CLEAT CHARACTERISTICS IN TERTIARY COAL OF THE MUARAENIM FORMATION, BANGKO AREA, SOUTH SUMATERA BASIN: Implications for Coalbed Gas Potential

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Abstract

The sub-bituminous coal seams of the Muaraenim Formation commonly overlie claystone, sandstone or shaly siltstone. Coal seams are mostly dull to bright banded lithotype, well developed of cleat system, maceral composition dominated by vitrinite with rare inertinite and minor liptinite and mineral matter. In order to determine cleat systems and a possible relationship with the development of coalbed gas potential within the coal seams, detailed observation on coal seams characteristics, determination and measurement on cleat pattern and orientation, as well an insitu gas in place content measurement (Q1) within the coal measures were performed. Field measurement from outcrops demonstrate well-developed cleat within the coal seams, with high in spacing (Σ8.93 cm) and moderate in density (0.1512/cm - 0.21/cm) and cleat aperture (1 - 3 mm). SEM analysis provides microcleat characteristics with a rare to medium density. Micro focus observation and examination on microcleat, face microcleats appears to be most prominent compared to butt microcleats. Microcleats also found mostly in open aperture. Gas content of the coal seam indicates a low to moderate methane content, with overall calculation of gas in place from six coal seams around 15.297,73 scf. Moderate level of mineral matter content in coal, as well as an excessive rare of clay minerals infill in microcleat may influence on increasing methane adsorption capacity. Moderate to high density and well continuity of cleat and microcleat could affect enhancing permeability, and plays important role in methane migration and production. Indeed, the coal characteristics and cleat systems of the Muaraenim Formation maybe favorable for coalbed gas potential.

Keyword: Coalbed gas, Cleat systems, Muaraenim Formation

S a r i

Lapisan batubara sub-bituminus dari Formasi Muaraenim biasanya menutupi unit batulempung, batupasir dan batulanau menyerpih. Lapisan batubara ini umumnya memiliki karakteristik dull sampai dengan bright banded, terkekarkan dengan sangat baik, komposisi maseral didominasi oleh maseral vitrinit, dengan sedikit maseral inertinite dan liptinite, serta jarang sekali mineral pengotor. Untuk menentukan sistem cleat dan kemungkinan hubungannya dengan potensi gas metana pada lapisan batubara tersebut telah dilakukan pengamatan rinci terhadap karakteristik batubara dilapangan dengan melakukan pengukuran pada pola dan orientasi cleat, serta melakukan pengukuran langsung kandungan gas metana dari setiap lapisan batubara. Hasil identifikasi singkapan batubara dan pengukuran dilapangan menunjukkan cleat sangat berkembang baik, dengan spasi (Σ 8,93 cm), densitas (0.1512/cm - 0.21/cm) dan ruang bukaan pada cleat (1 - 3 mm). Analisis SEM memberi gambaran karakteristik microcleat dengan densitas jarang sampai dengan menengah. Pengamatan mikrofokus dan pemeriksaan terhadap microcleat, menunjukkan bahwa face cleat lebih dominan bila dibandingkan dengan butt cleat, keduanya umumnya memiliki aperture yang terbuka. Kandungan gas metana pada lapisan batubara umumnya menujukkan kategori rendah sampai sedang, dengan kandungan sekitar 15, 297.73 scf. Relatif rendahnya kandungan mineral pengotor dan sangat jarangnya mineral lempung pengisi microcleat dapat mempengaruhi pada peningkatan kapasitas adsorpsi gas metana pada lapisan batubara tersebut. Densitas cleat yang relatif tinggi dan kontinuitas dari cleat yang sangat baik juga dapat mempengaruhi peningkatan permeabilitas. Kedua hal tersebut diatas memiliki peranan yang sangat penting dalam migrasi gas metana pada lapisan batubara serta produksinya. Pada akhirnya dapat diambil simpulan bahwa karakteristik batubara dan sistem cleat dari Formasi Muaraenim memiliki potensi untuk pengembangan gas metana batubara.

Kata kunci : gas pada lapisan batubara, Karakteristik Cleat, Formasi Muaraenim

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Introduction

Tertiary coal measures of the Muaraenim Formation are well confined as major methane resources in the South Sumatera Basin. Coal characteristics in this area raise significantly the opportunity for the CBM exploration in the future. The coal bearing unit of Muaraenim Formation is generally composed of underlying and overlying coal seam that comprises claystone, mudstone, siltstone, and sandstone, commonly tuffaceous. The mudstone and claystone dominate the rock unit. Tuffaceous sandstone lenses or wavy bedded tuffaceous sandstone are common to be recognised.

Based on the previous field observation, five coal seams can be recognized in the Bangko area, consisting of Seam Keladi, Merapi, Petai, Suban and Mangus (Suwarna and Heryanto., 2007). The coal seams commonly overlie by claystone, sandstone or shaly siltstone, and in turn underlie carbonaceous mudstone layers or hard - black shaly coal, where both layers are light grey, and show parallel lamination structure. Coal lithotype varies from dull banded to bright banded, with dirt bands (clay/mud layers), pyrite, and also tonsteins or silicified coal layers.

The coal characteristics of the Muaraenim Formation and their relationship with the coalbed methane potential have been determined by previous workers or co-workers in several areas in the South Sumatera Basin (Suwarna *et al*., 2006; Suwarna and Heryanto, 2007; Permana, 2008, Hermiyanto and Setiawan, 2010). They summarized that the coal lithotype and coal geochemistry from the Muaraenim Formation are favorable for coalbed methane development. Megascopic observations of the cleat development of the Muaraenim coals and its association with the coal lithotype also have identified by some previous researchers (Suwarna *et al*., 2006). Moreover, on the micro-scale, Panggabean (2005) identified the characteristics of microcleat, including size, shape, aperture, spacing or density on the some coal seams of the Muaraeniem Formation, by using scanning electron microscopy (SEM) analysis. However, the relation of the nature cleat characteristics and coalbed methane potential in the Muaraenim Formation is not really known yet. This paper provides the characteristics of Muaraenim coals and its relationships with coalbed gas resources, with also highlights on the cleat systems of the Muaraenim coals, and a possible relationship with the development of coalbed gas reservoir.

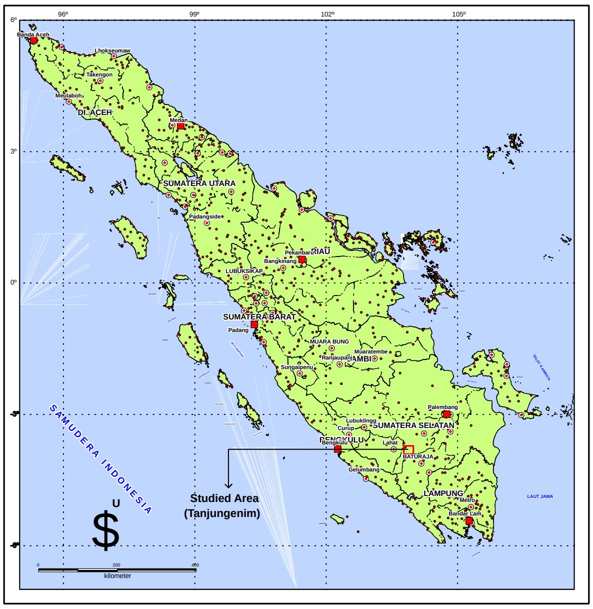


Figure 1. Location map of the study area (Bangko Area, PT Bukit Asam Coalfield).

Methods

The study area is located in the Darmo Village, approximately 25 km to the southeast of Tanjungenim, in the area of PT. Bukit Asam Coalfield, Bangko Area (Figure 1). Geologically, this area is included into the Muaraenim Anticlinorium of the "Garba Trend" with NW-SE fold axis trending. The study is mainly focused on coal seams of the Late Miocene-Pliocene of the Muaraenim Formation.

Geological field investigations and laboratory techniques were conducted, to achieve the aims of the study. The fieldwork investigations including detailed observation on coal seams characteristics, determination and measurement on cleat pattern and orientation were performed in selected site of the study area, as well an insitu gas in place content measurement (Q1) within the coal measures (Figure 2).

A series of coal samples from selected area of the Bangko Area, PT Bukit Asam Coalfield were collected, and then were subjected to several analytical techniques. Six blocks polished were examined under the organic microscopic analysis, by using a Zeiss Axioplan reflected light microscope, with both white (100 W halogen) and blue violet (HBO) light sources. This analysis was applied to determine the coal rank type and maceral composition. The other six coal samples were also examined under SEM to get more detailed modes and occurrence of maceral and mineral matter composition, as well as identified micro-cleat system on the coal samples.

Furthermore, to gain more information about gas in place content within the coal measures, gas desorption during transportation (Q2) and residu gas (Q3) were determined. Some coal samples were also subjected to proximate analysis (volatile matter) for determining gas content based on Barbara and Winter Diagram.

Result of Investigation

Coal Lithotypes

The coal seams in the area are suggested to occupy the low geologic condition region, due to fault disturbances taking place within the area that is hardly observed. Commonly, the coal seams overlie claystone, sandstone or shaly siltstone, and in turn underlie carbonaceous mudstone layers or hard - black shaly coal, where both layers are light grey, and show parallel lamination structure. Based on the core samples present, thickness of each sub-seam is more than 1.0 m.

Megascopically, in general, the coal lithotype varies from dull banded to bright banded (Figure 3). The coal is characterized by black – brownish black colour, black – brownish black streak, brittle – friable, even-uneven, resin patch and striation content, dirt bands (clay/mud layers), pyrite, and also tonsteins or silicified coal layers with thickness of 0.15 – 0.40 cm. Thickness of the coal outcrop and cores varies from 0.20 – 6 m, averaging in 2.5 m. Dip of the coal seam around 15^{o} – 30^{o}.

Figure 2. In-situ measurements (Q1) of gas methane content by using simple field equipment in the Bangko Area of PT. Bukit Asam, Tanjungenim, South Sumatera.

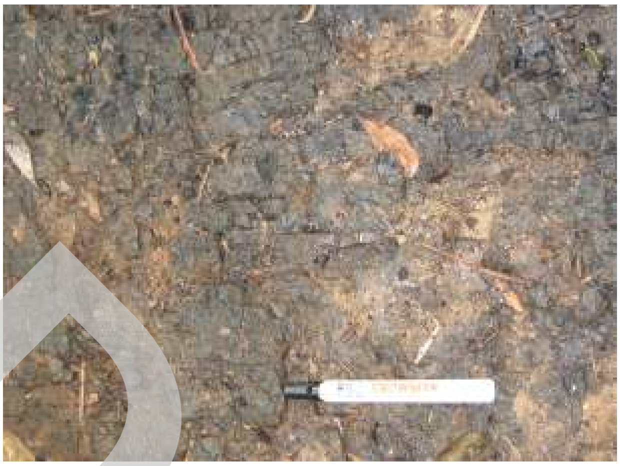


Figure 3. Coal lithotype of the Muaraenim Formation, showing well cleated dull banded.

Maceral analysis

Petrographic analysis shows that the coal is dominated by vitrinite (71.8 – 89.0 %), with minor amount of inertinite (3.6 – 39.8 %), liptinite (1.8 – 3.8 %) and mineral matter (2.4 – 14.4 %). Vitrinite reflectance having values of 0.43 – 0.45 %, tends to indicate a sub-bituminous coal rank, which can be classified as a low rank level (UN-ECE, 1998).

Vitrinite is mainly composed of detrovitrinite and telovitrinite, with small amount of gelovitrinite. Detrovitrinite is essentially composed of desmocollinite and densinite. Desmocollinite together with gelovitrinite are present as structureless groundmass, in some cases in association with cutinite and pyrite (Figure 4a). Telovitrinite shows a massive texture, with fairly uniform structures, while corpocollinite is usually present as discrete, with various shapes in sub-rounded to round.

Liptinite consists of mainly liptodetrinite and resinite, with sparse of sporinite, alginite, suberinite. Liptodetrinite is usually found as fine disperse fragment, while resinite is a common maceral found as rounded of in situ cell filling. Furthermore, inertinite is predominantly composed of sclerotinite and semifusinite, with small amount of fusinite and inertodetrinite. Sclerotinite is in association with detrovitrinite and semifusinite, originally derived from fungal with characteristics rounded shape (Figure 4b).

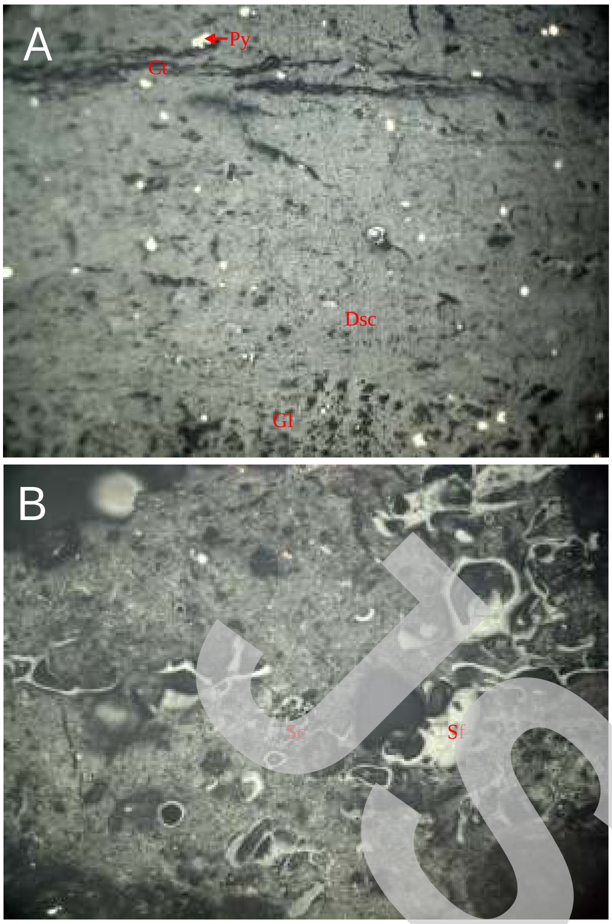


Figure 4. Photomicrograph of vitrinite and inertinite macerals; A: Desmocollinite (Dsc) together with gelovitrinite (Gl) present as structureless groundmass, in some cases in association with cutinite (Ct) and pyrite (Py); B: Semifusinite (Sf) in association with rounded shape of sclerotinite (Sc).

Mineral matter ranges from 2.4% to 14.4%, which mainly consists of pyrite and clay mineral. Clay mineral was identified commonly as small lenses and cell lumens infillings in association with detrovitrinite, while pyrite is mainly found as rounded shape infillings the detrovitrinite. Pyrite may occur as both framboidal and non framboidal.

Mode of maceral and mineral matter occurrence was also identified by SEM. Under the SEM analysis, maceral is composed of predominantly vitrinite and inertinite, with minor liptinite. They mainly occur in association with mineral matter. Telovitrinite is in association with rounded isolated of inertinite (fusinite) and lenses of clay mineral. Clay mineral (chlorite) is mostly found as small to large lenses within the telocollinite and fusinite sub-macerals (Figure 5).

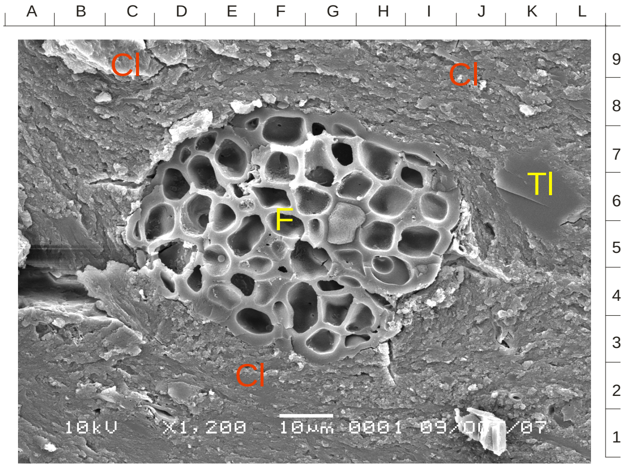


Figure 5. Photomicrograph of the maceral composition from the SEM analysis (10 Kv, 1x, 10 µm, sample code: 07 NIR 07A). Rounded shape of fusinite (F) maceral in association with the telocolinite (Tl), with dispersed of clay minerals (Cl).

Cleat Characteristics

Cleats can be determined and observed by megascopic (macro cleats) and microscopic (microcleats, micropores, and microcracks) analyses. Field investigation on cleat system (megascopic) was conducted on an area of 1 x 1m of coal of each seam cropping out. It includes detailed observation the type of cleat features and measurement of cleat orientation, cleat spacing, cleat aperture and cleat density.

The orthogonal cleat set is general type of cleat geometry that can be identified in the study area. This set is found as strike or sub-curve line, which is mainly perpendicular or oblique to the coal seam bedding. The cleat set has both face and a butt cleat feature, which is well developed in the brighter coal lithotypes. Face cleats appear to be most prominent compared to butt cleats. Microcleats are found within the coals that are mostly open aperture (Figure 6A, B), with very rare irregular kaolinite clays infilling in particular case, formed by epigenetic processes during the coalification. This epigenetic kaolinite was formed by fluid circulation within the coal seam. Spears and Caswell (1986) indicate that the kaolinite mineralization is formed in response to pore fluid evolution and movement during the burial diagenesis.

Detailed measurement on cleat from coal exposures in the Bangko area demonstrates that the dip direction of coal face cleat varies from N30°E to N330°E with dip of 55° to 88°; cleat space ranges between 0.2 cm to 25 cm, with averaging 8.93 cm; aperture of 1 to 3 mm, and density of 0.1512/cm to 0.21/cm.

7 (seven) coal samples analyzed have been labeled as 07NIR 02A, 07NIR 03A, 07NIR 04A, 07NIR 06A, 07NIR 07A, 07NIR 08A and 07NIR 09A. Of those samples, one sample (07NIR 04A) is shally coal, whilst the other six samples are purely coal. Each sample of a total 7 (seven) coal samples examined carefully under SEM method has been analyzed for determining mode of mineral and maceral occurrences, as well cleat system development within the coal seam. Summary of the SEM results on microcleat characters and measurements of each coal sample is listed in Table 2. Detailed observation and examination on cleat occurring within coal samples were carried out; it includes frequency density, length, aperture and the type of cleats (face or butts).

The density of microcleats ranges from 0.02 micron square/freq. microcleat to 0.08 micron square/freq. microcleat. Five coal samples (labeled as 07 NIR 02A, 07 NIR 04A, 07 NIR 06A, 07 NIR 07A and 07 NIR 09A) have high density value of microcleats ranging from 0.06 to 0.08 (Table 2), while the others two samples have low density value (0.02 to 0.03). It means that those five coal samples may be favorable for CBM reservoirs.

SEM analysis has shown that the microcleats occur as un-mineralized face and butt microcleats, which is mainly strike or sub-curve line, with open aperture (Figure 7). The calculation from the SEM analysis the aperture ranges from 0.1 to 0.8 micron (Table 2). Thus, this may indicate that the microcleats may be good connector for the pathway of gas migration and adsorption within the coal seam.

Coalbed gas Resources

Considering the availability of Tanjungenim field and laboratory data set required for calculating CBM resources, the calculation of gas in-place potential in the area was conducted. Parameters used to calculate the gas in-place potential of the Tanjungenim consist of theoretical gas content based on Barbara and Winter Diagram, and Lost Gas during drilling (Q1) plus gas desorption during transportation (Q2) and residu gas (Q3). Thereby, the parameter used is the theoretical gas content calculation on the basis of the Barbara/Winter Diagram (Figure 8).

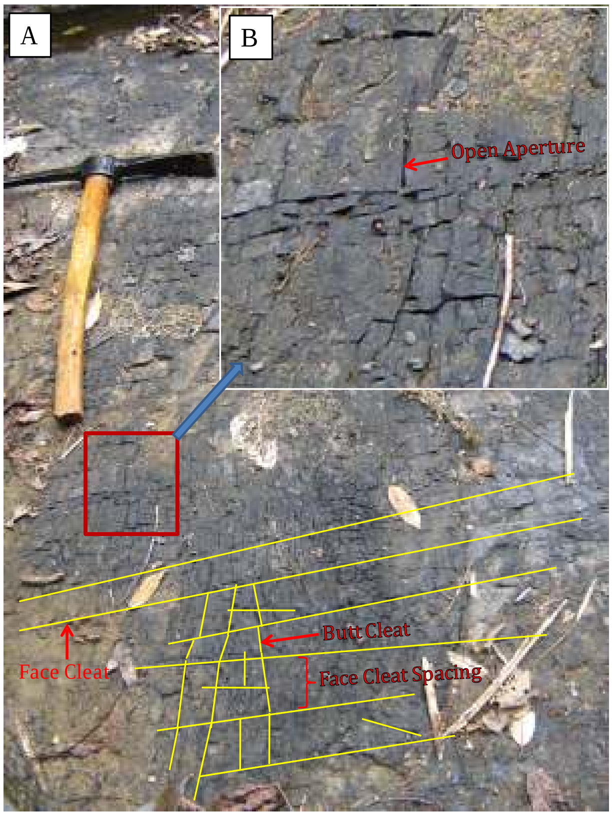


Figure 6. Megascopic features of the cleat system from the Muaraenim coals, showing the orthogonal cleat set, with open aperture of both face and butt cleats.

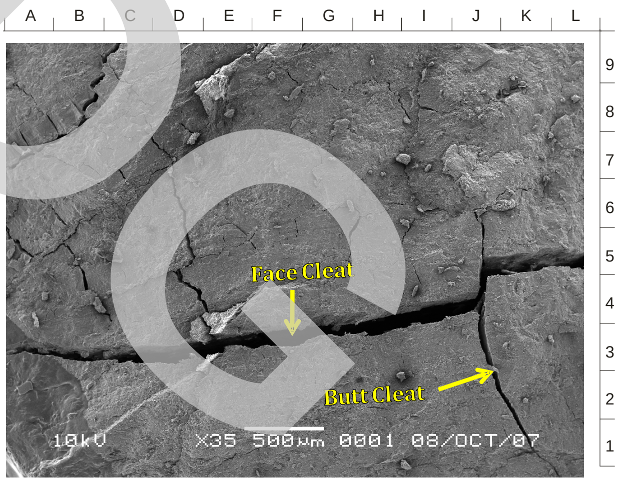


Figure 7. Photomicrograph of the cleat types in the Muaraenim coal seam (SEM, 10kv, 35x, 500 µm, sample Code: 07 NIR 04A), showing the strike line of face microcleats, with open aperture, cross cut by the sub-curve of butt microcleats.

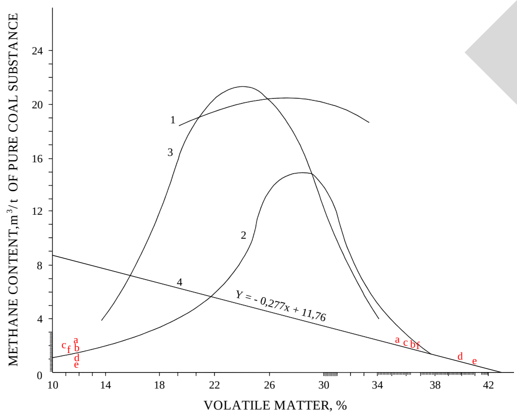
In order to calculate the theoretical gas in-place potential of the study area, the required important parameter is the volatile matter content (from proximate analysis) of the coal. The graphics of Volatile Mater versus Methane content according to Barbara-Winter are shown in Figure 8. The content of methane gas within the coal seam in the Bangko Area ranges from 0.53 m^3/t – 2.02 m^3/t. = 18.65 scf/t – 49.85 scf/t .

The calculation or formula for the gas in-place calculation has been also proposed by some researchers (Maccarthy *et al*., 1996; Aminian, 2007), with some modifications as written below:

Based on this formula (which is supported by the Q1, Q2 and Q3 values), gas in-place of the Bangko and surrounding areas have been calculated as shown in Table 3. The total reserve of gas in reservoir in the investigated area (six coal seams) is 15.297,73 scf.

Discussion

Coal seam may be found as both source and reservoir rock for coalbed methane (Levine 1993; Rice 1993). An extremely richness in organic matter may possibly be coal seam as an excellent for source rock, while



LEGEND :

1. ACCORDING TO SCHULZ
2. ACCORDING TO WINTER
3. ACCORDING TO STUFFKEN EXPERIMENTAL MINE
4. ACCORDING TO BARBARA

Code Samp.	Coal Seam	Volatile Matter	Methane Content	
			(4)	(2)
07 NIR 02A	a	35,30	2,02	0
07 NIR 04A	b	36,47	1,71	0
07 NIR 06A	c	35,88	1,89	0
07 NIR 07A	d	39,77	0,82	0
07 NIR 08A	e	40,91	0,53	0
07 NIR 09A	f	36,68	1,68	0

Figure 8. Gas content determinations of the six coal samples from the Bangko area, based on Barbara and Winter Diagram, showing the methane content ranges from 0.53 to 2.02 m3/t.

due to well developed of cleat or fracture system within the coal seam may be the reason coal as possible effective reservoir rock for coalbed methane. Tremain *et al*. (1991) indicates that the distribution cleat type and density of cleat within the coal seam are important role in affecting the rate and direction of gas or water flow in the coal. In the following section will be discussed the characteristics of the Muaraenim coals in the light of its potential as coalbed gas source and reservoir.

Coalbed gas source

Coal properties are influenced by both coal rank and type. These are interdependent parameters, increasing coal rank during the coalification process, changing the physical and chemical properties of maceral that reflected changes in properties and behavior of the coal (Diessel, 1992). Thus, the coalification process and variation of coal composition may profoundly affect the source rock potential of coal for gas production.

Some workers believe that that coal type influences gas adsorption by coal (Faiz et al., 1992; Lamberson and Bustin, 1993; Crosdale and Beamish, 1995). In the similar coals rank, they indicate that vitrinite rich coal may have greater methane adsorption capacity than inertinite-rich. However, Faiz *et al*., (1992) show that almost no correlation may be found between adsorption capacity and maceral composition. In particular case, inertinite rich coals have been found to have greatest methane adsorption capacity (Ettinger *et al*., 1996).

Beamish and Gamson (1993) have shown the relationship of gas sorption and coal type from the Bowen Basin, Australia. They indicate that the bright coals are shown to have significantly higher methane adsorption capacities than dull coal from the same seam. The bright coals are vitrinite rich, while the dull coals are dominated by inertinite, particularly semifusinite. Studies on the maceral composition in the relation with gas content from the Muaraenim Coals may have similar case. Relatively bright coals with vitrinite rich maceral indicate have higher gas content than the dull (inertinite rich maceral). It can be seen from coal samples 07 NIR 04A and 07 NIR 06A, which is relatively high content of vitrinite 89% and 81% (Table 1), have higher gas content about 74.752 m^2/t and 78.442 m^2/t respectively (Table 3). Thus, this may indicate that the vitrinite rich coal from the Muaraenim Formation is potentially good source rock for coalbed gas resources.

Table 1. Coal maceral composition from the Muaraenim coals, Bangko Area, Tanjungenim.

No	Sample Code	TC	TL	Dns	Dsm	DT	Crp	GL	V	Sp	Cu	Re	Sb	Alg	Lipt	L	F	Sf	Sc	Intr	IN	Cly	Crb	Py	MM	Rv min	Rv max	Rv mean
1	07 NIR 02A	11.6	11.6	10.6	48.0	58.6	1.6	1.6	71.8	0.8	-	1.0	0.4	0.6	1.0	3.8	-	1.0	8.4	0.6	10.0	0.4	1.0	13.0	14.4	0.4	0.5	0.4
2	07 NIR 04A	10.4	10.4	10.0	67.4	77.4	1.2	1.2	89.0	1.0	0.4	-	-	0.6	0.4	2.4	-	-	3.6	-	3.6	2.0	-	3.0	5.0	0.4	0.5	0.5
3	07 NIR 06A	28.0	28.0	12.0	40.0	52.0	1.0	1.0	81.0	-	-	0.6	0.6	0.6	-	1.8	-	2.0	7.6	1.6	11.2	3.0	-	3.0	6.0	0.4	0.5	0.4
4	07 NIR 07A	39.4	39.4	16.0	18.0	34.0	4.4	4.4	77.8	0.4	0.6	1.4	-	-	1.4	3.8	-	2.6	9.0	3.6	15.2	2.0	0.6	0.6	3.2	0.4	0.5	0.4
5	07 NIR 08A	23.0	23.0	4.6	22.6	47.2	3.0	3.0	73.2	-	0.4	1.4	-	0.6	-	2.4	1.0	26.4	6.4	6.0	39.8	1.6	0.4	2.6	3.6	0.4	0.4	0.4
6	07 NIR 09A	26.4	26.4	9.6	48.8	58.4	1.2	1.2	86.0	-	-	-	0.4	1.0	1.4	2.8	-	2.6	5.4	0.8	8.8	2.0	-	0.4	2.4	0.4	0.5	0.4

Notes:								
	TC	Telocolinite	Sp	Sporinite	F	Fusinite	Cly	Clay
	TL	Telovitrinite	Cu	Cutinite	Sf	Semifusinite	Crb	Carbonates
	Dns	Densinite	Re	Resinite	Sc	Sclerotinite	Py	Pyrite
	Dsm	Desmocolinite	Sb	Subrinite	Intr	Inertodetrinite	MM	Mineral matter
	DT	Detrovitirnite	Alg	Alginite	IN	Inertinite	Rv min	Vitrinite Reflectance minimum
	Crp	Corpocolinite	Lipt	Liptodetrinite			Rv max	Vitrinite Reflectance Maximum
	GL	Gelovitirnite	L	Liptinite			Rv mean	Vitrinite Reflectance Mean
	V	Vitrinite						

Coalbed gas reservoir

Beside coal lithotype and maceral composition, porosity or permeability is also primary factors on CBM development. Cleat characteristics in coal have a significant contribution to permeability in controlling the distribution and production of coalbed methane (Tremain *et al*. 1991; Faraj *et. al* 1996; Gamson *et al*. 1996; Clarkson and Bustin, 1997). Moreover, Close et al. (1990) reveal that permeability is perhaps the most important aspect of a CBM play. They have shown that fracture permeability could be the most critical control on CBM production in parts of the San Juan Basin.

The permeability of coal derives from the natural fracture system or cleat system within the coal seam. Cleat originally forms from a number of independent influences, including lithification, dessication, coalification and tectonic stress (Close 1993; in Ayers, Jr., 2002). The cleats exist in two mutually systematic, orthogonal fracture systems (face and butt) that are commonly perpendicular or nearly perpendicular to bedding, which impact significant permeability anisotropy to a particular coal reservoir for the transfer of methane. The face cleat orientation reflects the far-field stress present during their formation (Laubach *et al*., 1998; in Ayers Jr., 2002). Cleat permeability is controlled by fracture density (spacing), aperture width and openness, extent, and connectivity. These factors, in turn, are controlled by coal rank, coal quality (ash content), maceral composition, bed thickness, tectonic deformation, mineralization, and in-situ stress (Close, 1993 and Laubach *et al*., 1998; in Ayers Jr., 2002).

As described in the previous section, the cleat system in the Muaraenim coals are mainly found as orthogonal cleat set and well developed in the mostly brighter coal lithotype. Maceral composition resulting from the selected coal sample of the study area was also indicated high vitrinite content (up to 90%). Smyth and Buckley (1993) have demonstrated that the vitrinite-rich (bright) coals are more permeable than dull coals, and have interpreted this to be due to greater abundance of cleating in the vitrinite-rich coals. Others studies from Australia, Beamish and Gamson (1993), Crosdale and Beamish (1993) have shown a good relationship between coal lithotype (coal rank and composition) and gas sorption. They reveal that the bright (vitrinite-rich) coals are shown to have significantly higher methane content adsorption capacities than their dull coal equivalents from the same seam in many cases. Thus, this may indicate that the well developed cleat system of the Muaraenim coals, with relatively high vitrinite content may contribute to increase permeability and methane adsorption within the coal seam in the study area.

Many researchers have shown that cleat spacing varies with coal type and ash content (Tremain *et al*., 1991; Law 1993). Bright coal lithotypes (vitrinite rich) generally have smaller cleat spacing than dull coal lithotypes (Stach *et al*., 1982). Coals with relatively low ash content tend to have smaller cleat spacings than coals with the high ash contents (Laubach *et al*., 1998). Moreover, some researchers (Tremain *et al*., 1991; Law, 1993) have shown that the average of cleat spacing is linearly proportional to coal lithotype layer thickness.

Dull to bright banded lithotype of the Muaraenim coals, with vitrinite rich maceral composition and low mineral content tend to be have smaller cleat spacing (mostly around 0.2 – 8 cm). Moderate to high density and well continuity of cleat and microcleat of the coal seams could affect enhancing permeability, and plays important role in methane migration and production.

Moderate level of mineral content within the Muaraenim coals from the study area, as well as an excessive rare of clay mineral infillings in microcleats may also influence on increasing methane adsorption capacity.

Conclusions

1. The Muarenim Coal Measures generally underlying and overlying coal seam comprise of claystone, mudstone, siltstone, and sandstone, commonly tuffaceous. Coal is characterised by the dull to bright banded, showing black – brownish black, brownish to black streak, brittle – friable, dull-greasy luster, even-uneven, dirty the fingers, containing resin patch and striation, dirt bands (clay/mud layers). Thickness of each coal sub-seam is more than 0.75 m. The interburden comprises light grey fine-grained sandstone, siltstone, claystone, and shale.
2. The dominant maceral is vitrinite (71.8 – 89.0 %), with minor amount of exinite (1.8 – 3.8 %), inertinite (3.6 – 39.8 %) and mineral matter (2.4 – 14.4 %). Vitrinite reflectance having values of 0.43 – 0.45 %, tends to indicate a sub-bituminous coal rank, which can be classified as a low rank level (UN-ECE, 1998).
3. Well developed of cleat system, with the dip direction of coal face cleat varies from N30°E to N330°E with dip of 55° to 88°; space ranges between 0.2 cm to 25 cm, averaging 8.93 cm; aperture of 1 to 3 mm, and density of 0.1512/cm to 0.21/cm.
4. Coalbed methane content of the coal seam, based on the Barbara-Winter Diagram, ranges from 0.53 m^3/t – 2.02 m^3/t. This character indicates an in-situ coal to have a low to moderate methane content. Gas in-place reserve in six coal seam supported by the Q1,Q2 and Q3 calculations shows a calculated various value 15.297,73 scf.
5. Relatively bright coals with vitrinite rich maceral, low mineral matter content, well developed of cleat system indicate that the Muaraenim coals are favorable for both source and reservoir rock in coalbed methane development.

Table 2. Detailed measurement of microcleats within the Muaraenim coal seam, by using SEM (Scanning Electron Microscope)

No.	No. Sample	Microcleat type	Length (micron)	Width of Aperture (micron)	Density (100 micron2/ FreqCleat	Remark
1	07NIR 02A	Face (75%); Butts (25%)	60; 30; 150; 25; 10; 25; 10; 100	0.5; 0.1; 0.3; 0,1; 0.2;0.1; 0.6; 0.5	0.06	Open aperture (100%)
2	07NIR 03A	Face (60%); Butts (40%)	250; 100; 110; 120; 50	0.7; 0.1; 0.2; 0.5; 0.2	0.02	Open aperture (100%)
3	07NIR 04A	Butts (90%); Face (10%)	1000; 500; 300; 1000; 100	0.8; 0.5; 0.5;0.8;0.5	0.06	Open aperture (100%)
4	07NIR 06A	Face (60%); Butts (40%)	500; 100; 300; 100; 100; 100; 120;	0.8; 0.5; 0.8; 0.5; 0.3; 0.3; 0.5	0.08	Open aperture (100%)
5	07NIR 07A	Face (60%) Butts (40%)	1000; 1200; 500; 200; 150; 500	0.8; 0.6; 0.6; 0.4; 0.4; 0.6	0.06	Open aperture (100%)
6	07NIR 08A	Butts (70%) Face (30%);	100; 75; 75; 100	0.8; 0.8; 0.4; 04	0.03	Open aperture (100%)
7	07NIR 09A	Face (60%); Butts (40%)	30; 30; 10; 30; 20	0.2; 0.2; 0.1; 0.3; 0.5	0.07	Open aperture (100%)

Table 3. Result of gas content (gas in place) calculation of the six coal samples from the Bangko Area, Tanjungenim

No.	No. Sample	Adsorption value	Geochemical content			Density	Gas In Place	
			Ash	Moisture	CO2 content		m2/t	Scf
1	07 NIR 02A	75.9770	0.9550	0.78	0.954	1.3	70.189	2516.99
2	07 NIR 04A	79.6102	0.9510	0.775	0.98	1.3	74.752	2680.59
3	07 NIR 06A	78.5936	0.9916	0.804	0.963	1.3	78.442	2812.93
4	07 NIR 07A	65.0744	0.9916	0.805	0.987	1.3	66.650	2390.09
5	07 NIR 08A	60.9047	0.9895	0.842	0.982	1.3	64.779	2322.97
6	07 NIR 09A	81.3064	0.9032	0.78	0.964	1.3	71.783	2574.15
								15,297.73

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