1976; Amijaya, 2005) and from the concession area awarded to Shell Mijnbouw N.V (Franks, 1978). The coals encountered at shallow depth (<200m) within the South Sumatra Basin are of low rank, except for some bituminous coals and anthracites, which originate from contact metamorphism due to emplacement of an igneous intrusion (Louis, 1996; Amijaya, 2005).

Methane in coal is derived from both biogenic and thermogenic processes. The proportion of these gases present in coal depends on the extent of coalification (rank), maceral composition, permeability, depositional environment, burial history

Table 1. Depths and thicknesses of the coalbed reservoirs for the fifth CBM wells in the Rambutan Field

Seam ID	CBM-1		CBM-2		CBM-3		CBM-4		CBM-5	
	Depth	Thickness	Depth	Thickness	Depth	Thickness	Depth	Thickness	Depth	Thickness
	(m)									
Seam 2	519.7	9.14	491.6	14.02	503.7	10.67	532.6	10.67	540.3	10.67
Seam 3	537.2	7.62	510.1	10.06	522.7	9.14	554.0	13.72	556.3	9.14
Seam 5	922.0	9.14	903.0	13.72	903.7	12.19	929.6	12.19	939.5	10.67

Table 2. Storage and Compositional Properties of the selected Muaraenim coalbeds from the fifth CBM wells in the Rambutan Field (representing 27 samples from all Seam 2, Seam 3 and Seam 5 only)

Reservoir Properties	Values
Coalbed Reservoir (Seam) Depth	
a. Top depth Seam 2 (m)	488 – 541
b. Top depth Seam 3 (m)	498 – 555
c. Top depth Seam 5 (m)	904 – 944
Coal Seam Thickness (m)	10 – 12
Gas Content (measured from canister, m3/ton)	0.43 – 5.84*
CH_4 Composition (measured from canister, mol %)	71 – 98*
CH_4 Composition (measured from seam/ well, mol %)	94 – 97
Storage Capacity at seam depth – as received (scf/ton)	184 – 830
Storage Capacity at seam depth – daf (scf/ton)	264 – 1,134
Langmuir Volume (scf/ton)	733 – 2,419
Langmuir Pressure (psi)	1,279 – 6,107
Vitrinite Maceral Group (%)	58.9 – 83
Moisture Content (%)	12.4 – 24.5
Volatile Matter (%)	29.1 – 53.97
Fixed Carbon	18.4 – 48.4
Ash Content (%)	5.6 – 19.8
Coal Density (g/cc)	1.3 – 1.5
CO_2 Content (measured from canister, mol %)	<1 – 26.8*
CO_2 Content (measured from seam/ well, mol %)	0.02 – 4.25
N_2 (measured from seam/ well, mol %)	0.15 – 2.37
Ro (%)	0.3 – < 0.5
Porosity (%)	4.77 – 9.98
Permeability (mD)	<10

Note: * Results were uncertainty due to no availability of a wireline-coring equipment at that time.

and basin hydrology. Hardly, any information is available about the origin and the CBM composition from the South Sumatra Basin. The range of the Muaraenim coal ranks in the Rambutan Field, it is highly likely that biogenic gas has been formed early in the burial history of these low rank coals (lignite to sub-bituminous rank Ro values <0.5%), and its generation and preservation are favored by rapid deposition. Primary biogenic gases generated during early coalification are generally dissolved in water and expelled during compaction (Rice, 1993). Moreover, secondary biogenic gasses was formed in association with meteoric water flow into permeable coals, subsequent to basin uplift (e.g. Faiz et al., 2003). The later will give additional saturation phase in a coalbed reservoir.

With increasing coalification resulting from higher temperatures and pressures, coals become enriched in carbon as large amounts of volatile matter rich in hydrogen and oxygen are released. The main generation of methane and associated hydrocarbons is thermal in origin and occurs at ranks of high-volatile bituminous and higher (Ro values >0.6%). With exception to the high rank coal for the Muaraenim coal in the surrounding intrusion areas (e.g. Tambang Air Laya), thermogenic process of methane generation for the Muaraenim coals does not seem very likely. It might be possible that at greater depths, the coals in the Talangakar Formation are in the thermogenic window.

b. Muaraenim Coalbed Reservoir Properties

Coal sorption isotherm is used to predict the maximum volume of gas that will be released from a coal seam as the reservoir pressure declines during long-term production (Mavor et al. 1990). It reflects the relationship between gas storage capacity of a given coal sample and its pressure. When compared with measured gas contents and reservoir pressure, the sorption isotherm data also provides a guide as to the relative gas saturation of the coal and the bottom-hole pressure required to initiate significant methane desorption (critical desorption pressure).

The values of isotherm parameters are calculated both in terms of absolute and gauge pressures. The sorption isotherms of CH_4 for the Muaraenim coalbeds from the Rambutan Field were obtained from the selected Seam 3 and Seam 5 only. These isotherms data obtained from all the five CBM wells. The absolute adsorption results are presented in Table 2 and Figure 4.

From the Figure 4, it is expected that the sorptive capacity of coal is increased with increasing depth, but it seems to decrease with increasing depth. Although it might be noted that there is not much of variability in terms of coal rank for these coals, whether it is an effect of the maceral composition or the coal quality, can still be debated. Also looking into the gas content measurements and the sorptive capacity of these coals (Table 2), there is a clear bit of disconnect in understanding the reason behind this effect. The maceral composition analysis of the coals from the fifth CBM wells show that the vitrinite content of the shallow coals ranges from 74.1 to 82.2% and that of the deepest coal seam is on an average 52.2%. Thus, a comparison of the gas adsorption capacity with the maceral composition shows that these properties have an important effect on the sorptive capacity. The maceral composition also influences the adsorption characteristics of coal, which are closely related to micropore development. Clarkson and Bustin (1996) found a general increase in the total number of micropore with increasing vitrinite content. Sosrowidjojo and Saghafi (2009) on the other hand has solely accounted for these differences to varying ash and moisture content of the coal samples from the CBM-1 well. One possible explanation in this regard is that the accessible micropore volume in moist coals is much less than in dry coals, due to either a reduction

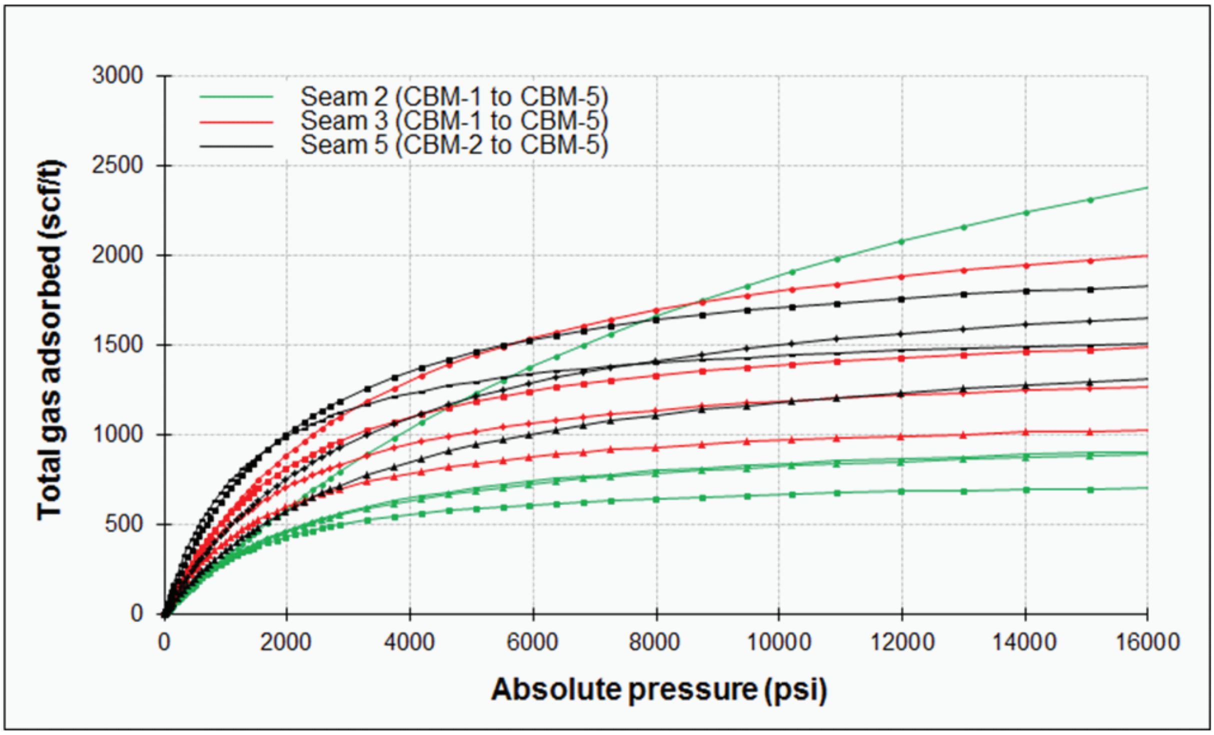

Figure 4. Representative methane adsorption isotherms data of respective Seam 2 (green) Seam 3 (red) and Seam 5 (black) for the CBM-1 to CBM-5 wells, respectively.

of pore size due to water adsorption or to swelling of the coals. More data points are needed to substantiate either of the proposed reasons for the anomaly in the sorption capacity with increasing depth. Since little is known of Indonesia's CBM resources, it crucial that the coal reservoir is assessed properly and that means using different techniques than what is normally used in conventional plays (Moore, 2010).

Comparing the gas storage capacity (sorption isotherm) with the actual gas yields, will give an estimation of the gas saturation of the coal seams. Measured gas content data from the CBM wells have been reported in Table 2. The measured Langmuir isotherms were conducted at reservoir temperatures (49°-61°C). The degree of under-saturation for each seam has been shown in Figure 6. Except for one coalbed sample from Seam 3, all other seams have high degree of under-saturation. Although the fifth CBM wells were drilled on the Rambutan structural high, if the under-saturation is representative, then there can be some serious thoughts behind the economic viability of a CBM project in this region. It was evident that the rig used to drill these wells did not have wireline coring facility and the retrieval of the coal cores once drilled, was time intensive. Time required to retrieve these cores was in excess of 11 hours in some cases. Thus it is understandable that a considerable amount of the gas was lost in the process of retrieving the cores and thus, the gas content measurements, therefore, are not very representative of the actual in-situ saturation.

CONCLUSIONS

The major findings of this evaluation for the Rambutan pilot samples can be summarized as follows:

- the rank of all the coalbed samples ranges between lignite and sub-bituminous. The maceral composition of them is primarily huminite, making its storage capacity and hydrocarbon generation potential favorable for CBM development;

- high degree of under-saturation indicative from gas content results was not conclusive and is too early to say whether the under-saturation is representative. Due to high of uncertainty on gas saturation as well as fracture permeability, proper corehole campaigns are carried out to determine these parameters through core analysis;

- it is also recommended to further integration of properties measured in the corehole campaign with focused on seismic and wells interpretation to allow a reduction of uncertainty in resource estimation and help determine potential economic viability of CBM prospect(s) in the area.

ACKNOWLEDGMENTS

This paper is fully funded by the Government of Indonesia. The author is indebted to the Management of Lemigas for permitting to publish this paper and also is grateful to the Editors of Indonesian Mining Journal, whose insightful comments helped to improve greatly the quality of this manuscript.

REFERENCES

Adiwidjaja, P. and de Coster, G.L., 1973. Pre-tertiary paleotopography and related sedimentation in South Sumatra. *Proceedings, IPA, 2nd Annual Convention*, p. 89-103.

Amijaya, H., 2005. Paleoenvironmental, paleoecological and thermal metamorphism implications on the organic petrograhy and organic geochemistry of Tertiary Tanjung Enim coal, South Sumatra Basin, Indonesia. *PhD Thesis, Rheinisch-Westfalischen Technischen Hochschule*, Aachen, 170 p. (online at: http://darwin.bth.rwth-aachen.de/opus/volltexte/2005/1266/pdf/Amijaya_Donatus.pdf.

Amijaya, H. and Littke, R., 2006. Properties of thermally metamorphosed coal from Tanjung Enim area, South Sumatra basin, Indonesia with special reference to the coalification path of macerals. *International Journal of Coal Geology 66*, p. 271-295.

Angraini, B.T. and Yonathan S., 2011. Sequence stratigraphy and facies analysis of Muara Enim Formation, to predict prospecting areas in TAC Pertamina-Pilona Petro Tanjung Lontar., *Proceedings, IPA, 35th Annual Convention*. In CD publication, Jakarta. file IPA11-G-157, 11 p.

Barber, A.J., Crow, M.J. and Milsom, J.S. (eds.), 2005. *Sumatra: geology, resources and tectonic evolution*. Geol. Soc., London, Mem. 31, 290 p.

Bishop, M.G., 2000. South Sumatra Basin Province, Indonesia: The Lahat/Talang Akar Cenozoic total petroleum system. *U.S. Geol. Survey Open File Report*, 99-50S, 22 p. http://pubs.usgs.gov/of/1999/ofr-99-0050/OF99-50S/index.html

Boyd, J.D. and Peacock, S.G, 1986. Sedimentological Analysis of a Miocene Deltaic Systems: Airbenakat and Muaraenim Formations, Central Merangin block, South Sumatra, *Proceedings, IPA, 15th Annual Convention*, p. 245-258.

Brom. R., 1976. A petrophysical study of the upgraded coals encountered in the Bukit Asam Mine Area. *Shell EP Report No. 2560*.

Clarkson, C.R. and Bustin, R.M., 1996. Variation in micropore capacity and size distribution with composition in bituminous coal of the Western Canadian Sedimentary Basin. *Fuel 75*, p. 1483-1498.

Darman, H. and Sidi, F.H., 2000. *An outline of the geology of Indonesia*. Indonesian Association of Geologists, Jakarta, 254 p.

Faiz, M., Stalker, L., Sherwood, N., Saghafi, A., Wold, M., Barclay, S., Choudhury, J., Barker, W. and Wang, I., 2003. Bio-enhancement of coal bed methane resources in the southern Sydney Basin. *APEA Journal, 43*, p. 595-610.

Franks, G.D., 1978. Explanatory Note to the Geological Map of the South Sumatran Coal Province. *Shell EP Report No. 52426*.

Gafoer, S. and Purbohadiwidjoyo, M.M., 1986. The geology of Southern Sumatra and its bearing on the occurrence of mineral deposits. *Bulletin of the Geological Research and Development Center, No.12*, Directorate General of Geology and Mineral Resources of Indonesia, Bandung, p. 15-30.

Hower, J.C. and Gayer, R.A., 2002. Mechanisms of coal metamorphism: case studies from Paleozoic coalfields. *International Journal of Coal Geology 50*, p. 215-245.

Kurnely, K., Tamtomo, B., Aprilian, S., and Doria, I., 2003. A Preliminary Study of Development of Coalbed Methane (CBM) in South Sumatra. *Paper SPE 80518*, 5 p., http://www.msitest.info/pertaminaep/downloadan/repository/spe-80518-cbm.pdf

Louis, L., 1996. Atlas of Hydrocarbon Distribution in Southeast Asia. *Shell EP Report No. 96-6050*.

Mavor, M.J., Owen, L.B. and Pratt, T.J., 1990. Measurement and Evaluation of coal Sorption and Isotherm Data, *Paper SPE 20728*, 14 p.

Mazumder, S. and Sosrowidjojo, I.B., 2010. The Late Miocene Coalbed Methane System in the South Sumatra Basin of Indonesia, SPE 133488-PP, Paper presented at the *SPE Asia Pacific Oil & Gas Conference and Exhibition*, Brisbane, Australia, 18-20 October 2010, 29 p.

Sirait, D. 2013. Indonesia Current Policy and Regulation, Paper presented in the A Regional Workshop on the Changing Global Gas Market and Conventional Gas, Jakarta, 7 May 2013, (unpublished)

Moore, T.A., 2010. Critical Reservoir Properties for Low Rank Coalbed Methane Resources of Indonesia, *Proceedings, IPA 34th Annual Convention & Exhibition*, In CD publication, file # IPA10-G-055, 5 p.

Orem, W.H. and Finkelman, R.B., 2003. Coal Formation and Geochemistry, In: Mackenzie, F.T. (ed) Holland, H.D. and Karl K., (Executive Eds) *Treatise on Geochemistry, Vol. 7*. Elsevier, p.191-222, http://adsabs.harvard.edu/abs/2003TrGeo...7..191O, DOI: 10.1016/B0-08-043751-6/07097-3

Pujobroto, A. and Hutton, A.C., 2000. Influence of andesitic intrusions on Bukit Asam coal, South Sumatra Basin Indonesia. *Proceedings of Southeast Coal Geology Conference*, Directorate General of Geology and Mineral Resources of Indonesia, Bandung, p. 81-84.

Pulunggono, A., Agus, H.S. and Kosuma, C.G., 1992. Pre-tertiary and tertiary fault systems as a framework of the South Sumatra Basin, a study of SAR maps. *Proceedings, IPA, 21st Annual Convention*, p. 339-355.

Rice, D.D., 1993. Composition and origins of coalbed gas. In: Hydrocarbons from Coal, AAPG Studies in Geology 38. B.E. Law and D.D. Rice (eds.). American Association of Petroleum Geologists, Tulsa, p. 159-184.

Santoso, B. and Daulay, B., 2005 Coalification trend in South Sumatra Basin, *Proceedings Joint Convention Surabaya, The 30th HAGI, The 34th IAGI and The 14th PERHAPI, Annual Conference and Exhibition*, JCS2005-M004.

Sosrowidjojo, I.B., 2006. Coalbed Methane Potential in The South Palembang Basin, *Proceedings of the International Geosciences Conference and Exhibition, IPA, 33th Annual Convention*. In CD publication, Jakarta. file # CH-05, 5 p.

Sosrowidjojo, I.B. and Saghafi, A., 2009. Development of the first coal seam gas exploration program in Indonesia: Reservoir properties of the Muaraenim Formation, South Sumatra. *International Journal of Coal Geology, 79*, p. 145-156.

Steinhauser, N.R. and van Delden J.M., 1973. A Geological study of the coal deposits in South Sumatra. *Shell EP Report No. 45138*.

Stevens, S.H. and Hadiyanto, 2004. Indonesia: coalbed methane indicators and Basin evaluation, SPE 88630. *SPE Asia Pacific oil and gas conference*, 18-20 October 2004, Perth, Australia, 8 p.

Stevens, S.H., Sani, K. and Hardjosuwiryo, S., 2001. Indonesia's 337 Tcf CBM Resource, a Low-cost alternative to Gas, LNG, *Oil and Gas Journal*, October 22nd, 2001, p. 40-45.

Van Gorsel, J.T., 1988. *Geological fieldtrip to South Sumatra and Bengkulu*, October 28-31, 1988. IPA, Jakarta, 42 p.

Wibowo, R. A., Hindadari, W., Alam, S., Silitonga, P. D. and Raguwanti, R., 2008. Fractures Identification and Reservoir Characterization of Gas Carbonate Reservoir at Merbau Field, South Palembang Basin, Sumatra, Indonesia. *Abstract, AAPG Annual Convention*, San Antonio, TX.