



# Middle Miocene Black Shale of Airbenakat Formation in Berau Areas, Jambi: are they potential as a source rock

Putri Dwi Afifah<sup>1\*</sup>, Budhi Setiawan<sup>2</sup>

<sup>1</sup>Geological Engineering Study Program, Sriwijaya University, Srijaya Negara street, Bukit Besar, Palembang

\* Corresponding author : afifahputridwi@gmail.com

Tel.: + 628-237-774-5121

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## Abstract

Geologically, the research area is located in Jambi Sub-basin that composed by Peneta Formation (KJp), Airbenakat (Tma), and Muaraenim (Tmptm). The research focuses on the physical characteristics and geochemistry of Middle Miocene black shale from Airbenakat Formation. The research aims to determine the potential of Middle Miocene black shale of Airbenakat Formation as a source rock. The research methods were field observation which included the description of rock samples and geological mapping, and laboratory analysis including rock geochemical analysis that show pyrolysis measurement and Total Organic Carbon. Three samples were taken from black and fine-grained shale. Total organic carbon (TOC) values of the three samples ranged from 0.38-0.42%, the weight of TOC indicates a potentially close enough to produce hydrocarbons. The pyrolysis results showed that the value of S1 and S2 data were below 0.5 and 2.5 HC/g rock respectively, so it can be seen that the three rock samples were not sufficient enough to produce hydrocarbons. Overall the sample have the S2/S3 ratio ranging from 0.09-0.23 and Tmax-HI data has values ranging from 8-19 mg HC/g TOC, therefore the S2/S3 ratio was less than 1 and the value of the index hydrogen was below 50 mg HC/g TOC, it can be concluded that the samples were type IV kerogen. The maximum temperature (Tmax) of pyrolysis showed a value of less than 4350C, ranging from 350-4280C. So, it can be interpreted that the three samples are immature source rocks because the catagenesis phase to produce hydrocarbons has not been achieved. The conclusions is the three samples of black shale indicate potential as immature source rock and has the close enough ability to produce hydrocarbons.

**Keywords:** Source Rock, Shale, Airbenakat Formation

## 1. Introduction

### 1.1 Sub Introduction

Geographically, the research area is located in Berau Village, Cermin Nan Gadang District (Figure 1). Geologically, the location of this research is in the Airbenakat Formation of Jambi Sub-basin.

Jambi Sub-basin is part of South Sumatra Basin which is in the back arc basin (Barber, et al., 2005). South Sumatra Basin has diverse geological characteristics, including geomorphological, stratigraphic, and geological characteristics. So that, the South Sumatra Basin is an excellent object to be studied. The Airbenakat Formation in this research area composed by sand and gray to black shale. The presence of black shale is being the background of this research. Geochemical analysis of black shale aims to find out whether this black shale has a potential or not as a source rock in Jambi Sub-basin.

## 2. Geological framework

According to Pulunggono, et al. (1992), South Sumatra Basin with the southern part of Sumatra Island oriented to NW-SE. The area of this basin is around 85.670 km<sup>2</sup> and consists of two sub-basins, namely Jambi and Palembang Sub-basin. Jambi Sub-basin is oriented towards the NE-SW and is bounded by the Tigapuluh Mountain in the north, Southern Lampung in the south, Sunda Shelf in the east, and Barisan Mountain in the west. Palembang Sub-basin is NNW-SSE trending, and between them is separated by normal NE-SW faults.

South Sumatra Basin is a large basin. The uneven relief as well as the reactivation of the bundle fault control the sedimentation and folding of the Tertiary layer. Tectonic developments in this basin are divided into four phases (Pulunggono, et al., 1992) (Figure 2).

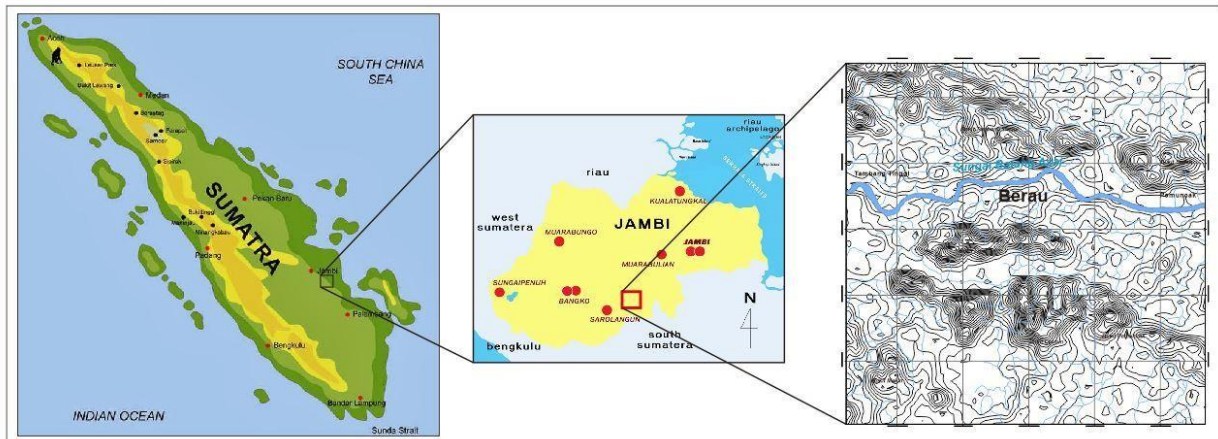


Fig.1 Research Location Map (BNPB of Jambi Province, 2010).

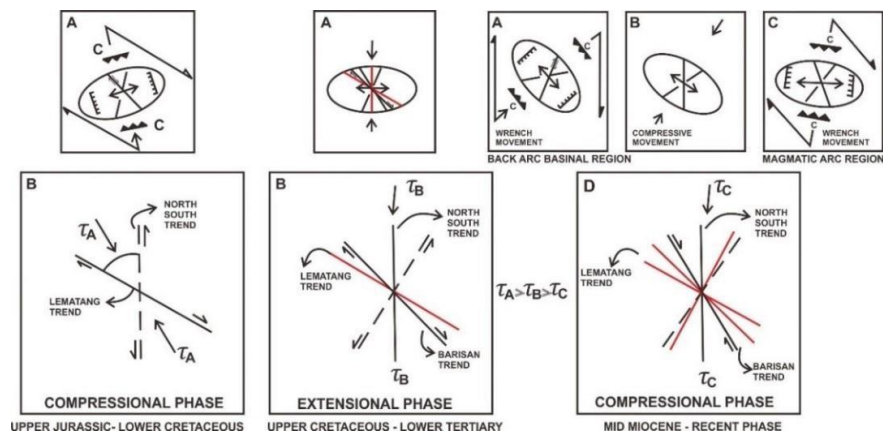


Fig.2 Tectonic developments of South Sumatra Basin (Pulungono, et al., 1992).

- Phase 1 (Jurassic-Lower Cretaceous)

The occurrence movement of the Indian Ocean Plate to the northwest, the mechanism will be compressed and in tandem with tectonic control, which is tilted towards the WNW-ESE line of Sundaland which induces its volcanic and accompanies the direction of its sliding fault (fault zone) which is currently seen as straightness musi and alignment of the lematang with N 30o W directed center of Indian Ocean Plate to a WNW-ESE Sundaland side edge line, convergence angle is 30o. As a result there is volcanism which produce granitoid intrusion, along with direction of fault of shear dekstral (Lematang Fault) cutting N-S Fault. Lematang Fault activity and the N-S fault is silent at an angle of 60°.

- Phase 2 (Upper Cretaceous-Lower Tertiary)

The second phase develops an extensional phase. This force is oriented N-S and WNW-ESE experiencing the spreading form graben or depression. This causes the Lematang Fault to be east of the Kikim Fault originating strike slip fault SW-NE (N 30° E), becoming a normal fault of N 300° E. Subsequent developments into Limau produce horst and graben blocks. The block is the basement builder of the South Sumatra Basin. Volcanic intrusions shifting and producing Garba Hill is the result of subduction pathways that has been spreading.

- Phase 3 (Sedimentation Process)

The commencement of sediments filling into grabben blocks over the bedrock along the volcanic activity. This is the phase of tectonic miocene which causes uplift at the edges of the basin and followed by the precipitation of the clastic material. When this occurs, the formation of Barisan Mountain is oriented N 320 ° E. It also makes in the third phase called Bukit Barisan Orogeny. As a result, strike slip fault structures developed during the Middle Miocene period were accompanied by an increase in the rate of volcanic activity.

- Phase 4 (Plio-Pleistosen)

Compressional phase, the subduction zone changing from Sumatra Island to the oblique convergence and its direction N 6° E. This makes a "Semangko" shear fault block formed. As a result of wrenching product, rejuvenation and tectonic inversion. This Barisan Mountain stretches from the north-south oblique and NW- SE oriented. These mountain are limiting the South Sumatra Basin to the southwest with Bengkulu Basin.

## 2.1 Stratigraphy

According to Barber, et al. (2005), the stratigraphy of the basins in Sumatra is divided into four phases of tectonostratigraphy: pre-rift phase, horst and graben phases (high and valleys), transgressive phases, and regressive phases (Figure 3).

- Pre-rift Phase (Eocene)

The Pre-rift phase of the Sumatra Basin occurred during the Eocene period which, after some time in a stable state, was affected by tectonic regime changes indicated by sedimentation on Sundaland's periphery. The sediments formed include the Eocene nummulitic limestone found at the edge of the Bengkulu Basin. In the period before the Horst and Graben periods indicated active volcanism activity was reinforced by the discovery of Kikim Tuffs consisting of tuffed sandstone, conglomerate, breksia, and clay, Late Cretaceous and Early Paleocene and the discovery of Old Andesites.

- Horst dan Graben Phase (Late Eocene-Oligocene)

After the Pre-rift phase, in the late Eocene-Oligocene period there is a change of tectonic regime where the lifting occurs causing the formation of Horst and Graben is then filled by rift sediments called Lahat/Lemat Formation in Middle Miocene until the final Oligocene. The Lahat Formation consists of breksia, a polymic conglomerate, and sandy gray sandstones.

The conglomerate fragments are derived from bedrock consisting of slate, phyllite, metasandstone, marble, basalt, andesite, and quartz veining. The depositional environment of Lahat Formation is interpreted as fluvial, alluvial fan, and lacustrin in the center of the basin. The Lemat Formation consists of tuffed shales, rocks, green- brown flakes, and sandstone with thin intercalation of coal, carbonate, and glauconite. In areas between fine- grained materials sometimes there is a granite wash material that interpreted as the result of erosion of the deposited granite not far from the source rock.

This phase has yet to separate sedimentation between the back arc basin and fore arc basin. The Barisan Mountain which separates the sedimentation area of back and fore arc basin marks the occurrence of regional tectonic changes in the final Oligocene which resulted in inversion by the folding of sediments deposited in the Horst and Graben periods. The appointment of Barisan Mountain accompanied by erosion also causes unconformity during subsequent sedimentation.

- Transgressive Phase (Late Oligocene-Middle Miocene)

The transgressive phase occurred during the Middle Oligocene-Middle Miocene, marked by regional subsidence in almost all basins in Sumatra. At this phase especially in the Late Oligocene there is also the appointment of Barisan Mountain or the establishment of the Sumatran arc system and separate the sedimentation of the back arc basin and sedimentation of the fore arc which the source of the sediment comes from Barisan Mountain. Sediments deposited in the early stages of this transgressive phase are Talang Akar Formations consisting of sandstones, rocks and shales that gradually change into carbonaceous flakes by insertion of coal into the basin with a precipitation environment that varies from fluvial to shallow marine.

Due to the subsidence of the basin and transgressive phase in the Early Miocene, the source of clastic rock in the north began to decrease as the Sunda Plain has undergone denudation and upgrading, and the entire South Sumatra Basin becomes the suspected carbonate deposition environment of the Ramp/Platform type.

High areas such as the Musi High and the Northern Palembang High, remain relatively high compared to the lowland areas and evidenced by the growing environment of reef which is easily exposed to the surface in connection with the decrease of sea water. The peak of regional subsidence leads to marine transgression in almost all of South Sumatra Basin, which indicates the presence of marine deposits. The Baturaja and Gumai Formations are formed at this stage. Maximum sea thread occurs in the Middle Miocene, where at present the Barisan Mountain is almost all drowned. Baturaja Formation consists of limestone sediment platforms and limestone reefs formed above the high of bedrock. In some places or more layered limestone textures with shale deposited in deeper environments. The Gumai Formation consists of shale containing patches containing foraminifera, the rocks with fine glauconitic sandstone inserts and tuff lenses.

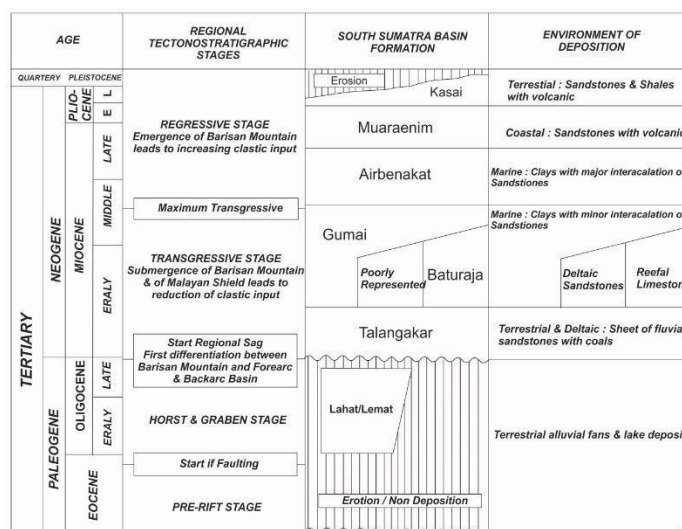


Fig. 3. Tertiary regional column of South Sumatra Basin (Barber, et al., 2005)

- Regressive Phase (Middle Miocene-Recent)

The subduction process accompanied by the reappointment of the Barisan Mountains causes the delta and coastal sediments to prograded away from the high areas so that Barisan Mountain becomes a source of sediment. The sediments formed in this phase are Airbenakat, Muaraenim, and Kasai Formation. Airbenakat Formation (Lower Palembang Formation) deposited during Middle Miocene and followed by the depositional of coal from Muaraenim Formation (Middle Palembang Formation) at Pliocene. The lithology of Airbenakat Formation includes shale with glauconite sandstone and limestone constituents deposited on the neritic environment at the bottom to a shallow marine environment at the top. In general the rock formation of this formation is deposited during the regressive phase. The Layer coating of this formation is a Middle Miocene shaped elbow composed of seafloor with glauconite and microforam in several places and layers of sandstone. The Muaraenim Formation was formed in the Late Miocene to Early Pliocene as shallow sea deposits, sublittoral and delta sediments consist of claystone, shale with sandstone intercalation and coal seams (Spruyt, 1956). This unit is deposited in marine brackish environments (at the bottom), delta plain, and non-marine environments. The fauna data from this formation does not exist, but it is estimated that this formation is Upper Miocene-Pliocene.

The peak of lifting and erosion period of the Barisan Mountains occurred in the late Pliocene and followed by intensive volcanism activities. The Kasai Formation was deposited at this time, largely a product of erosion from the elevations of Barisan and the Tigapuluh Mountains, and by the lifting of folds that occurred in the basin during the orogenesis. This formation consists of tuffed sandstone, gravel clay, and there is a thin layer of coal with varying thickness and composition.

## 2.2. Geology Structure

Ginger and Fielding (2005) divides the tectonic history of the Sumatra Basin into three Megasekuen tectonics. First is the Syn-Rift Megasequence, it is characterized by subduction in the western part of Sumatra that produces the North-South trending horizontal graben sequence. Second is the Post Rift Megasequence, in this megasekuen initially a thermal decline so that the phase of transgresi still occur, at the end of this megasekuen no thermal decline and increased sediment supply, there was a regression phase until depositional of Muaraenim Formation.

The third is Inversion Megasequence, this megasekuen is marked by the rise of Barisan Mountain on the western part of Sumatra Island, this megasekuen produces a structure that has a direction from the South-East fold. The three megasekuen tectonic changes lead to the formation of different lineaments according to the phases in the geological period. The structural pattern of Sumatra Island is relatively south-east based on the direction of Semangko Fault, due to the process of South Sumatra Basin has three antiklinorium consist of Antiklinorium Pendopo-Limau, Palembang, and Muara Enim. The Muara Enim

anticline is characterized by an assymetrical-overtuned wing with a fairly steep wing on the North with the general direction of the northwest to southeast.

The development of structures and the evolution of the basin since Tertiary is the result of interaction of three main structural directions, northeast-southwest direction or called Jambi Pattern, and Sumatra Pattern in South- Southeast direction, and North-South direction called Sunda Pattern. This is what makes the geological structure in South Sumatra Basin more complex than other basins on Sumatra Island. The geologic structure of Jambi Pattern is very clearly observed in the Jambi Sub-basin. The formation of Northeast-Southwest trending structures in this area is associated with the formation of a graben system in the South Sumatra Basin. The folding structure that develops on the Jambi Pattern is caused by the reactivation of normal faults in the Plio-Pliocene compressive period associated with horizontal fault.

## 3. Method

Methods of this research are field observation and laboratory analysis. Field observations consist of geological mapping, lithologic descriptions, and rock sampling. The sample for laboratory analysis comes from 3 rock samples taken laterally (Figure 4 and 5). Each sample was given a sample number and code of the location, then megascopically description was carried out. in the Laboratory of Research and Development of Oil and Gas Technology (Lemigas).

Geochemical analysis aims to determine Total Organic Carbon (TOC) and Rock Eval Pyrolysis, the results of Rock Eval Pyrolysis are a way to know the hydrogen content. Rock Eval Pyrolysis can estimate the hydrogen content from organic content through the value of S2. In addition, by measuring Rock Eval Pyrolysis, we can obtain S1, S3, Maximum Temperature (Tmax) data and Potential Yield (The Sum of S1 and S2), Oil Production Index (division between S1 and Potential Yield), Hydrogen Index ((S2/TOC)x100), and Oxygen Index ((S3/TOC)x100)).

## 4. Sample Description

The sample for the geochemical analysis in this research is shale of Airbenakat Formation with megascopic characteristics are fresh, solid, black (as an indication of organic content), massif structure, rounded, and very well sorted. The three samples taken on the limbs of the Berau Anticline, so that, tectonically, the three samples affected by the geological structure.

## 5. Data and Analysis

As an analogy study of source rock formation, sediment samples in the Jambi Sub-basin area have been evaluated by Rock Eval analysis and TOC content. The results of the analysis will be used in determining rock organic content, rock capacity as source rock, type of organic content, level of thermal maturity, and rock potential in producing hydrocarbons (Table 1)

Table 1. Total Organic Carbon (TOC) and Rock Eval Pyrolysis from geochemical analysis.

No.	Code of Sample	Lithology	TOC (%)	S1 (mg HC/g sample)	S2 (mg HC/g sample)	S3 (mg HC/g sample)	PY	PI	Tmax(°C)	HI	OI
1.	SFAB 1	Black Shale	0,38	0,04	0,07	0,30	0,11	0,36	414	19	80
2.	SFAB 2	Black Shale	0,39	0,02	0,03	0,31	0,05	0,40	428	8	79
3.	SFAB 3	Black Shale	0,42	0,03	0,07	0,36	0,10	0,30	350	17	87

TOC : Total Organic Content  
 S1 : Quantity of free hydrocarbon  
 S2 : Hydrocarbon quantity from kerogen  
 S3 : Organic Carbondioxide (CO2)  
 Tmaks : Maximum Temperature (°C) for hydrocarbon formation from kerogen  
 PY : Pyrolysis Yield (S1+S2)  
 PI : Production Index = S1/(S1+S2)  
 HI : Hydrogen Index (S2/TOC) x 100  
 OI : Oxygen Index (S3/TOC) x 100

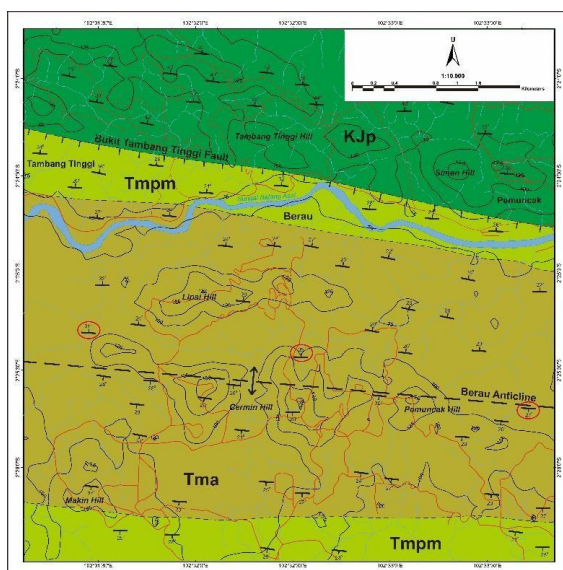


Fig. 4. Geological map of research area, the three samples taken in the location with symbol O on the map.



Fig. 5. Three black shale samples were taken for geochemical analysis (a) sample of observation location 35, (b) 36, and (c) 42.

## 5. 1. Total Organic Content

One of the parameters that must be considered to determine the potential of source rock is the value of Total Organic Carbon (TOC). TOC is a parameter that measured in percent (%), which is the percentage of organic carbon from the total weight of the rock sample. The TOC value generated by the sample has a range of 0.38-0.42%. A rock have potential as a source rock if it has a TOC content of more than 1.5% (Clayton, 2005). So that, it can be seen that the three samples are categorized as rocks with the capacity as negligible source rock (Waples, 1985) or have insufficient potential (poor) to produce hydrocarbons (Peters and Cassa, 1994) (Table 2).

Table 2. The organic content in the three rock samples analyzed based on the classification of rocks potential in producing source rock (Peters and Cassa, 1994).

Sample	Result of Analysis	TOC (%)	Classification of hydrocarbon Potential
		0-0,5	Poor
SFAB 1	0,38	0,5-1,0	Fair
SFAB 2	0,39	1,0-2,0	Good
SFAB 3	0,42	2,0-4,0	Very Good
		>4,0	Excellent

The data of S1 represents the amount of free hydrocarbons present in the rock (Clayton, 2005). The samples showed that the S1 is less than 0.5 mg HC/g and S2 showed values less than 2.5 mg HC/g of rock. Thus it can be concluded that the organic content in the three rock samples is not sufficient enough to produce hydrocarbons (Peters and Cassa, 1994).

## 5. 2. Type of Organic Content

Types of organic content are important in determining the potential of source rock. The material referred to this study is kerogen. Kerogen is an organic carbon deposited on rocks and composed of various organic contents such as algae, pollen, spores, and plant resins. Kerogen types will determine hydrocarbons that will be formed such as oil, gas, or oil and gas. The type of organic content from the three samples was determined using an S2/S3 ratio and hydrogen index value (HI) (Figure 6).

The plot of data shows that the ratio of S2/S3 ranges from 0.1 to 0.23, while the HI value ranges from 8-19 mg HC/g TOC. So that it can be seen that organic content from the three samples are type IV kerogen. if the value of the S2/S3 ratio is below 1 and the hydrogen index value is below 50 mg HC/g TOC then the type of organic content is type IV kerogen (Peters and Cassa, 1994).

The determination of organic content type can also be determined using the Tmax vs HI diagram (Peters,

1986). Based on the results of the plot diagram, it is found the suitability with the results of the previous diagram that showed the type of organic matter is kerogen type IV (Figure 5). Based on these results it can be concluded that the three rocks come from type IV kerogen of organic content that cannot produce hydrocarbons (Peters and Cassa, 1994).

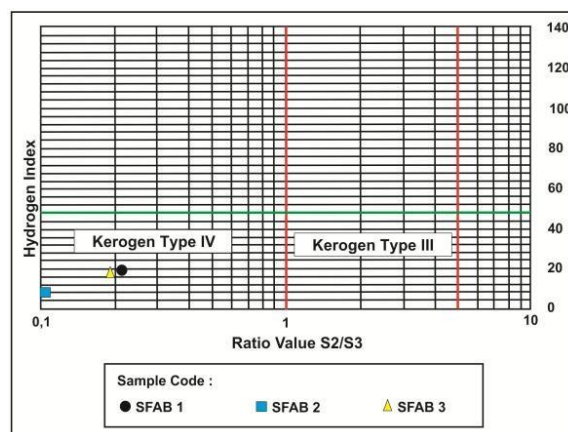


Fig. 6. Diagram of S2/S3 ratio versus hydrogen index (HI)

Type IV kerogen is interpreted come from organic content that have undergone oxidation process. The kerogen are materials that have been transported from the environment where the material comes from (Waples, 1985; Peters and Cassa, 1994; Mc Carthy et al., 2011). This interpretation is in line with the depositional environment of black shale Airbenakat Formation which is deposited on the marine environment, where sedimentary material is the result of transportation from terrestrial material.

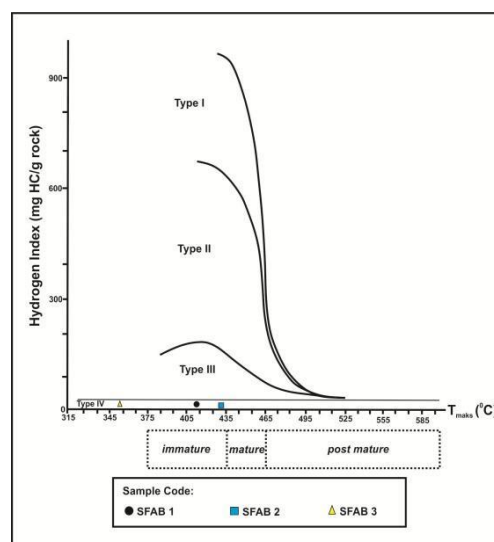


Fig. 7 Diagram of Tmax versus hydrogen index (HI) (Peters, 1986)

## 5.3. Thermal Maturity

Based on Tmax data (Table 1), all three samples have Tmax values ranging from 350-4280C. The value range is less than 4350C which is the lower limit of the rock maturity value. Therefore, it can be concluded that

all three samples are categorized as immature source rock.

## 6. Discussion

Based on the analysis and interpretation, it is possible to evaluate the source rock for the entire sample. The sample has low total organic content so that the capacity of source rock is negligible (Waples, 1985) and categorized as insufficient potential (poor) to produce hydrocarbon (Peters and Cassa, 1994). In this regard, it is necessary to verify the sample before analyzing TOC and Rock Eval Pyrolysis. The dark color contained in rocks is not only because it has a high content of organic matter but can be given by mineral pyrite which is abundant or can also be because the sample is in wet conditions.

Type of organic content in the sample is type IV kerogen. This type of kerogen cannot produce hydrocarbons (Peters and Cassa, 1994) because it comes from organic content that have undergone oxidation and transport processes from the environment where the material comes, this is makes the reduction of organic carbon value in rocks eventually decrease. This case was in line with the interpretation of the depositional environment of black shale Airbenakat Formation which is deposited in the marine environment, where sedimentary material is the result of transportation from terrestrial material.

The entire sample shows a thermal maturity value of less than 4350C, the rock sample has not reached thermal maturity (immature) because the cathagenesis phase to produce hydrocarbons has not been reached. This is affected by the young age and shallow depth of the formation, so there is a low burrial procees that makes small pressure values and low geothermal gradients.

## 7. Conclusion

Source rock evaluation of three black shale of Airbenakat Formation through TOC and Rock Eval Pyrolysis gives the following conclusions:

1. The source rock evaluation in this research focuses on elements that must be fulfilled to be said as source rock, such as the total of organic content, types of organic content, and thermal maturity.
2. Total Organic Carbon indicates the poor category to produce hydrocarbons.
3. The types of organic content is type IV kerogen, which suitable to the depositional environment of the Airbenakat Formation.
4. Tmax value less than 4350C indicates that the entire sample is in immature condition (the sample has not reached the cathagenesis phase).

## Acknowledgments

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## References

Barber, A. J., Crow M. J., and Milsom J. S., 2005. Sumatra : Geology, Resources, and Tectonic Evolution, Geological Society. Oxford.

- Clayton, C., 2005. Petroleum Generation and Migration. Nautilus, Ltd.
- Ginger, D., and Fielding, K., 2005. The Petroleum System and Future Potential of the South Sumatra Basin. Proceeding 30th Annual Convention and Exhibition, Indonesian Petroleum Association., 2005.
- McCarty, K., Rojas, K., Niemann, M., Palmowsky, D., Peters, K., and Stankiewicz, A., 2011, Oilfiel review Summer: 23/2, Schlumberger.
- Peters, K. E., 1986, Guidelines for Evaluating Petroleum Source Rock Using Programmed Pyrolysis, The American Association of Petroleum Geologists Bulletin, No. 3, Vol. 70, p. 318-329.
- Peters, K.E and Cassa, M.R., 1994, Applied Source Rock Geochemistry in The Petroleum System From Source to Trap, USA: AAPG Memoir.
- Pulunggono, A., Haryo, A. and Kosuma, C.G., 1992. Pre- Tertiary and Tertiary Fault systems as a framework of the South Sumatera Basin; A Study of SAR-MAPS. In Proceedings Indonesian Petroleum Association 21th Annual Convention.
- Spruyt, J.N., 1956. Subdivisions and Nomenclature of The Tertiary Sediments of The Jambi-Palembang Area. Pertamina Internal Report.
- Waples, D., 1985. Geochemistry in Petroleum Exploration. Boston, s.n.



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