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GAS CONTENT APPRAISAL OF SHALLOW COAL SEAMS IN THE SOUTH PALEMBANG BASIN OF SOUTH SUMATRA

Ana Asmina[1], Edy Sutriyono[2], Endang Wiwik Dyah Hastuti[3]
[1]Postgraduate Study Program of Mining Engineering of Sriwijaya University
[2,3]Geology Study Program of Engineering Faculty of Sriwijaya University
Jl. Srijaya Negara, Bukit Besar, Palembang, Indonesia

Corresponding Author, Received: 27 April 2016, Revised: 10 Oct. 2016, Accepted: 30 Nov. 2016

ABSTRACT: The gas content of coal seams in the South Palembang basin has been assessed using well log data and core analysis. The seams are stratigraphically exposed at shallow levels (<300 m), and present in the Late Miocene-Early Pliocene Muara Enim sequence. The coal thickness of single bed in each well varies between ~7 m and ~14 m. All samples analyzed are low rank coals, suggesting subbituminous and high volatile bituminous. Vitrinite reflectance (VR) measurements vary from 0.49-0.59%, but there appears an increase in the VR value with depth. The coals contain predominantly huminite (56-86 vol. %), whereas liptinite and inertinite are less abundant, ranging from 0.2-12.2 vol. % and 4.2-19.2 vol. % respectively. These low rank coals comprise a small number of minerals (6-11 vol. %), high moisture content of 2.4-12.6 wt. %, volatile matters of >39 wt. %, and fixed carbons of >43 wt. %. The amount of gas within individual coal layer varies from 4.1-5.3 m^3/t, but the gas content tends to increase with deeper burial. The sum of the estimated gas-in-place is approximately $3{,}019 \times 10^6$ m^3. In addition, the onset of gas generation within these near surface coals may occur due to biogenic controls during the coal-forming processes, as a result of sedimentation of the overburden in Pliocene time prior to the subsequent basin inversion commencing in the Plio-Pleistocene.

Keywords: Coal Seam Gas, Low Rank Coal, South Palembang Basin

1. INTRODUCTION

Natural gas adsorbed within coal layers, known as coal seam gas or coalbed methane (CBM), has recently become one of promising unconventional energy resources. This is true especially in the USA since it has contributed up to 7% of total gas production for the state [1]. Such a phenomenon to some extent has led initiation of extensive CBM exploration in several other countries, such as Indonesia, China, India, Vietnam, and South Africa. The results of exploratory activities in the Indonesian region have been reported for instance by [2]-[9].

Indonesia has been recognized to have at least eleven onshore coal basins with a considerable amount of CBM resources. Studies on deep coal seams (>300 m) suggested that the country may possess the gas-in-place potential of about 213 tcf [10], [11], approximately 337 tcf [12], and around 453 tcf [13], [14]. The variety of gas content appraisal reported by those authors indicates that Indonesia's CBM is still poorly constrained. This may be in part due to the lack of a data set available for the evaluation, owing to difficulties in getting access to a package of information about the sub-surface geology, and in many cases some experimental yields necessary for the gas measurements remain strictly confidential.

Amongst the Indonesian onshore basins, the South and Central Sumatra basins in Sumatra and the Barito and Kutei basins in Kalimantan are presumably to have the vast amount of CBM resources. Indeed, the most economically significant coal deposits occur in those areas. More importantly, the deep coal seams in the islands are apparently to be the key reservoir system that currently becomes the main target for CBM exploration. Based on volumetric calculation, the South and Central Sumatra basins are inferred to have CBM prospectivity of approximately 183 tcf and 145 tcf respectively [13]. Besides, these authors reported that the Barito coal seams hold natural gas of about 120 tcf, and the Kutei basin comprises gas potential of around 51 tcf. Several workers have suggested that the South Sumatra region is the most prospective coalfield for coal seam gas exploration in Indonesia [2], [15], [16].

The present study was aimed at evaluating the CBM content of the relatively near surface exposure of low rank coals in Air Laya mining area. The region is administratively included in the Muara Enim Regency, which is one of the coal producing areas in South Sumatra Province. This work has employed log observation from seven shallow wells and core analysis for the coal beds of the sequence. The locality of each well is shown in Fig.1.

Tectonically, the region is situated within the South Palembang basin, which is one of four depocenters forming the Paleogene South Sumatra basin. The basin is commonly referred to as a graben-like structure extending in a back-arc setting. The initial development of this basin took place in the Eocene [17], coincident with the inception of tensional regime at the SW margin of Sundaland in the Early Tertiary. The history of sedimentation is generally attributed to two different major events with respect to sea level changes, transgression through Late Oligocene-Early Miocene time and regression during Middle Miocene-Pliocene time.

The close of transgressive regime took place in the Middle Miocene, followed by regression in relation to the commencement of regional compressive strain fields in the region. The basin was under the influence of regression up to the early Late Pliocene. The cessation of a regressive phase occurred in conjunction with the onset of regional uplift in response to the Plio-Pleistocene orogeny. The Late Neogene event in this area is considered as the latest tectonic episode responsible for basin inversion, leading to the formation of the present geologic features throughout the entire region.

The Neogene coal bearing sequence in the basin is the Mio-Pliocene Muara Enim Formation. The thick coal seams are present in this unit. The succession consists mainly of paralic mudstones and sandstones intercalated with siltstones and coals, developed during widespread sea level lowstands in the Late Tertiary. Previous studies suggested that the coal deposits of this formation are fluvio-deltaic in origin [18], [19]. The area of an interest of the present study is the coal seams of the Mio-Pliocene rock series (Fig. 2) in the South Palembang basin of South Sumatra.

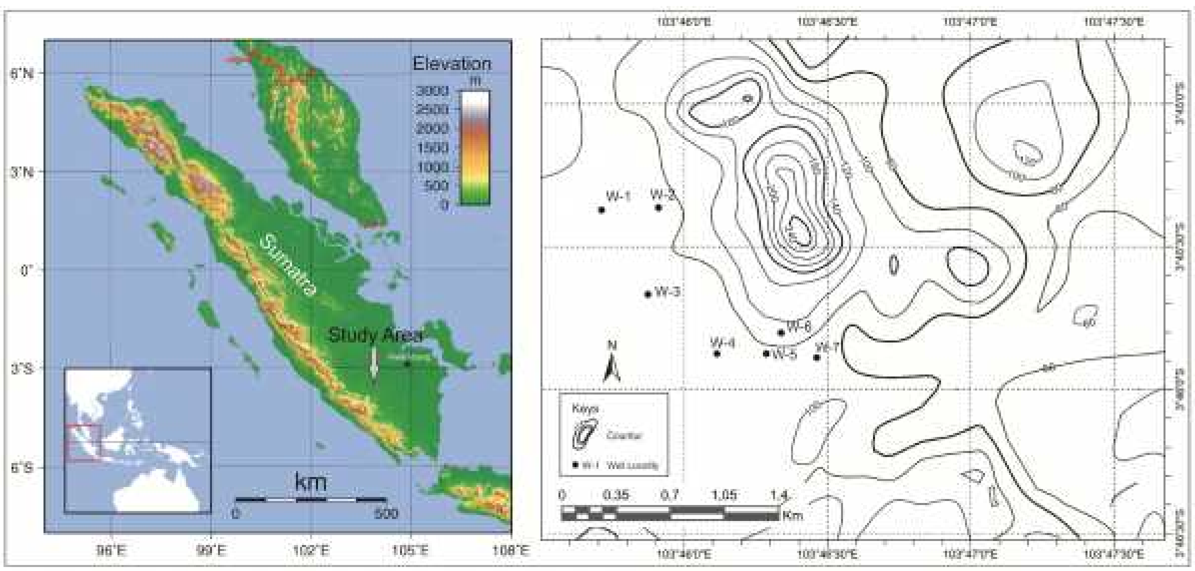

Fig. 1 A map showing the locality of study area in South Sumatra (left). Also shown is a contour map displaying the location of wells studied in the present work (right). The wells drilled at topographic elevations between 80-100 m above sea level

2. METHODS

This study evaluates the CBM content of low rank coals exposed at shallow depths, using log profiles and core samples derived from seven wells. The wells were drilled and penetrated the coal bearing formation in the Air Laya mining region of South Palembang basin. The thickness and depth of coal seams are interpreted primarily on the basis of log data. The lateral continuation and the variety of coal thickness are determined by correlating all logs observed. Analysis of core samples is undertaken to gain the principal parameters accounted for the gas volume measurements, thus the amount of gas-in-place within the seams. The yielded coal parameters, including maceral content, organic matter, moisture content, fixed carbon, volatile matter and relative density, are utilized for determining the rank of coals.

The gas volume is calculated by following the procedure proposed by [20], but with some necessary modification in order to be more appropriate geologically for the area studied, as carried out by [21]. The modified parameters in calculation are the geothermal gradient value and the approximate surface temperature of the region. The volumetric formula used in the appraisal of gas content generally adopts the geothermal gradient of 1.8°C/100 m and the surface temperature of 11°C. However, the present assessment has employed the temperature gradient of 4.97°C/100 m and the ambient surface temperature of 22°C. In this paper, the sum of gas-in-place within the coal seams has been assessed by adopting the equation of [22].

3. GEOLOGY: AN OVERVIEW

The South Sumatra basin has long been recognized as one of oil as well as coal producing areas in Indonesia. The history of the basin began in Early Tertiary, following the initiation of tensional forces in the southwestern margin of Sundaland in Eocene or ~40 Ma [17]. The initial tension allowed the formation of graben-like structures and fault blocks in the pre-Tertiary crystalline rocks underlying the basin. Hence, the pre-Tertiary sequence was fragmented by faults, forming blocky and rough basement topography. In a regional context, this tectonic stress field is generally considered to have been responsible for the development of back-arc basins extending along the eastern side of Sumatra [17], [23], [24].

The island forms the western section of the amalgamated continental blocks of Sundaland. Evolution of this composite landmass from Late Paleozoic to Late Mesozoic time has been overviewed recently by [25], and it may be beyond the main purpose of the present paper to discuss the development of these continental fragments.

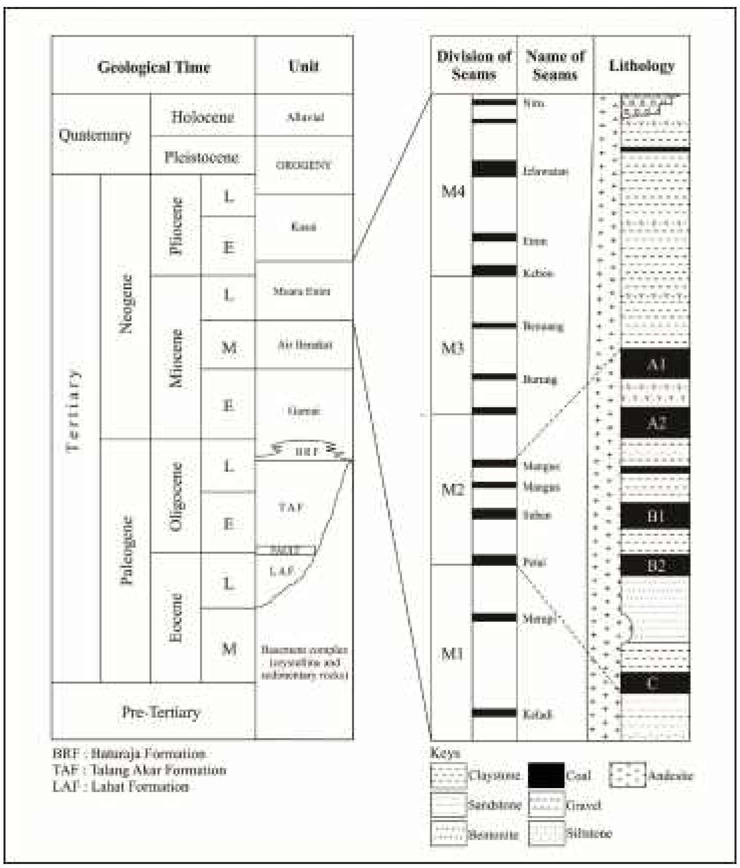

Fig. 2 Generalized stratigraphy of the Paleogene South Sumatra basin redrawn from [26] (left). Also shown is the division of coal seams within the Muara Enim Formation (right). The coal layers studied in the present work are part of the M2 seam group

As a tensional regime proceeded, the region underwent a rifting event, the depocenter deepened and widened in the southwestern and central section of the basin, and sea level highstands commenced in the Oligocene [27]. During the rifting period, widespread sedimentation of clastic materials took place from terrestrial to shallow marine environments. The deposition that formed the basal Lahat sequence occurred in the Late Eocene-Early Oligocene. The clastic sediments were sourced principally from the surrounding basement highs, and accumulated in terrestrial environment.

Owing to a rifting episode continued and subsidence of the basin accelerated in the Late Oligocene-Early Miocene, the depositional environment shifted from initially smaller and separated to deeper and broader lakes [28]. This changing phase was followed by a sea level rise, which gradually encroached into basinal area. At this time, sedimentation resulted in the Talang Akar sequence, which is composed mainly of sandstones, siltstones, shales, and few coal seams [23]. Subsequent deposition took place throughout Early-Middle Miocene time as transgression proceeded. This period was the time of extensive sea level highstands in the basinal area. Sedimentation resulted in predominantly carbonates constituting the Baturaja Formation, and mainly shales and claystones forming the Gumai Formation.

In the late Middle Miocene, the regressive cycle commenced as transgression ended, and sedimentary environments gradually shifted from deeper marine to shallow marine, to transitional or deltaic condition, and eventually to terrestrial sites [23]. This cycle resulted in consecutively the Air Benakat succession, the coal bearing Muara Enim sequence, and the Kasai rock unit. Sedimentation during regression ceased in Plio-Pleistocene time, marked by the deposition of tuffaceous and pumiceous materials sourced from the Quaternary volcanoes. Owing to the Late Neogene orogeny, the basin underwent inversion and uplift, as well as extensive denudation to form the present geologic configuration in the entire region.

4. EXPERIMENTAL RESULTS

Log data used in this study were measured from seven wells with reference number W1-W7 (Fig.1). The W1 and W3 wells were drilled to a total depth (TD) of less than 200 m, and the rest W2, W4, W5, W6, and W7 wells penetrated the TDs ranging from 240-278 m. All wells encountered the coal bearing Muara Enim Formation. The sequence is one of coal bearing successions in the Paleogene South Sumatra basin, containing a large amount of coal deposit, as well as its associated natural gases. The coal seams constitute approximately 10-20% of the whole unit [19]. The correlation of seams on logs implies that lateral continuity of strata is extensive. This interpretation is concordant with that proposed by [13] and [19]. Results of log observation show that there appear at least four major coal beds, known as A1, A2, B, and C seams (Fig. 3). With respect to the regional stratigraphy, layers A1 and A2 are part of Mangus seams, whereas beds B and C are included within Suban and Petai units respectively. However, unless stated otherwise the division names (Mangus, Suban, and Petai) are not used for the simplicity, instead the sorter terms A1, A2, B, and C are utilized throughout this paper.

In the study area, the coal seams of the Muara Enim succession occur at stratigraphic levels between 166-264 m (Table 1). Individual seam determined from each log varies in thickness. Coal bed A1 is 6.9-9.5 m thick with mean 8.2 m. The apparent thickness of layers A2, B, and C ranges between 7.0-10.3 m, 11.5-16.3 m, and 1.3-9.9 m and average 8.6 m, 13.7 m, and 6.7 m, respectively. These data indicate that the B bed is the thickest coal seam, and the C bed is thinnest coal stratum. Maceral analysis reveals that the Air Laya coals are composed predominantly of vitrinite or huminite (73-74 vol. %), but individual seam varies in huminite content, ranging from 56-86 vol. %. Components such as liptinite (3-6 vol. %), inertinite (11-16 vol. %), and mineral matters (6-11 vol. %) are apparently less abundant. In addition, the results of petrographic analysis in this study are commonly similar to those reported by [29].

Analysis of core sample A1 yielded VR values ranging from 0.38-0.77%, with mean 0.49%. The VR measurements of coals A2, B, and C resulted in 0.33-0.64% with mean 0.49%, 0.40-0.83% with mean 0.52%, and 0.40-0.58% with mean 0.59% respectively. These data suggest that the analyzed coals may be of subbituminous and high volatile bituminous. The VR yields show that there is an increase in vitrinite reflectance with depth. The values seem slightly higher than those proposed by [19], possibly due to the more locally thermal influence on the coal seams analyzed. The increase in degree of maturation with depth for the South Sumatran coals has also been reported elsewhere [1], [13], [29], [30]. Importantly, the yielded VR may imply that the onset of gas generation within these low rank coals might have occurred due to biogenic processes, as the coal bearing sequence was subjected to the zone of higher paleogeothermal gradient through deeper burial in Pliocene time. The essay on biogenic origin has also been suggested by [19].

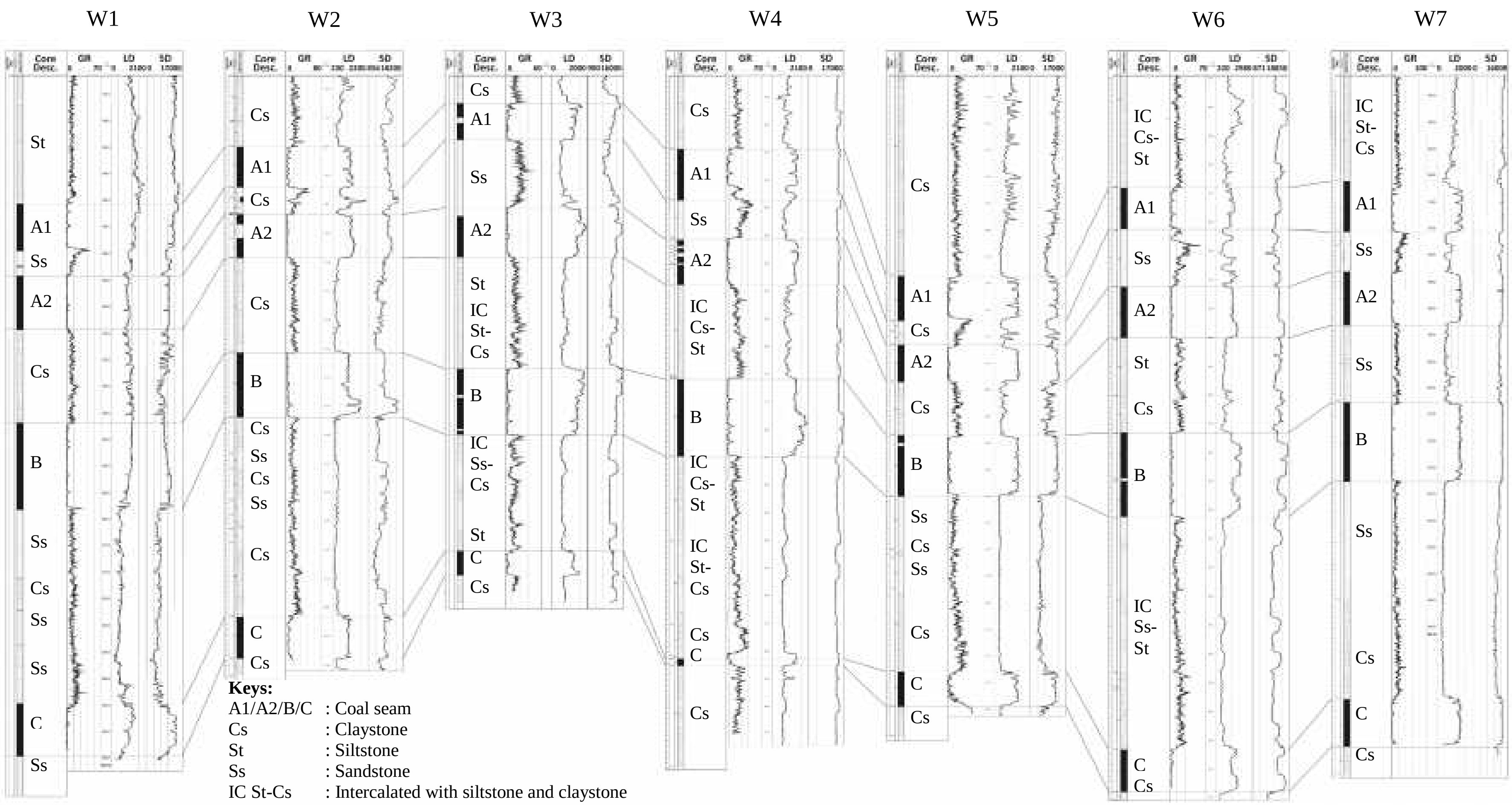

Fig. 3 Correlation of the well logs studied showing a variety of coal thicknesses and a lateral continuation of beds throughout the region

Table 1 Analytical results of CBM appraisal in the Air Laya mining region of South Palembang basin

Observation	Parameters (unit)	Coal Seams								Remarks
		A1		A2		B		C		
		yields	mean	yields	mean	yields	mean	yields	mean	
Log	Depth (m)	79.4-166		100.3-183		126.5-207.5		164.4-263.5		Log analysis
	Thickness (m)	6.9-9.5	8.2	7-10.3	8.6	11.5-16.3	13.7	1.3-9.9	6.7	
Core	Vitrinite (vol. %)	56-86	74.7	65.8-80.6	73.8	64.6-78.8	73.9	65.4-81.4	73.8	Petrographic analysis
	Liptinite (vol. %)	1.2-6.6	3.6	0.2-7.6	3.1	2.2-12.2	5.6	3.4-9.2	5.9	
	Inertinite (vol. %)	4.2-14.8	11.1	9.0-19.2	15.5	14.0-16.4	14.7	6.2-15.8	11.5	
	Minerals (vol. %)	3-30	10.6	2.8-10	7.6	3-9	5.8	5.4-15.0	10.0	
	VR (%)	0.38-0.77	0.49	0.33-0.64	0.49	0.40-0.83	0.52	0.40-0.58	0.59	
	Ash (wt. %)	4.02-30.43	10.77	3.50-9.99	7.28	6.39-7.94	6.11	4.31-12.13	6.78	Proximate analysis
	Moisture (wt. %)	3.90-12.59	7.24	2.75-10.58	6.07	3.85-9.18	6.47	2.36-7.45	4.97	
	FC (wt. %)	32.55-48.95	43.14	42.21-59.35	47.69	43.42-53.23	46.80	43.74-54.32	47.81	
	VM (wt. %)	33.08-42.41	38.84	32.62-42.07	38.94	40.35-41.57	40.47	31.19-43.85	40.44	
	TS (wt. %)	0.62-0.91	0.76	0.20-1.10	0.42	0.23-1.06	0.41	0.60-2.17	1.28	
	CV (cal/g)	4,903-7,150	6,303	5,823-7,524	6,697	6,351-7,319	6,805	6,543-7,350	6,949	
	RD (g/cm^3)	1.23-1.51	1.31	1.23-1.31	1.27	1.22-1.28	1.26	1.22-1.29	1.26	
Gas content*) (m^3/t)		3.3-4.8	4.1	4.2-5.6	4.9	4.4-5.4	4.9	4.9-5.7	5.3	Average 4.1-5.3
Gas-in-place**) ($x10^6$ m^3)		554		623		1,049		793		Total 3,019

VR: vitrinite reflectance; FC: fixed carbon; VM: volatile matter; TS: total sulphur; CV: calorific value (gross value); RD: relative density; *) estimated using the modified formula of [20]; **) calculated using the method of [22].

The proximate parameters, including ash content, inherent moisture, fixed carbon (FC), volatile matter (VM), total sulphur (TS), calorific value (CV), and relative density (RD), have been analyzed on air dried basis (adb) (Table 1). In order to better understand the characteristics of coals within the region, each of these parameters is compared to the result of proximate analysis reported by [29]. Most of the coal elements are in general akin to those suggested by these authors. The ash content of the A1 samples ranges from 4.0-30.4 wt. % with mean 10.8 wt. %, whereas the A2, B, and C seams have ash composition in that order of 3.5-10 wt. % with mean 7.3 wt. %, 6.4-7.9 wt. % with mean 6.1 wt. %, and 4.3-12.1 wt. % with mean 6.8 wt. %. Inherent moisture varies among the coal beds, but they are all characterized by high values. To compare with the analytical results published by [29], the Air Laya mining coals are relatively lower in moisture content.

Individual coal bed contains fixed carbons that range from 32.6-49.0 wt. % with mean 43.1 wt. % for seam A1, 42.2-59.4 wt. % with mean 47.7 wt. % for seam A2, 43.4-53.2 wt. % with mean 46.8 wt. % for seam B, and 43.7-54.3 wt. % with mean 47.8 wt. % for seam C. The present value is apparently higher than that shown by [29], but remains on the range of values typical for the low rank coals. The VM content obtained from analysis of sample A1 ranges from 33.1-42.4 wt. % with an average of 38.8 wt. %. The other coal specimens result in various VM contents, ranging from 32.6-42.1 wt. % with an average of 38.9 wt. % (seam A2), 40.4-41.6 wt. % with an average of 40.5 wt. % (seam B), and 31.2-43.9 wt. % with an average of 40.4 wt. % (seam C).

Analysis of the sulphur content yields the mean value ranging from 0.4-1.3 wt %. Each coal seam varies in the total sulphur matter. The A1 coal results in 0.6-0.9 wt. % and average 0.8 wt. %, the A2 and B bed possess exactly the same value of 0.2-1.1 wt. % and average 0.4 wt. %, and the C layer has 0.6-2.2 wt. % and average 1.3 wt. %. The calorific data generated from of the analyzed cores indicate that the A1 coal is subbituminous with calories varying between 4,903-7,150 cal/g and average 6,303 cal/g, whereas the A2, B, and C coals are high volatile bituminous with calorific values ranging from 5,823-7,524 cal/g and average 6,697 cal/g, 6,351-7,319 cal/g and average 6,805 cal/g, and 6,543-7,350 cal/g and average 6,949 cal/g respectively. The density of these subbituminous-high volatile bituminous coals is relatively constant with mean of 1.3 g/cm^3.

The average gas volume for the Air Laya mining coals is approximately 4.1-5.3 m^3/t, but each seam has slightly different content. The estimate for the A1 bed ranges from 3.3-4.8 m^3/t with mean 4.1 m^3/t, whilst the A2, B, and C coals comprise natural gas in the range of 4.2-5.6 m^3/t with mean 4.9 m^3/t, 4.4-5.4 m^3/t with mean 4.9 m^3/t, and 4.9-5.7 m^3/t with mean 5.3 m^3/t, respectively. The resulted gas estimates suggest that there is an increase in gas content with depth or temperature gradient (Fig. 4). This implies that the higher coal rank, principally due to the deeper burial, may contain the higher gas volume. Evaluation of gas-in-place in the present study indicates that individual seam possesses distinctive values, but the total gas in all seams is about 3,019x10^6 m^3.

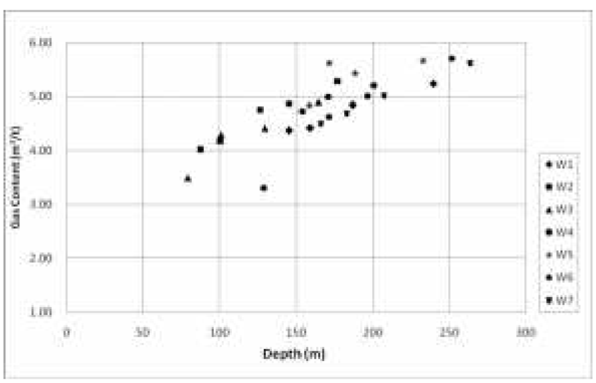

Fig. 4 Diagram displaying the depth vs gas content relation. The gas content tends to increase with depth

5. CONCLUSIONS

In order to conclude the above discussion, some remarks are drawn as the following:

1. The coal seams in Air Laya mining area are subbituminous and high volatile bituminous with various apparent thickness and extensive lateral distribution throughout the region.
2. The average gas content is about 4.1-5.3 m^3/t, and there appears an increase in gas content with depth.
3. The total of gas-in-place is approximately 3,019x10^6 m^3.

6. ACKNOWLEDGEMENT

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