Shale Hydrocarbon Potential of Brown Shale, Central Sumatera Basin Based on Seismic and Well Data Analysis

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Abstract. The development of unconventional shale hydrocarbon is really depending on integrating approach of wide range disciplines. The integrated approach for analysing organic-rich shale reservoirs involves calibration of core and well-log data, building petrophysical and rock-physics models, and finally characterizing the key reservoir parameters (TOC, porosity, and natural fractures) and mechanical properties evaluation from seismic data. In this research, integrated approach of geochemical, geomechanical, mineralogy, petrophysical, and geophysical analysis are carried out in Brown Shale, Central Sumatera Basin. Total Organic Carbon (TOC), maturity, and brittleness index are the main parameters used in this study to analyse the shale hydrocarbon potential. The result of geochemical analysis shows that the maturity level of shale in the interest zone in oil window, which means it can generate shale oil in early mature phase at depth of 6400 ft. Quantity of shale hydrocarbon potential is indicated by the TOC value of 0.5-1.2 wt. % (fair to good), with average of shale thickness for over 50 ft. The result of geomechanical analysis shows that brittleness index of interest zone for over 0.48 and rock strength below 10000 Psi.

1. Introduction
Indonesia has shale hydrocarbon potential within selected marine-deposited formations, as well as more extensive shale resources within non-marine and often coaly shale deposits. The best overall potential appears to be mostly oil-prone, lacustrine deposited shales within the Central and South Sumatra basins, which sourced the prolific nearby conventional oil and gas fields [1]. Central Sumatra basin is situated in a tectonically active region as a result of subduction of the Indian - Australia plate. Central Sumatra basin is located between North Sumatra Basin and South Sumatra basin, surrounded by Asahan uplift in the north and northwest, Tigapuluh uplift in the southeast, Sunda Shelf in the east, as well as the Bukit Barisan in the west and southwest [2]. Brown Shale formations are known as a main source rock in the presence of oil and gas in Central Sumatra Basin [1]. Depositional environment of this formation was formed from Lacustrine with lithology rock consists of laminated shale, brown colour, rich in organic material, which indicates the depositional environment with calm water conditions.

Previous studies of shale hydrocarbon in Indonesia mostly analysed in terms of geochemistry, which focus on the characteristics of shale for the content value of Total Organic Content (TOC), the type of kerogen, and level of maturity. Geomechanics analysis, which is determined from brittleness index is also the important parameter to define the economically production.
Hydrocarbon basin in Sumatra has a wide distribution of shale, particularly in Central Sumatra Basin. Brown Shale formation is the main source rock for oil and gas in Central Sumatra Basin. According to published paper [3], TOC content of Brown Shale Formations reach 3-5% with a thickness of 300-1000 feet. The maturity level of this formation is on the mature phase (oil-gas window). This research will be conducted integrated study of the results of geochemical analysis, geomechanics, mineralogy, petrophysical and geophysics in Brown Shale Formation, Central Sumatra Basin. By looking at the relation between TOC, maturity and the brittleness index on seismic data and wells, we could be able to identify the characteristics of potential shale hydrocarbon in Brown Shale Formation, Central Sumatra Basin.

2. Methods and Analytical Procedures

Characteristics of oil shale is almost similar to shale gas, the only difference is from the hydrocarbon content in the shale, kerogen type and level of maturity. Jarvie (2012) stated that the value of vitrinite Reflectance (Ro) for oil shale ranged from 0.6% to 1.1% (oil window), but it could be up to 1.4%. Then for the kerogen type it could be Type I, II or Type III with Ideally type II [4].

The integrated approach for analysing organic-rich shale reservoirs involves calibration of core and well-log data, building petrophysical and rock-physics models, and finally characterizing the key reservoir parameters (TOC, porosity, and natural fractures) and geomechanical were carried out in Brown Shale, Central Sumatera Basin to achieve the aims of this study.

3. Geochemical and Petrophysical Analysis

A number of selected sample of the Pematang Formation have been analysed to obtain organic geochemical data and pyrolysis values. Results of the present analysis were compared with those of the published work [4] in order to better understand geochemistry of the source system throughout the region.

In this work, geochemical analysis on the core data were carried out to determine TOC, mineralogy, Tmax, and kerogen type. Geochemical analysis of the source rock was used to analyse the quality, quantity and level of maturity. The parameters used are the parameters of Peter [5]. Then to determine the brittleness index value it could be divided into two ways, by mineralogy or geomechanics. The difference is, in mineralogy is based on the minerals composition in the shale sample and using formula that often used in determining the brittleness index values as mineralogy initiated by Jarvie et al [6] and Wang & Gale [7]. But in terms of geomechanics used equation was initiated by Grieser and Bray for calculating brittleness index value using value of Young's modulus and Poisson's Ratio [8,9].

Our assessment to potential Brown Shale of wells Afaf-1 and Fahed-2, in term of maturity, it can be explained based on cross-plot between Tmax versus depth and Ro, which is shown in Figure 1a. Those, it can be classified into early mature phase with Tmax of 435°C and Ro of 0.55%, which is located at a depth of 6400 ft. In term of kerogen type, the modified van Krevelen diagram (Figure 1b) showing the HI vs. OI plot based on the Pematang Brown Shale pyrolytic data, which is taken from wells Afaf-1 and Fahed-2, indicating that the source section is gas prone and type III kerogen.

However, our observation on diagram Ro vs. depth shows that the sample data is mostly in oil window, therefore it could be concluded that this Pematang Brown Shale Formation potentially generated oil. It has also been confirmed with the results of cross-plot between Hydrogen Index (HI) with Tmax in Figure 1c. From the results cross-plot between HI to Tmax, the shale formation Pematang Brown Shales entered phase early to peak maturity, which means could generate oil and has type III kerogen. It was also confirmed from mud log data at Fahed-2 well, which has oil show at a depth 8500ft.
Figure 1. Pore (a) Cross-plot of depth versus Tmax (left) and Cross-plot of depth versus Ro (right). (b) Plot of Van Krevelen Diagram and (c) Plot of Hydrogen Index versus Tmax of Afaf-1 and Fahed-2 well.

Figure 2. (a) TOC vs. depth for Brown Shale Formation, (b) Depth structure map and (c) Brittleness Index calculation at Pematang Brown Shale Formation using Geomechanical method [9] equation of Fahed-2 well.

The TOC content of the selected samples of Brown Shale ranges from 0.5 to 1 wt. %, which means the quantity of shale into the medium category (fair). This condition is because of the well location Fahed-2 is on the edge of the sub-basin (Figure 2a) so gives the low value of TOC. If the well located at the centre of the basin (Figure 2b), the TOC value will be higher due to the central basin sedimentation rate is slower and gives rich organic material. In contrast, the edge of the basin areas tends to have a high sedimentation rate so rarely found in shale with rich in organic material.

The next assessment to the potential Pematang Brown Shale is intended to Brittleness Index (BI), which is based on mineralogy content. Table 1 shows the test results of X-Ray Diffraction (XRD) of
the sample data Fahed wells core-2. The result of X-Ray Diffraction (XRD) on wells Fahed-2 is used to determine the value of Brittleness Index (BI). In common, the BI is estimated by using Jarvie (2007) and Wang (2009) approximation. Figure 2c shows Brittleness Index calculation of Pematang Brown Shale Formation using Geomechanical method Grieser equation [9] of Fahed-2 well.

**Table 1.** Mineralogy of X-Ray Diffraction (XRD) test for Fahed-2 well.

| No | Well | Lithology | CLAY MINERALS (%) | CARBONATE MINERALS (%) | OTHER MINERALS (%) | TOTAL (%) |
|----|------|-----------|-------------------|------------------------|-------------------|----------|
| 1  | Fahed-2 | Sand    | - 3 10 -          | - 87 -                 | tr 13 tr 87      |          |
| 2  | Fahed-2 | Shale   | - 30 45 -         | - 25 -                 | 75 tr 25         |          |
| 3  | Fahed-2 | Sand    | - 3 24 -          | - 72 -                 | 27 1 72          |          |
| 4  | Fahed-2 | Sand    | - 7 14 5          | - 74 -                 | 26 - 74          |          |
| 5  | Fahed-2 | Sand    | - 4 7 -           | - 89 -                 | 11 - 89          |          |
| 6  | Fahed-2 | Sand    | - 2 3 -           | - 95 -                 | 5 - 95           |          |

Since the limitation of sample number, therefore we only have a few TOC data, which is not cover for the whole depth. In order to patch the lack of this data, we need to estimate the TOC information as function depth by applying Multi-linear Regression. The following is derived equation from Multi-linear Regression as function of GR, Density, NPHI, Sonic and Resistivity.

\[
\text{TOC} = -14.8534 + (-0.0168 \times \text{GR}) + (3.9498 \times \text{Density}) + (4.7925 \times \text{Neutron porosity}) + (0.0751 \times \text{Sonic}) + (0.0651 \times \text{Resistivity})
\] (1)

Our estimation based on equation (1), the TOC value for potential of Pematang Brown Shale is identified as fair to good (0.5-1.2 wt.%) with thickness of 50 ft and brittle brittleness index (BI > 0.48). The depth of target zone is in interval of 8450-8660 ft. Our assessment on the sensitivity analysis, shale is not significantly separated with sand because the shale thickness is low and intercalated with sand.

4. Geophysical analysis

The geophysical analysis is performed to transform the seismic data, which has lateral resolution, into the organic geochemical data. This strategy is very helpful in mapping the potential of hydrocarbon shale laterally. In order to transform seismic data to organic geochemical data, we first applied the seismic inversion to produce the AI section. Further, we did sensitivity analysis as a reference to define shale potential zones. Based on sensitivity analysis, the shale potential hydrocarbon zones was indicated by having AI higher than 43750 ft/s*g/cc, TOC of 0.5-1.2 wt % (fair - good) and Rock Strength value less than 10000 Psi.

Figure 3a shows AI inversion result at seismic line 4777. The resulted AI is then distributed to all seismic line guided with top and bottom Pematang Brown Shale Formation to produce TOC section, which is illustrated in Figure 3b. The same step is done to define rock strength map and illustrated in Figure 3c. After having all 2D seismic line was transformed into TOC section, then we interpolate TOC and rock strength section to make TOC and rock strength map. Figure 3d shows a map of Rock Strength, which is overlaid with TOC structure, dark area indicates sweet spot potential brown shale that has Rock Strength less than 10000 psi and TOC value is more than 1%. Furthermore geological structure of this area is a basin structure which possibly makes sediment turns mature phase by sedimentation in high temperature.
Figure 3. (a) AI section of inverted seismic line 4777, (b) TOC section for seismic line 4777, (c) Rock strength section for seismic line 4777, (d) Rock Strength map, which is overlaid with contour of TOC for delineating sweet spot of potential shale hydrocarbon.

5. Conclusions
The integrated approach for analyzing organic-rich of Pematang Brown Shale Formation has been completely carried out for characterizing the key hydrocarbon shale parameters geochemical (TOC, Ro, and kerogen type) and mechanical properties evaluation from seismic and well data. The potential of Pematang Brown Shale Formation show fair to an excellent hydrocarbon potential level, and classified into phase early to peak maturity, which means could generate oil and has type III kerogen. It was also confirmed from mud log data at Fahed-2 well, which has oil show at a depth 8500ft.

Our delineation by integrating geochemical and geomechanical analysis show that potential shale hydrocarbon distribution was indicated by having following parameters such as TOC - 1.2 0.5 wt.% (Fair - good), a thickness up to 50 ft., Brittleness Index above 0.48 and Rock Strength value below 10000 Psi. From the results of acoustic impedance inversion, seen that the shale with hydrocarbon potential has acoustic impedance value above 43,750 ft/s*g/cc. Directions deployment zone of potential shale hydrocarbon is in the southern part sub-basin around wells Nagib-1, Maya-1 and Lulu-1.

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