Characterization Of Lower Baong Formation As A Potential Reservoir In Shale Hydrocarbon System In Langkat Area, North Sumatra

Denny Suwanda Djohor, Benyamin Sapiie, M. Emmy Relawati, Agus Guntoro, Budi Widyarta

Abstract—Uncertainty in exploration has found large conventional hydrocarbon reserves in the North Sumatra Basin, encouraging unconventional hydrocarbon exploration studies. The studies methodology used includes: (1) Data collection and data laboratory analysis. (2) Data processing method, starting with identifying the existence of the Lower Baong Formation from the data well log and report. (3) Data analysis method in the form of analysis of patterns produced from data processing. (4) The characteristics of lithology and the potential of shale hydrocarbons quantified in the attributes of geomechanics. The results of the studies: a) The Lower Baong Formation can be divided into 5 (five) lithofacies. The characteristics of each lithofacies in each well have different lithological variations and compositions. b) The results of the calculation of the brittleness index (BI), indicating that the lithology of Calc. Siltstone has the highest BI value than lithology of Calc. Shale. c) Based on mineralogical composition, it can be a conclusion that BI values are strongly related to mineralogical composition; indicated by the presence of brittle minerals, and clay minerals. d) Lithology Calc. Siltstone in PPT-3 well (depths of 2187 - 2125 and 2095 - 2035 meters) are zones that have potential as a reservoir in shale hydrocarbon systems. e) Correlation of northwest-southeast wells shows sediment deposition thickness in several different wells; this is due to the paleogeography of the basin during the deposition process of the Lower Baong Formation which is estimated to be controlled by the presence of low and height caused by tectonic processes.

Index Terms—brittleness index, lithofacies, Lower Baong Formation, geomechanics, reservoir, shale hydrocarbons, unconventional.

1 INTRODUCTION

Uncertainty in exploration has found large conventional hydrocarbon reserves in the North Sumatra Basin, encouraging unconventional hydrocarbon exploration studies. The effort was carried out as an alternative to find new resources by evaluating the presence of hydrocarbons directly in the host rock. Shale that is rich in organic material and has reached maturity [1], in addition to functioning as host rock, under certain conditions and types can function as a thermogenic gas reservoir, known as shale hydrocarbons (unconventional hydrocarbons); are intended to describe very small reservoir permeability, whereas conventional ones have permeability higher than 0.1 mD [2].

Yuan Zhong Zhang [3] show the shale gas reservoir has clear characteristics in the conventional well log profile, i.e., both the GR log and the resistivity show high values. RLLD and RLLS values indicate moderate or low, low density, and low sonic wave velocity.

Rickman R. [4], show integrated mineralogy and geomechanics with petrophysics to optimize fracture program design and concluded that not all shales are the same, describe mineralogical (clay content) and geomechanical conditions required on an excellent shale gas play. Britt, L.K. [5], they recommended adopting mineralogical and static elastic cutoffs, below which shales were not considered prospective from a brittle fracturing perspective. Hydraulic fracturing is more effective in the zone of brittle lithology, called the sweet spot. Britteness is generally considered from a qualitative aspect to describe the mode of behavior in failure. Failure is related to the sudden loss of material resistance, i.e., the peak in the stress-strain curve. Failure is related to the sudden loss of material resistance, i.e., the peak in the stress-strain curve. Failure is related to the sudden loss of material resistance, i.e., the peak in the stress-strain curve. Failure is related to the sudden loss of material resistance, i.e., the peak in the stress-strain curve. Failure is related to the sudden loss of material resistance, i.e., the peak in the stress-strain curve.

The Lower Baong Formation is one of the main rocks in the North Sumatra Basin with a total content of shale hydrocarbon gas of 4,450 Mmboe and for oil 2,230 Mmbo [8]. Meckel, L.D. [9] show with over 100 years of production, North Sumatra Basin is one of Indonesia’s most prolific sedimentary basins.

Thus, the studies location chosen in the Langkat area, which is part of the North Sumatra, with the target of the Lower Baong Formation. The characteristics of the Lower Baong Formation lithology integrated with geomechanical components (brittleness index) are expected to be the first method of identifying zones that have potential as a reservoir in shale hydrocarbon systems.

Evaluating the potential of shale hydrocarbons in a sedimentary basin in Indonesia, it is not appropriate to analogize the shale characteristics produced in America. Every sedimentary basin has unique features, and this will affect the type and deposition of shale and soon the nature of geomechanical. Based on the results of studies from a field playing shale hydrocarbons that have been producing in Barnett, North America, this indicates that shale lithology is not homogeneous, this will be related to the nature of geomechanical [10].

The scope of the problem in this study is limited to the analysis and synthesis of petrology, and the nature of geomechanical (brittleness index); based on subsurface data in the Langkat area, North Sumatra.

2 METHODOLOGY

The studies methodology used includes (1) Data collection methods, including regional geological data from the studies area and subsurface data, including well data (in the form of

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electric logs and mud log), and data from laboratory analysis. (2) Data processing method, starting with identifying the existence of the Lower Baong Formation shale from the well data log and report. (3) Data analysis method in the form of analysis of patterns produced from data processing which includes lithology grouping carried out based on rock composition, log correlation and depositional environment, then integrated with geomechanical rock properties (brittleness index); is obtained based on the method of XRD data [4]. This petrophysical analysis used Well Pantai Pakam Timur-3 data, which is relatively more complete with well data. The petrophysical analysis methodology consists of four basic steps, namely: determining the volume of shale (Vsd), formation water resistivity value (Rw) using assumptions, the effective porosity value and water saturation value (Sw). (4) Geological synthesis is used to map the characteristics of shale lithology and the potential of shale hydrocarbons quantified in the features of rock mechanics.

3 REGIONAL GEOLOGY OF STUDIES AREA

Geological Regional, the North Sumatra Basin is restricted by the Malacca Platform to the east, to the south by Asahan Arch, to the west by the Barisan Mountains and the northern part of the basin open to the Andaman Sea. The lithostratigraphy summary of the North Sumatra Basin has widely discussed in several studies (see Figure 1). The Baong Formation divided into three unofficial units [11], namely: Lower Baong Shale, Middle Baong Sandstone (MBS) and Upper Baong Shale. The lower Baong Shale unit, composed of the predominance of dark-gray calcareous shale, is rich in forams, showing a marine depositional environment. The maximum thickness calculated is 700 feet. The MBS unit consists mainly of light gray, very fine-grained, calcareous and glauconitic sandstones; this unit often found in the Aru area (Blok owned by Pertamina). The upper part of the member is characterized by a layer of sandstone, while the lower part of the sandstone layer is right above the Lower Baong Shale. Both the top and bottom, they do not represent a particular time correlation. The thickness of the sandstone sequence varies between 300 - 850 meters. The bottom part of the sequence Baong shales deposited at a deeper depth compared to the middle Baong sandstone. Tectonic activity The North Sumatra Basin is distinguished between pre-Miocene and Miocene to post-Miocene. The north-south trending structure mainly produced by pre-Miocene tectonics. The pattern of Miocene - post-Miocene structure is mainly in the northwest-southeast direction; the orientation of the structure is related to the elevation of Bukit Barisan. The fault pattern of the north-south (pre-Tertiary pattern) and northwest-southeast and northeast-southwest patterns is a Plio-Pleistocene fault reactivation since the Middle Miocene.

The North Sumatra Basin is one of three back-arc basins formed during the Tertiary (Early Oligocene), on the Eurasian plate or Sunda Shelf [11]. Extensional tectonics dominates the history of the Sumatra Basin at the beginning of the Tertiary and forms high and low structures, forming a trap and growing place for reefs as a kitchen area. The second tectonic is compressional, which also forms a trap as an inversion structure.

![Northern Sumatra Lithostratigraphy](image)

**Fig. 1. Northern Sumatra Lithostratigraphy (modification after Ryacudu et al., 1992 vide Ricky A. T. et al., 2017).**

4. DATA ANALYSIS AND DISCUSSION

4.1 Data Availability

Availability of well drilling and seismic (seismic) data in the studies area and those included in the Pertamina EP WK Sumbagut Area, which provides for eight wells (see Table 1 and Figure 2).

**TABLE1**

*Well, data in studies area.*

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<th>No.</th>
<th>Well Name</th>
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Explanation: V = Data is available.

4.2 Log Analysis

Detailed stratigraphic sequence analysis was carried out using the log and mud log data from 8 wells covering the studies area. From the results of the analysis of the stratigraphic sequence of the Lower Miocene (N13) Lower Baong Formation, there was five parasequence set. The lower limit of the Lower Baong Formation limited by the sequence boundary (SB.3) and the upper limit defined by maximum flooding surface (MFS.4).
Log analysis on Well PantaiPakam Timur-3 shows the lithofacies distribution in the Lower Baong Formation, namely Lower Baong PS.5 - MFS 4 (1840 m - 1930 m) with lithofacies Calcareous Shale intercalated Calcareous Siltstone. MFS 4 - Lower Baong PS.4 (1930 m - 2005 m) with lithofacies Calcareous Shale intercalated Calcareous Siltstone and Carbonate rock. Lower Baong PS.4 - Lower Baong PS.3 (2005 m - 2125 m) with lithofacies Calcareous Shale intercalated Calcareous Siltstone, Lower Baong PS.3 - Lower Baong PS.2 (2125 m - 2215 m) with lithofacies Calcareous Siltstone intercalated Calcareous Sandstones and the upper parts of Carbonate rock, and Lower BaongPS.2 - Lower BaongPS.1 (2215 m - 2300 m) with Calcareous Shale intercalated Carbonate rock.

The results detailed of log analysis and well report data (Figures 3) and plotting of GR vs. RHOB, GR vs. ILD, and GR vs. DT (Figure 4).

4.3 XRD Analysis

Secondary data from the XRD analysis of the Well PantaiPakam Timur-3 drill powder sample Pertamina [12] from the Lower Baong Formation (Figure 5). The results of XRD analysis and using the formula BI (brittleness index) of Wang & Gale (2009), are as follows:

- Depth of 2281 - 2223 meters is part of the lithology Calcareous Shale (lithofacies Calcareous Shale intercalated Calcareous Siltstone and Carbonate rock), obtained BI value is 0.24.
- Depth of 2187 - 2125 meters is part of the lithology Calcareous Siltstone (lithofacies Calcareous Siltstone intercalated Calcareous Sandstones and the upper part of Calcareous Shale), then the BI value is 0.51.
- Depth of 2095 - 2035 meters is part of the lithology Calcareous Siltstone (lithofacies Calcareous Siltstone intercalated Calcareous Sandstones and the upper part of Calcareous Shale), obtained BI value is 0.52.
- Depth 1995 - 1961 meters is part of the lithology Calcareous Shale (lithofacies Calcareous Shale intercalated Calcareous Siltstone and Carbonate rock), obtained BI value is 0.44.
- The depth of 1929 meters is part of the lithology Calcareous Shale (lithofacies Calcareous Shale intercalated Calcareous Siltstone), obtained BI value is 0.36.

Based on the results of XRD laboratory analysis and the calculation of the brittleness index (BI), it shows that the lithology of Calcareous Siltstone has the highest BI value (brittleness index); that is around 0.51 and 0.52 while lithology Calcareous Shale show the lowest BI (brittleness index) value; which is 0.24.

The mineralogical composition of lithology which shows a high BI value (0.51 - 0.52), as follows: quartz mineral = 38-48%, feldspar = 2-6%, calcite = 3-7%, dolomite = 1%, pyrite & siderite = 1-2%, I/S = 10-19%, I/M = 10-18%, chlorite = 1-2%, kaolinite = 4-7%. While the mineralogical composition of lithology which has low BI (0.24), as follows: quartz mineral = 17-27%, feldspar = 3-6%, calcite = 3-8%, dolomite = 1-2%, pyrite & siderite = 1-2%, I/S = 23-28%, I/M = 14-16%, chlorite = 4%, kaolinite = 11-15%.
During diagenesis, the percentage of mixed illite-smectite (I/S) gradually increased with increasing diagenesis degrees, indicated by the percentage I/S on lithofacies Calcareous shale intercalated Calcareous siltstone and Carbonate rock at a depth of 2223 - 2281 meters showing I/S content = 23-28 % higher than lithofacies Calcareous shale intercalated Calcareous siltstone at a depth of 1929 meters, i.e. I/S = 14%. Based on the mineralogical composition of the two lithologies, show differences in the BI (brittleness index) value. It can conclude that BI values are strongly related to mineralogical composition; i.e., for lithology which has a high BI value indicated by the presence of brittle minerals, such as abundant quartz, calcite and dolomite, types of clay minerals, chlorite, and relatively low kaolinite. The main shale gas producing regions of the United States, brittle mineral content (quartz, calcite, dolomite) minerals are generally higher than 50%, and clay content is less than 50% [13]. So the lithology of Calcareous Siltstone (lithofacies Calcareous Siltstone intercalated Calcareous Sandstone and Calcareous Shales) in well Pantai Pakam Timur-3 (depths of 2187 - 2125 meters and 2095 - 2035 meters) are potential zones in the shale hydrocarbon system. The shale-gas plays that contain greater than 50 wt% quartz or carbonate tend to have a more brittle character that responds well to current well stimulation practices (Passey Q.R. et al., 2010)

4.4 Petrophysics Analysis

In this petrophysical analysis, the Well Pantai Pakam Timur-3 data used which more complete with the availability of well data. The petrophysical analysis methodology consists of four necessary steps, i.e., determining the volume of shale (Vshale) & interpreting lithology, determining the formation water resistivity value (Rw) using assumptions, determining the effective porosity value and determining the water saturation value (Sw). Presented in petrophysical lumping data (Figures 6, Tables 3, and 4). Petrophysical characteristics of Well Pantai Pakam Timur-3 show that lithofacies Calcareous Shale intercalated Calcareous Siltstone have an average phi value of 34.7%, average Sw of 76.01%, average Vshale of 55.66%, average BI of 0.25, average TOC of 1.31 with the Middle Shoreface depositional environment.

6. DEPOSITIONAL ENVIRONMENT

The lithofacies Calcareous Shale intercalated Calcareous Siltstone and Carbonate rock have an average phi value = 31.68%, averages Sw = 60.85%, averages Vshale = 43.31%, averages BI = 0.31, averages TOC = 2.18. Calcareous Shale intercalated Calcareous Siltstone have an average phi value = 27.65%, averages Sw = 58.22%, averages Vshale = 41.78%, averages BI = 0.36, averages TOC = 1.28. Lithofacies Calcareous Shale intercalated Carbonate rock have an average phi value = 33.74%, averages Sw = 76.38%, averages Vshale = 50.41%, averages BI = 0.37, average TOC = 1.34. In lithofacies Calcareous Shale intercalated Calcareous Sandstone and the upper part of Calcareous Shale has an average phi value = 27.65%, averages Sw = 58.22%, averages Vshale = 41.78%, averages BI = 0.36, averages TOC = 1.34. Lithofacies Calcareous Shale intercalated Carbonate rock have an average phi value = 18.06%, averages Sw = 47.66%, averages Vshale = 27.16%, averaged BI = 0.5, average TOC = 2.03.

**TABLE 2.** SUMMARY of LUMPING DATA

**TABLE 3.** CHARACTERISTICS of PETROPHYSICALLITHOFACIES in WELL PANTAI PAKAM TIMUR-3.
4.5 Depositional Environment

Deposition environment in The Lower Baong Formation based on a parasequence set (PS) that represents each lithofacies in several drilling wells, as follows:

- **Deposition environment in The Lower Baong Formation (PS.1)** is divided into three main depositional environments, namely the upper shoreface, middle shoreface, and lower shoreface. Upper shoreface depositional environment is interpretation at Pantai Pakam Timur-3 well; middle shoreface interpreted in Diski-1 well; the lower shoreface is interpreted in Bohorok-1 well, Basilam-A1, Darat Utara-1, Tungkam-1, and Besitang-1 well.

- **The deposition environment in the Lower Baong Formation (PS.2)** is divided into two main environments, namely the middle shoreface and lower shoreface. Middle shoreface depositional environment is interpreted in Diski-1 well, and lower shoreface is interpreted at Pantai Pakam Timur-3 well, Bohorok-1, Basilam-A1, Darat Utara-1, Tungkam-1, and Besitang-1 well.

- **The deposition environment in The Lower Baong Formation (PS.3)** is divided into two main environments, namely the middle shoreface and lower shoreface. Middle shoreface depositional environment is interpreted in Diski-1 well, Pantai Pakam Timur-3, Tungkam-1, Besitang-1; and lower shoreface facies are interpreted in Bohorok-1 well, Basilam-A1 well, and Darat Utara-1 well.

- **The deposition environment in The Lower Baong Formation (PS.4)** is divided into three main environments, namely the upper shoreface, middle shoreface, and lower shoreface. The upper shoreface depositional environment is interpretation in Pantai Pakam Timur-3 well; middle shoreface is interpreted at Pantai Pakam Timur-3 well, Diski-1, Bohorok-1, and lower shoreface are interpreted in Basilam-A1 well, Darat Utara-1, Tungkam-1, and Besitang-1 well.

- **Deposition environment in The Lower Baong Formation (MFS 4)** divided into three main environments, namely the upper shoreface, middle shoreface, and lower shoreface. Upper shoreface depositional environment is interpretation in Diski-1 well; the middle shoreface is interpreted in Pantai Pakam Timur-3 well, Diski-1, Basilam-A1, Darat Utara-1, Tungkam-1, and Besitang-1; and lower shoreface was interpreted in Bohorok-1 well.

- **The depositional environment in the Lower Baong Formation (PS.5)** is divided into three main environments, namely the upper shoreface, middle shoreface, and lower shoreface. The upper shoreface depositional environment has been interpretation at Pantai Pakam Timur-3 well; the middle shoreface is interpreted in Tungkam-1 well, Besitang-1; and the lower shoreface is interpreted in Bohorok-1 well, Pantai Pakam Timur-3, Diski-1, Basilam-A1, Darat Utara-1 (Figure 18).

- Based on the location of the well and the results of the depositional environment analysis in each drilling well, it shows the direction of sediment transport in the studies area from the northeast-southwest.

5 CONCLUSIONS

- The results of the sequence stratigraphic analysis are carried out using the log and mud log data from 8 wells in the studies area, The Lower Baong Formation which is the Middle Miocene (N13) can be divided into 5 (five) parasequence sets and 5 (five) lithofacies. The characteristics of each lithofacies in each well have different lithological variations and compositions, as well as varying thicknesses.

- Based on the results of XRD laboratory analysis (secondary data) and the calculation of the brittleness index (BI), indicating that the lithology of Calcareous Siltstone has the highest BI value; that is around 0.51 and 0.52, while lithology Calcareous Shale has the lowest BI value that is 0.24.

- Based on the composition of mineralogy it can be concluded that BI values are strongly related to mineralogical composition; i.e. for lithology which has a high BI value indicated by the presence of brittle minerals, such as abundant quartz, calcite and dolomite, and mix I/S clay minerals and chlorite, and relatively low kaolinite.

- Lithology Calcareous Siltstone (lithofacies Calcareous Siltstone intercalated Calcareous Sandstone and Calcareous Shales) in Pantai Pakam Timur-3 well (depths of 2187 - 2125 meters and 2095 - 2035 meters) are potential zones as a reservoir in shale hydrocarbon systems.

- Correlation wells of northwest-southeast show sediment deposition thickness in several different wells. Namely in Tungkam-1 well, Basilam A-1, and Pantai Pakam-1 in the first place the sediment deposition was thicker than the thickness of sedimentary rocks in Besitang-1 well and Diski-1 well; this is due to the paleogeography of the basin during the deposition process of the Lower Baong Formation which is estimated to be controlled by the presence of low and height caused by tectonic processes. Correlation wells of the northeast-southwest (Pantai Pakam Timur-3 well to Bohorok-1 well); shows the deposition of the lower sedimentary Baong Formation to the southwest to be thinner, reflecting the high morphology to the southwest.

- The correlation between wells and combined with biostratigraphic data and environment deposition, for sediment transport in The Lower Baong Formation in the studies area from the northeast-southwest.

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