The Role of Coal Facies to Adsorption of Methane Gas: Case Study on Warukin and Tanjung Formation Binuang Area, South Kalimantan Province

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***Abstract*—Adsorption of methane gas is affected by coal facies, as a consideration when exploring Coal Bed Methane (CBM). The Binuang area located in South Kalimantan is an area where coal carrier formations, namely the Warukin Formation and the Tanjung Formation, are well exposed. Sampling of coal was carried out using a channel sampling method from the youngest coal in the Warukin Formation to the oldest coal in the Tanjung Formation. The methodology applied in this research uses mineral analysis and adsorption of methane gas to find out the coal facies using a diagram conducted by previous researchers. There are two types of coal facies in the Warukin Formation, namely coal facies delta plain wet forest swamp and delta plain fen. In Tanjung formation, the coal facies that develops is delta plain wet forest swamp and delta plain fen. Changes in coal facies will cause the different ability of methane gas adsorption. Coal with a depositional environment (facies) of Delta wet plain swamp has more excellent adsorption of methane compared to adsorption of methane gas in delta plain fen facies.**

***Index Terms*—coal facies, gas adsorption, peat, Tanjung Formation, Warukin Formation**

I. INTRODUCTION

The Barito Basin in South Kalimantan province has several thick and widespread coal seams,One of the area that the coal currently being explored is Binuang area. The Binuang area is an area where the coal carrier formation is exposed. Coal outcrops include coal in the Miocene. Warukin Formation [1] and the Eocene Tanjung Formation [2]. Coal in the Barito basin is currently exploring the potential of coal methane gas (GMB). Based on hypothetical calculations, the volume of coal methane gas is quite large, namely 101 TCF [3]. The volume of coal methane gas is influenced by the ability to absorb methane gas in each different coal layer. The physical properties of coal influence the difference in adsorption of methane gas; one of the physical properties is maceral. The composition of maceral can be used to determine the environment in which peat is obtained (facies) [4]-[6]. The depositional environment (facies) of coal resulting from maceral observations has been used since 1950 [7]. The environment of deposition of peat can be seen from the coal maceral composition [8]. Unfortunately, the problem adsorption of methane gas has not been of particular concern in coal methane gas exploration. In order for efficient methane gas exploration to estimate the volume of methane gas, it is necessary to consider the condition of the coal facies. Determination of coal facies from coal mineral composition can be done by using the Gelification Index (GI) diagram - Tissue Preservation Index (TPI) and the Ground Water Index (GWI) diagram - Vegetation Index (VI) [9] which is very popular and has been applied to coal formed in the delta environment. According to Zhao, 2017 there is a close relationship between facies of coal in the delta environment with a small amount of adsorption of coal methane gas.

Adsorption of methane gas formed during the coalification process will be absorbed in the coal micropore. The adsorption capability of coal methane gas is related to the physical properties of coal, including coal mineral and rank are essential factors in evaluating CBM [10], [11]. Coal facies built by maceral composition and coal structure are closely related to gas adsorption characteristics.

Calculation of gas adsorption by theoretical using the Langmuir equation [12]. Several previous experts have applied calculations in calculating the adsorption of coal methane gas, which is considered a monolayer. Although the adsorption of coal methane is not a monolayer, the Langmuir model is still valid; it is applied because coal has an isotherm adsorption type [13].

Manuscript received January 16, 2020; revised May 22, 2020.

doi: 10.18178/ijges.6.2.20-26

Based on the above reasons, a more detailed assessment is needed in coal methane gas exploration. This study aims to determine the relationship of coal facies to the adsorption behavior of coal methane gas. This research was conducted to assess the condition of coal facies in absorbing methane gas, coal quality, and finding solutions to problems in methane gas exploration to be faster and more efficient.

The research location is in Binuang area, Tapin Regency, South Kalimantan Province, Indonesia, with coordinates 298560 mN, 9664676mE in the Northern part and 294624 mN, 9638097 mE in the Southern part. The research objective is to produce a conceptual model of coal facies and its effect on the adsorption of methane gas in methane gas exploration.

II. METHOD

This research was carried out by applying analytical methods using primary data. Primary data is carried out by surface geological mapping and sampling in the field.The coal sampling using the channel sampling method on coal in the Warukin Formation consists of 3 (three) samples including Warukin Atas coal, Middle Warukin coal, and lower Warukin coal and 2 (two) coal in the Tanjung Formation covering coal seam B, and coal seam C, the correlation between deep drill wells located at coordinates 2648024 mN and 9617637 mE with coal outcrops can be seen in Fig. 1, the coordinates of each outcrop are as follows (Table I).

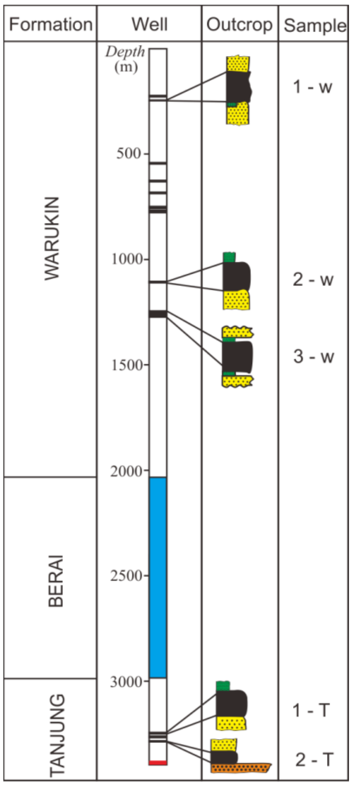

Figure 1. Correlation well log with outcrop along with number sampling.

The coal samples were dried at 40˚C then crushing, then samples were taken with a 250-gram reliable method sieving with 1 mm particle for coal petrographic analysis and 0.121 mm for Isotherm adsorption analysis.

TABLE I. COORDINATES OF COAL OUTCROP

Code of sample	Northing (mN)	Easting (mE)
1 - W	292906	9661384
2 - W	295725	9661292
3 - W	298560	9664676
1 - T	294624	9638097
2 - T	294618	9638075

Samples resulting from sieving 0.6 - 1.0 mm sizes were used to make polishing incisions with the Meta Serv 250 tool, standard observation procedures [14]. Vitrinite reflectance was measured using the Craic Coal Pro microscope (ASTM 2856, 1986. ASTM 2009).

The procedure for knowing vitrinite reflectance is that the sample is standardized first with the standard measurement of vitrinite reflectance in the microscope, namely: Spinel = 0.427, Sapphire = 0.505, N Last 46 A = 1.37, after standardizing the vitrinite reflectance and then observing the magnitude of the vitrinite reflectance.

The isotherm adsorption test is carried out based on the volumetric method to determine sorption capacity as a function of pressure; the gas used is methane gas (CH4) purity 99.9%. The volumetric method refers to Australia's Commonwealth Scientific and Industrial Research Organization (CSIRO), in this method the volume of gas absorbed by the sample is measured indirectly by injecting methane gas gradually with pressure varying to a pressure of 16 Mpa (2320 psi) with varying temperatures. This test kit is operated automatically via a computer with the CSIRO.

Adsorption Isotherm System software so that the pressure when injection can be controlled. The relationship of volume - pressure at a certain temperature (sorption isotherm) can be used to determine the gas storage capacity and estimate the volume of released gas from the sample in line with the decrease in reservoir pressure. In general, the relationship between storage gas capacity and pressure uses the Langmuir equation (1).

$$\mathrm{GI} = \frac{\mathrm{VLP}}{\mathrm{PL+P}} \qquad (1)$$

where: *Gs* = Storage gas capacity, m3 / ton
P = Pressure, KPa
VL = Langmuir Volume Constant, m3 / ton
PL = Langmuir pressure constant, KPa

To determine the coal deposition environment uses deposition environment diagram from Diessel (1986)with the following equation (2) and (3).

$$\mathrm{GI} = \frac{\mathrm{Vit+Mac}}{\mathrm{Fus+Semi+Iner}} \qquad (2)$$

where: *GI* = Gelification Index, *Vit* = Vitrinite, *Mac* = Macrinite, *Fus* = Fusinite, *Semi* = Semifusinite, *Iner* = Inerdetrotrinite

$$\mathrm{TPI} = \frac{\mathrm{Tel+Telo+Fus+Semi}}{\mathrm{Des+Vitro+Gelo+Corpo+Iner+Mac}} \qquad (3)$$

where: *TPI* = Tissue Preservation Index, *Tel* = Telinite, *Telo* = Telocolinite, *Des* = Desmocolinite, *Vitro* = Vitrodetrinite, *Gelo* = Gelocolinite, *Corpo* = Corpocolinite.

There is a close relationship between indicators of coal facies and the appropriate depositional environment [15]. These indicators are the Gelification Index (GI) and Tissue Preservation Index (TPI). This model has been carried out on low-rank coal [16].

Another method that is commonly used to determine the coal deposition environment from the indicator Groundwater Index (GWI) and Vegetation Index (VI) refer to Eq. (4). GWI is based on the ratio between vitrinite and internal structure (telinite and telocollinite) to vitrinite which shows no internal structure (gelocolinite, desmocolinite, and corpocolinite) and Mineral matter. Vegetation Index (VI) shows vegetation type. Maseral from plants rich in plants shows a dry environment, plants with little lignin are found in aquatics.

$$\mathrm{VI} = \frac{\mathrm{Tel+Telo+Fus+Sub+Res}}{\mathrm{Des+Iner+Al+Li+Spor+Cut}} \tag{4}$$

where: *VI* = Vegetation Index, *Sub* = Suberinite, *Res* = Resinite, *Al* = Algenite, *Lip* = Liptodetrinite, *Spor* = Sporinite, *Cut* = Cutinite.

III. RESULT AND DISCUSSION

The maseral content of vitrinite group in the coal of Warukin Formation ranges from 58% - 62%, in general, the vitrinite group is dominated by submaceral telocollinite and desmocollinite. Inertinite group is generally abundant, sample 1 -W inertinite group is 36.8%, sample 2 - W Inertinite group is 37%, sample 3 - W inertinite group is 37.6%, generally compiled by sclerotinite. semifusinite and fusinite are spread in almost all samples with a range of 0.4% - 9.4%, the value of Vitrinite Reflectan is 0.31% - 0.34%.

The maseral content of the vitrinite group in the coal of Tanjung Formation is around 68% - 75.8%, in general, the vitrinite group is dominated by submaceral telocollinite and desmocollinite. Inertinite group is generally abundant, sample 1 - T inertinite group is 31%, sample 2 - W inertinite group is 23.8%, generally composed by sclerotinite. Semifusinite and fusinite are scattered in almost all samples with a range of 0.6% - 12.4%, the value of Vitrinite Reflectanis 0.57% - 0.62%.

Liptinite group is rarely found only in samples 3 -W and 1 - T with a content of 0.4% - 2.8%, generally in the form of resinite submaseral. The mineral matter with a content of 0.4% - 3% is generally in the form of pyrite, the form of euhedral or framboidal pyrite found in filling holes in maceral inertinite.

Based on the results of previous researchers suggested that the depositional environment of the Warukin Formation is lower delta plain - upper delta plain, a type of coal facies in the form of wet forest swamps. Woody plants dominate the plant composition of peatlands, and there are herbaceous plants [17]. Deposition environment of Tanjung Formation upper - lower delta plain with facies of wetforest swamp coal [18].

The results of the calculation of the TPI value in the coal seams of the Warukin Formation in samples 1-W and 3 - W were obtained TPI 2.29 - 2.41 and in the 2 –W sample obtained TPI 1.27. The high TPI value in samples 1 -W and 3 - W shows the percentage of presence of more wood plants (in this case indicated the percentage of large maceral telocolinite. TPI in sample 2 - W value is lower than the sample above, this shows the low percentage of presence of plants woody (in this case higher percentage of maceral desmocolinite) (Table II).

The value of TPI coal of the Tanjung Formation in sample 1 - T has a TPI value of 1.10 and 2 - T sample obtained TPI value of 2.36. Plotted in the Diessel diagram coal facies (Fig. 2) it can be interpreted that the coal seams in the Warukin Formation (samples 1 –W and 3 - W) and the Tanjung Formation (sample 2 - T) are formed in the same depositional environment which is at the stage of wet forest swamp.

The results of GWI calculations on coal in the Warukin Formation and Tanjung Formation coal are classified as low <0.5%. The low value of GWI shows the low tide (siltation) located in the ombrotrophic bog. The results of calculating VI coal seams in samples 1 - W, 3 - W, and 2 - T are 1.70 - 2.85, indicate a smaller percentage of the origin of herbaceous plants. Coal samples 2 - W and 1 - T values VI 0.75 - 1.13 (Table III), this shows the percentage of the origin of more herbaceous peat plants.

The results of the calculation of TPI and GI values plotted in the Diessel facies diagram (1986) can be interpreted as facies of coal in the Warukin Formation (2 –W sample and Tanjung Formation (1-W) deposited in telmatic conditions with depositional environments (facies) located at Fen stage.

TABLE II. PETROGRAPHIC COMPOSITION OF STUDIED COAL SAMPLES (VOL%)

No.	**Sample**	Vitrinite group			Inertinite group					Liptinite Group			Mineral		
	code	**T**	**D**	**ΣV**	**F**	**S**	**Sc**	**M**	**ΣI**	**R**	**L**	**ΣL**	**Py**	**ΣM**	**Romax**
1	1 - W	33.5	28.4	61.9	0.6	14.4	20.2	1.6	36.8	0	0	0	1.6	1.6	0.28
2	2 - W	25.2	31.9	57.1	0.4	8.6	18.5	9.4	36.9	2	0	2	4	4	0.33
3	3 - W	43.2	18.2	61.4	1	7.6	18.4	10.6	37.6	0	0	0	1	1	0.33
4	1 - T	21.5	41.1	62.6	0.6	8.4	18.6	3.4	31	0.4	0	0.4	6	6	0.53
5	2 - T	46.4	29.4	75.8	0	4	19.4	0.4	23.8	0	0	0	0.4	0.4	0.58

T,Telocolinite; D, Desmocolinite; ΣV, Sum Vitinite; F, Fusinite; S, Semifusinite; Sc, Sclerotinite; M, Macrinite; ΣI, Sum Inertinite; R, Resinite; L, Liptinite; ΣL, Sum Liptinite; Py, Pyrite; Ro max, maximum ReflectanVitrinite

TABLE III. THE CALCULATION RESULTS OF PI, TPI, GWI, AND VI

Sample	TPI	GI	GWI	VI
1-W	2.29	1.80	0.03	1.70
2 - W	1.28	2.42	0.07	1.13
3 - W	2.44	2.67	0.02	2.85
1 - T	1.10	2.39	0.10	0.75
2 - T	2.36	3.22	0.02	1.72

Based on the values of the Tissue Preservation Index (TPI) and Gelification Index (GI) which are then the results of the calculation of TPI and GI values plotted in the Diessel facies diagram (1986) can be interpreted as facies of coal in the Warukin Formation (2 –W sample and Tanjung Formation (1-W) deposited in telmatic conditions with depositional environments (facies) located at Fen stage.

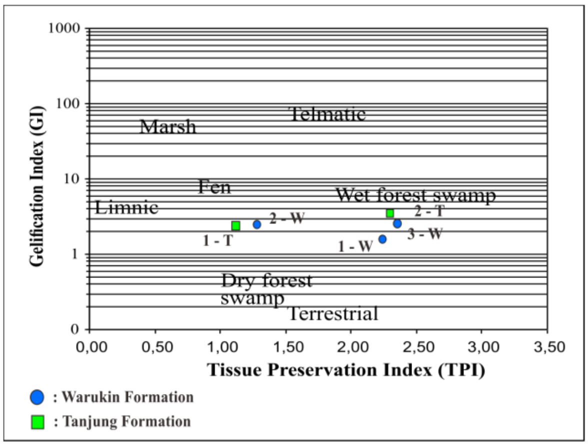

Figure 2. GI – TPI diagram for coal facies types of studied samples (base map modified from Diessel,1986).

Based on the plot of the Ground Water Index (GWI) and Vegetation Index (VI) values in the diagram Calder *et al.*, 1991, coal in the Warukin Formation and Tanjung Formation is formed in the ombrotrophic bog deposition environment (Fig. 3) formed under acidic conditions with supply low food (oligotrophy). Based on plots of GWI and VI values from the modified Calder *et al.*, 1991 (Fig. 4) diagram of Zhao *et al.* (2017), coal facies in the Warukin Formation and Tanjung Formation can be grouped into two types of coal facies:

a). Delta Plain Wet Forest Swamp is a mire formation zone which is controlled by variations in surface water. This facies is characterized by coal that is relatively moist with peat filling plants with a small herbaceous percentage. b). Delta Plain Fen is a zone of peat or mire formation which is controlled by transgression and regression processes. Plants formed at this stage are herbaceous plants that supply the formation of peat in wet conditions. Arborescent plants are scarce at this stage, and the plant tissue is decomposed very strongly. Active decomposition will cause a reduction in micropores. In this fen stage during a flood, it will cause high preservation of organic sulfur, which causes high sulfur content.

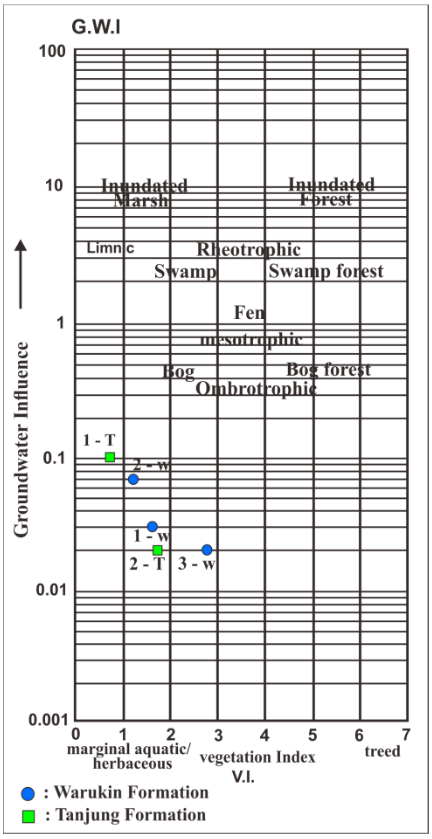

Figure 3. GWI – VI diagram for coal facies types of studied samples (base map modified from Calder, 1991).

The process of evolution of peat will be significantly influenced by plants, water conditions, acidic or essential properties, and redox conditions [19]. In general, if the hydrodynamic conditions are weak, fewer loose materials are brought into the mud, which will cause less ash content. Analysis of research results shows a positive correlation between sulfur content and ash content (Fig. 5).

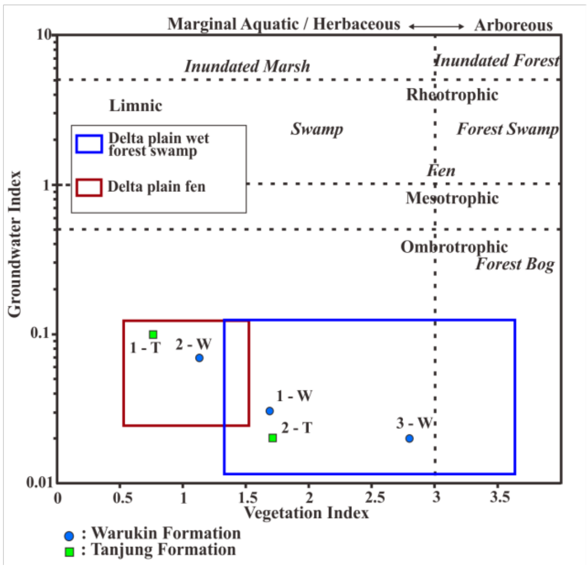

Figure 4. GWI-VI diagram for coal facies types of studied coal samples (base map from Calder *et al.*, 1991, modified from Zhao *et al.*, 2017).

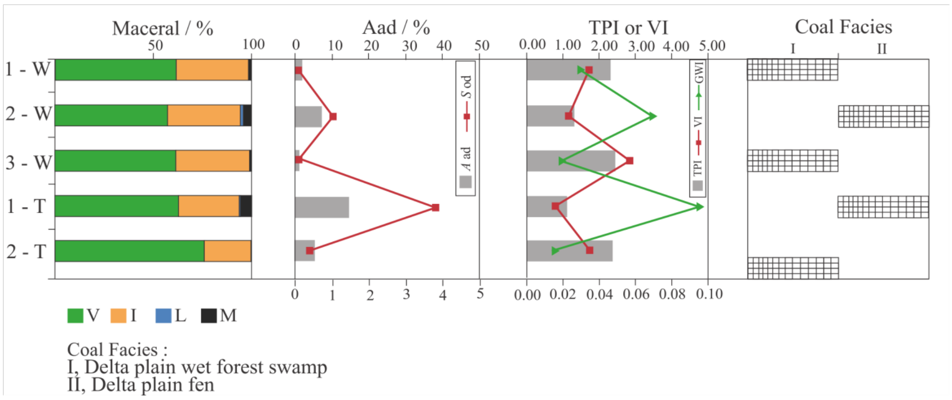

Figure 5. The relations of maceral, proximate, TPI-GWI-TPI, and coal facies in the study area.

A positive correlation is also formed between GWI and ash content, so also between ash content and TPI has a positive correlation (Fig. 5). The levels of ash, pyrite, GWI, and TPI are useful indicators to explain the evolution of peat in the study the facies of coal in the Warukin Formation in sample 3 - W (below) is afacies delta plain wet forest swamp, then sample 2 - W (middle) coal facies is a delta plain fen facies, then in sample 1 – W (Upper) returns to coal facies delta wet forest plain swamp. This shows a change in the history of peat formation. The lower coal layer (3-W) is formed in the facies delta plain wet forest swamp, and the transgression process occurs which causes changes in the coal depositional environment to delta plain fen (2-W). The regression process occurs in the upper coal seam (1 - W) marked by the depositional environment (facies) turned into a delta plain wet forest swamp.

Coal facies (2 - T) deltaic environment delta plain wet forest swamp, then due to the transgression process occurs a change in the sedimentary environment in to facies delta plain fen (1- T). The transgression process continues to become a sea trough, the formation of limestone Berai Formation indicates this.

Based on the adsorption analysis of methane gas isotherm, the adsorption capacity of methane gas in each sample can be seen in Table IV.

TABLE IV. ANALYSIS RESULTS OF ADSORPTION METHANE GAS

Sample	Depth (m)	Hydrostatic pressure at seam depth (psi)	Adsorbed CH4 storage capacity at seam depth (scf t-1)	
			as receive (scf/ton	daf (scf/ton)
1- W	427.48	628	97	203
2 - W	587.95	823	158	205
3 - W	685.74	1008	182	224
1 - T	3410.85	2229	315	336
2 - T	3420.02	2247	431	450

Based on the adsorption value of coal methane gas in Table IV for sample 2 - W the adsorption value of methane gas approaches the value of methane gas in sample 1 - W even though between samples 1 - W with 2 - W have much different depths. Samples 1 - T and 2 - T have small depth differences of 12 m, while gas adsorption values in 1 - T samples are compared with adsorption of methane gas in 2 - T samples smaller in value for sample 1 - T. According to Zhao *et al.*, 2017 states that there is a link between the adsorption of coal methane gas and depositional environment (facies). Adsorption of coal methane gas in different facies will cause different gas uptake; this difference is strongly influenced by peat-forming plants and different water conditions. Arborescent plants will decrease in percentage from delta plain wet forest swamp to delta plain fen, while herbaceous plants in the delta plain fen have a higher percentage, this is characterized by greater maceral desmocolinite (Table II). Herbaceous plants will experience decomposition resulting in micropores. In the delta plain fen water conditions that increase, this is indicated by the higher GWI values in the samples 2 -W and 1-T compared to the GWI values in samples 1 - W, 3 -W, and 2 - T. Changes in water conditions will also cause changes in plant tissue, oxidation, and mineral content. Adsorption of abundant methane gas if the accumulation of peat and peat landfill is running fast and the mineral content will occur a little in the Upper Delta plan for wet forest swamp. Fig. 4 shows the ash content and sulfur in sample 2 - W (Warukin Formation) and sample 1 - T (Tanjung Formation) is relatively larger with other samples. This shows that the two samples were deposited in the delta plain fen, based on Fig. 3 shows that the adsorption value of coal methane gas in the 2 –W sample is relatively smaller compared to the sample 1 –W (Warukin Formation) and sample 1 - T the adsorption value is smaller compared to sample 2 - T (Tanjung Formation).

The adsorption of coal methane gas in the Warukin Formation with coal facies in the delta plain wet forest swamp (sample 1-W and 3 _W) is higher than the adsorption of methane gas in coal facies of delta plain fen (sample 2 - W) and Tanjung Formation with coal facies in delta plain wet forest swamp (sample 2 - T) the adsorption value is higher for coal facies delta plan fen (sample 1 - T) (Table IV).

The effect of the presence of pyrite in the pores in maceral sclerotinite causes a smaller pore, which results in reduced adsorption of methane gas [20]. This can be shown in Table I where pyrite in coal Formation Warukin samplesis 2 W (4%) and pyrite in Tanjung Formation coal samples 1- T value (6%), this will cause reduced adsorption of methane gas due to micropores in scelotinite is filled with pyrite with a framboidal form which results in reduced micropore resulting in reduced adsorption of coal methane gas.

IV. CONCLUSION

Based on the GI-TPI and GWI-VI diagrams, coal facies in the Warukin Formation are delta plain wet forest swamp and delta plain fen. Coal facieses in the Tanjung Formation are delta plain wet forest swamp and delta plain fen. Delta plain wet forest swamp in coal of Warukin Formation isat the bottom and top, while atthe middle part of the developing facies is delta plain fen. Coal facies in the Tanjung Formation at the bottom develop in delta plain wet forest swamp, while atthe upper part develops facies delta plain fen.Based on the absorption value of methane in each coal facies changes. Absorption of methane gas in coal facies in the delta plain wet forest swamp is large, while the absorption of methane gas in delta plain fen facies is small.

Changes in adsorption of methane gas in different faciesare due to different plant factors and changes in water activity at the time of peat formation.

CONFLICT OF INTEREST

The location research was located in several companies including PT Antang Gunung Meratus, PT BMB, and PT Tanjung Alam Raya. However, this research was carried out without any conflict of interest.

AUTHOR CONTRIBUTIONS

Ir. Sugeng, MT conception, design, acquisition, analysis and interpretation of data drafting the article. Prof. Dr. Ir. Sari Bahagiarti Kusumayudha, MSc critical reviewing language and final approval of the version be submittd. Dr. Ir. Heru Sigit Puwanto, MT critical revieing and final approval of the version be submitted. Dr. Ir. Basui Rahmad, MT review of coal petrology, coal facies, content of the article, and final approval of the version be submitted. Nanda Ajeng Nurwantari, ST review of coal facies, content of the article, final approval of the version be submitted, and presentation of paper.

ACKNOWLEDGMENT

The research was carried out Due to the assistanceship by the Institute of Research and Community Service, Universitas Pembangunan Nasional "Veteran" Yogyakarta and several companies including PT AntangGunungMeratus, PT BMB, and PT TanjungAlam Raya for which the authors expressed their gratitude.

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