CHARACTERIZATION SHALE OF THE LOWER BAONG FORMATION AS A POTENTIAL RESERVOIR IN A SHALE HYDROCARBON SYSTEM IN NORTH SUMATRA

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Abstract - Detailed studies of shale characteristics as a reservoir in shale hydrocarbon using surface data to configure the lithology and rock mechanics properties are considered as not much done in Indonesia. Therefore, shale potential as a reservoir in shale hydrocarbon system is not yet known well, it is due to the lack of surface and sub-surface data, especially from the core. The study of lithology characteristics of shale from lower Baong Formation integrated with rock mechanics properties (Brittleness Index), can be early method in identifying potential zone as a reservoir for oil and gas exploration in the future in Indonesia, especially in the mature basins so that it can lead to a new discovery in Indonesia. The Research stage is composed of data acquisition samples from filed observation, data processing and laboratory analyses, followed by analyzing and interpreting data based on a pattern of data. The results of the study can be listed as follows: a) on the basis of laboratory analyses, it is concluded that lithological characters of lower Baong Formation can be divided into 10 lithologies; b) result from calculation of Brittleness Index show that lithology having the highest BI value is Sandy Claystone and Sandy Mudstone, whereas has low BI value is; Claystone. Sandy Claystone and Sandy Mudstone with the highest BI value is considered as the zone having the most potential as a reservoir in the shale hydrocarbon system.

Keywords: reservoir, unconventional, shale hydrocarbon, lithology, rock mechanics, Lower Baong Formation.

1 INTRODUCTION

THE shale hydrocarbon concept is proven to be successful in many sedimentary basins in the United States, such as for the Barnet shale in the north to west Texas, the Antrim Shale in Michigan, Bakken shale in Williston, Fayetteville shale in Arkansas, Marcellus shale in Appalachian basin, Woodford shale in Oklahoma, Haynesville shale in East Texas – west Louisiana [1]. The accomplishment of shale hydrocarbon systems in the United States has motivated the unconventional hydrocarbon study in Indonesia. The shale hydrocarbon potential in the Indonesian sedimentary basin has unique characteristics different from those shale hydrocarbons already produced in the United States. First, the shale hydrocarbon in Indonesian sedimentary basins is of Cretaceous to Tertiary age, a lot more recent than the Carboniferous basins in the U.S. Therefore, it is not entirely appropriate to equate the Indonesia shale characteristics to those in the U.S. shale play. There is a significant difference in the lithology of shale as well as the brittleness, from one shale hydrocarbon play to another, and with those in already producing basins [2],implying that shale characteristic is not homogenous. In response to that, a detailed study of the characteristics of Indonesian shale as a potential reservoir is highly required. The high uncertainty in finding large conventional hydrocarbon reserves in the North Sumatra basin has prompted the study of unconventional hydrocarbon exploration. The study attempts to find a new resource by evaluating the hydrocarbon occurrence in the source rock. This paper aims to determine the potential reservoir zone of Lower Baong Formation shale by understanding its lithology and rock mechanics. The methods employed included the petrology of shale (petrography, calcimetry, granulometry, and XRD), and determination of the brittleness index. This method is needed to determine the potential zones for hydraulic fracturing in order to increase shale permeability, thus enabling the production of artificial hydrocarbons. The research area administratively includes the Aceh Tamiang Regency and East Aceh Regency, Aceh Province, and includes the Langkat Regency, North Sumatra Province.

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2 METHODS AND MATERIALS

2.1 Methods

Methods applied in this study consist of three stages, the first stage involved detailed mapping and collection of samples at four traverses (Fig.2.1). The second stage consisted of stratigraphic analysis, selection of shale samples, petrography, calcimetry, and granulometry to obtain the detail $CaCO_3$ and grain-size variation in the rock sample. XRD was carried out to identify the bulk mineralogical composition, type, and percentage of clay minerals, and nannoplankton and benthonic foram analysis to determine the relative age and paleogeography. The third stage is the analysis of patterns resulted from field and laboratory data processing. Brittleness index is quantified using the Jarvie method [3], which calculates the ratio of brittle minerals (quartz, calcite, dolomite) to the total minerals in the rock from XRD analysis. Synthesis of geological condition was made to characterize the lithology of shale and the potential of shale gas is quantified by its rock mechanics characteristics. The integration of lithology characterization with rock mechanics characterization (brittleness index) is expected to be able to be the first indicator of the shale reservoir potential.

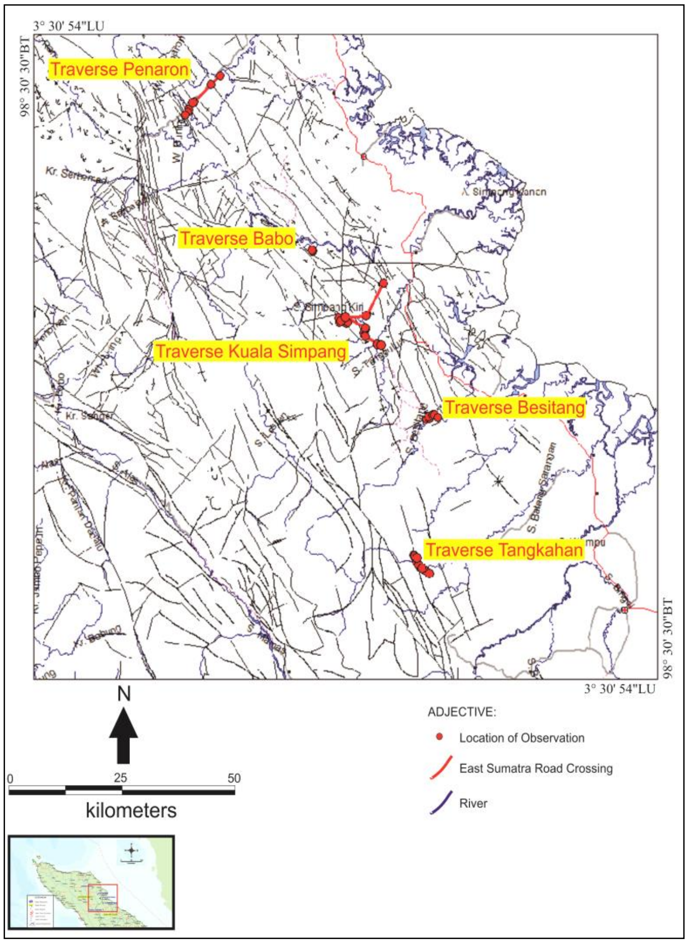


Fig.2.1 Map of the traverse and location of the observation in the research area, part of North Sumatra, and Aceh.

2.2 Materials

In this study, laboratory analysis of calorimetry, granulometry, petrography, and XRD of more than 32 surface samples, because there are some rock outcrops that have experienced weathering is quite strong.

3 RESULT AND DISCUSSION

The results of field observations from one of the observation traverses, the Batangsarangan River track, in the Tangkahan area, show that the limestone of Belumai Formation outcropped at the bottom part, and 150 m to the downstream carbonaceous shale of Lower Baong Formation is found. The complete stratigraphic column of the Batangsarangan River traverse can be seen in Fig. 3.1. Nannoplankton analysis shows the age of NN5 – NN7 (Middle Miocene), and benthonic foram analysis shows the depositional environment of upper bathyal to middle neritic.

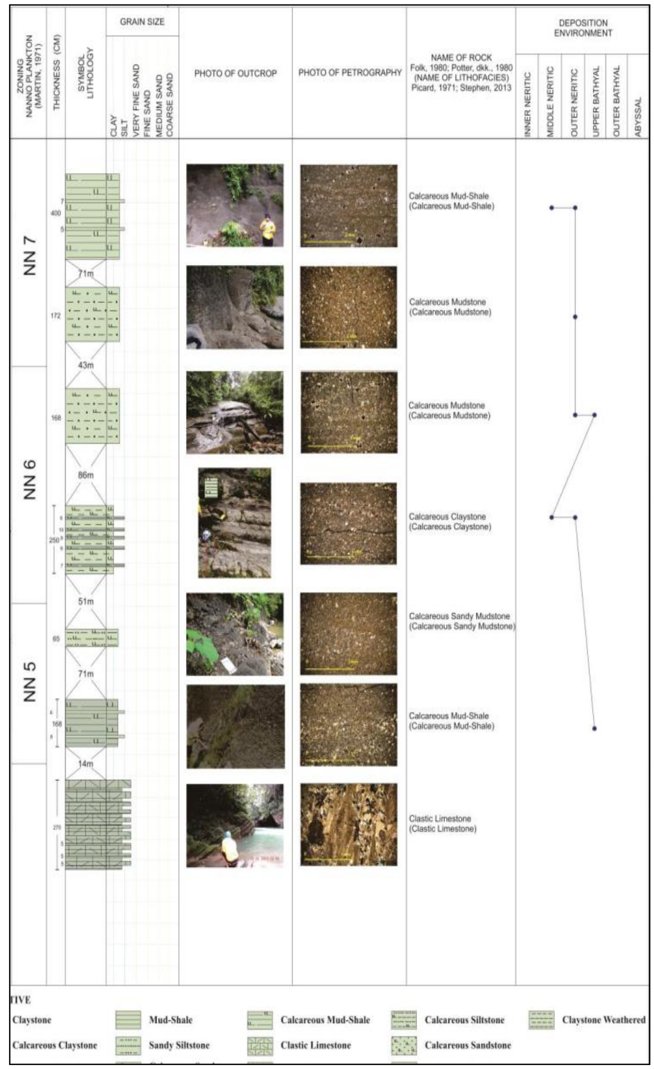


Figure 3.1 Stratigraphic column observation of Batangsarangan River, Tangkahan area.

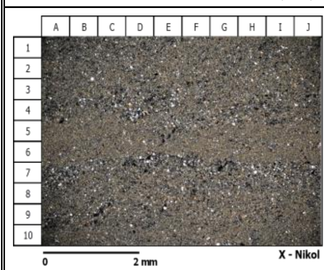
The lithology of the Lower Baong Formation consists of siliciclastic sediment of clay to very fine sand size, using classification by Folk [4], and Remus at al. [5] based on grain size and micro fissility. The lithology variations of the Lower Baong Formation in the study area consists of 10 lithologies show in table 3.1. Each lithofacies has different characteristics, texture, and mineralogical composition. For detailed characteristics of Calcareous Mud Shale, and Sandy Mudstone can be seen in Fig.3.2 and Fig.3.3. Thin section photograph reveals that the Calcareous Mud-shale lithology, shows the parallel orientation of silt-sized grain (Fig.3.2), as this parallel orientation for silt grain is not seen in Sandy Mudstone (Fig.3.3).

TABLE 3.1
LITHOLOGY VARIATION OF LOWER BAONG FORMATION

No. Sample	LITHOLOGY	No. Sample	LITHOLOGY
DS.03	Calc. Mud-Shale	DS.01	Calc. Mudstone
DS.04	Calc. Mud-Shale	DS.06	Calc. Mudstone
DS.07	Calc. Mud-Shale	DS.33	Calc. Mudstone
DS.16	Calc. Mud-Shale	DS.34	Calc. Mudstone
DS.30	Calc. Mud-Shale	DS.36	Calc. Mudstone
DS.37	Calc. Mud-Shale	DS.08	Claystone
DS.05	Calc. Claystone	DS.20	Claystone
DS.15	Calc. Claystone	DS.28	Calc. Silty Claystone
DS.21	Calc. Claystone	DS.35	Calc. Silty Claystone
DS.26	Calc. Claystone	DS.31	Calc. Clay-Shale
DS.09	Sandy Mudstone	DS.32	Calc. Clay-Shale
DS.12	Sandy Mudstone	DS.10	Mudstone
DS.13	Sandy Mudstone	DS.11	Mudstone
DS.14	Sandy Mudstone	DS.18	Calc. Sandy Mudstone
DS.22	Sandy Mudstone	DS.17	Mud-Shale
DS.24	Sandy Mudstone		

Rock name:	Calcareous Mudstone (Gilbert, 1982) / **Calcareous Mud-Shale** (Stephen, 2013; Remus dkk., 2015)
No. Sample:	DS.03, DS.04, DS.07, DS.16, DS.30 dan DS.37
LITHOLOGY PROPERTIES	
Texture:	Grain size < 0.004 mm - 0.05 mm, up to 0.06 mm, rounded - subrounded shape, floating grains and a small portion of contact, pin-point contact, medium-poor sorting.
Composition:	Quartz (20% - 30%), feldspar (1% - 5%), mica (0-1%), opaque minerals (1% - 2%), planktonic (1% - 8%) and bentonic (3% - 7%), clay material (35 - 52%), non-clay (8% - 16%). Porosity (2% - 8%), intragranular, dissolution, moldic and fracture.
Diagenesis:	The process of replacement the granules is unstable, the mineral feldspar is partially replaced to clay mineral and part of the shell of the foram is replaced by calcite spar and some has dissolution into a pore.

Thin section Photomicro (DS.16)



Thin section Photomicro (DS.37)

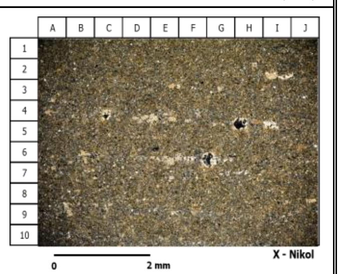
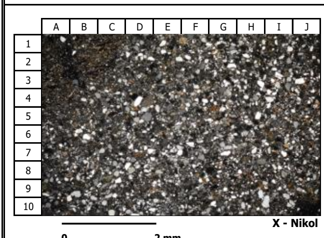


Figure 3.2 Lithology characteristics of the Lower Baong Formation are base on petrographic analysis.

Rock name:	Sandy Mudstone (William, 1982) / **Sandy Mudstone** (Folk, 1980 , Stephen, 2013; Remus dkk., 2015)
No. Sample:	DS.09, DS.12, DS.13, DS.14, DS.22 dan DS.24.
LITHOLOGY PROPERTIES	
Texture:	Grain size < 0.004 mm - 0.1 mm to 0.4 mm, shape rounded - subroundeded, a few grain suppoted, pin-point and long contacts, medium-poor sorting.
Composition:	Quartz (40% - 50%), feldspar (3% - 8%), mica (2% - 4%), carbon material (2% - 5%), opaque mineral (1% - 2%), clay (33 % - 43%), non-clay (0% - 5%). Porosity (2% - 7%), intergranular type and fracture.
Diagenesis:	The process of replacement the grain is unstable, mineral feldspar is partially replaced to clay mineral. It appears that some quartz grains have been observed to be overgrowth indicated by the angular shape. Showing the rock has undergone a compacting process.

Thin section Photomicro (DS.22)



Thin section Photomicro (DS.24)

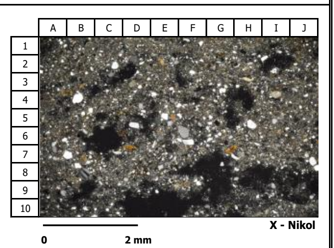


Figure 3.3 Lithology characteristics of the Lower Baong Formation are base on petrographic analysis.

Brittleness index calculations are made according to Jarvie's method [3], which is the ratio of brittle minerals (quartz, calcite, dolomite) to the total mineral content based on XRD result (Table 3.2). Results show that the lithofacies with high brittleness index is the Sandy mudstone (BI = 0.63–0.70) and Calcareous Sandy Mudstone (BI = 0.60), as characterized by abundant quartz of 53–67% and fewer clay minerals presence of 29–31%. For the Calcareous Clay Shale lithology, the brittleness index is low (BI = 0.22–0.26), as characterized by a low quartz presence of 20% - 24%, and abundant clay minerals of 60% - 67% (Table 3.3). Lithology which shows the value of the brittleness index (BI)> 0.50 [1], is more likely to produce natural fractures and fractures caused by external forces. The quartz mineral content is an important factor that influences the development of fractures, that is quartz-rich shale would be more brittle [6]. Noted that the main shale gas producing regions in the United States have brittle minerals of more than 50% and clay minerals of less than 50% [7,8].

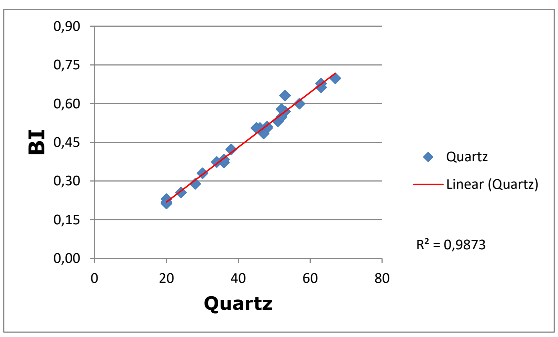
TABLE 3.2
THE RESULT OF THE CALCULATION BI

Loc.	No. Sample	Clay mineral (%)				Carbonate mineral (%)			Other mineral (%)						Total (%)						BI
		Smektite	Illite	Kaolinite	Chlorite	Calcite	Dolomite	Siderite	Quartz	K-Feldspar	Plagioklas	Pyrite	Gypsum	Zeolite	Clay	Carbonate	etc	Quartz	Calcite	Clay	
1	DS.01	5	14	6	9	12	?	?	46	?	4	4	?	?	34	12	54	46	12	34	0,50
3	DS.03	8	10	6	9	10	?	3	48	?	4	2	?	?	33	13	54	48	13	33	0,51
4	DS.04	6	8	6	6	12	?	2	53	?	4	3	?	?	26	14	60	53	14	26	0,57
6	DS.06	7	5	14	8	24	?	?	36	?	2	4	?	?	34	24	42	36	24	34	0,38
7	DS.07	8	10	12	8	5	?	4	48	?	1	4	?	?	38	9	53	48	9	38	0,51
8	DS.08	22	20	14	5	?	?	?	30	4	2	3	?	?	61	0	39	30	0	61	0,33
10	DS.10	20	12	8	2	?	?	3	46	2	1	4	2	?	42	3	55	46	3	42	0,51
11	DS.11	24	10	6	4	?	?	?	45	3	2	6	tr	?	44	0	56	45	0	44	0,51
12	DS.12	20	3	5	3	1	?	?	63	2	1	2	?	?	31	1	68	63	1	31	0,66
13	DS.13	22	2	4	3	?	?	?	53	2	2	7	5	?	31	0	69	53	0	31	0,63
15	DS.15	32	22	5	4	5		4	20	1	1	3	3		63	9	28	20	9	63	0,22
17	DS.17	0	18	12	10	1	?	2	52		2	3		?	40	3	57	52	3	40	0,55
18	DS.18	0	5	5	6	22	?		57	?	2	3	?	?	16	22	62	57	22	16	0,60
20	DS.20	0	40	18	14	tr	?	2	20	?	4	2	?	?	72	2	26	20	2	72	0,21
21	DS.21	0	20	20	16		?	5	36	?	1	2	?	?	56	5	39	36	5	56	0,37
22	DS.22	0	18	6	6	?	?		63	4	3		?	?	30	0	70	63	0	30	0,68
24	DS.24	0	16	6	7	?	?	?	67	1	3	?	?	?	29	0	71	67	0	29	0,70
26	DS.26	0	24	26	14	?	?	5	28		1	2	?	?	64	5	31	28	5	64	0,29
28	DS.28	20	16	6	3	7	?	5	34	1	1	4	?	3	45	12	43	34	12	45	0,37
30	DS.30	24	12	6	5	8	?		38	2	3	tr	2	?	47	8	45	38	8	47	0,41
31	DS.31	3	27	18	12	7	?	3	24	1	3	2	?	?	60	10	30	24	10	60	0,26
32	DS.32	4	30	18	15	6	?	?	20	?	4	3	tr	?	67	6	27	20	6	67	0,22
33	DS.33	18	16	10	6	6	?	?	44	1	2	?	?	?	50	6	44	44	6	50	0,44
34	DS.34	8	20	8	6	10	?	?	38	2	3	1	4	?	42	10	48	38	10	42	0,42
35	DS.35	5	26	20	8	8	?	?	20	1	4	3	5	?	59	8	33	20	8	59	0,23
36	DS.36	3	12	8	5	8	?	2	52	2	3	3	2	?	28	10	62	52	10	28	0,58
37	DS.37	22	9	2	1	8	?	3	51	?	1	3	tr	?	34	11	55	51	11	34	0,53

Sandy mudstone and Calcareous Sandy Mudstone lithology of BI index 0.60–0.70 are the zones that have the ability to fracture. This feature is very decisive for the development of fractures needed to increase permeability and enable artificial production.The relationship between the percentage of presence of quartz and clay minerals to the value of Brittleness Index (BI), shows the increasing % of the presence of quartz minerals and the reduced % of the presence of clay minerals, shows the value of the Brittleness Index index (BI) is higher (Fig.3.4). The comparison of the lithological characteristic of Lower Baong Formation in Langkat Aru, North Sumatra with other shale gas producing formations from worldwide basins can be seen in Tables 3.4.

Table 3.3
Lithology Variations Of The Lower Baong Formation And E Result Of The Calculation The Brittleness Index (BI)

Number	No. Sample	Lithology	Mineral			B I	
			Quartz	Calcite	Clay		Average
1	DS.03	Calc. Mud-Shale	48	13	33	0,51	0,51 - 0,57
	DS.04		53	14	26	0,57	
	DS.07		48	9	38	0,51	
	DS.37		51	11	34	0,53	
2	DS.15	Calc. Claystone	20	9	63	0,22	0,22 - 0,37
	DS.21		36	5	56	0,37	
	DS.26		28	5	64	0,29	
3	DS.01	Calc. Mudstone	46	12	34	0,50	0,38 - 0,58
	DS.06		36	24	34	0,38	
	DS.33		44	6	50	0,44	
	DS.34		38	10	42	0,42	
	DS.36		52	10	28	0,58	
4	DS.12	Sandy Mudstone	63	1	31	0,66	0,63 - 0,70
	DS.13		53	0	31	0,63	
	DS.22		63	0	30	0,68	
	DS.24		67	0	29	0,70	
5	DS.08	Claystone	30	0	61	0,33	0,21 - 0,33
	DS.20		20	2	72	0,21	
6	DS.28	Calc. Silty Claystone	34	12	45	0,37	0,23 - 0,37
	DS.35		20	8	59	0,23	
7	DS.31	Calc. Clay Shale	24	10	60	0,26	0,22 - 0,26
	DS.32		20	6	67	0,22	
8	DS.10	Mudstone	46	3	42	0,51	0,51
	DS.11		45	0	44	0,51	
9	DS.18	Calc. Sandy Mudstone	57	22	16	0,60	0,60
10	DS.17	Mud-Shale	52	3	40	0,55	0,55



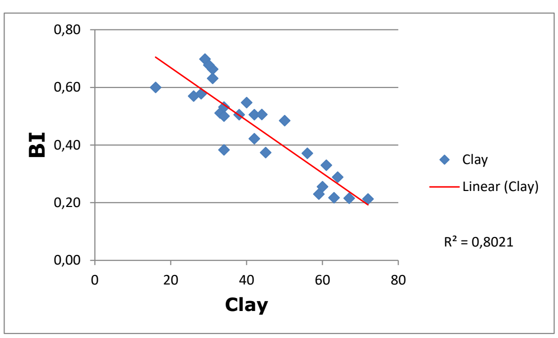


Fig. 3.4The relationship between the percentage of presence of quartz and clay minerals to the value of Brittleness Index (BI), shows the increasing% of the presence of quartz minerals and the reduced% of the presence of clay minerals, shows the value of the Brittleness Index index (BI) is higher.

TABLE 3.4
MINERAL COMPOSITION COMPARISON BETWEEN TONGCHUAN SHALE, NORTH AMERICAN SHALE AND LOWER BAONG SHALE PART OF NORTH SUMATRA (MODIFIED FROM YAO ZHIGANG [6]).

Shale Reservoirs	Clay mineral content (%)	Quartz Content (%)
Barnett shale, Forth Worth Basin (Loucks et al,2007; Jarvie et al, 2007)	20 - 60	20 - 70
Devonian-Mississippian mud rock, Seaga Basin (Ross et al, 2008)	5 - 80	48,9
Green River shale, Umta Basin (Hunt, 1996)	< 10	
Heather shale, North Sea Region (Hunt, 1996)	< 5	53 - 57
Woodford shale, Oklahoma area (Isaacs, 1987)		85- 95
Bakken shale, Willistton Basin (Hao Fang, 2005)	< 20	
Tongchuan black shale, Ordos Basin (Yao Zhigang, 2013)	8 - 31	19 - 64
Lower Baong Shale, Langkat-Aru Area, part of North Sumatra Basin, Indonesia	16 - 17	20 - 67

Brittleness index calculations are made according to the Jarvie method [3], showing the Brittleness Index indicator is lithology. Sandy mudstone and Calcareous Sandy Mudstone show the high Brittleness index (rich in quartz minerals) and Calcareous Clay Shale (rich in clay minerals) shows a low Brittleness index. Then the value of the Brittleness index is to show the size of the brittle mineral volume fraction (such as Quartz) as part of the overall matrix volume and grain size. The presence of a carbonated mixer can reduce the value of the Brittleness Index, as indicated by the value of the Brittleness Index Sandy Mudstone and Calcareous Sandy Mudstone.

4 CONCLUSIONS

- Based on the results of observation in the field and laboratory analysis, the Lower Baong Formation of the Middle Miocene (NN5 - NN7) age can be grouped into 10 lithologic units, i.e.: Calc. Mud-Shale, Calc. Claystone, Calc. Mudstone, Sandy Mudstone, Claystone, Calc. Silty Claystone, Calc. Clay-Shale, Mudstone, Calc. Sandy Mudstone, and Mud-Shale.
- Results show that the lithofacies with high brittleness index is the Sandy mudstone (BI = 0.63–0.70) and Calcareous Sandy Mudstone (BI = 0.60), as characterized by abundant quartz of 53–67% and fewer clay minerals presence of 29–31%. For the Calcareous Clay Shale lithology, the brittleness index is low (BI = 0.22–0.26), as characterized by a low quartz presence of 20% - 24%, and abundant clay minerals of 60% - 67% (Table 3). The higher the percentage of quartz and

the lower the clay mineral percentage, the higher the BI value. The increase of illite and chlorite presence also contributes to the brittleness of rocks.

- Sandy Mudstone and Calcareous Sandy Mudstone lithology are feasible for producing natural fractures and fractures induced by outside forces and are the potential reservoir zone for shale hydrocarbon systems.
- Finally, it can be summarized that the Lower Baong Formation in the Langkat-Aru area of the North Sumatra Basin has several potential zones to produce unconventional hydrocarbon

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