Integrated Approach for Characterizing Unconventional Reservoir Shale Hydrocarbon: Case Study of North Sumatra Basin

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Abstract. Integrated analysis of geochemical, rock mechanic and geophysics were carried out to characterize and map the unconventional reservoir shale hydrocarbon in Baong field, North Sumatera Basin, which is proven with the large potential hydrocarbon, particularly in the sand reservoir. The new challenge of this field is the present of thick shale layer, which is offering the new concept of an unconventional reservoir. The shale layer has the double role as source rock and reservoir. In this work, we performed geochemical analysis on the core data to determine the Total Organic Carbon (TOC), mineralogy, Tmax, and Kerogen type. In term of rock mechanic, the Rock Strength was calculated to determine the hardness and brittleness index. While for petrophysical analysis, we performed multi-linear regression of log data to estimate TOC relationship with the seismic attribute. In term of geophysics, we carried out seismic inversion to produce acoustic impedance, which is useful to map shale distribution.

Our analysis shows that the target of shale layer has TOC range from 2 up to 3.5 wt.% with brittleness index of 0.48. Based on the predicted Tmax, this shale layer is categorized into early mature phase and classified into II Kerogen type, which means it has a potential to produce oil. The shale layer was indicated by the result of acoustic impedance inversion which has a value for over 25000 ft/s *g/cc and Rock Strength less than 3000 Psi.

1. Introduction

In term of energy resource exploration, the generation potential of shale hydrocarbon from organic-rich shale has been considered intensively as new and unconventional energy resources. The hydrocarbon shale has long been of an interest for indirect energy resource and has unique petroleum system where shale was playing a role as a source rock and reservoir hydrocarbon. Finding other alternative energy resources of fossil fuel origin requires a serious effort for geoscientists to overcome the continuing decline of petroleum supplies, accompanied by increasing costs of petroleum-based products may present opportunities for hydrocarbon shale to produce some of energy needs. Thereby, the hydrocarbon shale potential in Indonesia, which have been abundantly identified, can be explored to meet the energy needs in the future [1].

The previously published paper discussed the hydrocarbon shale potential, which was identified in some parts of Sumatra, including Baong filed in North Sumatra. Those shales have preliminary been studied, however, their potential and quality has not been known well yet. These hydrocarbon shale beds seem to superimpose the oil, gas, and coal seam basin, and thereby the basin setting is similar to the tectonic configuration of the clastic depositional system [1][2].
Tectonically, North Sumatra Basin is a back-arc basin which covers an area of 60,000 square km in offshore and onshore northern Sumatra Island. The Basin is a prolific hydrocarbon basin in western Indonesia and produces hydrocarbons [3]. Exploration history began in the late 19th century in which the oil field was first discovered in the Basin of North Sumatra that field Telaga Said (1885), followed by the field of Land (1889), Perlak (1990), Serang Jaya (1926), Rantau (1929), Gebang (1936), and the west Palu (1937). Arun field is a large field discovered in 1971 with reserves at that time is estimated around 17TCF.

Stratigraphically, Baong shale is younger than Bampo shale in North Sumatera but the availability of well data only up to Baong formation. Baong formation was formed in the deep lacustrine environment and consists of darks shale. In term of stratigraphy, Baong Shale is divided into three sections, Lower, Mid and Upper Baong [4]. In mid-section, shale was intercalated with sand then act as a reservoir. The regional structure is high in the southwest and north due to the Bukit Barisan high and the Asahan High [5].

The integrated analysis including geochemical, rock mechanic, and geophysics reported in the present paper aimed to characterize and map the unconventional reservoir shale hydrocarbon in term of potential source rocks, and thermal maturity of the rock succession in Baong field, North Sumatera Basin. The availability of data consists of 2D seismic data and 3 well will be used to characterize and map shale hydrocarbon, which is guided by AI, TOC, and Rock Strength.

2. Methods and analytical procedures
To achieve the goal of this study, we used core laboratory and geophysical analysis. Primary laboratory work activity includes accurate determinations, observations, and measurements on organic matter characteristics, and detailed seismic interpretation containing shale of Baong Formations, North Sumatra Basin. Afterward, we generated some approximation model from the limited data to gain the relation between the field (samples) and calculated data for geochemical and organic petrographic analyses. The samples are gained from a freshest relatively selected representative core of shale and mudstones.

3. Geochemical and petrophysical analysis
The quantities of organic matter in shale samples were determined based on the total content of organic carbon (TOC). In this work, geochemical analysis on the core data was carried out to determine TOC, mineralogy, Tmax, and Kerogen type. Geochemical data are collected from cutting sample for each well. Geochemical data of shale sample in the form of Rock-Eval Pyrolysis from each well were taken from Baong Formation.

Geochemical analysis of 3 existing wells is shown in different color point where blue is well A; red is well B, and green is well C. The location of well A and B are in close each other, well B located about 10 km from well A and C. Figure 1a shows the distribution of Tmax from each well. Figure 1b shows that well A and B are categorized as Kerogen type II which potentially generate oil but has different amount of Hydrogen Index (HI). Figure 1c shows that Well A and B shows temperature less than 435°C which is categorized immature and on the other side Well C indicates temperature in early mature phase. The distribution of TOC data from each well has variation 0.5 – 4 wt.%. TOC collected from geochemical analysis at certain depth while TOC data is needed for entire depth. Therefore TOC data is derived from mathematical relationship to gain TOC as a function of depth (in the range of shale formation) by using Multilinear Regression method. The mathematical relationship of TOC data will be the function of GR, Density, Neutron Porosity, Sonic, and Resistivity is given by equation (1) as follow:
Figure 1. Geochemical analysis of three available well a) Diagram plot Tmax vs. depth, b). The relationship of Tmax and HI, and c). Diagram plot TOC vs. depth.

\[ \text{TOC} = 1.8994 - 0.1076 \times \text{Density} + 20.893 \times \text{Neutron Porosity} - 0.0488 \times \text{Sonic} + 0.321 \times \text{Resistivity} \]  

(1)

The correlation between the TOC lab and the calculated TOC using Multi-linear regression, which is illustrated in equation (1), shows good correlation and the derived equation will be used to distribute the calculated TOC along the seismic section, which is guided by Acoustic Impedance (AI).

In term of petrophysical analysis, we determine the relationship between AI and TOC in the way of cross plotting analysis to see the separation of sand on shale. Figure 2 shows that shale was well separated from sand in a certain range. Shale hydrocarbon potential is indicated by AI of 25000 ft/s*g/cc and GR around 70 GAPI. The Rock Strength parameter is determined from well data using Horsrud [6], which is derived from sonic log [6]. The relation between Rock Strength and brittleness index is inversely proportional, where brittleness was determined from the percentage of reversible strain.

Figure 2. Cross-plotting analysis to see the separation of sand with respect to shale a), and cross section as a function of depth b), which is represented by AI and GR.
In term of mineralogy analysis, we applied the equation of Brittleness Index (BI) that has been defined by Jarvie et al. and modified by Wang and Gale [7][8]. They modified the equation by adding dolomite fraction into their equation which could increase brittleness index value. In this study area, the presence of mineral plagioclase is dominant. It was shown that presence of plagioclase around 2-6 %. Our observation to the both calculated BI from Jarvie and Wang and Gale, show similar trends of BI. Figure 3 shows the relationship of BI and Rock Strength, where more brittle shale the Rock Strength decreases. Our assessment of the total potential of shale rock refers to more brittle rock, less Rock Strength, and higher TOC value. In general, the potential of shale rock has TOC range from 2 up to 3.5 wt.% with brittleness index of 0.48 and Rock Strength less than 3000 Psi.

![Figure 3. The panel from left to right is illustrating Gamma Ray, Brittleness Index, and Rock Strength. More brittle shale will have less strength.](image)

4. Geophysical analysis

The geophysical analysis is performed to transform the seismic data, which has the lateral resolution, into the organic geochemical data. This strategy is very helpful in mapping the potential of hydrocarbon shale laterally. The available seismic data has different vintage so that seismic data should be applied conditioning such as amplitude matching and balancing.

To transform seismic data to organic geochemical data, we first performed the seismic inversion to produce the AI section. Further, we did sensitivity analysis as a reference to define potential shale zones. Based on sensitivity analysis, the shale hydrocarbon zones was indicated by having AI of above 25000 ft/s*g/cc, TOC of 2-3.5 wt.% (good to very good quality) and Rock Strength less than 3000 Psi. The prospect zone is marked by the black ellipse. Figure 4a show AI inversion result at seismic line 77 through well A. The resulted AI is then distributed to all seismic line guided with top and bottom Baong Formation to produce TOC section, which is illustrated in figure 4b. The same step is conducted to define Rock Strength section as displayed in figure 4c. After having all 2D seismic line were transformed into TOC, then we interpolate TOC and Rock Strength section to make TOC and Rock Strength map.

Figure 4d shows TOC distribution, where high TOC was shown at the south-eastern part of the study area. Thus overlay between Rock Strength map and TOC shows the potential sweet spot where the color legend indicates Rock Strength and contour indicates TOC distribution. The area which has high TOC and low Rock Strength is shown in the south-eastern area.
Figure 4. a) AI section b). TOC section and c) Rock Strength section, and d) TOC surface of Baong Formation. The dashed-line is the sweet spot of potential shale.

5. Conclusions
Integreted analysis of geochemical, rock mechanic and geophysical was successfully applied to characterize and map the unconventional reservoir shale hydrocarbon in Baong field, North Sumatera Basin. The shale hydrocarbon of Baong Formation shows fair to very good hydrocarbon potential level, with Kerogen contained is classified into Type II at depth of 1500m. They can be categorized as gas-prone source-rock, with thermal maturity significantly varies from immature to early mature level, dominated by immature stage. Our delineation by integrating geochemical and geomechanical analysis show that sweet spot can be identified in the south-eastern part of the study area. Based on the integrated analysis, we identified that potential shale layer has TOC range from 2 up to 3.5 wt.% with brittleness index of 0.48. The shale layer was indicated by the result of acoustic impedance inversion which has a value for over 25000 ft/s *g/cc and Rock Strength less than 3000 Psi.

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