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Analysis of Unconventional Oil and Gas Reservoirs using Well Logging, Geochemical and Seismic Data

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Abstract

Since conventional oil and gas is under a depletion phase, unconventional oil, and gas have become prime candidates for current and future oil and gas production. Based on this, investment and research have increased significantly related to unconventional oil and gas exploitation, especially in the North East Java Basin, one of the sedimentary basins producing oil and gas. The research was conducted in the form of well-logging, geochemical, and seismic data analysis to determine the quality and quantity of oil and gas reservoirs. The thickness and TOC value of the reservoir were determined using well-logging data using the Passey method, resulting in a thickness ranging from 900-954 ft and an average TOC value of 3.87 Wt% in the Kujung III Formation. Based on geochemical data analysis, the reservoir has type II kerogen with an immature-early mature maturity level (Ro and Tmax). Meanwhile, based on seismic data, the reservoir thickens to the northwest, ranging from 500-600 m. Unconventional oil and gas reservoirs in the research area have the potential to be developed because they meet several criteria, such as being rich in organic material and thick, even though the maturity level is still in the immature phase. It is estimated that deeper areas will produce different levels of maturity as pressure and temperature increase.

Keywords: geochemistry; reservoir; seismic; unconventional oil and gas; well logging.

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Introduction

The North East Java Basin is one of the oil and gas basins that have the potential to produce oil and gas, marked by a new well owned by a subsidiary of PT. Pertamina Hulu Energi Tuban East Java is capable of producing 531 BPOD of oil (Suharyati et al., 2019). In addition, according to Mudjiono & Pireno (2002), the North East Java Sea Basin has petroleum systems such as source rocks, reservoirs, and cap rocks that are scattered in various formations. The Lower "OK" Member, Kujung Unit II Formation, and Ngimbang Formation have the potential to be good source rocks with Total Organic Carbon (TOC) values of more than 1%. The Lower "OK" Member shale has the potential to be a good source rock. The Kujung Formation Unit I is equivalent to the Prupuh deep-sea limestone in the East Java or Madura Basin. This unit has the best reservoir characteristics in the North East Java Sea Basin. The main cap rocks in the North East Java Sea Basin are the thick shale facies of the Kujung Formation Unit II (for the Ngimbang Formation reservoir) and the shale in the Rancak Unit (for the Kujung Formation Unit II reservoir). These shales are generally deposited on top of the Kujung Unit I Formation's reefs and effectively cover the trapped hydrocarbons (Satyana & Purwaningsih, 2003).

Source rocks are sedimentary rocks that contain fine-grained organic material such as clay or shale and have the potential to produce and become oil and gas reservoirs (Muther et al., 2021). In conducting unconventional oil and gas exploration, several methods can be used, such as the well-logging method (Szabó et al., 2021), seismic method (Harilal & Tandon, 2012), and geochemical analysis (Setyawan et al., 2020). The well-logging method is one of the methods used to obtain subsurface physical information by drilling directly (Fatahillah et al., 2017). The data obtained by using the well-logging method has a depth domain. The seismic method is a method used to obtain subsurface information laterally by utilizing a seismic wave propagation system. Data obtained from measurements using the seismic method has a time domain. These two data are equalized in the domain so that further processing can be carried out so as to explain the subsurface conditions vertically and laterally (Field et al., 2015). The geochemical analysis uses chemical principles to explain the quality of the source rock through kerogen type and maturity level of the source rock (El-Khadragy et al., 2018).

This study aims to determine the kerogen type and maturity level of the reservoir, the TOC value, and the unconventional oil and gas reservoir zone based on seismic data in Field "X", North East Java Basin.

The Jendral Sudirman Road, Muara Bulian, Batang Hari crosses 2 formations, which are the alluvial formation (Qa), and the kasai formation (QTk) based on the Regional Geological Map of Muara Bungo Sheet.

Physiographically, the Batang Hari area is located in the western part of the South Sumatra Basin, which is a lowland area in eastern Sumatra, bounded by the Semangko Fault and Bukit Barisan to the southwest, the Sunda Shelf to the northeast, the Lampung Plateau to the southeast separating the basin from the Sunda Basin, and the Twelve Mountains and Thirty Mountains to the northwest separating the South Sumatra Basin from the Central Sumatra Basin (Barber et al., 2005).

Well Logging Method

An unconventional oil and gas reservoir zone can be interpreted qualitatively and quantitatively using well data using GR logs, resistivity logs, and sonic logs (Sumotarto et al., 2017). Qualitatively, a log will represent a potential source rock if it has high GR, high resistivity, and high sonic values (Passey et al., 2010).

There are various methods to quantitatively analyze the organic material content of well log data. One of the most commonly used methods is using sonic and resistivity logs. The method has been widely modified and is known as "ΔLogR" by Passey et al. (1990) (Figure 1). This method can determine the TOC value by performing an empirical calculation using the following equation.

$$TOC = \Delta LogR \; x \; 10^{(0{,}297-0{,}1688.LOM)} \quad (1)$$

$$\Delta LogR = Log10 \left(\frac{R}{R_{baseline}}\right) + 0{,}02 \; x \; (t - t_{baseline}) \quad (2)$$

with,
TOC = *Total Organic Carbon* (wt%)
LOM = *Level of Maturity*
ΔLogR = Separation curve between resistivity and sonic log data
R= Measured resistivity value (Ωm)
$R_{Baseline}$= Resistivity value at non-source zone (Ωm)
t = Measured transit time (us/f)
$t_{Baseline}$ = Transit time at non-source zone (us/f).

Using Passey's method, LOM values can be obtained from Vitrinite Reflectance (Ro) data correlated on a graph as shown in Figure 2.

Quantitatively, a reservoir zone can be recognized through the Total Organic

Carbon (TOC) content contained therein. TOC analysis is a stage to analyze the overall organic content of a rock. The depositional environment affects the organic carbon content of a rock. The Table 1 can be used as a reference in determining the richness of the source rock (Wibowo, 2013).

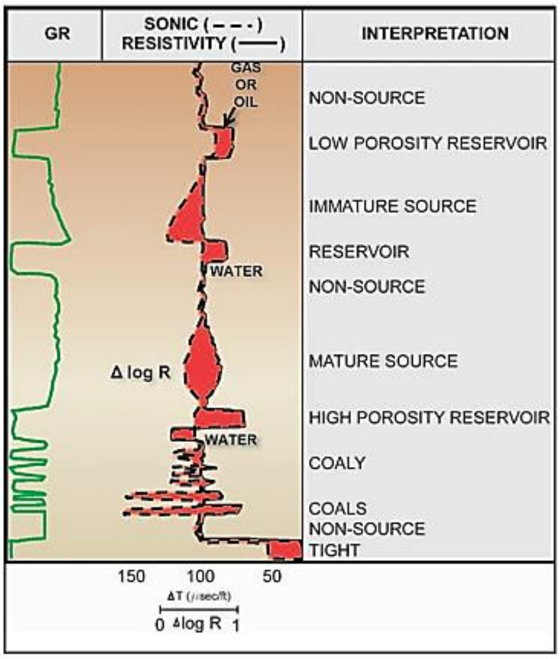

Figure 1. Response of Log Curve to Source Rock Zone (Passey et al., 2010).

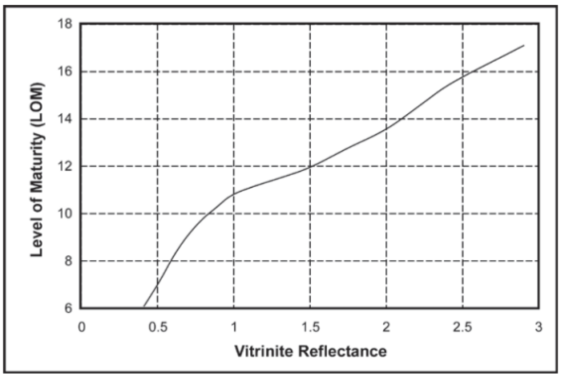

Figure 2. LOM graph from Ro data (Crain, 2000).

Table 1. TOC content of source rock quality (Peters & Cassa, 1994).

Total Organic Carbon (%)	Quality
0 – 0.5	Poor
0.5 – 1	Fair
1 – 2	Good
2 – 4	Very Good
>4	Excellent

Geochemical Analysis

Quantity and quality analysis of an unconventional oil and gas reservoir can also be known by using geochemical data (Zhao et al., 2019). The quantity of a reservoir can be known from the organic material content (TOC) as in Table 1. Meanwhile, the quality of a reservoir when viewed using geochemical data can be known through the type of organic material (Kerogen Type) and the level of maturity. Kerogen is the content of organic material in a sedimentary rock that is insoluble in organic solvents. There are four types of kerogen, which are Kerogen Type I, Kerogen Type II, and Kerogen Type III (Brooks et al., 1984; Olatunde, 2016; Scheeder et al., 2020).

Geochemical data such as Hydrogen Index (HI) and Thermal maturity level (Tmax) are used to determine the kerogen type and maturity of a reservoir. HI represents the amount of atomic hydrogen content of organic material contained in a rock (Niu et al., 2018). These hydrogen atoms are the basic elements that form hydrocarbon chains. The type of hydrocarbon formed will be influenced by the amount of hydrogen that forms hydrocarbon chain bonds. Thermal maturity based on the Tmax value indicates the maturity level of the source rock (Peters & Cassa, 1994). According to Peters & Cassa (1994), the maturity level of the source rock can be classified into immature, oil zone, and gas zone given in the van Krevelen Diagram.

Using the van Krevelen Diagram, these two data are correlated with each other to obtain information on the kerogen type and maturity level of the source rock (Song et al., 2013). According to Brooks et al. (1984), van Krevelen Diagram is a plot diagram of geochemical data such as the Hydrogen Index (HI) with Organic Index (OI) to characterize coal and qualify it (Brooks et al., 1984). This diagram was later modified to provide information on kerogen type and thermal maturity of organic material as shown in Figure 3.

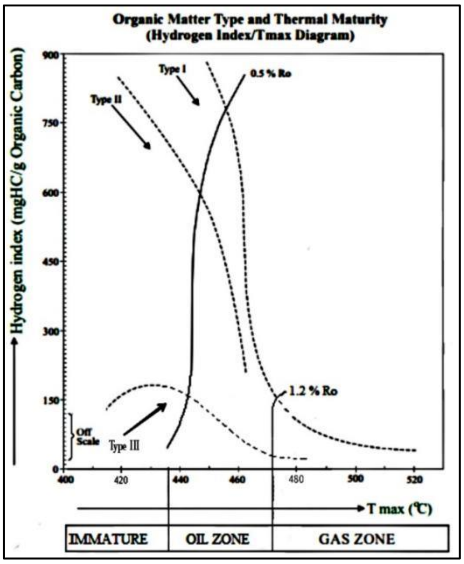

Figure 3. Modification of van Krevelen Diagram (Brooks et al., 1984).

In addition, the maturity level of a source rock can also be known from the Level of Maturity (LOM) value (Devi et al., 2017). This LOM value can be obtained from the pyrolysis stage of a rock sample. Pyrolysis is a stage to analyze the hydrocarbon component in a source rock. This pyrolysis stage is carried out by gradually heating a sample that does not contain oxygen in an inert atmosphere using a certain temperature. Pyrolysis parameters are divided into several types, which are as follows (Scheeder et al., 2020).

1. S1, is the total free hydrocarbons contained in the rock sample.
2. S2, is organic material that produces hydrocarbons through maturation and burial stages.
3. S3, is the total CO_2 produced during the pyrolysis stage. S2 is linearly related to TOC at a certain LOM of a source rock (Figure 4).

The relationship between Ro and LOM can be seen in Figure 2. A source rock can be said to be mature if it has a maturity level value or LOM between 7 - 12. If the LOM value is less than 7, then a source rock is classified as an immature source rock. If it has a LOM value of more than 12, then a source rock can be said to be past mature (Crain, 2000).

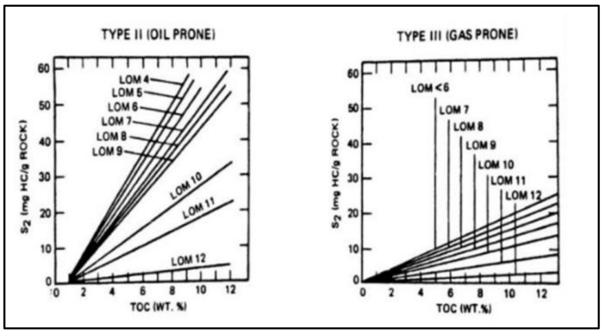

Figure 4. The relationship between S2 and TOC to determine the level of maturity (Brooks et al., 1984).

Seismic Method

The seismic method is one of the geophysical methods that can describe the subsurface of the earth laterally well (Wibowo et al., 2020).

The earth, which is the medium for wave propagation, consists of heterogeneous rock layers so that the discontinuity of the nature of this medium causes seismic waves to propagate some of their energy and will be reflected and some other energy will be forwarded to the medium below. Seismic surveys are conducted by creating vibrations using a source (Zou et al., 2018). The source will produce vibrations that will propagate in various directions under the earth's surface as a vibrating wave (Helal et al., 2015). Data recorded in the form of the travel time of reflected waves will provide information about the speed of wave propagation in a rock layer that it occupies (del Monte et al., 2018).

By using seismic data, lateral subsurface information of potential reservoir zones can be identified (Habib et al., 2016). In the petroleum system sequence, reservoirs are located below and tend to be in low areas. This can be said because a mature source rock is affected by higher temperatures and pressures (Athmer et al., 2014).

From the seismic data, a surface will be generated that is able to inform the high and low areas of the research site. A source rock tends to be in the low area (Fajana et al., 2019).

Research Method

The methods used in this research are seismic method, well-logging method, and geochemical analysis. The three methods are used to determine the qualitative and quantitative potential of unconventional oil and gas reservoirs in Field "X" of the North East Java Basin. In this study, three well data were used, which are Well S-1, Well K-1, and Well C-1. The types of logs used in this study are the Gamma-Ray (GR) log, resistivity log, and sonic log. In addition, 50 lines of post-stack 2D seismic data were used, and geochemical data on Well S-1. The geochemical data include maturity level data (Ro and Tmax) Hydrogen Index (HI), Total Organic Carbon (TOC), and S2. Then, check-shot data is used to equalize the domain between seismic data and well data.

In the first stage, this research analyzes well-logging data, for reservoir zone determination and qualitative analysis. The next stage is the geochemical analysis which aims to evaluate the potential reservoir zone qualitatively and quantitatively. The final stage is to see the distribution of reservoir potential based on seismic data.

Results and Discussion

Well Logging Analysis

In this study, qualitatively analyzed log data at Well S-1 to determine the reservoir zone in the study area. In Figure 5, there is a high GR log value and a separation between the DT log and the LLD log. So it can be said qualitatively that Well S-1 has a zone with the potential as a reservoir. If the zone indicated as a reservoir in Figure 5 is scaled up, it looks like Figure 6.

This method uses the empirical equation as in equation 1 to obtain the value of organic material content (TOC). Based on calculations using the Passey method, data were obtained as in Table 2.

Table 2. Results of TOC Value Calculation using the Passey Method.

Depth (ft)	$\Delta LogR$	TOC
5820	0.705	2.756
6000	0.358	0.669
6090	0.675	0.602
6180	0.778	0.307
6270	1.003	1.734
6360	0.551	0.201
6450	0.642	0.171
6630	0.530	1.071
6720	0.731	2.016

Based on Table 2 and Figure 5, it can be said that the organic material content of the reservoir zone in Well S-1 with a depth of 5820 - 6720 ft is quite very good (Table 1) although qualitatively based on Peters & Cassa (1994) it can be said to be immature (Tmax 361 - 437^{0}C). As in previous research conducted in this basin, the zone that is said to have the potential to become the source rock is around the Kujung Unit II Formation (Aprilana et al., 2018).

Table 3. Calculation Results of TOC Value of Well K-1 using Passey Method.

Depth (ft)	**ΔLogR**	TOC
5000	0.552	7.210
5109	0.303	3.964
5241	0.498	6.506
5400	0.466	6.085
5475	0.810	10.57
5540	0.268	3.504
5690	0.072	0.945
5806	0.066	0.873
5952	0.006	0.090

Based on the data from Well K-1, it can be seen that qualitatively there is a source rock zone at a depth of between 5000 ft to 6000 ft. This can be said to be so because of the presence of separations. This can be said because of the separation formed between the sonic and resistivity log curves shown in yellow. Based on the type of log curve response (Passey et al., 2010), the shape of the separation in Well K-1 indicates that the reservoir zone is immature as shown in Figure 7.

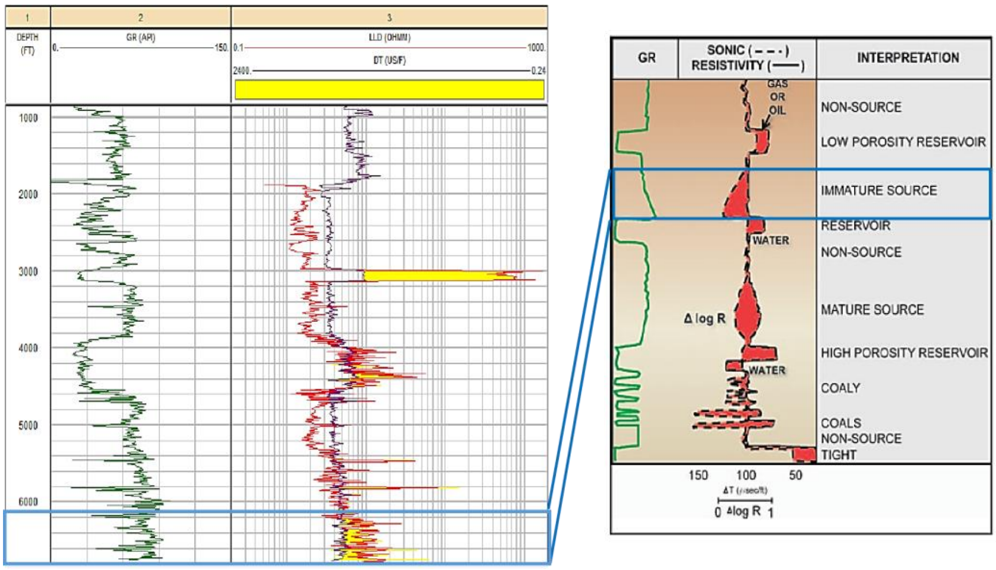

Figure 5. The Source Rock Zone of Well S-1 with yellow separation is the response curve based on Passey et al. (2010).

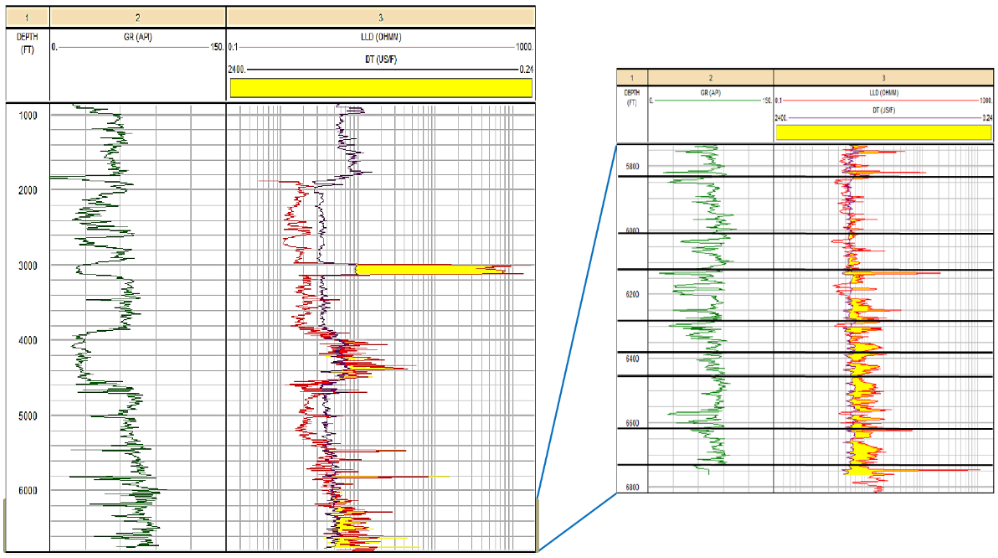

Figure 6. The TOC calculation process in Well S-1 with yellow separation is a curve response based on Passey et al. (2010).

In terms of quantity, the amount of organic material in Well K-1 was obtained using the same method as in Well S-1, which is the Passey method. Based on this calculation, the quantity of organic material in Well K-1 is obtained as shown in Table 3 and Figure 8. In Well K-1 there is a reservoir zone at a depth between 5000 - 5925 ft with reservoir quality characteristics from fair to very good and immature maturity level (Tmax 426 - 435^{0}C). The source rock zone is included in the Kujung Unit III Formation and at the beginning of the CD Formation.

Based on the high GR log curve response in Well K-1, it can be said that both formations are shale lithologic. The reservoir zone has an organic material content (TOC) of 0.1 - 7.2 wt% as shown in Table 3.

Based on the log curve response type (Passey et al., 2010), the separation shape in Well C-1 indicates that the reservoir zone is immature as shown in Table 4 and Figure 9. The quantity of organic material in Well C-1 was obtained using the same method as in Well S-1, which using the Passey method. Therefore, several sample points were used to calculate the quantity of organic material. In Well C-1, five sample points were used as shown in Figure 10.

Table 4. Calculation Results of TOC Value of Well C-1 using Passey Method.

Depth (m)	$\Delta LogR$	TOC
1100.9	0.055	1.065
1131	0.056	1.058
1141.4	0.306	5.892
1158.1	0.121	2.330
1172.3	0.718	13.83

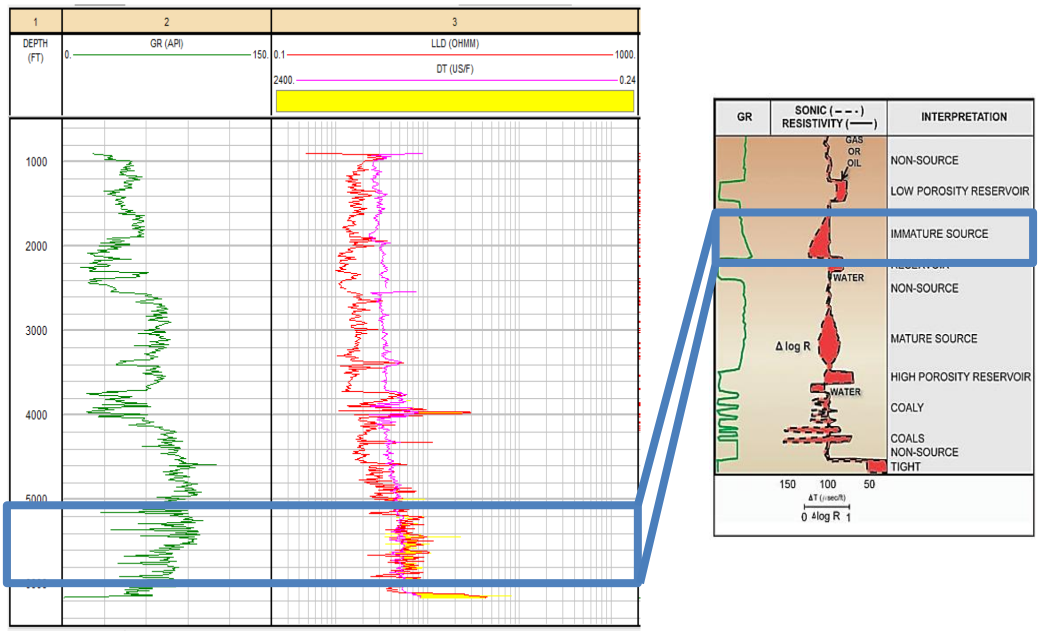

Figure 3. The Source Rock Zone in Well K-1 with yellow separation is the response curve based on Passey et al. (2010).

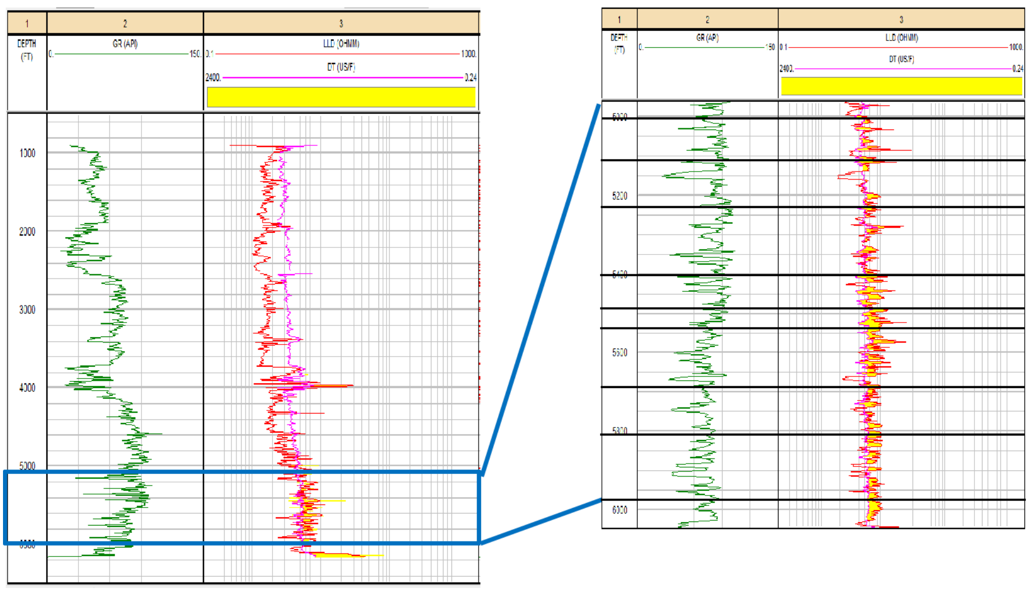

Figure 4. The TOC calculation process at Well K-1 with yellow separation is a curve response based on Passey et al. (2010).

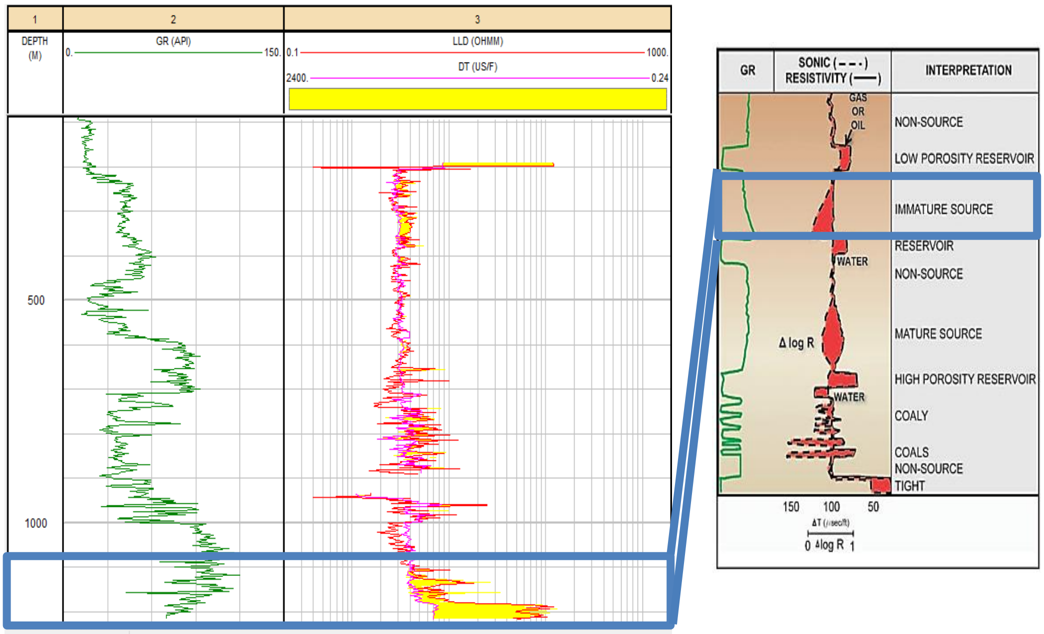

Figure 5. The reservoir zone in Well C-1 with yellow separations is the response curve based on Passey et al. (2010).

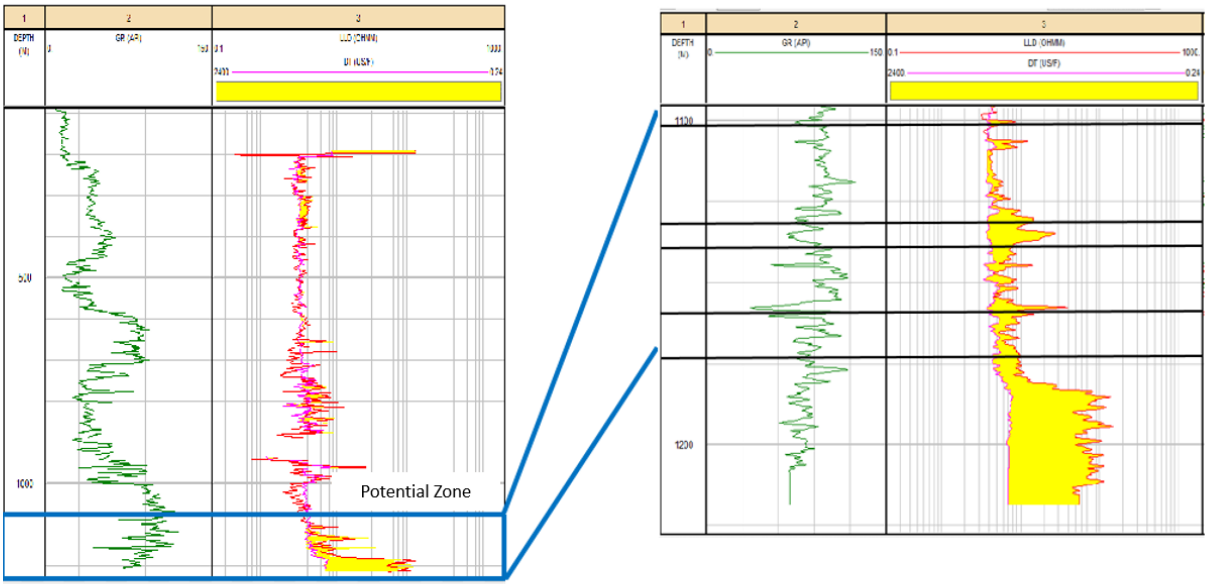

Figure 6. The TOC calculation process at Well C-1 with yellow separation is a curve response based on Passey et al. (2010).

Based on data processing carried out at Well C-1 using the Passey method, it can be said that the reservoir zone qualitatively and quantitatively based on well data is at a depth of between 1100 m to 1200 m, including the end of the Kujung Formation to the Talang Akar Formation, and is classified as an immature reservoir zone. Based on the high radioactive log curve response in Well C-1, it can be said that both formations are shale lithologic. The reservoir zones have an organic material content (TOC) of 1 - 13 wt% with good to excellent quality.

Geochemical Analysis

In general, the prediction of TOC values using the Passey et al. (1990) method produced a good correlation with R^2 0.853 (Table 5). The quality of a source rock can be assessed by the type of kerogen and the type of hydrocarbons that will be produced. Kerogen is the ability of the source rock to produce products in the form of oil or gas. Kerogen itself has several types, which are kerogen types I, II, and III. Where each type of kerogen has a different product. One way to find out the type of kerogen from a source rock is to cross-correlate the Tmax data with the Hydrogen Index (HI) data on the van Krevelen Diagram. In Figure 11, which is a cross-correlation between HI and Tmax data in the van Krevelen Diagram, it can be indicated that the source rock in Well S-1 has immature type II kerogen (Figure 11). According to Muther et al. (2021), source rocks with kerogen type II have the potential to produce oil and gas products. Kerogen type II is a type of kerogen that is formed from several sources, such as marine algae, spores, and pollen, the waxy layer of a plant, plant fats, and fossil resins.

Table 5. Correlation results between TOC value calculation using Passey Method and TOC core.

Depth (ft)	$\Delta LogR$	TOC Passey	TOC Core	R^2
5820	0.705	2.756	1.973	0,853
6000	0.358	0.669	0.964	
6090	0.675	0.602	1.231	
6180	0.778	0.307	0.411	
6270	1.003	1.734	1.691	
6360	0.551	0.201	0.225	
6450	0.642	0.171	0.184	
6630	0.530	1.071	1.172	
6720	0.731	2.016	2.034	

In addition, the maturity level of a source rock can be determined by using the correlation between S2 data and TOC data. The combination of these two data can be used to obtain the Level of Maturity (LOM) value.

Based on the correlation results of S2 data with TOC in Figure 12, this research data has a maturity level with a dominant LOM value of less than 7. So, it can be said that the source rock is classified as immature.

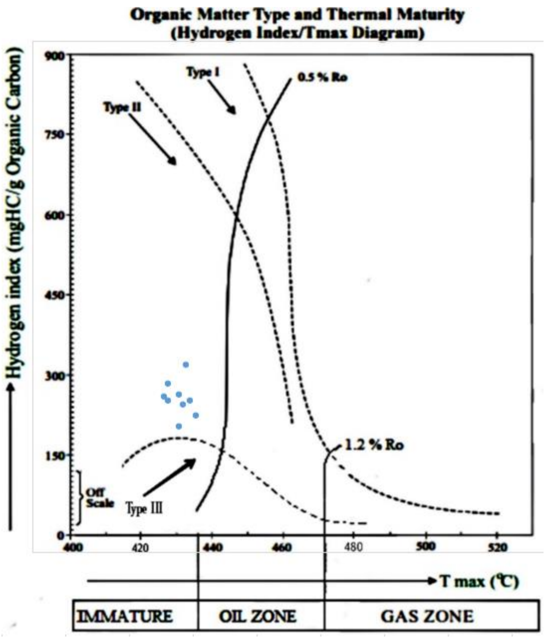

Figure 11. Quality of the Source Rock Zone at Well S-1.

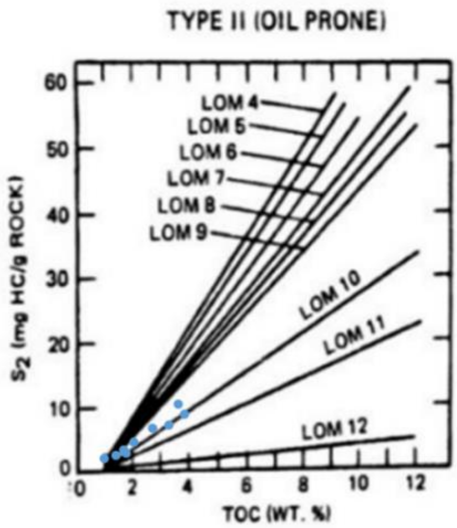

Figure 7. LOM values are based on S2 and TOC core data.

Seismic Data Analysis

Figure 13 is 2D seismic data on line A-79 which is traversed by K-1 well data. This line will be a reference in making composite lines and picking horizons at a later stage. Figure 13 shows the results of horizon picking on line A-79 which is a reference in picking horizons on other lines. The pink line shows the upper layer of the source rock and the light blue line shows the lower layer of the source rock.

Figure 14 is an interpretation of the lithology of the source rock zone (reservoir) on seismic data. Based on the figure, it can be said that the reservoir zone has a high GR value, so it has a shale lithology.

Figure 15 is the Top (upper layer) of the reservoir zone. Based on Figure 15, it can be seen that there is a low area indicated by light blue to dark blue color, ranging in value between 2100 m - 2700 m. If observed, the area around Well K-1, Well S-1, and Well C-1 includes a low area that allows it to be interpreted as a geological structure in the form of a syncline. Thus, it is possible that there is a hydrocarbon trap on the North-West side of the study area. Figure 16 shows the bottom of the reservoir zone. Based on Figure 16, it can be seen that there is a low area indicated by light blue to dark blue color, ranging in value between 2500 m - 3100 m.

If observed, the area around Well K-1, Well S-1, and Well C-1 includes a low area that allows it to be interpreted as a geological structure in the form of a syncline. So that it can allow the existence of hydrocarbon traps on the North-West side of the study area.

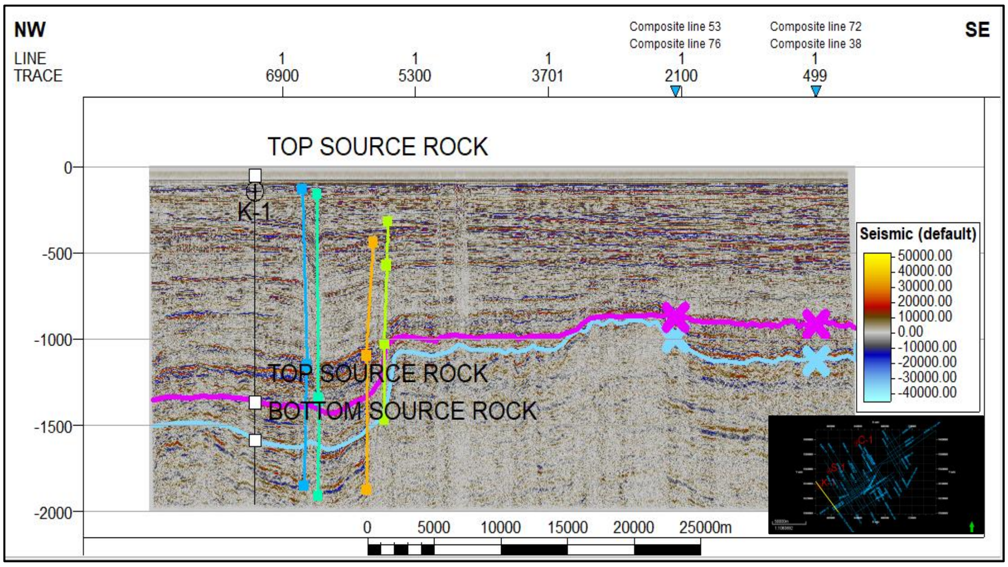

Figure 8. Horizon on Line A-79.

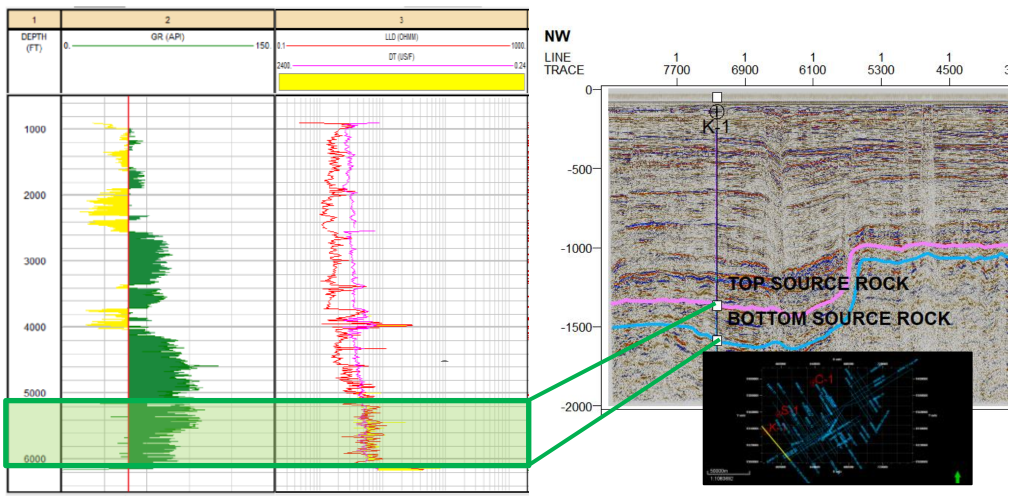

Figure 9. Source Rock Zone on Line A-79.

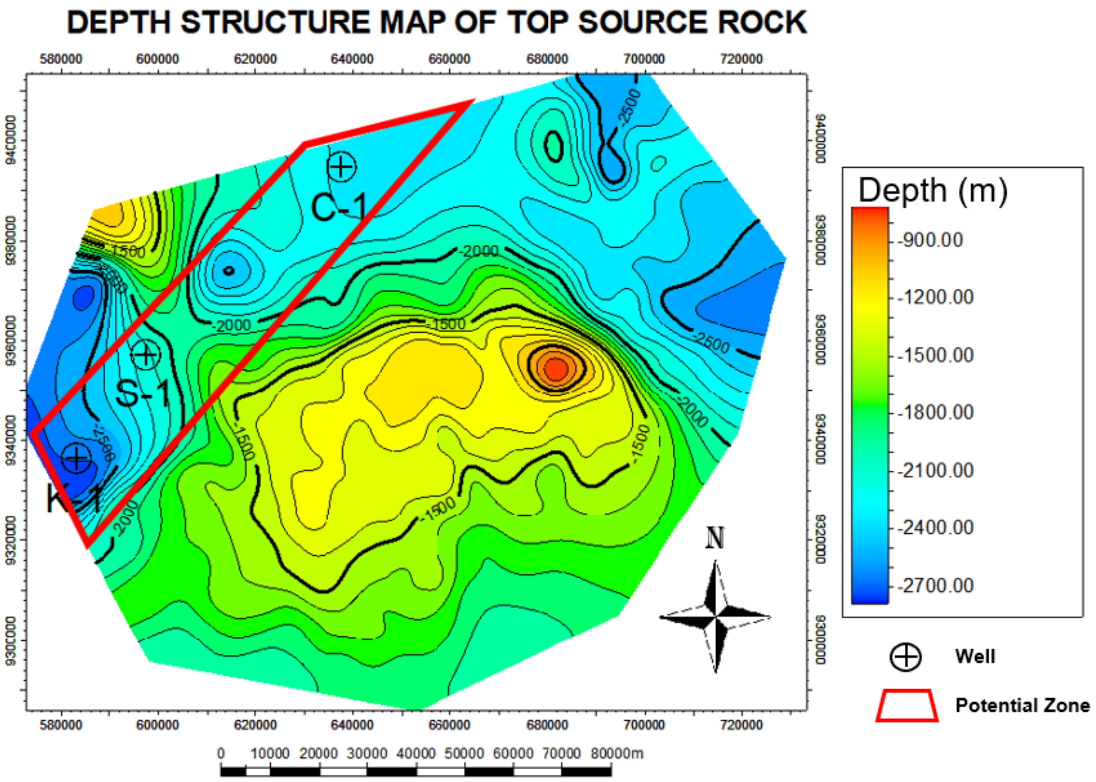

Figure 10. Top Reservoir Depth Structure Map.

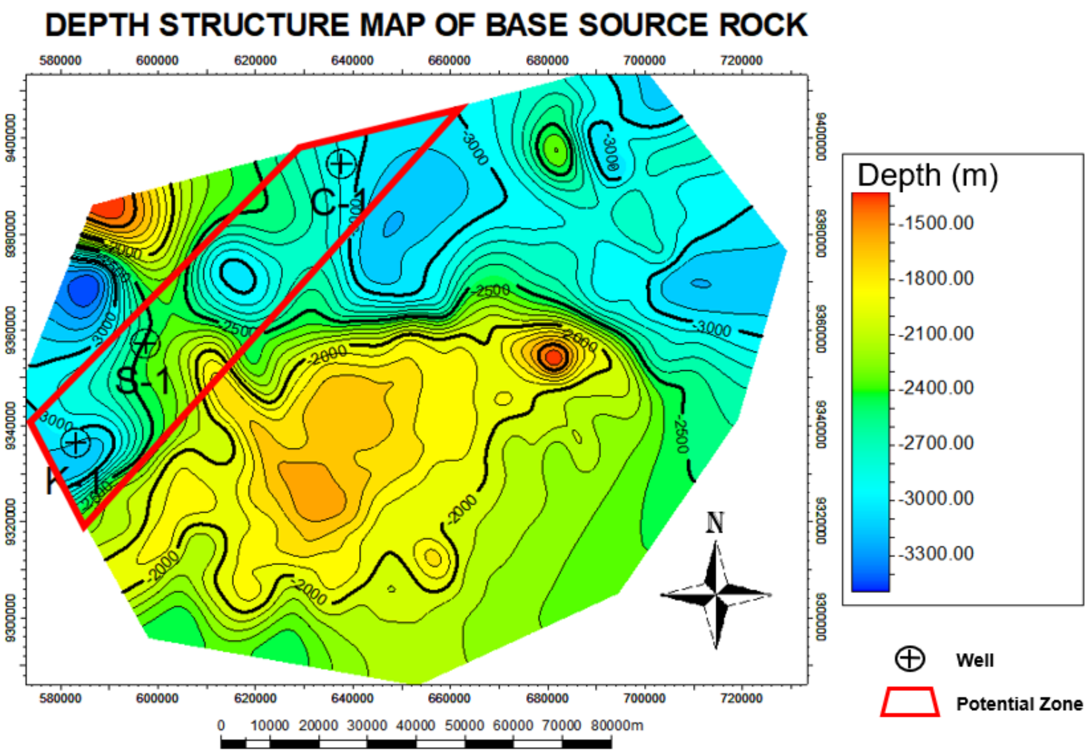

Figure 11. Bottom Reservoir Depth Structure Map.

Conclusion

Based on the results of qualitative and quantitative analysis based on well data, geochemical data, and seismic methods, the results of this study can be concluded as: The first, geochemical data analysis in Well S-1 shows that the reservoir zone in Field "X" of the North East Java Basin has Type II kerogen and an immature maturity level.

The second, based on prediction using the Passer method, the reservoir zone in Well S-1 has an average TOC value of 2.38% with very good quality. Well K-1 has an average TOC value of 4.41% with excellent quality, and Well C-1 has an average TOC value of 4.83% with excellent quality. The last, the reservoir zone in Field "X" of the North East Java Basin is in a low area in the northwest direction of the study area.

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Author Contribution

Rahmat Catur Wibowo: Conceived and designed the experiments, Performed the experiments, Analyzed and interpreted the data, and Wrote the paper; Aryka Claudia Eka Putri: Performed the experiments; Ordas Dewanto: Analyzed and interpreted the data.

Conflict of Interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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