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# Identification of biogenic gas reservoir zone using log, petrophysics and geochemical data in S-1 well of Nias basin, North Sumatera

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**Abstract.** The fore-arc basin has been become a target of reservoir searching for a long time based on previous expert studies, where the indications of Late-Miocene carbonate age that could act as a hydrocarbon reservoir was found. S-1 Well located in the Nias Basin, one of the fore-arc basin located in West of Sumatera. As the object of this study, it is hoped that the hydrocarbon reservoir in the fore-arc basin is expected to be discovered and to identify the characteristics of rocks that potential to become hydrocarbon reservoirs. Geochemical data becomes supporting data regarding the presence of gases that are identified as biogenic gases because of the content of methane as the main composition. Identification of the existence of reservoir zones and source rock is done by qualitative interpretation of log data from the S-1 well. Then, the petrophysical parameters are analyzed in the form of shale volume (Vsh), effective porosity, resistivity water (Rw), and water saturation (Sw) to determine the type of reservoir's fluid. The results of the interpretation indicated that the presence of biogenic gas was detected in Late-Miocene with limestone lithology with Sw value 39.90 – 41.51 %.

Keywords: petrophysical, shale volume, effective porosity, water saturation

## 1. Introduction

The existence of shale material in Indonesia is indeed quite a lot, so it is estimated that in the next few years there will be many sources of oil and gas [4]. However, the process of changing material into oil and gas requires a very long time [4] so that using oil and gas is increasingly rare and difficult to do. This makes biogenic gas become a solution as an alternative energy source to replace the using of oil and natural gas. Biogenic gas is an environmentally friendly type of fuel because it produces less carbon dioxide than other types of fuel. In addition, the investment costs of biogenic gas are cheaper than non-conventional gas because of its more general existence of 1,000 m on the sea bed, so researchers are now more focused on biogenic gas research that is more profitable to do.

Biogenic gas is a flammable hydrocarbon gas, has the shortest carbon chain (C1) so it is the lightest gas, which is about 0.7 lighter than air [14]. Therefore, if used as an energy source, biogenic gas is a

type of fuel that is environmentally friendly. Biogenic gas is a gas with a methane content> 98% and has a low S and $CO_2$ content and can be detected in the presence of the carbon isotope $\delta$13C CH4 which is -62 to -66% [8]. Biogenic gas contained in this earth almost reaches 20% of all natural gas sources [14] but its presence is spread in small gas bags of various sizes and at varying depths [10].

The formation of this gas occurs in the diagenetic phase where in this phase forms the source rock which is thermally immature. Methane gas is formed with the following main processes [15]:

1. Acetate bacterial fermentation in the chemical-rich sedimentary layer (gas charged sediment) chemically: $CH_3COOH \rightarrow CH_4 + CO_2$.
2. The process of reducing $CO_2$ by bacteria from naturally occurring volcanic or magmatic rocks: $CO_2 + 2H_2O \rightarrow CH_4$.

The Nias Basin, a fore arc basin, characterizes a cool basin with a smaller geothermal gradient up to the average [8]. This affects the process of maturation of existing host rock. Because the geothermal gradient or heat flow is low, the heat received by the rocks is also small so that the Miocene-aged parent rock in this basin is generally immature. However, in older or deep-buried rocks it might reach maturity. Temperature can affect organic substances contained in sediments where an increase in temperature will convert heavy petroleum into light petroleum, then condensate and finally only gas [4].

Determination and analysis of reservoir parameters can be done by two methods, namely core analysis in the laboratory and interpretation of log data [11]. As for this research, a log data interpretation in the form of a quick-look qualitative interpretation and a quantitative interpretation in the form of petrophysical analysis is carried out in an effort to determine the detailed conditions of a petroleum system. Petrophysical analysis itself is a process that is carried out to validate the hydrocarbon density and determine the characteristics of the hydrocarbon reservoir and source rock.

## 2. Research Method
### 2.1 Reservoir Qualitative Interpretation

Qualitative reservoir interpretation is done by lithology zoning and hydrocarbon prospect area analysis using gamma ray, resistivity, RHOB and NPHI logs. First, a quick-look reservoir zone identification is based on NPHI and RHOB log separations. This separation indicates the existence of a reservoir where the reservoir has the characteristics of a low NPHI and RHOB values. Then the existence of a hydrocarbon reservoir is also characterized by a medium resistivity (Rt) value for oil and a high resistivity value for gas. In addition, the value of gamma ray is also important in identifying the quantity of clay found in rocks. The gamma ray log records the gamma ray radiation of rocks which shows the radioactive intensity in it. Clay minerals contain a large quantity of radioactivity and high clay content is found in claystone or shale lithology.

### 2.2 Reservoir Quantitative Interpretation

Once the hydrocarbon reservoir zone is identified through a quick-look analysis, a full-analysis is carried out in the form of petrophysical analysis through quantitative interpretation. To conduct petrophysical analysis, the shale content of rocks in the study area is a parameter whose value must first be determined. Calculation of clay content in S-1 Wells uses the Larionov tertiary equation because the age of the rock is relatively young based on the stratigraphy of the existing Nias Basin as follows [1]:

$$V\text{s} = 0.08336\,(2^{3.7\,x\,\text{IGR}} - 1) \tag{1}$$

Then porosity ($\emptyset$) calculation using the equation as follows [15]:

$$\emptyset_e = \sqrt{\frac{\emptyset_{Ncor}{}^2 + \emptyset_{Dcor}{}^2}{2}} \tag{2}$$

Resistivity water (Rw) determination by plotting pickett plots in the software Interactive Petrophysics in areas filled with water (Sw=1). This zone is characterized by a very low resistivity (Rt) value and coinciding with the NPHI and RHOB log curves. Then calculating water saturation (Sw) using the Indonesian Sw equation so that it does not neglect the presence of impurities contained in rock formations as follows:

$$\frac{1}{\sqrt{R_t}} = \left( \sqrt{\frac{\emptyset e^m}{a \times R_w}} + \frac{V_{sh}^{1-0,5V_{sh}}}{\sqrt{R_{sh}}} \right) \times S_w^{\frac{n}{2}} \tag{3}$$

**2.3 Source Rock Qualitative Interpretation**
For qualitative interpretation of source rock, gamma ray logs, resistivity logs and sonic logs are used. Based on the separation form of the sonic and resistivity log curves, the source rock type and its presence can be known in the well. This bedrock is usually in shale or siltstone lithology which has impermeable rock characteristics with high GR values, very high sonic log values and low value of resistivity logs.

The resistivity and sonic logs are overlaid to make it easier to see the shape of the separation. The first rule that needs to be known is when the GR (or SP) deflection to the left means the zone is clean and reservoir rock can be indicated. When the GR is deflected to the right, it indicates shale lithology (not characteristic of reservoir rocks). Then, the second rule is the porosity log (in this case the sonic log) is set on a high to low scale. Then the third rule is the resistivity log set on a low to high scale. High resistivity indicates the presence of hydrocarbons or low porosity, while low resistivity indicates an indication of shale or water zone [2].

The separation between resistivity log and DT log shows anomaly. When separation is formed to the right of the baseline it can be estimated that the separation shows the existence of source rock, and the rock is mature (mature). Whereas the separation formed to the left of the baseline shows that the depth is estimated as source rock, but immature, or as coal, and other non-source rock. Mature source rock has characteristics of high resistivity value, and high sonic log, while immature source rock has characteristic value with low resistivity value and not too high sonic log. Large log resistivity and sonic log separations are called ΔLogR [7].

**2.4 Distribution Area of Biogenic Gas Reservoirs Modelling**
Qualitative interpretation of source rock zones based on the overlay of DT and resistivity logs, and the biogenic gas reservoir based on quantitative interpretation and model of S-1 well can be identified.

**3. Result and Discussion**
**3.1 Result of Reservoir Zone Identification**
S-1 well has a total depth of 6990 ft. The presence of gas can be identified using qualitative log interpretation using gamma ray log, resistivity log, and separation between RHOB and NPHI logs as shown in **Figure 1** and **Figure 2**. In this well, reservoirs were identified in two zones, at depths of 5026-5130 ft, and 5198-5216 ft.

This is also evidenced by the small gamma ray log response in the both zones, namely in the range of 20 - 73 API, then the NPHI value has a range of 8 – 20 % and RHOB 2.13 - 2.45 g/cc. The resistivity log has a range a large enough value that is 0.5 - 66.8 ohm.m, so it does not support interpretation. The presence of th gas is also verified by geochemical data that explains the presence of gas with high methane composition, which is valued at 98.96% at depths of 5034 - 5090 ft and 98.95% at depths of 5198 - 5216 ft as listed on **Table 1** below.

Based on S-1 well biostratigraphic data (**Figure 3**) it is known that in the both zones has Late Miocene age which according to the Nias Basin stratigraphy that the growth of reef limestone at that time is intensive in the depositional environment bathyal to the outer shelf environment.
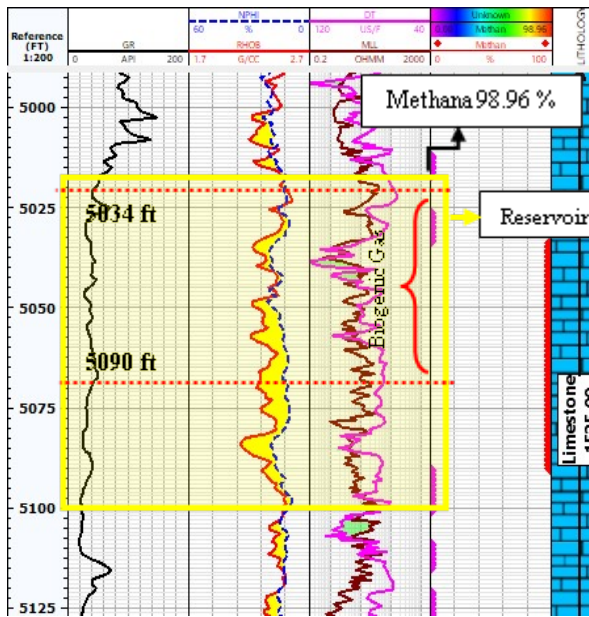
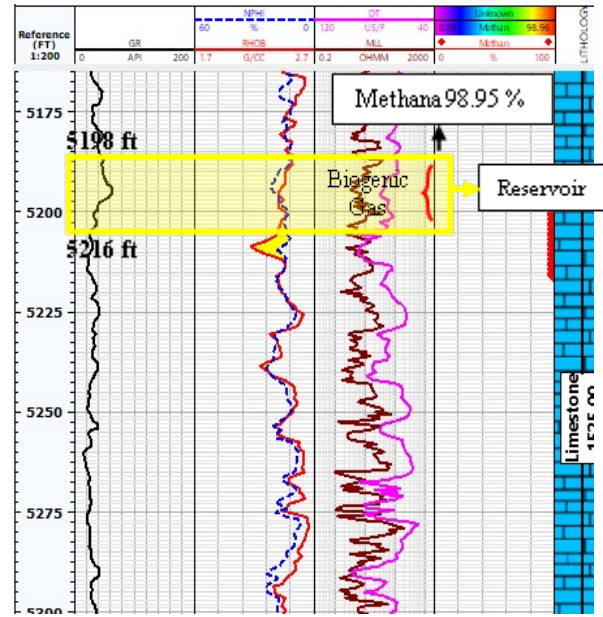**Figure 1.** Reservoir Zone 1 based on Qualitative Interpretation.



**Figure 2.** Reservoir Zone 2 based on Qualitative Interpretation.
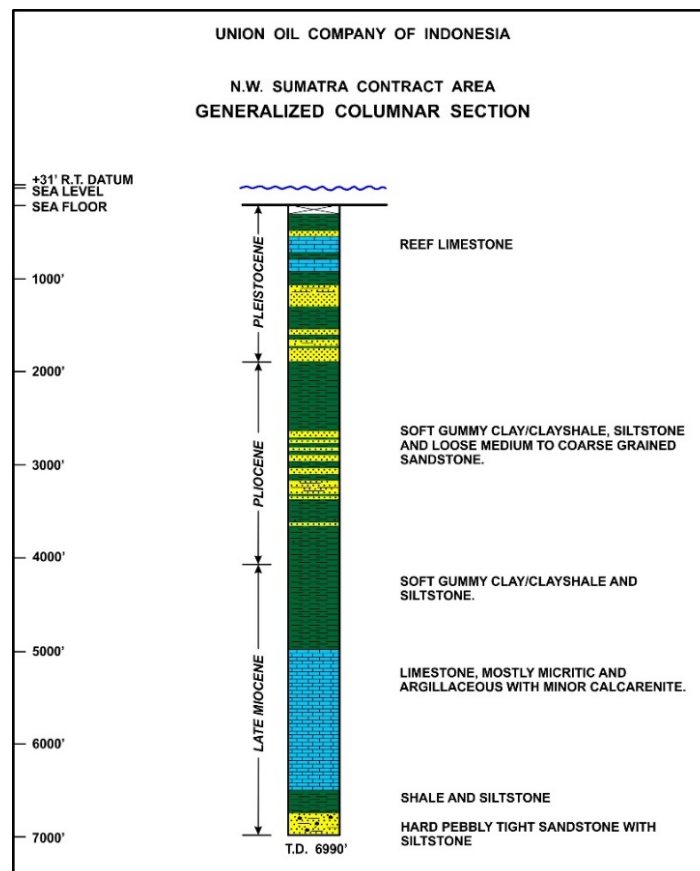


**Figure 3.** S-1 Well Stratigraphy Columnar Section (Union Oil Company of Indonesia) [12].

**Table 1.** Geochemical Data of S-1 Well (Union Oil Company of Indonesia, 1978).

| Components | S-1 | |
|---|---|---|
| | Water Depth | |
| | DST 2 | DST 3 |
| | 5198 FT – 5216 FT | 5034 FT – 5090 FT |
| | Late Miocene | Late Miocene |
| | % | % |
| Hydrogen | - | - |
| Helium | - | - |
| Carbon Monoxide | - | - |
| Hydrogen Sulphide | - | - |
| Carbon Dioxide | 0.29 | 0.23 |
| Oxygen | - | - |
| Nitrogen | 0.56 | 0.61 |
| Methane | 98.95 | 98.96 |
| Ethane | 0.18 | 0.19 |
| Propane | 0.02 | 0.01 |
| Iso-Butane | - | - |
| n-Butane | - | - |
| Iso Pentane | - | - |
| n-Pentane | - | - |
| Hexanes | - | - |
| Hexanes Plus | - | - |
| **Total Percentage** | **100** | **100** |
| **Molecular Weight** | **16.222** | **16.209** |
| **Gravity** | **0.56** | **0.5595** |

**Table 2. Indicated Fluid based on Quantitative Interpretation.**

| Zone | Depth | Vsh (%) | PHIE (%) | Rw | Sw Indo (%) | Fluid |
|---|---|---|---|---|---|---|
| 1 | 5026 - 5130 | | 16.89 | | 41.51 | Biogenic Gas |
| | | 21.25 | | 0.04 | | |
| 2 | 5198 - 5216 | | 17.18 | | 39.90 | Biogenic Gas |

A good formation as a reservoir is a formation with little shale content because the presence of large amounts of shale can inhibit rocks from flowing fluid. This type of formation is important to calculate, to know the type of Sw equation that will be used later. Based on **Table 2**, it is known that in the S-1 Well, there is an impurity content of 21.25%

The large porosity allows rocks to hold more hydrocarbon fluids. The porosity calculation is performed until an effective porosity value is obtained, that is the porosity which is not influenced by the clay content. This is done to avoid errors in interpretation where clay content can bind large amounts of formation water so that the calculation will be unrepresentative. It can be seen in **Table 2** that the total porosity value of the reservoir zone in the S-1 Well is greater than the effective porosity. This difference in value is not too large at around 0.5%. The effective porosity value itself is good according to scale of determining whether or not the quality of the porosity value of a reservoir rock [9].

The water-bearing zone in the S-1 Well is at a depth of 5230 - 5242 ft where the response curve of the log can be seen in **Figure 4**.
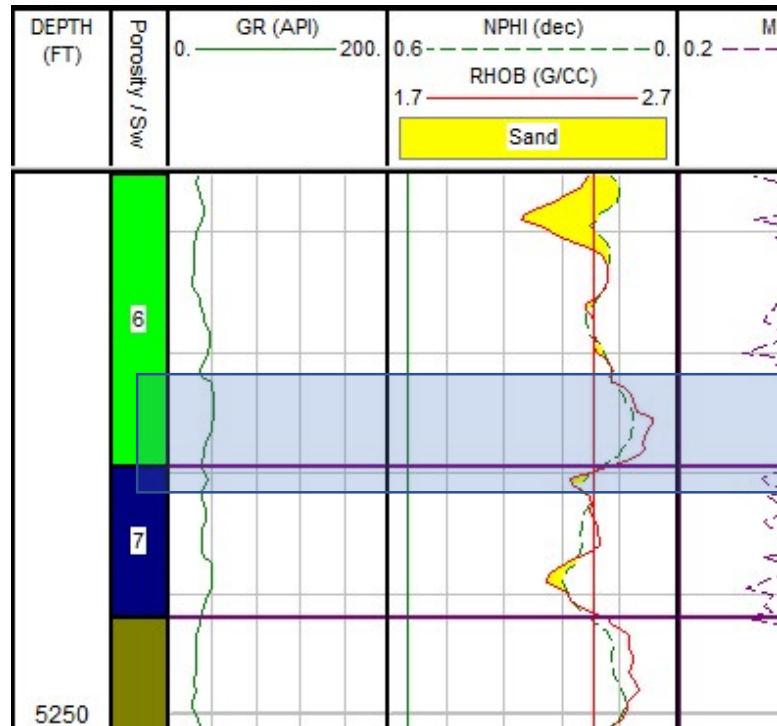

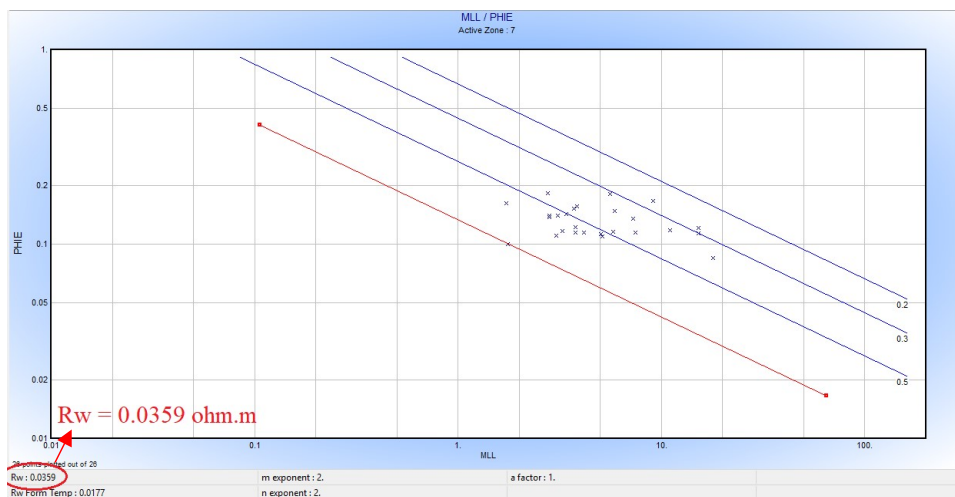
**Figure 4.** Water bearing zone in S-1 well.



**Figure 5.** Rw on S-1 Well.

Rw in well S-1 as we can see on **Figure 5** above, shows a value of Rw 0.0359 ohm.m where this value is plotted in areas with low log resistivity values below 10 ohms.m and indicates the presence of water bearing zone.

Formation water saturation is the ratio of the pore volume filled by water to the total porosity volume [6]. The water saturation (Sw) value represents the water content in a rock formation. The greater the value of Sw, it is indicated that the formation contains only a small amount of hydrocarbon fluid and is dominated by water. Sw in S-1 well was identified to contain hydrocarbon fluid in the

form of biogenic gas based on its average Sw value of 40.71%. The determination of the type of content in the reservoir (gas, oil and water) is obtained from the calculation of the formation water saturation (Sw) in the result of general limits of Sw prices for unknown fields where the average range of Sw values for gas is < 50%, the average range of Sw values for oil and gas is <60%, the average range of Sw values for oil is around 50% - 70%, and for water is> 70% [3].

Biogenic gas itself is identified based on existing geochemical data regarding the presence of methane gas in the S-1 Well. This methane gas was identified as biogenic gas because of its almost 100% methane composition and its presence in the low arc basin of the island of Sumatra. Therefore, in the reservoir zone contained in this well there is indicated hydrocarbons in the form of oil and biogenic gas.

Biogenic gas is formed at temperatures that are not too high and at depths that are not too deep. In the S-1 well, biogenic gas was identified at a depth of 5034 - 5090 ft and 5198 - 5216 ft in rocks of Late Miocene age. In S-1 well, it is known that the rocks that act as reservoirs are limestone with 98.95 - 98.96% methane gas content. The formation of this gas occurs in the diagenetic phase wherein this phase forms the source rock which is thermally immature.

The difference between biogenic gas and thermogenic gas usually lies in the diagenetic process and temperature. Biogenic gases are formed by the activity of methanogenic bacteria at low temperatures. Temperature can affect organic substances contained in sediments where an increase in temperature will convert heavy petroleum into light petroleum, then condensate and finally only gas [4].

### 3.2 Result of Source Rock Identification

Based on the results of qualitative interpretation according to Crain (**Figure 6**) on the S-1 well, identified source rock is identified in two zones, namely at depths of 6379 - 6388 ft, and 6524 - 6558 ft as shown in **Figure 7** and **Figure 8**.
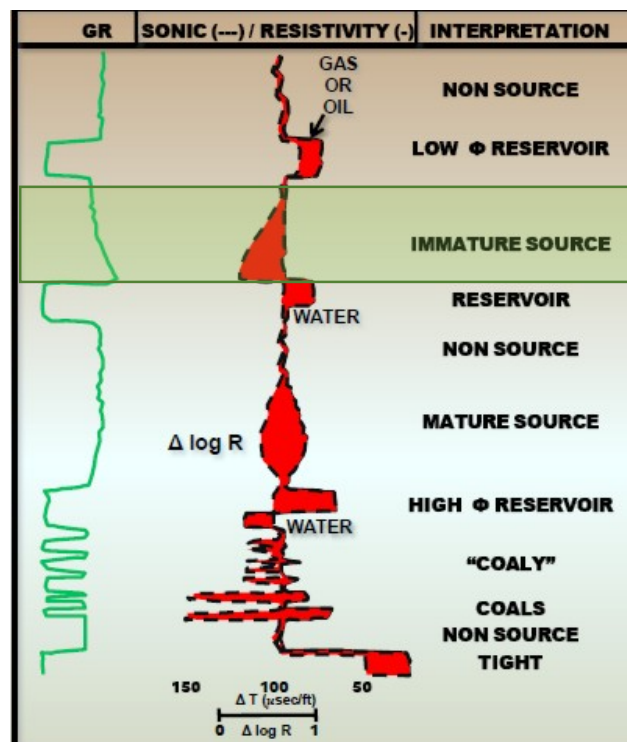


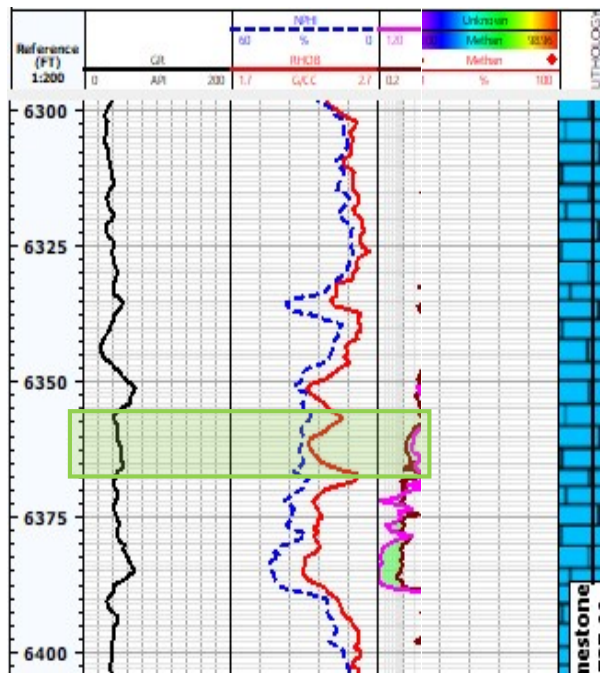**Figure 6.** Interpretation of Immature Source Rock on S-1 well [2].

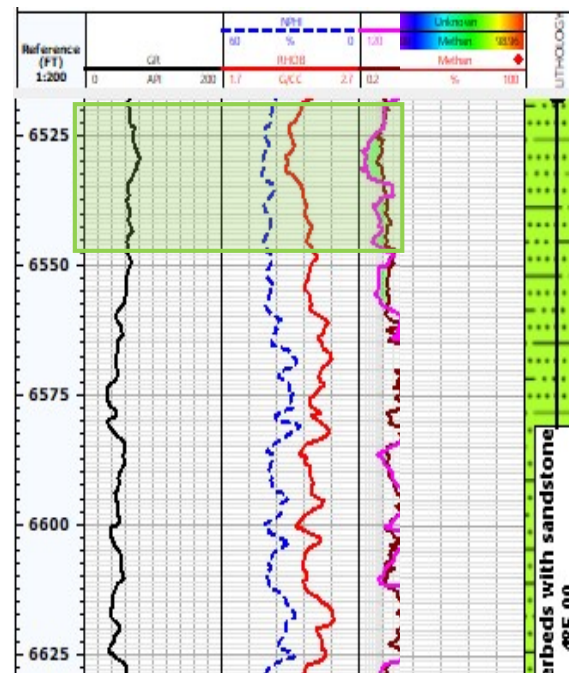**Figure 7.** Source Rock Zone 1 of S-1 well.      **Figure 8.** Source Rock Zone 2 of S-1 well.

Based on biostratigraphic data, it is known that in these two zones also located in Late Miocene age. Main rocks of Middle and Late Miocene age indicate immature maturity. The cross between the DT and resistivity curves according to Crain (2010) in **Figure 6** also shows the immature source rock form. Deposition environment in this zone according to biostratigraphic data is the inner shelf.

The response of gamma ray log is low - middle value in the first SR zone which shows the lithology of the rock is limestone dominated clay. Then the low-high GR log response in the second zone validating the stratigraphic data that the area at this depth has lithology of claystone interbedded with sandstones.

The gamma ray log response is small in both zones, namely in the range of 20-73 API, then the NPHI value has a range of 8-20% and RHOB 2.13 - 2.45 g / cc. For the resistivity log has a range of values large enough that is 0.5 - 66.8 ohm.m,

The Nias Basin's position in the fore-arc region between Sumatra Island and the Indian Ocean results in a relatively low geothermal gradient and heat flow in this basin, which is around 1.2 HFU on average [13]. This low heatflow and geothermal gradient are ideal for biogenic gas formation. The temperature value in a rock chamber, is one of the important parameters in the process of determining the maturity of organic matter, to predict the maturity of hydrocarbons in sedimentary rocks [5].

### 3.3. Reservoir and Source Rock Distribution Area

Correlation of the reservoir area of five well in the Nias Basin is done to determine the existence of source rock and reservoir distribution contained in the S-1 well. It can be seen in **Figure 9** and **Table 3**, that in this study area immature source rock and biogenic gas reservoirs in identified.
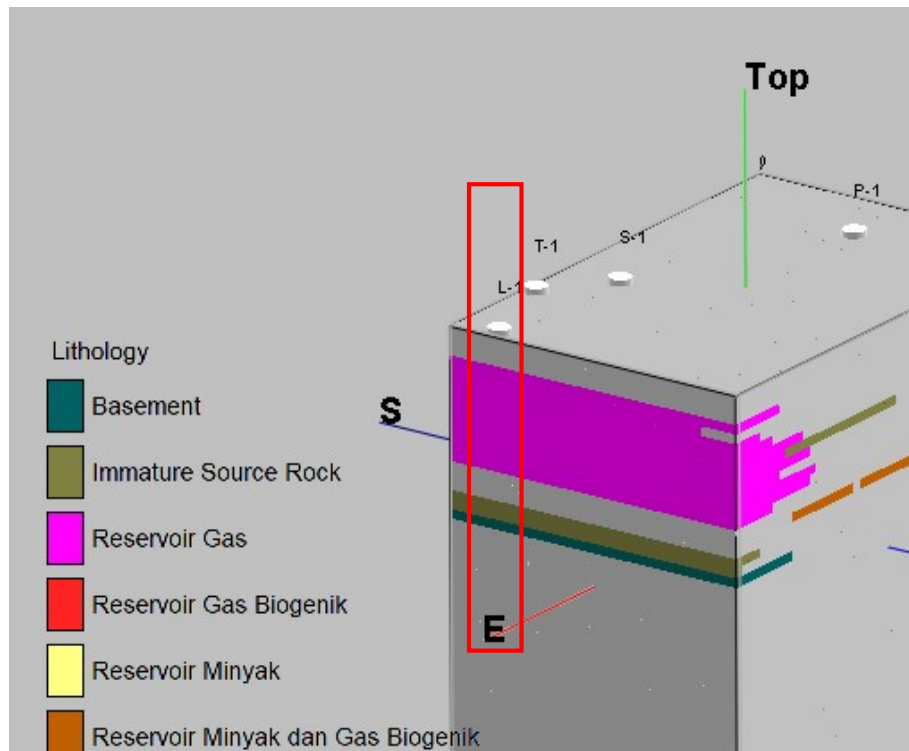
**Figure 9.** Reservoir and Source Rock Distribution Area Model.

**Table 3.** Reservoir and source rock existence in S-1 well.

| Depth 1 (ft) | Depth 2 (ft) | Age | Lithology | Petroleum System |
|---|---|---|---|---|
| 5026 | 5216 | Late Miocene | Limestone | Biogenic Gas Reservoir |
| 6379 | 6558 | Late Miocene | Clay | Immature Source Rock |

The biogenic gas reservoir in S-1 well has limestone lithology of Late Miocene age and immature source rock in the lithology of silty clay on a Late Miocene rocks. It can be seen that the study area is dominated by Late-Miocene rocks where at this age the limestone growth in the Nias Basin is very intensive due to the quiet period and lack of material supply from the mainland so that these rocks are the main target in the search for reservoirs.

## 4. Conclusions

Based on the outcome of this research, it can be concluded that:

1. Biogenic gas reservoir zones in the S-1 Well were identified as being in two zones at depths of 5026-5130 ft and 5198-5216 ft which were qualitatively shown in permeable layers (small value GR) and the separation between NPHI and RHOB, but qualitative interpretation less supportive because of the low resistivity value in the interest zone. While quantitative interpretation is very supportive based on PHIE value 16.89 - 17.18 ohm.m and Sw is around 39.90 - 41.51%.

2. The immature source rock layer is qualitatively determined by the separation form of the sonic and resistive log curves with a range of sonic log values of 101-120 us/ft and resistivity logs of 2.15 - 2.39 ohm.m on silty clay lithology of Late Miocene rocks.

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