BRITTLENESS INDEX AND TOC AS POTENTIAL PARAMETERS IN BROWN SHALE FORMATION PEMATANG GROUP ON OUTCROP IN LIMAPULUH KOTO AREA, WEST SUMATRA

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Abstract

Brittleness index is an important parameter for success in hydraulic fracturing planning (Ju Hyeon Yu, et al, 2016). Jarvie et al (2007) and Wang and Gale (2009), stated that the brittleness index determines the magnitude of ductile and brittle values of the rock formations, based on their mineral content. Brittleness of shale hydrocarbon, required for initiation and propagation of fractures, and fracture re-opening. Rock formation with high brittleness value is easier to do hydraulic fracturing (Jingqi Xu, 2016).

Shale fracability can be determined based on mineralogical evaluation for optimal hydraulic fracturing planning. The XRD test of rock samples from the Brown Shale Formation, Pematang Group in the Central Sumatra Basin, was conducted to obtain mineral content, which then can be used to determine the brittleness index.

A sample test of 8 rock samples was carried out from the outcrop of Brown Shale Formation, Pematang Group in Limapuluh Koto Area, as it was difficult to obtain core data from well drilling at the research site, as an approach considered to represent target formation for the identification of shale hydrocarbon potential.

From laboratory test result of samples from Brown Shale Formation in Limapuluh Koto Area, it was quantitatively obtained that total organic carbon (TOC) value is 4 - 17 wt%; Brittleness Index: and 0.61 - 0.83 (average 0.73). From the results of Brittleness and TOC analysis, it can be concluded that Brown Shale Formation has a good unconventional shale hydrocarbon potential and can be used for further research, due to that oil production from conventional reservoir Indonesia in general has decreased significantly.

Keywords: unconventional, shale gas, shale oil, brittleness index, Limapuluh Koto, West Sumatra

1. Introduction

Brittleness index is an important parameter for success in hydraulic fracturing planning (Ju Hyeon Yu, et al, 2016). Jarvie et al (2007) and Wang and Gale (2009), stated that the brittleness index determines the magnitude of the ductile and brittle values of the rock formations, based on their mineral content. Brittleness of shale hydrocarbon, required for initiation and propagation of fractures, and fracture re-opening. Rock formation with high brittleness value is easier to do hydraulic fracturing (Jingqi Xu, 2016). Based on fracture mechanics, it appears that a more brittle formation is easier to fracture (A.T. Zehnder, 2012 in Mao Bai, 2016). As a result, identifying the brittle zones in unconventional reservoirs to achieve effective fracturing has become the focus of current research (Mao Bai, 2016).

The Pematang Formation of the Central Sumatra basin has been shown to be the primary source for the basin's 10 billion barrels of recoverable oil. This lacustrine unit, which is restricted to a series of Paleogene half-grabens, typifies the variability present in many rift source rock systems (Katz, B.J, et al, 1994). The Pematang Formation is known only in the subsurface, where it may obtain thickness in excess of 1,800 meters (Williams et al., 1985 in Katz, B.J, et al, 1994), the oil-prone Brown Shale Member may reach thicknesses in excess of 580 meters. Stratigraphically equivalent lacustrine rocks, which also display oil source rock characteristics, are present in the Ombilin basin to the southwest of the Central Sumatra (Koning and Aulia, 1984 in Katz, B.J, et al, 1994). Brown Shale Unit is based on a recent fieldwork in Karbindo Coal Mine which is part of the Pematang Formation as defined by some previous investigators (Aswan et al., 2009; Carnell et al., 2013; Widayat et al., 2013 in Edy Sunardi, 2015).

Core samples of 8 rock samples were sampled from the Brown Shale in Limapuluh Koto Area, due to the difficulty of obtaining core data of Pematang Formation from well drilling at the research site, as an approach considered to represent target formation for potential identification shale hydrocarbon.

Brittleness is defined as how strong a material breaks at a given pressure. Brittleness analysis is very important in planning hydraulic fracturing on shale hydrocarbon to reduce production costs and increase initiation efficiency and fracture propagation.

Determination of the original total organic carbon (TOC_o) of a source rock provides a quantitative means to estimate the total volume of hydrocarbons that it can be generated depending on kerogen type. Heavily explored areas generally have source rocks that are thermally mature, so it is not straightforward to determine original values. Consideration of the components of TOC assists in understanding how to restore highly mature TOC to TOC_o (Jarvie, 2007).

In this paper, we will discuss two parameters of shale play for determining the potential of shale hydrocarbon in the Pematang Group Formation, namely the brittleness index and TOC. In this study, core samples were taken from the Brown Shale Formation in Limapuluh Koto Area, West Sumatra which according to some researchers was equivalent to the Pematang Group Formation, Central Sumatra Basin. Map of Outcrop Location for Limapuluh Koto, West Sumatra is shown in Figure-1.

2. Basic Theory

The Central Sumatra Basin is the largest tertiary sedimentation hydrocarbon basin in Indonesia. Judging from its tectonic position, the Central Sumatra Basin is the back basin of the arc.

Rift (Pematang Siklis) as a whole, the filling sediments of the basin in the extensional tectonic phase (rift) are classified as Pematang Group which is composed of claystone, carbonaceous shale, fine sandstone and various siltstone. Weak seismic reflection and strong amplitude in seismic data give an indication of facies associated with lacustrine environment. Precipitation at the beginning of the rifting process is in the form of sedimentation of land clusters and lacustrine from the Lower Red Bed Formation and Brown Shale Formation upward towards the late rifting phase, sedimentation is completely changed to the lacustrine environment and deposited by the Pematang Formation as Lacustrine Fill sediments (Figure-2 and Figure-3).

3. Methodology

Jarvie et al. (2007) proposed a definition of the Brittleness Index (BI) based on the mineral composition of rocks, and divided minerals which were most brittle with the number of constituent minerals in rock samples, namely quartz, carbonate, and clay, and most of the quartz was a stiff mineral, indicating high level of brittleness, which is shown in Equation-1. Equation is shown by Eq.1 below.

$$BI_{Jarvie\,(2007)} = \frac{Qz}{Qz + Ca + Cly} \quad \ldots(1)$$

where Qz is fractional quartz content, Dol is dolomite content, Ca is calcite content, and Cly is clay content by weight in the rock.

There are other ways that are easier to determine brittleness with only clay mineral content. If the shale mineral component is higher than 35 - 40%, this indicates ductile behavior and is not economically feasible in the shale gas reservoir (Britt and Schoeffler, 2009).

The BI and brittleness average are commonly used to define brittleness in quartz-rich shales. In the case of the Barnett Shale, brittleness is dominated by quartz, whereas ductility is dominated by clay content and calcite, and from the data population is classified into four equal petrotypes, setting the BI between 0 and 0.16 as ductile, between 0.16 and 0.32 as less ductile, between 0.32 and 0.48 as less brittle, and greater than 0.48 as brittle (Perez, 2014).

4. Case Study

4.1 Brittleness Index

From mineralogy analysis, several shale samples from the fieldwork were selected, representing the target hydrocarbon shale formations (Brown Shale Formation, Pematang Group), from the Limapuluh Koto Area, namely Sarilamak and Batubalang, as shown in Figures-4 and 5.

The results of the bulk analysis and clay oriented analysis of XRD are shown in Table-1 and Table-2, which in general from Table-1 shows the dominance of quartz (quartz) minerals, and furthermore the brittleness index can be calculated using Jarvie (2007) equation resulting the average brittleness outcrop samples (shale) in the Limapuluh Koto Area is 0.73 (Figure-6), while from XRD analysis for clay oriented shows that the content of clay (Illite and Kaolinite) is less than 40% (Table-2). This clay content of less than 40% will not interfere hydraulic fracturing as it is not swelling when dissolved in water during a hydraulic fracturing process.

From the results of the bulk analysis, plots are made on the ternary diagram according to Perez (2013). Perez divides brittleness into three categories, namely Brittle Quartz, Brittle Carbonate and Ductile. Bulk analysis test results from XRD to outcrop samples Limapuluh Koto is included in the Brittle Quartz category as shown in Figure-7.

4.2 Total Organic Carbon (TOC)

Determination of the original total organic carbon (TOC_o) of a source rock provides a quantitative means to estimate the total volume of hydrocarbons that can be generated depending on kerogen type. Heavily explored areas generally have source rocks that are thermally mature, so it is not straightforward to determine original values. Consideration of the components of TOC assists in understanding how to restore highly mature TOC to TOC_o (Jarvie, 2007).

Total organic carbon in a source rock comprises three basic components: (1) organic carbon in retained hydrocarbons as received in the laboratory (C_{HC}); (2) organic carbon that can be converted to hydrocarbons, C_C, called convertible carbon (Jarvie, 1991) or reactive or labile carbon (Cooles et al., 1986); and (3) a carbonaceous organic residue that will not yield hydrocarbons because of insufficient hydrogen commonly referred to as inert carbon (Cooles et al., 1986; Jarvie, 1991), dead carbon, or residual organic carbon (C_R). As organic matter matures, C_C is converted to hydrocarbons and a carbonaceous residue, and eventually resulting in a reduced TOC when expulsion occurs (Jarvie, 2007). Total Organic Content (TOC) result of outcrop samples from Limapuluh Koto Area can be seen in Table-3.

Based on the cross plot of data between S1 + S2 versus TOC (Figure-8) on the outcrop samples from Limapuluh Koto Area, the TOC content is 4 - 17 wt% so that it can be categorized as good to excellent in the source rock category, S1 + S2 values of 16 -

58 mg / g have good hydrocarbon potential, so that the source rock can produce oil.

5. Result and Discussion

Shale parameters to enhance commercial production are: TOC > 2%; Moderate clay content < 40% (Matt McKeon, 2013), and Bitleness Index > 0,48 (Perez, 2014). Based on that parameters, the result of laboratory work for outcrop samples from Limapuluh Koto Area, can be summarized in Table-3.

6. Conclusion

XRD analysis results of Limapuluh Koto shale samples show that the outcrop samples from Limapuluh Koto is categorized as the brittle shale because of the dominant quartz (quartz rich), and the overall dominant shale samples is brittle.

Based on the correlation of laboratory analysis results with shale parameters to enhance commercial production (Matt McKeon, 2013 and Perez, 2014), Shale Brittleness Index, Moderate clay content, and TOC, Brown Shale members of the Pematang Group Formation meet the following criteria :

- TOC : average 8,18% (> 2%),
- Moderate clay content : average 24,04 (< 40%),
- Brittle Index shale : average 0,73 (> 0,48).

Outcrop samples from Limapuluh Koto Area have TOC content of 4 - 17 wt% so that it is categorized as good to excellent in the source rock category. S1 + S2 value of 16 - 58 mg/g has good hydrocarbon potential so that the source rock can produce oil.

From the results of Brittleness and TOC analysis, it can be concluded that Brown Shale Formation has a good unconventional shale hydrocarbon potential and can be used for further research, due to that oil production from conventional reservoir Indonesia in general has decreased significantly.

7. Recommendation

Samples from the surface (outcrop) or from the subsurface (core and cuttings) are needed for more representative results

8. Acknowledgement

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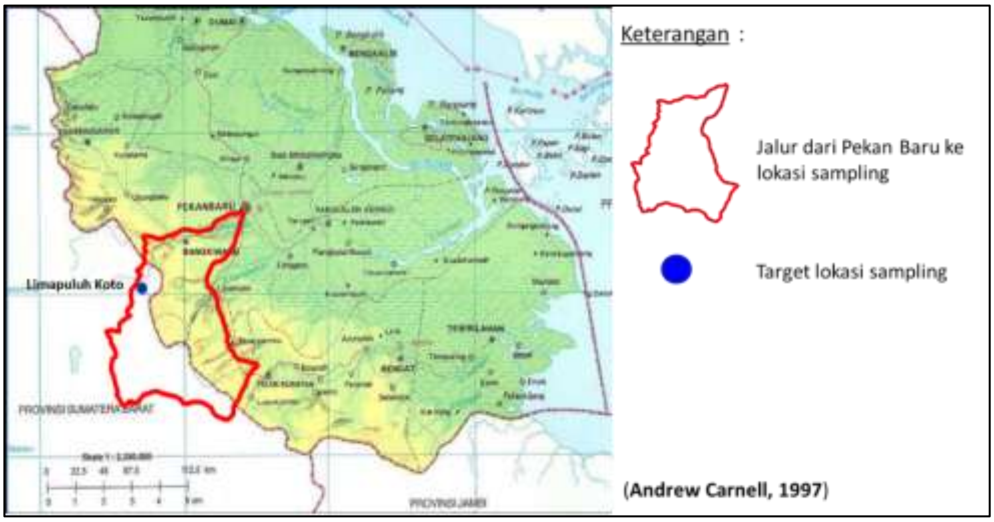


Figure 1. Map of Outcrop Location Limapuluh Koto, West Sumatra

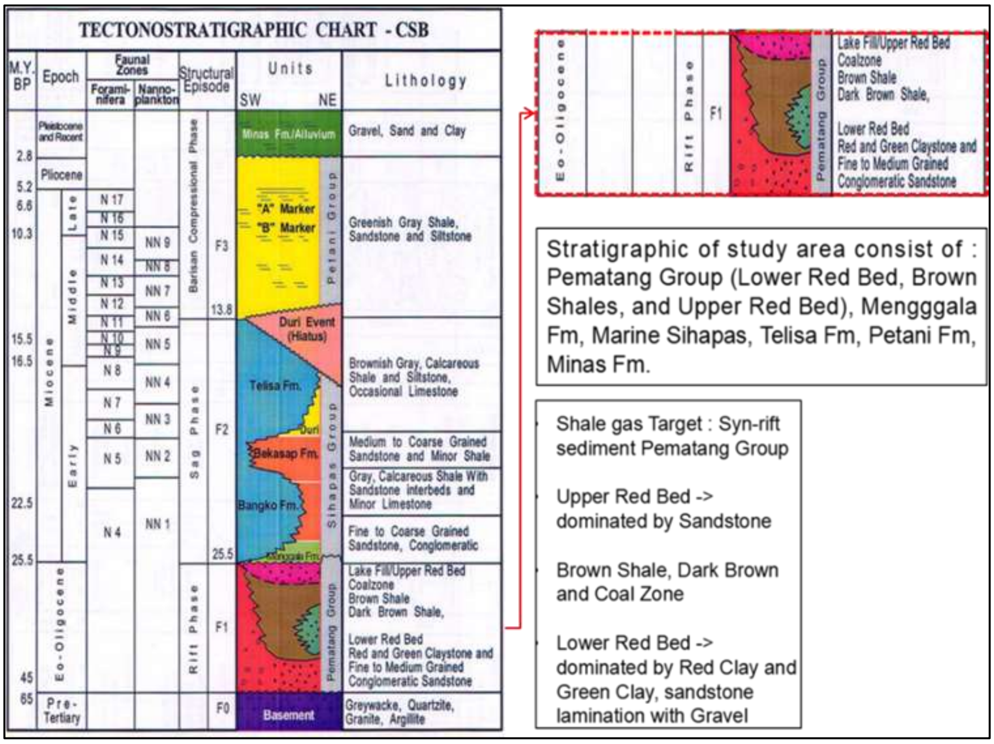


Figure 2. The tectonostratigraphic chart of Central Sumatra Basin (after Heidrick and Aulia, 1993; the Pematang Group is shown in a black circle, dalam Edy Sunardi, 2015)

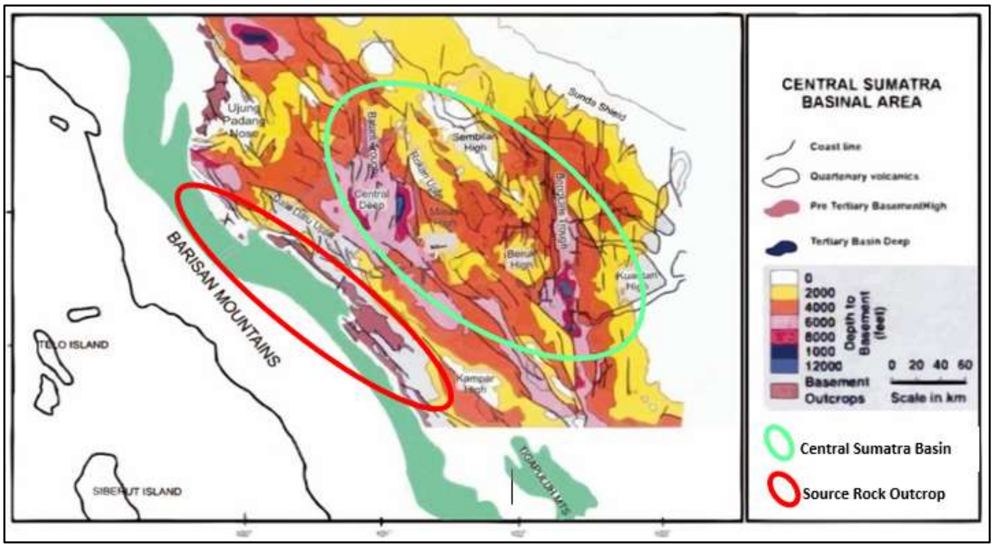


Figure 3. Basin Configuration of Central Sumatra (BPPKA-PERTAMINA, 1996)

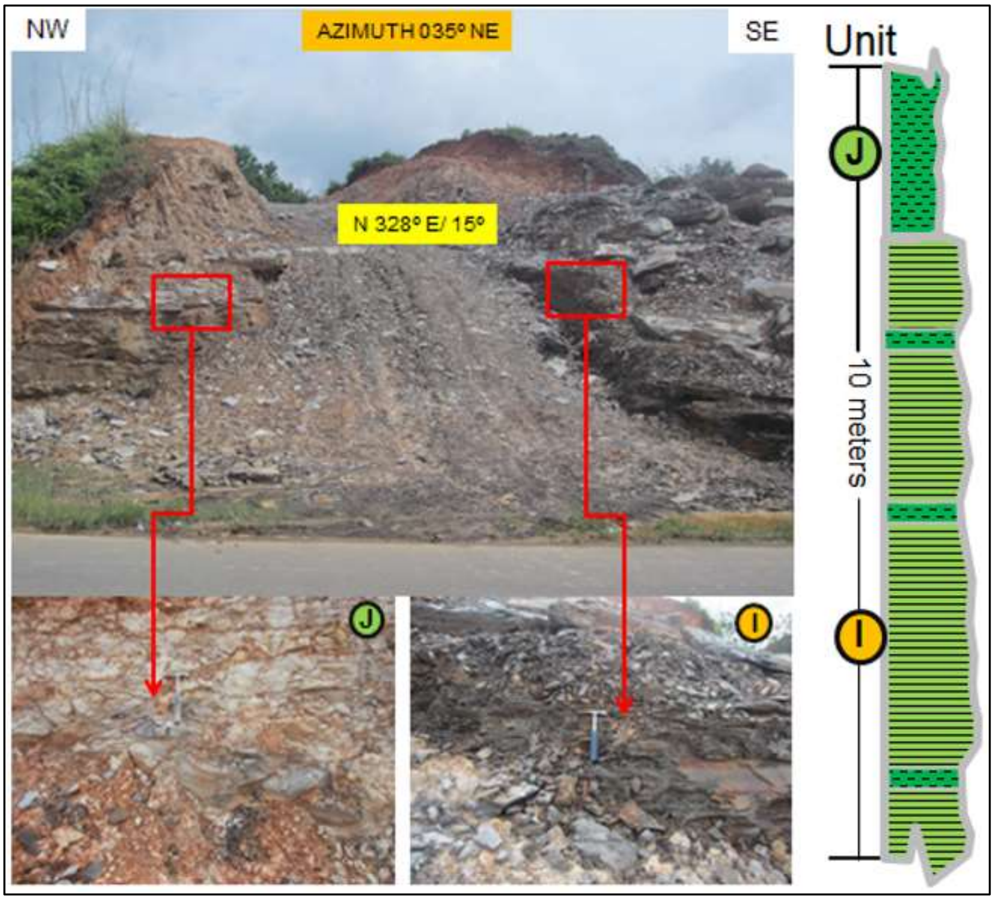


Figure 4. Outcrop location of claystone and shale along with its profile in Sarilamak Village (Limapuluh Koto Area) Geographic Coordinate: E 100,688º; S 0.155º

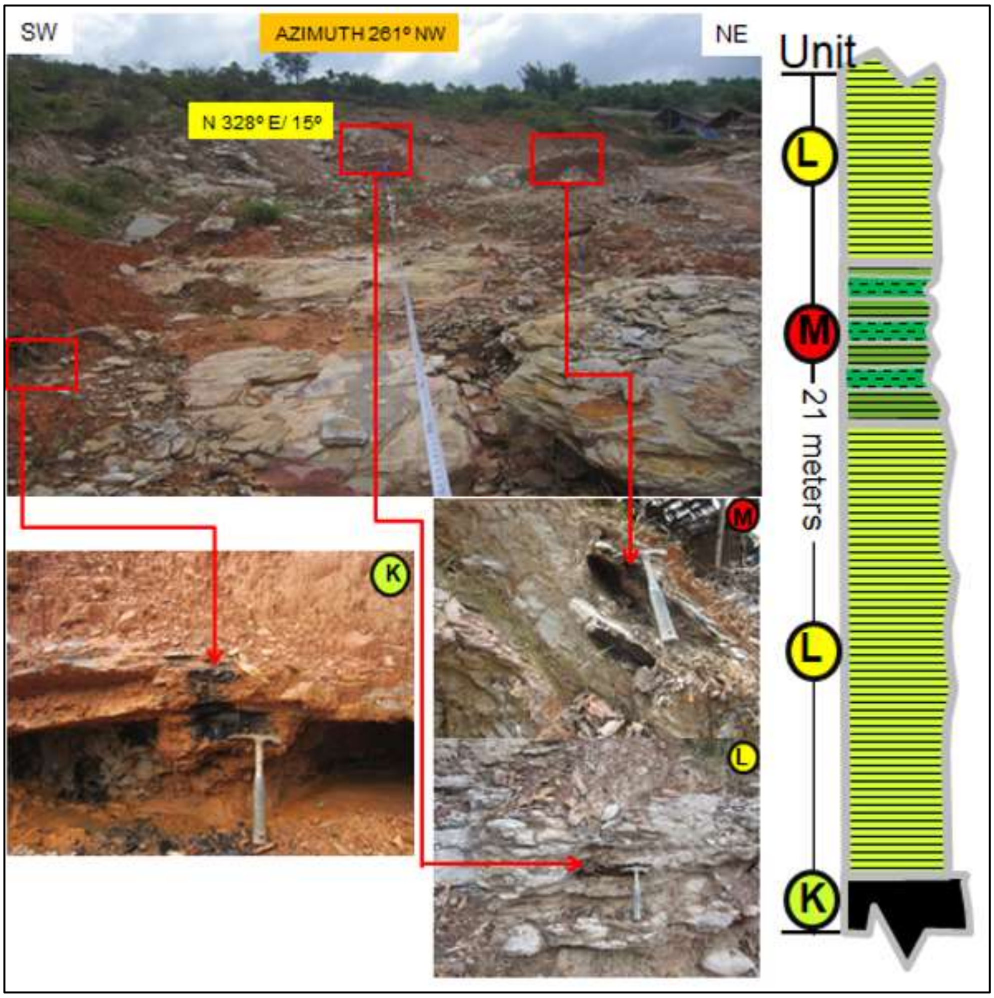
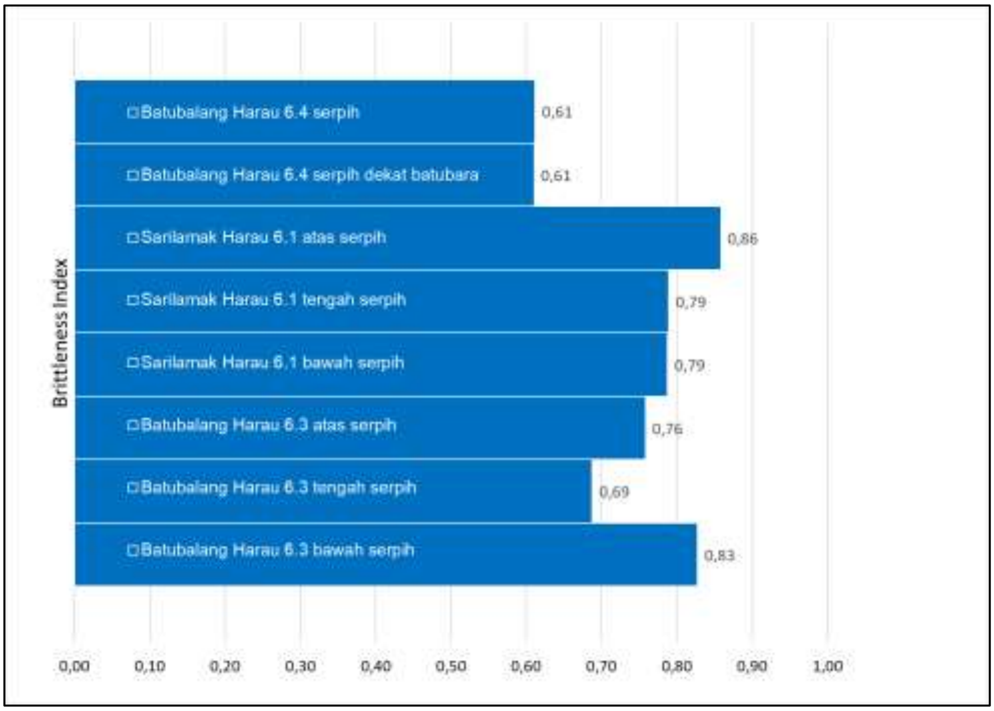


Figure 5. Outcrop location of shale and coal along with its profile in Batubalang Village (Limapuluh Koto Area) Geographic Coordinate: E 100,688°; S 0.155°



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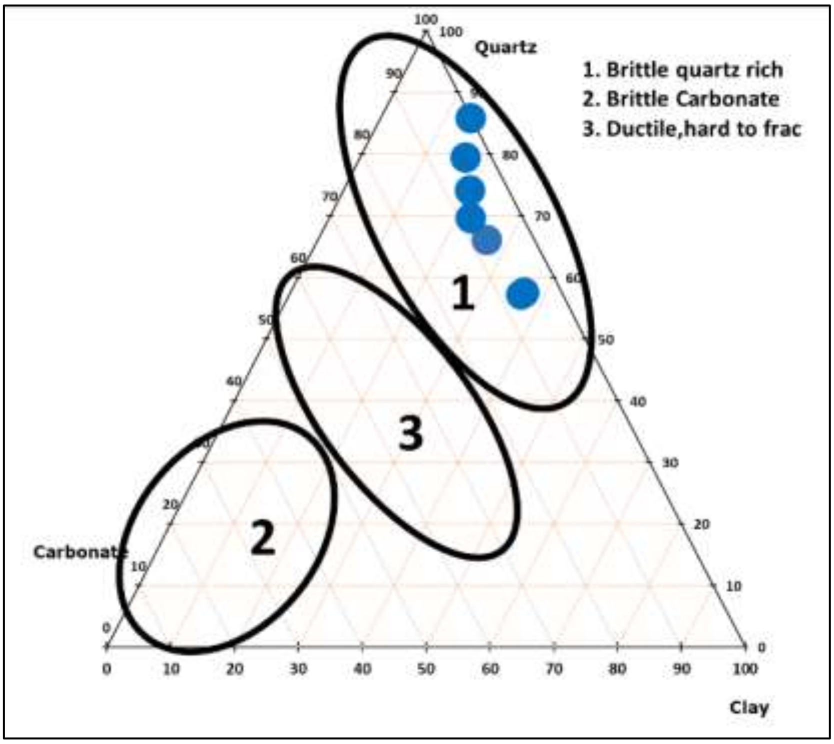

Figure 7. Plots on ternary diagrams for grouping the level of brittleness for outcrop samples in Limapuluh Koto Area (Sarilamak and Batubalang)

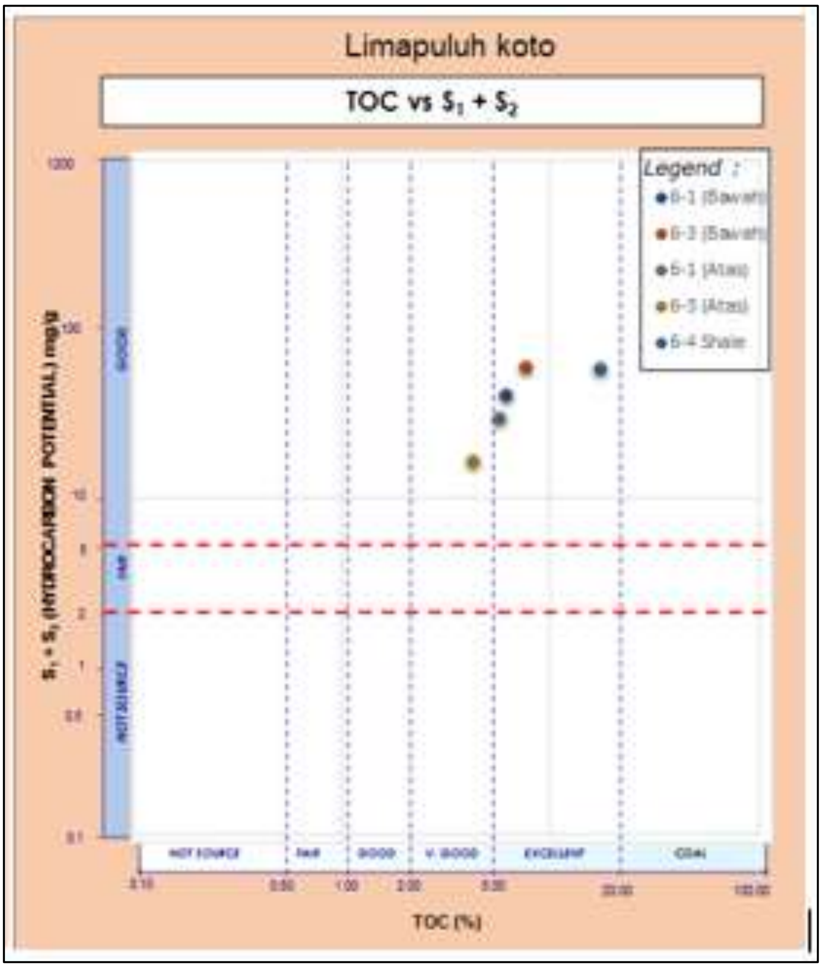

Figure 8. Cross plot TOC vs S1+S2 Outcrop Sampel dari Limapuluh Koto Area

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Table 1. Bulk Analysis Results from XRD at Outcrop Samples Limapuluh Koto Area (Sarilamak and Batubalang Villages)

No	Sample ID	Quartz (%)	Calcium (%)	Clay		Other Mineral	
				Illite (%)	Kaolinite (%)	Feox (%)	Pyrite (%)
1	Batubalang Harau 6.1 Shale	57.59		16.45	20.1		5.86
2	Batubalang Harau 6.4 Shale (near coal)	57.09		11.20	25.22		6.49
3	Sarilamak Harau 6.1 Upper Shale	85.83		6.11	8.06		
4	Sarilamak Harau 6.1 Middle Shale	74.08		9.34	10.46	6.12	
5	Sarilamak Harau 6.1 Lower Shale	74.5		9.04	11.07	5.39	
6	Batubalang Harau 6.3 Upper Shale	69.66		8.14	14.06	8.14	
7	Batubalang Harau 6.3 Middle Shale	66.1	3.64	11.09	15.35		3.82
8	Batubalang Harau 6.3 Lower Shale	79.39		5.67	10.91		4.02

Table 2. Clay Oriented Analysis Results from XRD at Outcrop samples Limapuluh Koto Area (Sarilamak and Batubalang Villages)

No	Sample ID	Clay		
		Illite+Kaolinite (%)	Smectite (%)	Chlorite (%)
1	Batubalang Harau 6.1 Shale	36.55		
2	Batubalang Harau 6.4 Shale (near coal)	36.42		
3	Sarilamak Harau 6.1 Upper Shale	14.17		
4	Sarilamak Harau 6.1 Middle Shale	19.8		
5	Sarilamak Harau 6.1 Lower Shale	20.11		
6	Batubalang Harau 6.3 Upper Shale	22.20		
7	Batubalang Harau 6.3 Middle Shale	26.45		
8	Batubalang Harau 6.3 Lower Shale	16.59		
	Minimum	14.17		
	Maximum	36.55		
	Average	24.04	Less than 40%	

Table 3. Total Organic Content (TOC) result of outcrop samples from Limapuluh Koto Area

No	Sample ID	Sample Type	TOC	S1 (mg/g)	S2 (mg/g)	S3 (mg/g)	Tmax (ºC)
1	Batubalang Harau 6.1 Shale	Outcrop					
2	Batubalang Harau 6.4 Shale (near coal)	Outcrop	17.30	0.72	56.67	2.35	434
3	Sarilamak Harau 6.1 Upper Shale	Outcrop	5.68	0.88	28.47	2.22	433
4	Sarilamak Harau 6.1 Middle Shale	Outcrop		-			
5	Sarilamak Harau 6.1 Lower Shale	Outcrop	6.08	1.15	38.80	0.79	432
6	Batubalang Harau 6.3 Upper Shale	Outcrop	4.23	0.56	15.89	2.25	420
7	Batubalang Harau 6.3 Middle Shale	Outcrop		-			
8	Batubalang Harau 6.3 Lower Shale	Outcrop	7.59	2.87	55.97	0.79	436
	Minimum		4.23	0.56	15.89	0.79	420
	Maximum		17.30	2.87	55.97	2.25	436
	Average		8.18	1.24	39.16	1.68	431

Table 3. Summary of the result of laboratory work for outcrop samples from Limapuluh Koto Area

No	Parameter	Reference	Lab Result
		Matt Mc Keon,2013	
1	TOC	>2%	8.18 (Avg)
2	Moderate clay content	<40%	24.04 (Avg)
		Perez, 2014	
3	Brittleness Index	>0.48	0.73 (Avg)