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IDENTIFICATION OF SHALE LAYER IN OFFSHORE FIELD OF NORTH EAST JAVA BASIN FOR NON-CONVENTIONAL OIL AND GAS EXPLORATION

Ordas Dewanto[1]*, Nanda Paquita Syaharani[1], Darsono[2], Andy Setyo Wibowo[3]
[1] Geophysical Engineering, Faculty of Engineering, University of Lampung, Bandar Lampung, Indonesia
[2] Department of Physics, Faculty of Mathematics and Natural Sciences, Sebelas Maret University, Surakarta, Indonesia
[3] Geological Survey Center, Diponegoro st. 57, Cibeunying Kaler Bandung, Indonesia
*ordas.dewanto@eng.unila.ac.id

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ABSTRACT

Shale is a rock that is rich in organic matter and is a target for un-conventional exploration, because it functions as a source rock and reservoir with a large volume of shale and low permeability. The shale distribution map can describe the thickness of the shale layer and has the potential to be a target for un-conventional exploration located in a thick shale layer. Based on this background, this study will identify shale layers in the offshore field of the North East Java Basin for un-conventional oil and gas exploration. The methods used are well logging and seismic methods. This study focuses on determining the location of the deepest part of the basin and the place of accumulation of shale layer hydrocarbons based on the shale distribution map as an initial step in localizing areas that will be targets for the development of unconventional hydrocarbon exploration. This study uses 29 2D seismic lines and 2 well data, namely wells NP-1 and NP-2. The results obtained from the shale distribution map show that the location of the deepest basin and the place of hydrocarbon accumulation of the Kujung Formation is in the northwest with a shale thickness of 600-800 meters, while the Ngimbang Formation is in the east with a shale thickness of 1000-1300 meters. From the location of the deepest basin and the place of hydrocarbon accumulation, it can be seen that this location has a wealth of organic material so that it has the potential as a source rock and reservoir.

Keywords: non-conventional; serpih; well logging; source rock; reservoir

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INTRODUCTION

Non-conventional hydrocarbons are generally produced in shale or carbonates with very low permeability [1]. To determine non-conventional hydrocarbons can be seen with impermeable zones, poor effective porosity and lithology in the form of shale, with a permeability range of <1 md [2]. Non-conventional oil and gas are hydrocarbons that are formed and stored in host rocks (shale) with very small permeability of around 0.001 MD to 0.0001 MD so that they cannot migrate to conventional reservoirs. One of the non-conventional hydrocarbon potentials in Indonesia is in the North East Java Basin [3]. The basin is known to be rich in hydrocarbon resources and has even been producing in some areas, due to the presence of petroleum systems in many formations. The North East Java Basin is a potential and mature hydrocarbon-forming basin with more than one source rock [4]. Shale is generally the source rock, but in the concept of non-conventional oil and gas, shale will be the source rock as well as the reservoir rock [5].

Some of the shale parameters that are potential or not for a formation include TOC, thermal maturity, hydrocarbon saturation, porosity, and mineralogy [6].

Looking at the background above, the researchers tried to identify the shale layer in the offshore field of the North East Java Basin for non-conventional hydrocarbon exploration. The objectives of this study are to determine the thickness of shale in the Kujung Formation and Ngimbang Formation; Provide information on the location of shale layers that have the potential as targets in the development of un-conventional hydrocarbon exploration in the Offshore Field of the North East Java Basin. Several studies on non-conventional hydrocarbons have been carried out by several researchers [7-13].

The geophysical methods used in this study are seismic and well logging methods [14]. Exploration and production of shale hydrocarbons will be successful if the initial data planning and analysis is done well, one of which is by analyzing the distribution and thickness of shale using seismic data and log data, so that knowing the area with a large enough shale thickness is expected to be an initial reference in the development of non-conventional oil and gas in the North East Java Basin, especially in the offshore area.

The research was conducted in the offshore field of the North East Java Basin as a back arc basin that has produced around 220 million barrels of hydrocarbons to date [15]. In the North East Java Basin there are more than one parent rock found in the Ngimbang, Kujung II, Tawun, and Tuban Formations [4]. This basin is one of the potential un-conventional hydrocarbon basins where there is 42 TCF (trillion cubic feet) of shale gas [3].

The seismic method is the best method for describing subsurface conditions. This method utilizes the propagation of seismic waves that pass through the earth's material. Seismic waves can come from artificial sources such as vibration generation from vibroseis equipment, dynamite explosions and so on. These sources can cause vibrations at the point of the wave to be reflected by the reflector below the surface and received by the gephone to produce a record in the form of a seismogram consisting of travel time and energy strength. The well logging method is a method to obtain subsurface data such as lithological information, calculation of petrophysical parameters, determination of hydrocarbon types in a target zone and so on. In the exploration process in an area, the seismic method is carried out for several passes while the well logging method is carried out at several points suspected of containing hydrocarbons. By tying seismic cross-sections and well data or what is called a well seismic tie, interpretation can be done to determine subsurface conditions more accurately and widely [16].

Good shale hydrocarbon prospect zones can be determined based on TOC≥0.5 wt% values [17-18]. Some parameters such as mobility and transmissibility greatly affect the determination of non-conventional reservoir areas. It is very important to explore information about the physical and chemical properties of non-conventional hydrocarbon resources in the North East Java basin, and according to [19] can provide very useful information in deciding whether hydrocarbons are worth exploiting or not. By knowing the thickness of shale in the Kujung Formation and Ngimbang Formation in the unconventional area of the North East Java Basin Offshore Field, it can be decided for oil and gas exploitation in the area. Information on the location of shale layers that have the potential to be targeted in the development of un-conventional hydrocarbon exploration in the Offshore Field of the North East Java Basin is very important for the oil and gas exploration stage.

RESEARCH METHODS

Data collection was carried out at the Geological Survey Center (PSG) Bandung, then data processing was carried out at the Geophysical Engineering Mitigation laboratory at the University of Lampung.

The data used is 2D seismic data. This data is used in the process of well seismic tie and picking horizon with the amount of 2D seismic data used as many as 29 lines located in the North East Java Basin Sea area. Some of the theories or equations used in seismic methods are [20] on Snellius Law; [21] and [22] on Wavelets; [23] and [24] on Reflection Seismic Method; [25] and [26] on Synthetic Seismogram; [27] and [28] on Fermat's Principle; [29] on Polarity and Phase; [30] on Acoustic Impedance; [31] on Huygens' Law; [32-34] on Well Seismic Tie, Picking Horizon; [35] on Time and Depth Structure Map.

Some of the theories or equations used in the well logging method are [36] about identifying the characteristics of subsurface rocks; [37] about well data being used as control data for the identification of subsurface rocks; [38] about parameters measured in wells being displayed in a series of curves that produce depth graphs; [39] about parameters of the physical properties of a formation at each depth continuously in drilling wells; [40] about the principles of gamma ray logs, sonic, density, porosity, resistivity and clay content. In this study, the well data used amounted to 2 data, namely well NP-1 and well NP-2.

Important data in seismic interpretation, especially used during the well seismic tie process as a binding process between depth-domain well data and time-domain seismic data. This study uses 1 checkshot data from the NP-1 well for the well seismic tie process.

The data contains information about the depth of the formations in the study area. The marker data used in each formation in this study is limited by top shale (Tsh) and bottom shale (Bsh). This research was carried out in several stages, namely:

1. Calculate shale volume and permeability
   - This step is done as a validation that the top and bottom shale used has a large amount of shale and has the potential to be a target for unconventional hydrocarbon exploration. Where, the larger the shale and the smaller the permeability value, the better the ability of the rock to inhibit fluid.
2. Carrying out the Well to Seismic Tying process
   - Before performing a well to seismic tie, the well data is tied to seismic data using sonic log data (P-wave) and checkshot data. This is done to convert well data in the depth domain to seismic data in the time domain. Then a time depth curve will be obtained which shows that depth has been correlated with time. From this study there is only 1 data that has checkshot data, namely NP-1.
3. Carry out the Picking Horizon process
   - The data used in this process are seismic data and marker data. Where, in seismic data a horizon is displayed by a seismic reflector with negative amplitude called through (valley) which is displayed as a blue horizon on the seismic cross section and positive amplitude as a peak (peak) which is displayed as a red horizon on the seismic cross section. In performing this process, a well seismic tie is required to tie the seismic horizon with the well data so that the horizon can be in the appropriate position. Picking horizon is making a horizon line with the continuity of the existing layers on the cross section to find out information about the geological conditions of the study area. The initial position when picking the horizon is on the track traversed by the well data because of the marker data used as a reference in this stage. Where the horizon in this

- study is limited by Tsh Kujung, Bsh Kujung, Tsh Ngimbang, and Bsh Ngimbang, resulting in 4 horizons on the seismic cross section.

4. Create Time and Depth Maps
   - Time map is a time-domain depth map of the geology of the study area generated from horizon picking. The time map produced is 4 based on the number of picking for each formation, namely picking top and bottom shale in the Kujung and Ngimbang Formations. Next, depth conversion will be carried out, namely by converting the time map domain into the depth domain (depth map). This conversion is done by performing a linear regression relationship of checkshot data in the form of TVD (depth) and TWT (time), where the x-axis is TWT and the y-axis is TVD. The regression results will produce a linear equation that becomes an input in making the depth map.
5. Create a Shale Distribution Map
   - After making the time and depth map, then create an isopach map that describes the thickness of a layer. This map is made by subtracting the results of the time or depth top shale formation map with the time or depth bottom shale formation so that it will produce a shale isopach map in each formation.

RESULTS AND DISCUSSION

Stratigraphy and Research Area of the North East Java Basin

The study area belongs to the Rembang physiographic zone. The stratigraphy of the North East Java Basin has the oldest stratigraphic unit above bedrock, the Ngimbang Formation [41]. Figure 1 shows the stratigraphic column of the Rembang zone in the North East Java Basin [42].

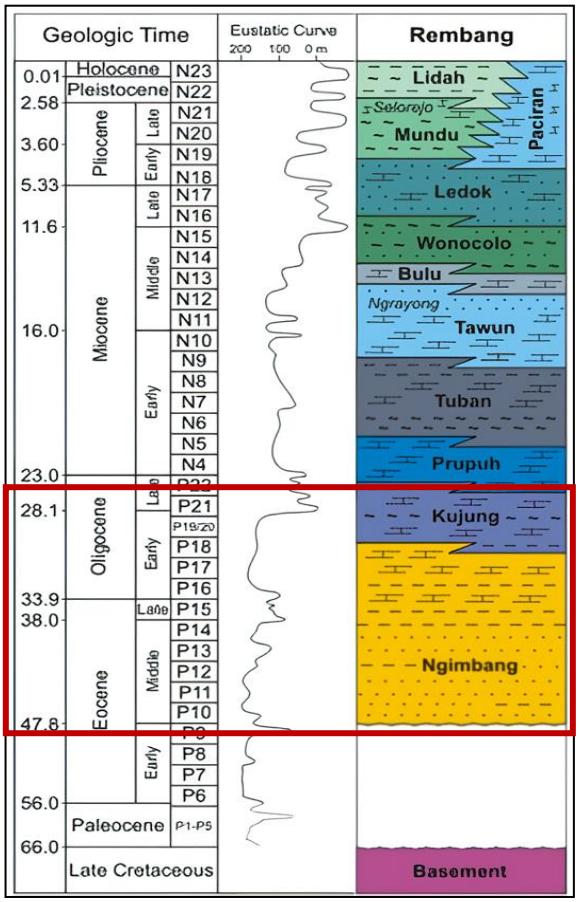

Figure 1. Stratigraphic column of Rembang Zone of North East Java Basin [42]

a. Kujung Formation
The Kujung Formation was deposited in harmony above the Ngimbang Formation with the formation dating from Early Oligocene to Late Oligocene. The Kujung Formation is the oldest formation exposed on the surface consisting of rock layers, namely limestone, shale, sandstone, and conglomerate sediments with coal inserts. This formation is spread along the Kujung Anticline on the Tuban Plateau and was deposited in an open sea environment.

b. Ngimbang Formation
The Ngimbang Formation is of Middle Eocene age and in this formation is divided into two parts, in the Early Eocene age the Pre-Ngimbang Formation is deposited consisting of sandstones with shale, siltstone and coal inserts which are synrift deposits and are found in the North Bali and East Kangean Offshore areas. The Ngimbang Formation was deposited in the Middle Eocene to Early Oligocene age, consisting of shale and sandstone and at the bottom consists of sandstone, shale, and siltstone with thin coal inserts.

The North East Java Basin is an offshore basin in Indonesia. The study area is located in the offshore (marine) field of the North East Java Basin shown in Figure 2.

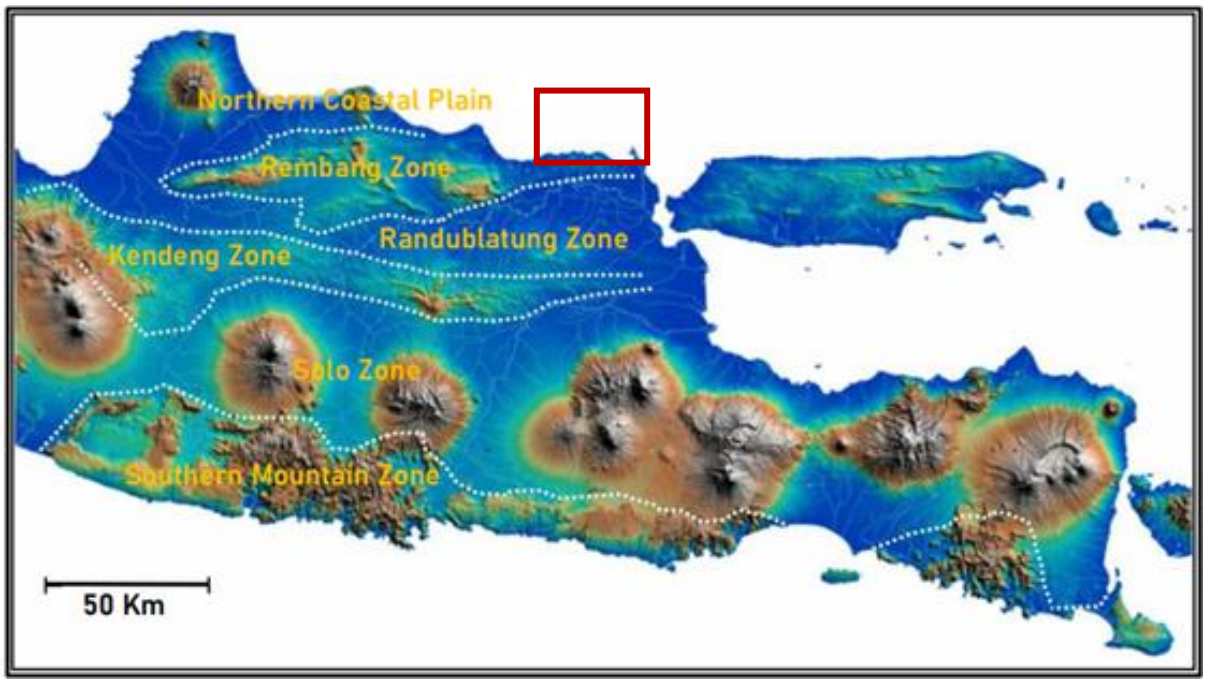

Figure 2. Location of the Research Area [42]

Non-Conventional Parameter Analysis

This research focuses on the shale layer which is the target of non-conventional exploration. In non-conventional hydrocarbons, there are several petrophysical parameters that need to be considered such as Vshale and permeability. These parameters are used to validate that the marker data used is appropriate to be used as a target for non-conventional exploration.

a. Shale Volume Calculation
Shale is an impermeable rock that can block the flow of fluids through other rocks. The shale volume calculation is used to validate that the research marker data has a large shale content. Where, the more shale content in a rock, the ability to inhibit fluid is greater so that the hydrocarbons in it will be trapped and cannot escape. With this property, a large shale value is very good for an non-conventional reservoir zone, where a good shale volume value is >35%.

b. Permeability Calculation

Permeability is the ability of a rock to pass fluid. Permeability is closely related to rock grain size, where large-grained rocks with large pores have large permeability values and fine-grained rocks with small pores have low permeability values. In this study, the calculation of permeability values uses the Eastern permeability calculation method using the calculation constants a=0.136, b=4.4 and c=2. The range of rock permeability values in gas fluid is <0.1 mD and oil fluid is <1 mD (milli Darcy).

Table 1. Vsh and permeability values in the Kujung Formation, well NP-1

Target Zone Marker	Depth (m)	Shale Volume (%)	Permeability (mD)
1	27.50 – 59.89	38.4%	20.161
2	60.04 – 92.96	46.2%	1.867
3	93.11 – 125.88	48.7%	0.878
4	126.03 – 148.00	51.4%	0.794

**yellow highlight indicates non-conventional target prospect zone*

The calculation of non-conventional parameter values is carried out in accordance with the marker target zone in each formation. The calculation of non-conventional parameters in wells NP-1 and NP-2 is shown in tables 1, 2, 3 and 4.

Table 1 shows the shale volume and permeability values of the Kujung Formation, well NP-1. The shale volume value obtained is in the range of 38.4% -51.4%, which means that the shale content in this formation is very large and its ability to inhibit fluid is also greater so that hydrocarbons will be trapped and cannot escape. Then the permeability values in target zones 3 and 4 have values of 0.878 and 0.794 mD. Based on a permeability value of less than 1 mD, it indicates that the hydrocarbon fluid is oil.

Table 2. Shale Volume and Permeability Values of the Ngimbang Formation, well NP-1

Target Zone Marker	**Depth (m)**	**Shale Volume (%)**	**Permeability (mD)**
1	353.56 – 385.87	53.9%	0.880
2	386.02 – 418.94	40.1%	4.265
3	419.10 – 451.86	51.2%	0.559
4	452.01 – 484.93	54.8%	0.021
5	485.08 – 517.85	41.3%	0.116
6	518.00 – 550.92	30.8%	5.399
7	551.07 – 561 m	34.4%	0.319

*yellow highlight indicates non-conventional target prospect zone

Table 2 shows the shale volume and permeability values of the Ngimbang Formation, well NP-1. Based on Table 2, the shale volume value is obtained in the range of 30.8%-54.8%, which means that the shale content in this formation is very large and its ability to inhibit fluid is also getting bigger so that hydrocarbons will be trapped and cannot come out. Then for permeability values in target zones 1, 3, 5 and 7 have values of 0.880, 0.559, 0.116, and 0.319 mD. Based on the permeability value that is less than 1 mD indicates hydrocarbon fluid in the form of oil while in zone 4 the value is 0.021 mD and the permeability value that is less than 0.1 mD indicates hydrocarbon fluid in the form of gas.

Table 3 shows the shale volume and permeability values of the Kujung NP-2 Formation Well. Based on table 3, the shale volume value is obtained in the range of 42.4%-72.5%, which means that the shale content in this formation is very large and its ability to inhibit fluid is also getting

bigger so that hydrocarbons will be trapped and cannot come out. Then for permeability values in target zones 2, 3, 5 and 6 have values of 0.189, 0.265, 0.588 and 0.182 mD. Based on the permeability value which is less than 1 mD, it indicates hydrocarbon fluid in the form of oil while in zones 4, 7, 8 and 9 the values are 0.038, 0.066, 0.056 and 0.015 mD and the permeability value which is less than 0.1 mD indicates hydrocarbon fluid in the form of gas. However, in zone 11 the permeability value is not readable due to data limitations.

Table 3. Shale Volume and Permeability Values of the Kujung Formation, well NP-2

Target Zone Marker	Depth (m)	*Shale Volume* (%)	Permeability (mD)
1	1095.14 – 1127.91	42.4%	5.567
2	1128.06 – 1160.98	63.9%	0.189
3	1161.13 – 1193.90	62.0%	0.265
4	1194.05 – 1226.97	67.3%	0.038
5	1227.12 – 1259.89	60.6%	0.588
6	1260.04 – 1292.96	63.1%	0.182
7	1293.11 – 1325.88	66.3%	0.066
8	1326.03 – 1358.95	66.8%	0.056
9	1359.10 – 1391.86	72.5%	0.015
10	1392.02 – 1424.94	55.9%	2.506
11	1425.09 – 1432.86	68.7%	-

**yellow highlight indicates non-conventional target prospect zone*
*(-): limited LLD data at Well NP-2

Table 4 shows the shale volume and permeability values of the Ngimbang Formation in Well NP-2. Based on Table 4, the shale volume value is in the range of 76.7%-80.9%, which means that the shale content in this formation is very large and its ability to inhibit the fluid is also greater so that hydrocarbons will be trapped and cannot come out. Then for the permeability value in this formation cannot be calculated because of data limitations.

Table 4. Shale Volume and Permeability Value of Ngimbang Formation in Well NP-2

Target Zone Marker	Depth (m)	Shale Volume (%)	Permeability (mD)
1	1558.13 – 1590.90	78.9%	-
2	1591.05 – 1623.97	80.9%	-
3	1624.12 – 1646.00	76.7%	-

*(-): limited LLD data at Well NP-2

Isopach Map Analysis

From the results of the time and depth map, an isopach map will then be made, namely, a map that describes the thickness of a layer. In the process of making it is done by the way the results of the time or depth map of the top shale formation are subtracted from the time or depth map of the bottom shale formation so that it will produce a shale isopach map in each formation.

The Isopach Map of the Kujung Formation Shales in the Time domain is shown in Figure 3. Then the Isopach Map of the Ngimbang Formation Shales in the Time domain is shown in Figure 4. Based on the isopach map of the Kujung Formation in the time domain, this formation is dominated by shale thickness of 40 ms to 240 ms. In Figure 3 it can be seen that the shale layer thickens in the northwest direction shown by the dark blue to purple color of 480 ms to 600 ms. In addition, there are also spots of fairly thick shale layer shown by light blue color of 280 ms to 440 ms in the east direction. Based on the isopach map of the Ngimbang Formation

in the time domain, this formation is dominated by shale thickness of 60 ms to 420 ms. In Figure 4, it can be seen that the shale layer thickens in the east direction as shown by the dark blue to purple color of 780 ms to 1020 ms. In addition, there are also spots of fairly thick shale layers shown by the light blue color of 480 ms to 720 ms in the southwest, northeast and southeast directions.

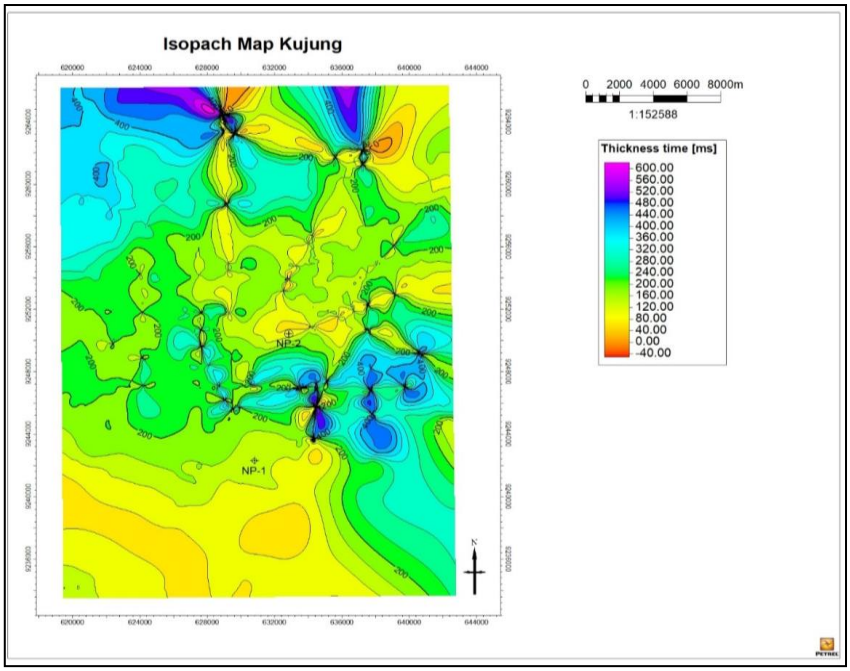

Figure 3. Isopach Map of Kujung Formation Shale with Time Domain

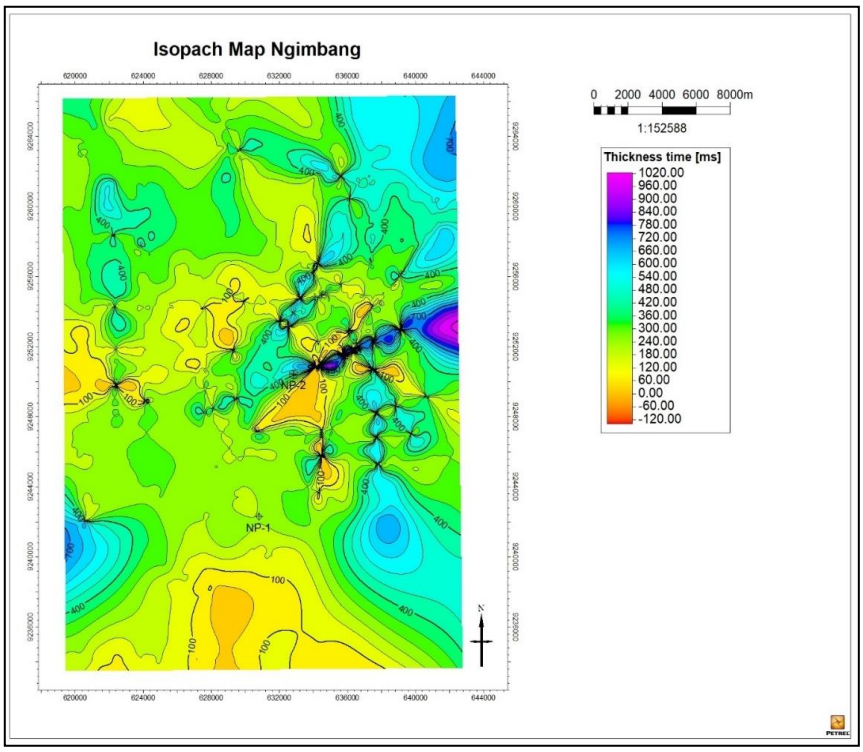

Figure 4. Isopach Map of Ngimbang Formation Shale with Time Domain

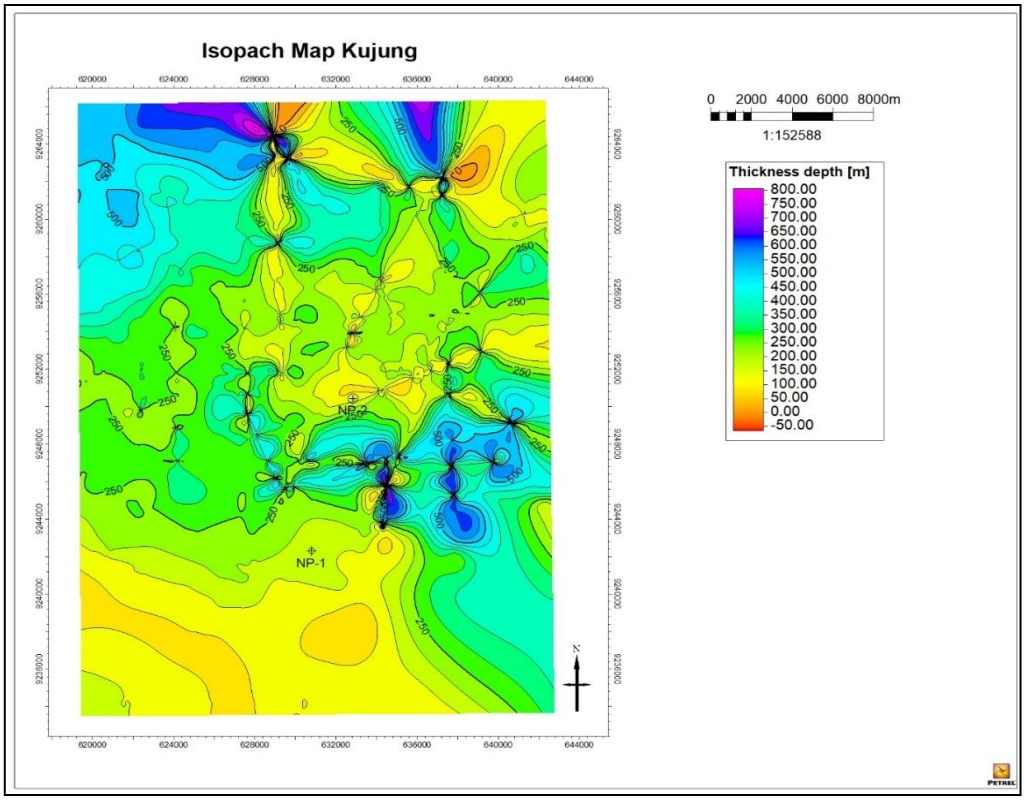

Figure 5. Isopach Map of Kujung Formation Shale in Depth Domain

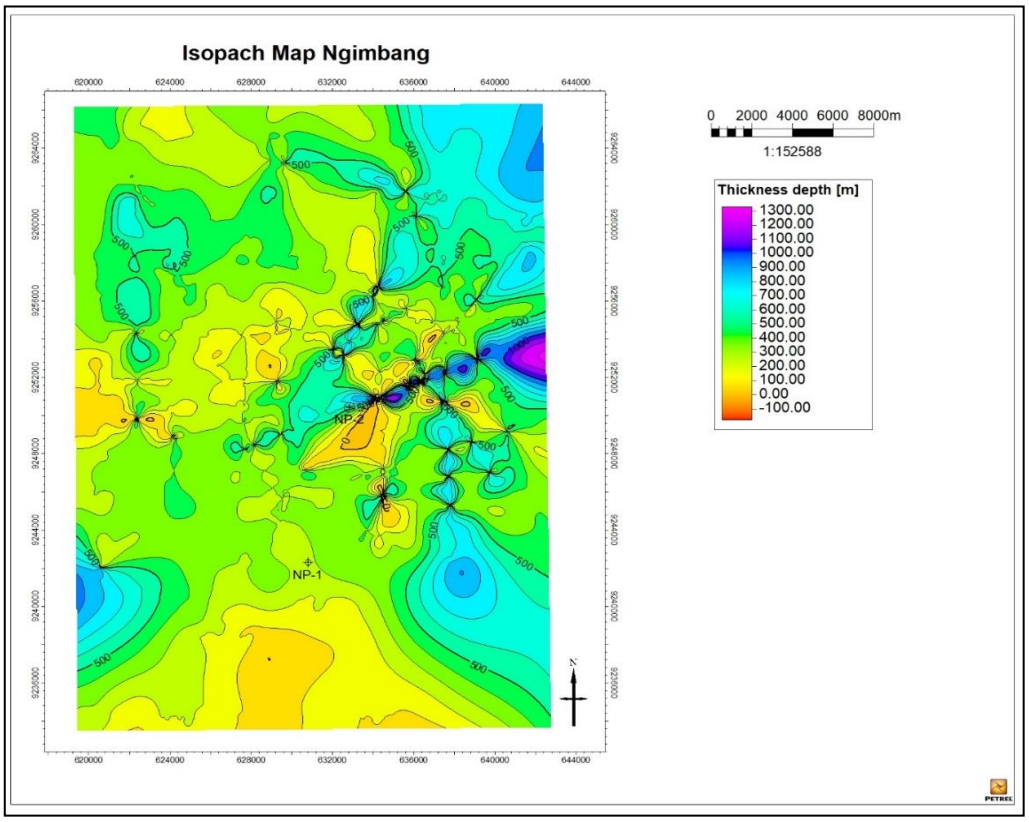

Figure 6. Isopach Map of Ngimbang Formation Shale in Depth Domain

Furthermore, the Kujung Formation Shale Isopach Map in the depth domain is shown in Figure 5, and the Ngimbang Formation Shale Isopach Map in the depth domain is shown in Figure 6. Based on the isopach map of the Kujung Formation in the depth domain, it is observed that the formation is predominantly characterized by shale thickness ranging from 50 meters to 300 meters. In Figure 5, it is clearly illustrated that the shale layer exhibits significant thickening towards the northwest direction, as indicated by the dark blue to purple coloration, representing thicknesses between 600 meters to 800 meters. Additionally, there are several distinct areas where the shale layer is considerably thick, depicted by light blue colorations, which indicate thicknesses ranging from 350 meters to 550 meters in the eastern direction. These observations highlight the variability in shale layer thickness within the formation, providing crucial insights into its geological characteristics and potential resource distribution.

Based on the isopach map of the Ngimbang Formation in the depth domain, this formation is dominated by a shale thickness of 100 m to 400 m. The shale layer thickens in the eastern direction as shown in Figure 6. In Figure 6, it can be seen that the shale layer thickens in the eastern direction shown by the dark blue to purple color of 1000m to 1300m. In addition, there are also spots of fairly thick shale layers indicated by the light blue color of 500 m to 900 m in the southwest, northeast, and southeast directions.

Prospect Zone Analysis

From the results of the isopach map above, a 3D model will then be made to see the 3D shale overlay so that it is easier to determine the location of the research area depocenter. Depocenter is the deepest part of a basin and the place where a thick sediment layer accumulates which will be the place where hydrocarbons accumulate. The creation of this 3D model using isopach map with depth domain can be seen in Figures 7 and 8.

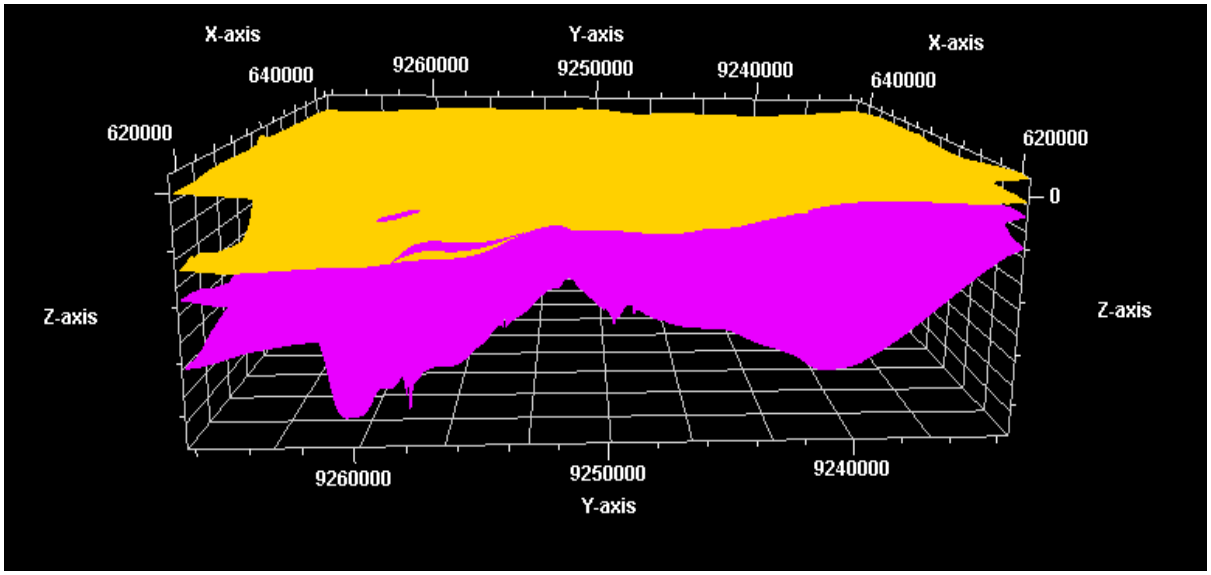

Figure 7. 3D of Shale Layer in the Offshore Region from the Western Direction (Kujung Formation in yellow and Ngimbang formation in pink)

From this 3D model, the location of the depocenter for each formation can be known. In the Kujung Formation, the location of the depocenter (the deepest part of the sub-basin) can be seen in Figure 7, located in the northwest with a thickness of 600-800 m, while in the Ngimbang Formation can be seen in Figure 8, the location of the depocenter is located in the east with a thickness reaching 1000-1300 m. From the location of the deposenter, it can be seen that the

location has a large wealth of organic material so that it has the potential to become a source rock.

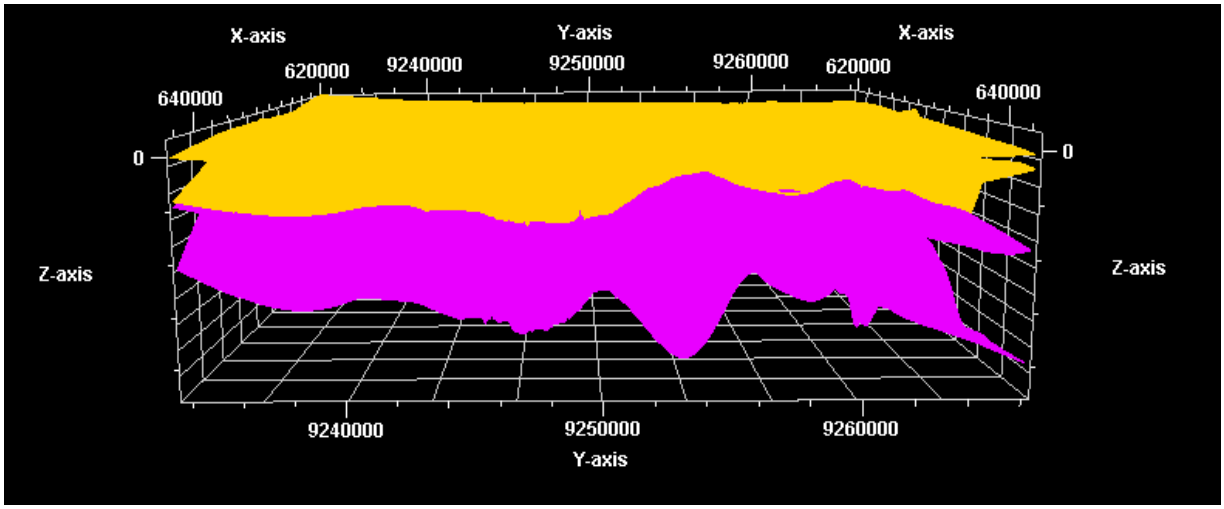

Figure 8. 3D Model of Shale Layer in the Offshore Region from the Eastern Direction (Kujung Formation in yellow and Ngimbang Formation in pink)

New Findings

Un-conventional hydrocarbons have a large volume of shale with small porosity values and low permeability to determine the hydrocarbon fluid content (oil or gas). Un-conventional hydrocarbons mature in source rocks and also act as reservoirs to form fluids (oil or gas) with low permeability values. The lithology of un-conventional source rocks and reservoirs is shale which has small porosity. Shale has a very high organic content so that it can form oil or gas hydrocarbons, and the first exploration carried out is to determine the magnitude of the shale lithology based on geological methods. Then also look at the organic content of formations in the northern basin of East Java.

After finding an area that contains a lot of shale, and there is information about large organic content, a survey is then carried out based on the well logging method to determine the vertical depth of the shale lithology. Next, we analyze the petrophysical properties, namely: shale volume, porosity and permeability to ensure that the area is un-conventional hydrocarbon. Then determined the shale content horizontally, to determine the shale area.

Based on the well logging method in the well target area in an area that contains a lot of shale, the results of the petrophysical analysis (namely: shale volume, porosity and permeability) can be distributed in that area.

It is known that unconventional oil and gas are hydrocarbons that are formed and stored in source rocks (shale) with very low permeability, namely around 0.001 MD to 0.0001 MD so they cannot migrate to conventional reservoirs [43]. Characterization of the Eocene-Miocene Source Rocks, Deep Middle, North East Java Basin has been studied by [44].

By identifying shale/shale layers in the offshore fields of the North East Java Basin, non-conventional oil and natural gas exploration can be carried out. Source rock or reservoir and its petrophysical properties (shale volume, porosity and permeability), as well as fluid content (oil or gas) can be determined, then non-conventional oil and gas exploitation can be carried out.

CONCLUSIONS

Based on the isopach map which represents the thickness of the shale layer, it is known that the Kujung Formation is in the northwest with a thickness of 600-800 meters, while the Ngimbang Formation is in the east with a thickness of 1000-1300 meters. meters. From the location of the deepest basin and the place where hydrocarbons accumulate, it can be seen that this location has a wealth of organic material so it has the potential to be a source rock and reservoir.

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