PAPER • **OPEN ACCESS**

Validation of shale brittleness index calculation from wireline log of well BETRO-001 by using XRD test results and uniaxial test as parameters for determining potential of shale hydrocarbon - brown shale of Pematang Group Formation, Central Sumatra Basin, Bengkalis Trough

To cite this article: A Buntoro *et al* 2018 *IOP Conf. Ser.: Earth Environ. Sci.* **212** 012069

Validation of shale brittleness index calculation from wireline log of well BETRO-001 by using XRD test results and uniaxial test as parameters for determining potential of shale hydrocarbon - brown shale of Pematang Group Formation, Central Sumatra Basin, Bengkalis Trough

A Buntoro[1*], C Prasetyadi[2], R A Wibowo[3], Suranto[1] and A H Lukmana[1]

[1]Petroleum Engineering Department, Faculty of Mineral Technology, Universitas Pembangunan Nasional Veteran Yogyakarta
[2]Department of Geological Engineering, Faculty of Mineral Technology, Universitas Pembangunan Nasional Veteran Yogyakarta
[3]UTC Pertamina

*corresponding author: arisbuntoro@upnyk.ac.id

Abstract. The parameter of the shale brittleness index is the key to success in hydrocarbon shale stimulation, as in Barnett Shale, Texas, USA, where brittleness is controlled by quartz content. Based on the mineral content of the shale, the ductility (opposite of brittleness) is controlled by the content of clay and calcite. The Brittleness index determines the value of ductile and brittle a rock formation, based on its mineral content. Brittleness of hydrocarbon shale, needed for initiation and propagation of hydraulic fracturing and fracture re-opening. Shale fractability can be evaluated based on geomechanical and mineralogical evaluations for optimization of stimulation planning. Laboratory tests on shale samples from the Brown Shale Formation, Pematang Group in the Central Sumatra Basin, were carried out to obtain elastic properties of rocks, such as Young's Modulus, Poisson's ratio, and unconfined compressive strength. Furthermore, mineralogical analysis is carried out to predict brittleness based on the results of the XRD test, which produces mineral content in rocks. Brittleness analysis is very important for hydraulic fracturing stimulation planning, and to get a valid calculation result from BETRO-001 well log data which is dynamic data, it must be validated using static data, namely from uniaxial compressive tests on in-situ rock cores, but because of the difficulty of obtaining core data from BETRO-001 well drilling and other wells in the research location, a coring approach from analog outcrops is considered to represent the target formation. From the results of prospect criteria according to Matt McKeon (2013), it can be concluded that the Brown Shale Formation in Bengkalis Trough has good hydrocarbon shale potential and can be carried out for further research, because oil production from conventional Indonesian reservoirs in general has experienced a significant decline.

I. Introduction

Brittleness index is an important parameter for success in planning hydraulic fractures (Ju Hyeon Yu et al, 2016). Jarvie et al (2007) and Wang and Gale (2009), stated that the brittleness index determines the amount of ductile and brittle values of rock formations, based on their mineral content. Brittleness of shale hydrocarbons, is needed for initiation and propagation of fractures, and re-opening of the fracture. Rock formations with high brittleness values are easier to do with hydraulic crackers (Jingqi Xu, 2016). Based on fracture mechanics, it appears that more brittle formations are more easily broken (T. Zehnder, 2012 in Mao Bai, 2016). Thus, identifying brittle zones in unconventional reservoirs to achieve effective fractures has become the focus of current research (Mao Bai, 2016). Various definitions of brittleness have emerged from various disciplines that introduce the development of an empirical relationship between brittleness of formation with the mechanical properties of rocks, such as the correlation of Young’s Modulus and Poisson’s Ratio.

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).

In this paper, brittleness evaluation will be carried out with the rock mechanical properties of the BETRO-001 well log data which is dynamic data, and validated using static data, namely from uniaxial press tests on in-situ rock cores, but because of the difficulty of obtaining data cores from the drilling of BETRO-001 wells and other wells in the research location, a coring approach from analog outcrops is considered to represent the target formation. The study location and target outcrop location equivalent to the Brown Shale Formation (source rock) of the Pematang Group is shown in Figure-1. Core samples were taken from the Brown Shale Formation in the Kiliran Jao Area (Karbindo Coal Mine) and Limapuluh Koto Area, because of the difficulty of obtaining the core data of Pematang Formation from well drilling at the research location, as an approach considered to represent the target formation for identification of potential shale hydrocarbons.

In this study, rock and core samples were taken from the Brown Shale Formation in the Kiliran Jao Area (Karbindo Coal Mine) and Limapuluh Koto Area (Sarilamak and Batubalang), West Sumatra which according to some researchers previously stated to be equivalent to Pematang Group Formation, Central Sumatra Basin. Map of Outcrop Kiliran Jao and Limapuluh Koto target locations, West Sumatra are shown in Figure-2.

2. Geological Overview at Pematang Group Formation

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 arc basin. This central Sumatra basin is relatively long-west-southeast, where its formation is influenced by the subduction of the Indian-Australian plate under the Asian plate (Figure-3). The southwestern basin boundary is the Barisan Mountains composed of pre-Tertiary rocks, while the Northeast is limited by the Sunda exposure. The southeastern boundary of this basin is the Tigapuluh Mountains which also separates the Central Sumatra Basin from the South Sumatra Basin. The northwestern basin boundary is the Asahan Arc, which separates the Central Sumatra Basin from the North Sumatra Basin (Eubank et al., 1981 in Wibowo, 1995).

Overall, the basin fill sediments in the extensional tectonic phase (rift) are grouped as Pematang Group 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 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 has changed completely to the lacustrine environment and deposited the Pematang Formation as Lacustrine Fill sediments (Koning & Darmono, 1984 in Wibowo, 1995).

Some areas, such as in the Safe Sub-Basin, there are two formations, namely Lake Fill and Fanglomerat are considered to be an equivalent unit of the Pematang Formation based on their characteristic and spread on seismic cross section.

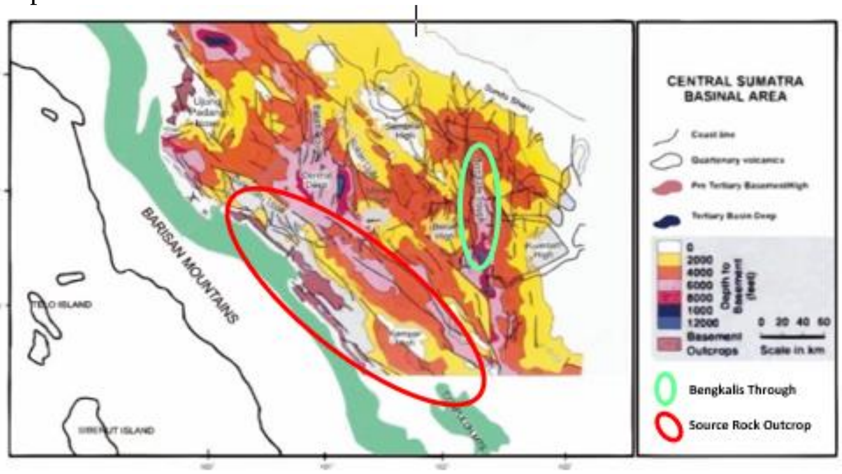

Figure 1. The location of Bengkalis Trough in the Central Sumatra Basin and equivalent outcrop of source rock targets (BPPKA-PERTAMINA, 1996).

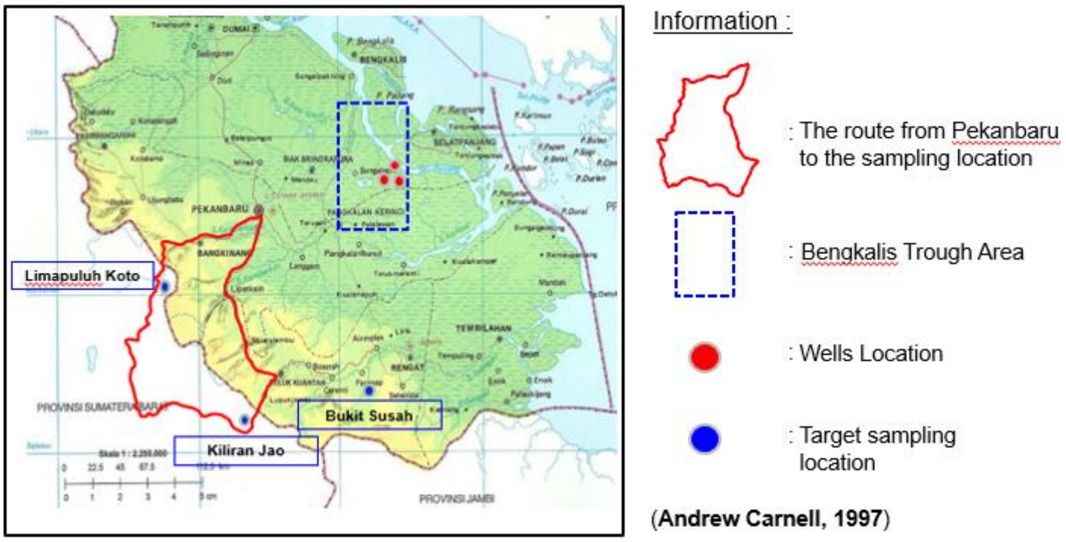

Figure-2. Research Location (**Andrew Carnell, 1997**)

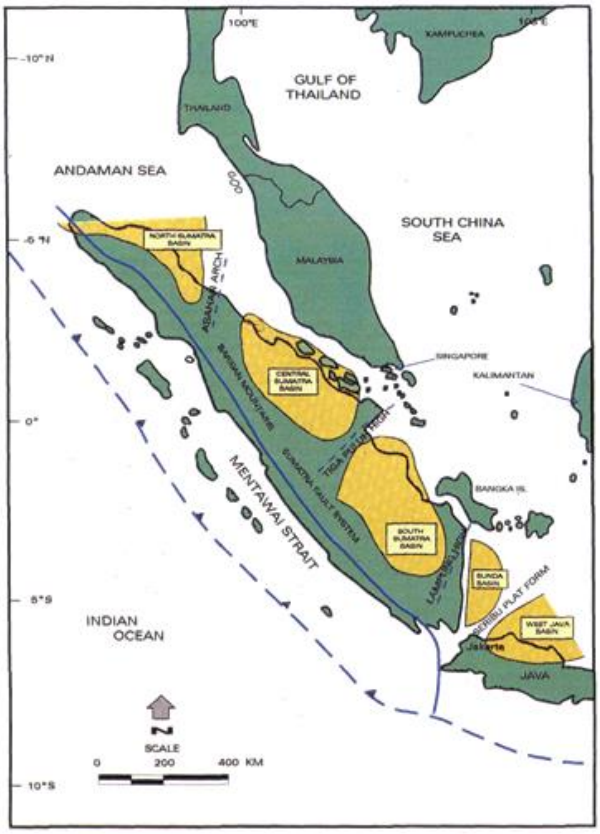

Figure 3. Location of the Central Sumatra Basin and its boundaries (Koning & Darmono, 1984 in Wibowo, 1995).

3. Brittleness Analysis Method and Prospecting Criteria

Shale is described as fine-grained fine-grained reservoir rock (Bustin, 2006) and is usually dominated by clay. Mineral composition and the presence of organic matter can not only affect the pore distribution and fluid saturation (Sondergeld et al., 2010), but also the effectiveness in the stimulation of hydraulic fracturing.

Bowker (2003) states that most of the production at Barnett Shale comes from 45% quartz zones and only 27% clay. In general, the average porosity is 6% with pore throats usually less than 100 nmDarcy (Bowker, 2003). Field experiments show that more effective hydraulic fracturing results in higher production (Saldungaray and Palish, 2012). In the Forth Worth Basin, Gale et al (2007) describes at least two sets of cemented natural fractures. However, they can be reactivated during the hydraulic fracturing process, providing greater rock volume and optimizing production.

3.1. Rock Mechanics Brittleness Index Analysis with Empirical Equations Using WellLog Data

Dynamic Young's Modulus of rock can be determined using empirical equations obtained from the P-wave velocity and S-wave velocity data. With limited data from Sonic Log that only has the P-waves velocity value, it is assumed that the S-waves value with the Castagna (1985) equation. Castagna plots between Vp and Vs in the dominant Shale formation, resulting in equation-1:

$$V_s = 0.862\ V_p - 1.172 \qquad (1)$$

with equation-2 the dynamic Young's Modulus can be calculated:

$$E = \rho V_s^2 \frac{(3V_p^2 - 4V_s^2)}{(V_p^2 - V_s^2)} \quad \text{.......(2)}$$

where :

v_p = P-wave velocity (km/second)
v_s = S-wave velocity (km/second)
ρ = rock density (g/cc)
E = Young's Modulus (Gpa)

Dynamic Poisson's ratio of rock can be determined using empirical equations obtained from P-wave velocity data and S-wave velocity with equation-3:

$$\upsilon = \frac{1-2\left[\frac{v_s}{v_p}\right]^2}{2\left[1-\left[\frac{v_s}{v_p}\right]^2\right]} \quad \text{or} \quad \upsilon = \frac{V_p^2-2V_s^2}{2(V_p^2-V_s^2)} \quad \text{.......(3)}$$

dimana:

v_p = P-wave velocity (km/second)
v_s = S-wave velocity (km/second)
υ = *Poisson's Ratio* (*dimensionless*)

In determining the sweet spot interval at the unconventional reservoir shale, it is necessary to know the value of the brittleness index in order to determine the shale which is brittle and ductile. The desired target for the sweet spot interval at the unconventional reservoir shale is a type of shale that is brittle because to produce oil or gas at the unconventional reservoir shale it is necessary to do hydraulic fracturing, with rocks having brittle properties, hydraulic fracturing will run more optimally. Before performing hydraulic fracturing, it is necessary to know the minimum pressure of fracture and fracture direction, to determine the minimum pressure fracture value and the fracture direction, it is necessary to know the in-situ stress that is working on the field. Determination of the brittleness of the stress-strain diagram (Hucka, 1974), of percent reversible strain. This principle was used by Coates (1966) based on the reversible strain ratio with the total strain at the point of failure. The concept of brittleness can be expressed by equation-4:

$$B_1 = \frac{\text{reversible strain}}{\text{total strain}} = \frac{DE}{OE} \quad \text{.......(4)}$$

Brittleness calculation of tensile and compressive strength. It was observed that the difference between compressive strength and tensile strength increased with increasing brittleness. Therefore, this fact can be used to measure brittleness. In this case brittleness can be represented by equation-5:

$$B_2 = \frac{\sigma_c - \sigma_t}{\sigma_c + \sigma_t} \quad \text{.......(5)}$$

where, σ_c is an unconfined compressive strength and σ_t is tensile strength.

3.2. Brittleness Index Analysis with Mineral Rock Component

Because tensile strength and compressive strength are measured only in the laboratory, it is difficult to extend this definition to the reservoir scale. The higher the Brittleness Index, the rock more brittle.

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 levels high brittleness, which is shown in Equation-6**:**

$$BI_{\text{Jarvie (2007)}} = \frac{\text{Qz}}{\text{Qz+Ca+Cly}} \quad \text{-------- (6)}$$

where Qz is fractional quartz 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 based only on 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 (Perez, 2013).

In this paper, core samples are taken from the Brown Shale Formation at Kiliran Jao Area (Karbindo Coal Mine) and Limapuluh Koto Area (Sarilamak and Batubalang), because of the difficulty of obtaining the core data of Pematang Formation from drilling wells at the study site, as the approach considered representative target formation for identification of potential shale hydrocarbons. Uniaxial compressive test was conducted to obtain unconfined compressive strength, Young's Modulus and Poisson's ratio. Mineralogical analysis of the shale sample with XRD test analysis, then can be correlated brittleness index of well log (dynamic) and rock mechanical properties from uniaxial tests on cores (static).

3.3. Shale Hydrocarbon Prospection Analysis
According to Matt McKeon, 2013, the shale hydrocarbon parameters that can be produced commercially include several criteria, as follows:

a. Permeability : greater than 100 nanodarcies
b. Porosity : less than 15%, more typically 4-7 %
c. Pressure : above normal
d. TOC : > 1%
e. Water saturation : < 45%
f. Shale thickness : > 100 ft
g. Moderate clay content : < 40%
h. Brittle Index shale : > 0,48
i. Brittle shale (fracability) : i.e. low Poisson's ratio & high Young Mudulus

This paper is only limited to the prospect of shale hydrocarbon prospecting based on the results of brittleness validation analysis associated with the value of brittleness index, clay content, shale thickness, and pore pressure.

4. Mineralogical Analysis (XRD Test)
For mineralogical analysis, several shale samples from the fieldwork were selected, at 2 locations representing shale hydrocarbon formation targets (Brown Shale Formation, Pematang Group), namely Kiliran Jao (Karbindo Coal Mine) and Limapuluh Koto (Sarilamak and Batubalang), as shown in Figure-4, Figure-5a and Figure-5b. For shale samples from Kiliranjao area, selected according to top-down layers, namely: B-7 (shale), B-11 (gastropod flakes), B-12 (gastropod shale), B-13 (gastropod shale), B-15 (gastropod shale), B-16 (gastropod shale), B-17 (shale), B-21 (shale), B-22 (shale), while shale samples from Limapuluh Koto area, are selected: Harau 6.4 (shale) , Harau 6.4 (shale near coal), Harau 6.1 top (shale), Harau 6.1 middle (shale), Harau 6.1 down (shale), Harau 6.3 top (shale), Harau 6.3 middle (shale), and Harau 6.3 bottom (shale).

The results of bulk and clay oriented analysis of XRD shale samples from Kiliran Jao area and Limapuluh Koto areas, are shown in Table-1a, Table-1b, Table-2a and Table-2b. From Table-1a and Table-1b generally shows the dominance of quartz minerals, although there are some that are dominated by calcium minerals, namely in the sample B-7 (shale), B-15 (gastropod shale), B-21 (shale), and B-22 (shale). The four shale samples were all from the Kiliranjao area, whereas in the Limapuluh Kota area calcium minerals were not found at all. Furthermore, the brittleness index can be calculated using the Jarvie (2007) equation, and the results are shown in Figure-5 and Figure-6, where the average brittleness at the location in Limapuluh Koto: 0.73, and average brittleness at the location of Kiliran Jao: 0.48. From XRD analysis for clay oriented shows that in general the content of clay (Illite and Kaolinite) is less than 40% (Table-2a and Table-2b). This clay content of less than 40% will not interfere with hydraulic fracturing, because it is not swelling when dissolved in water during a hydraulic fracturing process.

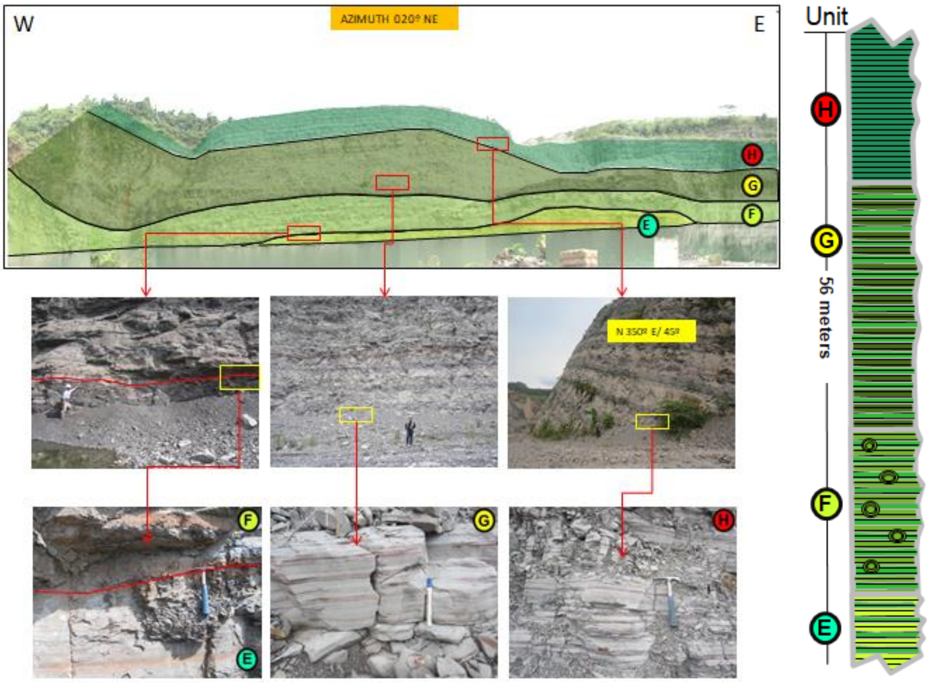

Figure-4. Outcrop location for sampling and coring at Coal Mine Karbindo, Kiliran Jao: Brown Shale Formation (Pematang Group), Geographic Coordinate: E 101,348 º S 0.848 º.

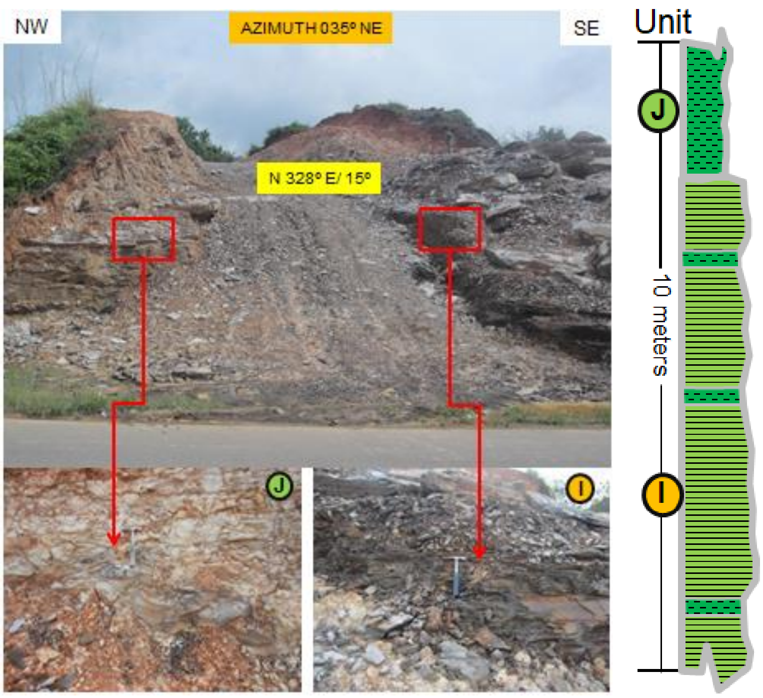

Figure-5a. Outcrop location claystone and shale along with its profile in Sarilamak Village (Limapuluh Koto Area), Geographic Coordinate: E 100,688 º; S 0.155 º.

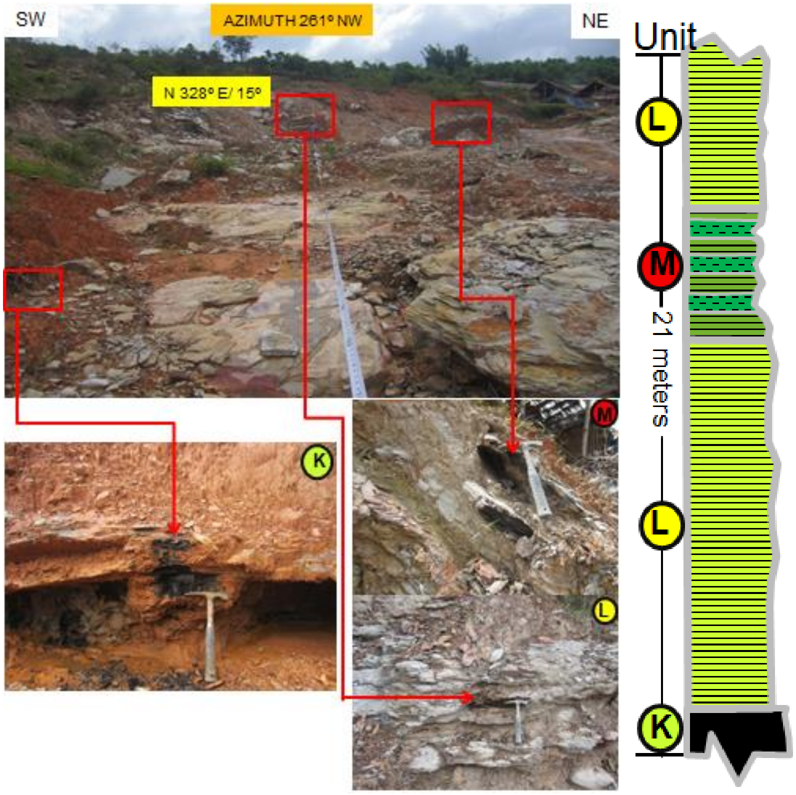

Figure-5b. Outcrop location (outcrop) of shale and coal along with its profile in Batubalang Village (Limapuluh Koto Area), Geographic Coordinate: E 100,688 °; S 0.155 °.

From Jarvie (2017) equation, the percentage of mineral composition can be calculated in the sample results of bulk analysis of XRD in Table-1a and Table-1b, namely quartz, calcium, and clay, so that the level of brittleness of each sample can be grouped from Kiliran Jao and Limapuluh Koto, as shown in Figures-6 and Figure-7. In Figure-6 it can be seen that there are four samples from Kiliran Jao which are shale brittle because they are rich in carbonate (carbonate rich), and there is 1 sample from Kiliran Jao shale which is ductile which is difficult to break. Whereas in Figure-7 it is seen that the sample in Limapuluh Koto includes the brittle shale group because of the dominant quartz (quartz rich). Overall shale samples are more brittle. Plot the value of the brittleness index for all samples in Ternary diagrams (according to Perez, 2013), shown in Figure-8.

Table-1a. XRD Analysis Results of shale samples from Kiliran Jao Area.

No	Sample ID	Quartz (%)	Calcium(%)	Clay		Other Mineral	
				Illite (%)	Kaolinite (%)	Feox (%)	Pyrite(%)
1	B-22 Serpih	17,86	**69,32**		3,35	9,47	
2	B-21 serpih	27,44	**51,88**		6,08	9,07	5,53
3	B-7 Serpih	24,60	**61,21**		4,20	9,99	
4	B-11 serpih gastropoda	49,38	31,68		18,94		
5	B-12 serpih gastropoda	76,84			17,39		5,77
6	B-13 serpih gastropoda	67,82	20,80		11,39		
7	B-15 serpih gastropoda	32,57	**54,07**		13,37		
8	B-16 serpih gastropoda	71,25	11,74		17,01		
9	B-17 serpih	67,98			32,02		

Table-1b. XRD Analysis Results of shale samples from the Fifty Koto Area

No	Sample ID	Quartz (%)	Calcium(%)	Clay		Other Mineral	
				Illite (%)	Kaolinite (%)	Feox (%)	Pyrite(%)
1	Batubalang Harau 6.1 Shale	57,59		16,45	20,10		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	74,50		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	66,10	3,64	11,09	15,35		3,82
8	Batubalang Harau 6.3 Lower Shale	79,39		5,67	10,91		4,02

Table-2a. 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	19,80	-	-
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-2b. Clay Oriented Analysis Result from XRD at Outcrop samples of Kiliran Jao Area (Karbindo Coal Mine).

No	Sample ID	Clay		
		Illite + Kaolinite (%)	Smectite (%)	Chlorite (%)
1	B-22 Serpih	3,35	-	-
2	B-21 serpih	6,08	-	-
3	B-7 Serpih	4,20	-	-
4	B-11 serpih gastropoda	18,94	-	-
5	B-12 serpih gastropoda	17,39	-	-
6	B-13 serpih gastropoda	11,39	-	-
7	B-15 serpih gastropoda	13,37	-	-
8	B-16 serpih gastropoda	17,01	-	-
9	B-17 serpih	32,02	-	-
	Minimum	4,20		
	Maximum	32,02		
	Average	16,33	(Less than 40%)	

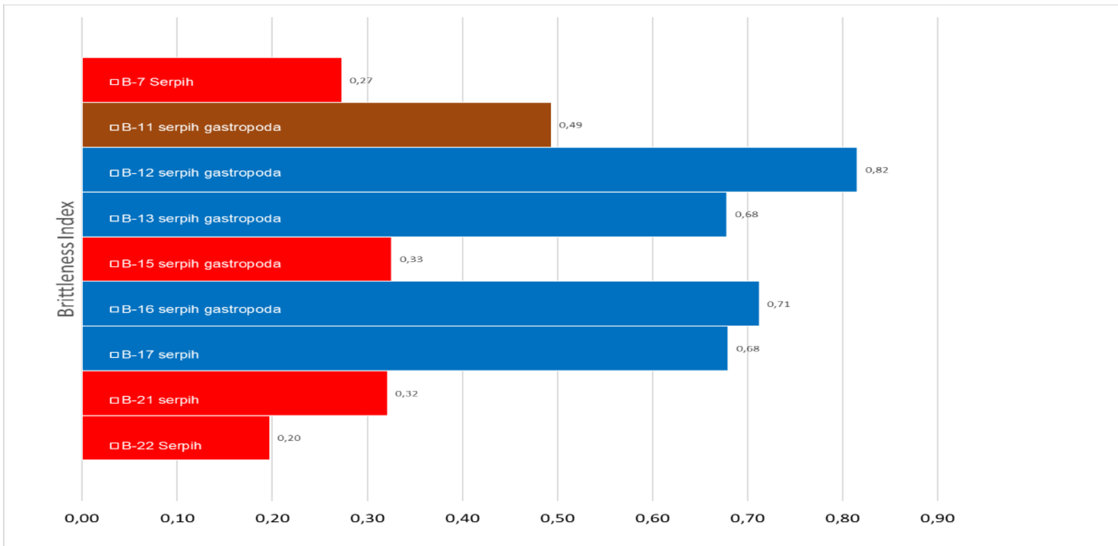

Figure-6. Graph of Calculation Results of Shale Sample Brittleness Index from Kiliran Jao Area (Karbindo Coal Mine) with Jarvie equation.

5. Uniaxial Compressive Test Analysis

For the uniaxial compressive test, several samples of cores shale were selected from the cores in outcrops at the Kiliran Jao site (Karbindo Coal Mine) representing the target of the shale hydrocarbon formation (Brown Shale Formation, Pematang Group), namely: B-2A (shale), B-6 (shale). B-6.1 (shale), B-8 (shale), B-11 (gastropod shale), B-17 (shale), B-21 (shale), B-22 (shale). The uniaxial compressive test results from the core samples are shown **in Table-3**, where the core samples B-6.1 and B-11 have been destroyed before being tested (because it is very brittle), and the average Poisson's ratio outcrop of the table is 0.14.

The stress versus strain relationship plot from the uniaxial compressive test results on the 6 core samples, namely samples: B-2A (shale), B-6 (shale), B-8 (shale), B-17 (shale), B-21 (shale), B-22 (shale) is shown in **Figure-9**, where all the samples are brittle, because they do not enter the plastic zone, meaning that in the elastic zone the sample of the core has ruptured.

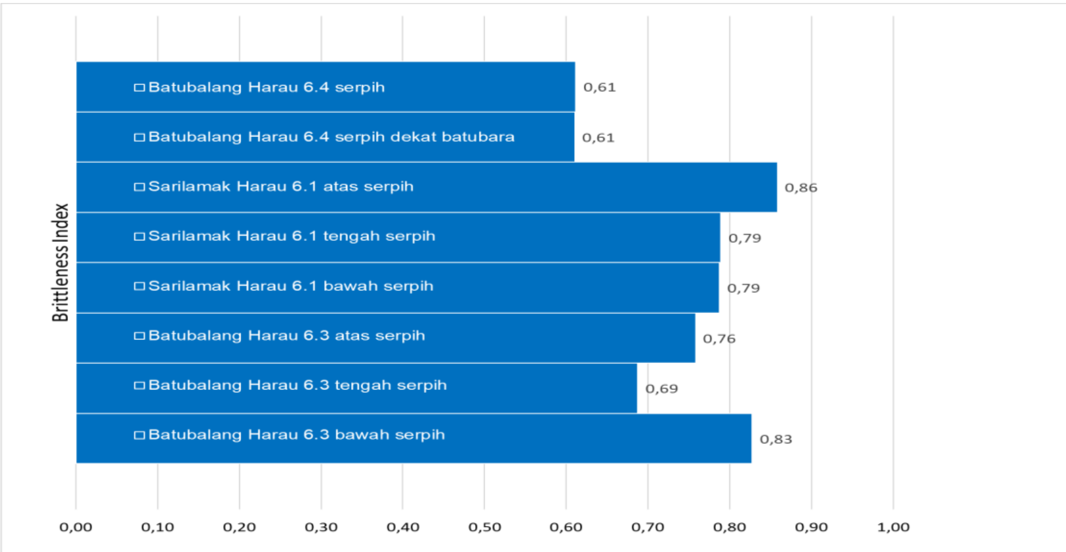

Figure-7. Graph of Calculation Results of Shale Sample Brittleness Index from Limapuluh Koto Area (Sarilamak and Batubalang) with Jarvie equation.

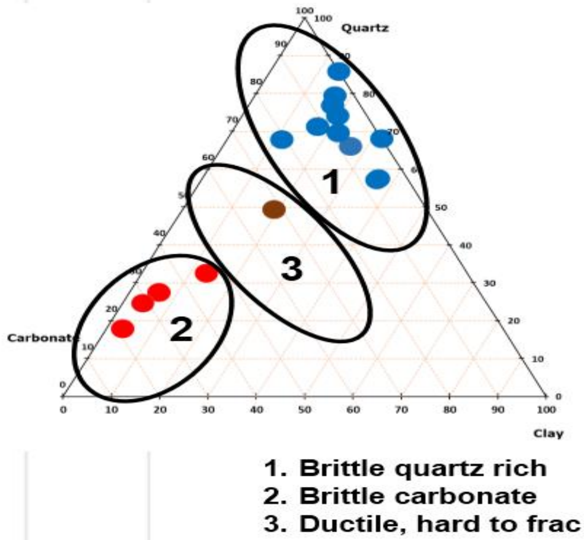

Figure-8. Plots on ternary diagrams for grouping the level of brittleness for samples from Kiliran Jao and Limapuluh Koto.

Table-3. Uniaxial compressive test results on cores from Kiliran Jao location.

Sample	Poisson ratio	Young Modullus (MPa)
B-2A	0,01	3261,23
B-22	0,18	2444,93
B-21	0,27	44,51
B-17	0,21	301,79
B-8	0,13	710,28
B-6	0,05	784,62
B-11	Sudah hancur sebelum diuji	
B-6.1	Sudah hancur sebelum diuji	

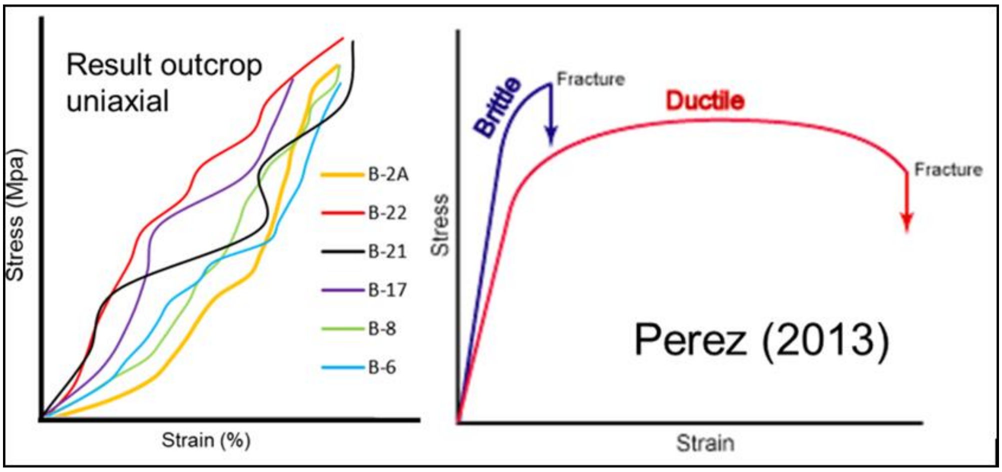

Figure-9. Stress versus strain relationship plot from uniaxial compressive test results on core samples from outcrops at Kiliran Jao Area.

6. Review

The calculation of the shale brittleness index can be done from the data: wireline log from well BETRO-001, mineralogical analysis (XRD) of rock samples from 2 sampling locations, and uniaxial compressive test from sample cores taken from outcrop at Kiliran Jao location. The wireline log data is data with dynamic conditions, while the core is data with static conditions (in-situ data), so that in conducting dynamic data analysis must be corrected with static data.

Uniaxial compressive test results (Table-3), produce elastic rock parameters, namely Poisson's Ratio and Young's Modulus. Based on the results of the uniaxial compressive test on 6 core samples, namely: B-2A (shale), B-6 (shale), B-8 (shale), B-17 (shale), B-21 (shale), B -22 (shale), obtained by the average Poisson's ratio outcrop of the table is 0.14

For the calculation of the brittleness index of the wireline log, starting from the determination of rock elasticity (Poisson's Ratio and Young's Modulus) by using two methods, namely: Castagna (1985) method produces Poisson's ratio 0.22 and Brocher (1986) method produces a Poisson's ratio of 0.25 and must be validated using the uniaxial comptressive test (static condition), the average Poisson's ratio outcrop value is 0.14, so for the brittleness calculation of the well log, the Poisson's ratio 0.22 (approaching the average Poisson's ratio) is used the outcrop of the table is 0.14).

Furthermore, from the results of the XRD analysis, shale samples from Kiliran Jao and Limapuluh Koto (Table-1a and Table 1b) can be used to confirm the dominance of minerals along the depth interval (lithology) of the Pematang Group Brown Shale Formation.

From the results of the validation above, from the results of the BETRO-001 well log analysis, correlation can be presented in tabulation form, and displayed in several columns, including: Depth (MD), Vshale GR, Shale Brittlenss Index, Normal Pressure, and Minimum Insitu Stress, as shown in Figure-10.

Based on the 1D model, which is the depth correlation (MD), Vshale GR, Shale Brittlenss Index, Normal Pressure, and Minimum Insight Stress in Figure 10, the parameters of the hydrocarbon shale to increase production commercially, according to Matt McKeon (2013), include with criteria: Moderate clay content < 40%, Brittleness Index > 0.48, shale formation thickness > 100 ft, and formation pressure > 0.433 psi / ft. Based on these parameter criteria, the results of the Betro-001 well log analysis calibrated with the results of the lab analysis (Uniaxial & XRD Test) cores from Kiliran Jao (Karbindo Coal Mine) are shown in Table-4.

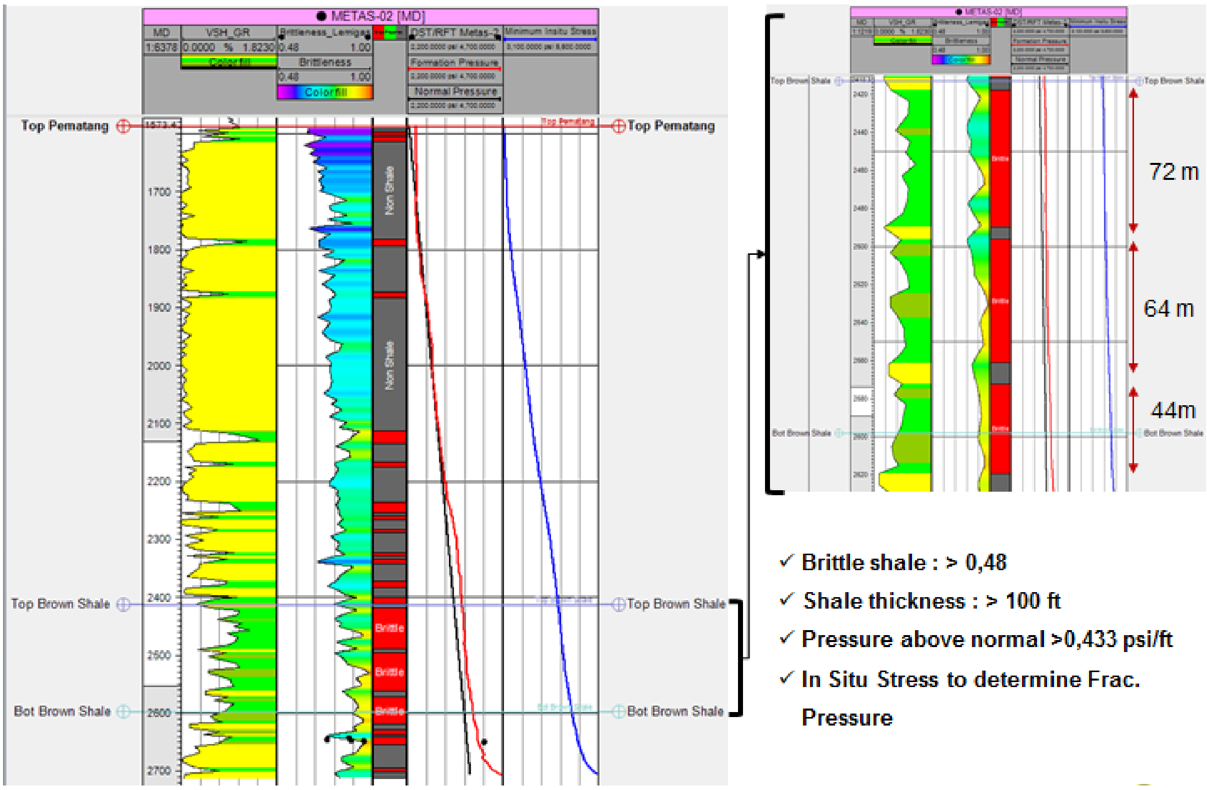

Figure-10. correlation of V_{shale} GR, Shale Brittlenss Index, Normal Pressure, and Minimum In-situ Stress

Table-4. Summary of the results of the BETRO-001 well log analysis calibrated with lab analysis results (Uniaxial & XRD Test) cores from Kiliran Jao (Karbindo Coal Mine).

No	Parameters	References	Log Analysis	Lab Analysis
		Matt Mc Keon, 2013	Result	Result
1	Shale thickness	> 100 ft	74 m, 64m & 44 m	
2	Moderate clay content	< 40%		Kiliran Jao : 16,33% (Avg) Limapuluh Koto : 24,04%
3	Brittleness Index shale	> 0,48	0,78 (Avg)	
4	Pressure : above normal	> 0,433 psi/ft	0,53 psi/ft	

7. Conclusions

1. The calculation of the brittleness of the well log of the well BETRO-001, used the Castagna method with a Poisson's ratio of 0.22, because it approaches the average Poisson's ratio of 0.14.
2. The results of XRD analysis of shale samples from Kiliran Jao and Limapuluh Koto showed that the samples from Limapuluh Koto included the brittle shale group because of the dominant quartz (quartz rich), whereas for the sample from Kiliran Jao there were four samples that were shale brittle because it was rich in carbonate (carbonate rich), and there is one sample from Kiliran Jao shale which is ductile which is difficult to fract. Overall shale samples are more brittle.

3. Based on the 1D model, which is the depth correlation (MD), V_{shale} GR, Shale Brittlenss Index, Normal Pressure, and Minimum In-situ Stress, according to **Matt McKeon (2013)**, that Shale Hydrocarbon in Bengkalis Trough meets the following prospect criteria:
a. Pressure : 0,53 psi/ft (above normal, 0,433 psi/ft)
b. Shale thickness : 74m; 64m; dan 44 m (> 100 ft)
c. Moderate clay content : Limapuluh Koto 24,04 Avg & Kiliran Jao 16,33 Avg (< 40%)
d. Brittle Index shale : 0,78 Avg (> 0,48)
4. From the results of the prospect criteria in item-3, it can be concluded that the Brown Shale Formation in Bengkalis Trough has good shale hydrocarbon potential and can be carried out for further research, because oil production from conventional Indonesian reservoirs in general has experienced a significant decline.

Acknowledgement
The authors would like to thank the PHE & BSP Consortium Join Study of Unconventional Hydrocarbon Resources in CPP Block for their data contribution. We would like to thank PT. Karbindo Abesyapradhi for access to the sampling and coring.

References
[1] Camell A et al 1998 *The Brown Shale of central Sumatra: A Detailed Geological Appraisal of A Shallow Lacustrine Source Rock*, Proceeding, Indonesian Petroleum Association, Twenty-Sixth Annual Convention.
[2] Castagna J P, Batzle M L and Eastwood R L 1985 *Relationships between compressional-wave and shear-wave velocities in clastic silicate rocks*. Dallas: Society of Exploration Geophysicists.
[3] Edy Sunardi 2015 *The Lithofacies Association of Brown Shales In Kiliran Jao Sub-basin, West Sumatra Indonesia*, Indonesian Journal on Geoscience Vol. **2** No. 2 August 2015 pp 77-90
[4] Eubank R T and Makki A C 1981 *Structural Geology of the Central Sumatra Basin*. IPA
[5] Grieser B and Bray J 2007 *Identification of Production Potential in Unconventional Reservoirs*. Oklohama: Society of Petroleum Engineers.
[6] Heidrick T L and Aulia K *1993 A Structural and Tectonic Model of The Coastal Plain Block, Central Sumatera basin, indonesia*. Jakarta: Indonesian Petroleum Assosiation
[7] Horsrud P 2001 *Estimating Mechanical Properties of Shale From Empirical Correlations*. Trondheim: Society of Petroleum Engineers
[8] Hucka V and B Das 1974 *Brittleness Determination of Rocks by Different Methods*. Great Britain: International Journal of Rock Mechanics and Mining.
[9] Jarvie D M, Hil R J, Ruble T E and Pollastro R M 2007 *Unconventional shale gas system: The Mississippian Barnet Shale of north-central Texas as one model for thermogenic shale gas assessment*. AAPG Bulletin
[10] Ju Hyeon Yu, Sung Kyung Hong, Joo Yong Lee and Dae Sung Lee 2016 *Brittleness Analysis Study Of Shale By Analyzing Rock Properties", Advances in Civil, Environmental, and Materials (ACEM16), jeju Island, Korea*.
[11] Jingqi Xu 2016 *Brittleness and Rock Strength of the Bakken Formation, Williston Basin, North Dakota*.
[12] Jin X and Shah S 2014 *A Practical Petrophysical Approach for Brittleness Prediction from Porosity and Sonic Logging in Shale Reservoir*. Amsterdam: Society of Petroleum Engineers
[13] Katz B J 1994 *Stratigraphic and lateral variations of source rock attributes of the Pematang Formation, Central Sumatra*, AAPG Internalionol Conference & Exhibilion '94, Kuala Lumpur, Malaysia
[14] Lobo C Molina, A Faraco A and J Delgadillo 2017 *Methodology for Petrophysical and Geomechanical Analysis of Shale Plays*. Case Study: La Luna and Capacho Formation, Maracaibo Basin. Buenos Aires: Society of Petroleum Engineers

[15] Mao Bai 2016 *Why Are Brittleness And Fracability Not Equivalent In Designing Hydraulic Fracturing In Tight Shale Gas Reservoirs,* Production and Hosting by Elsevier on behalf of KeAi
[16] McKeon M 2011 *Horizontal Fracturing in Shale plays*. Halliburton
[17] Perez R and Marfurt K 2014 *Mineralogy-based brittleness prediction from surface seismic data: Application to the Barnett Shale, ConocoPhillips School of Geology and Geophysics, Norman, Oklahoma, USA.*
[18] Rickman R, Mullen M, Petre E, Grieser B and Kundert D 2008 *A Practical Use of Shale Petrophysics for Stimulation Design Optimization: All Shale Plays Are Not Clones of the Barnett Shale.* Colorado: Society of Petroleum Engineers
[19] Roderick Perez Altamar and Kurt Marfurt 2013 *Calibration of Brittleness to Elastic Rock Properties via Mineralogy Logs in Unconventional Reservoirs,* Search and Discovery Article #41237 (2013)
[20] Rojas L F, Pena Y Q and Carrillo Z H 2016 *Brittleness Analysis: A Methodology to Identify Sweet Spot In Shale Gas Reservoir.* Buenos Aries: Society of Petroleum Engineers
[21] Tariq Z, Elkatatny S, Mahmoud M and Abdulraheem A 2016 *A Holistic Approach to Develop New Rigorous Empirical Correlation for Static Young's Modulus*. Abu Dhabi: Society of Petroleum Engineers
[22] Wang H, Marongiu-Porcu M and Erconomidas M J 2016 *Poroelastic and Poroplastic Modeling of Hydraulic Fracturing in Brittle and Ductile Formation*. Society of Petroleum Engineers.
[23] Yang Y, Sone H, Hows A and Zoback M 2013 *Comparison of Brittleness Indices in Organic-rich Shale Formations*. San Francisco: American Rock Mechanics Association
[24] Zendehboudi S 2016 *Shale Oil and Gas Handbook*. Joe Hayton
[25] Zoback M 2006 *Reservoir Geomechanics: Earth Stress and Rock Mechanics Applied to Exploration, Production and Wellbore Stability*. Stanford University: Department of Geophysics