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Study Of Hydrocarbon Distribution In The "RDA" Field Using The Amplitude Variation With Offset (AVO) Method On 3D Seismic Angle Stack Data

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Abstract— Hydrocarbons, derived from fossil sources such as oil and natural gas, are critical energy resources. In Indonesia, the increasing population has led to a rising demand for hydrocarbon resources, which is inversely related to their availability, necessitating research into optimizing hydrocarbon exploration. Hydrocarbon exploration can be performed using the Amplitude Variation with Offset (AVO) method, which analyzes variations in seismic wave amplitudes with respect to changes in offset to detect hydrocarbon presence. This research aims to delineate potential hydrocarbon accumulation zones and assess the number of potential hydrocarbon prognosis wells within the "RDA" field. The research employs 3D seismic angle stack data to enhance the resolution and accuracy of subsurface structural identification. The findings indicate that eight potential hydrocarbon accumulation areas were identified in the "RDA" field, based on consistent amplitude anomalies and hydrocarbon-associated characteristics observed in several areas. This suggests significant potential for gas field development at the study site. Furthermore, the research identifies 11 potential hydrocarbon prognosis wells, each with distinct net pay and reserve estimates, indicating considerable hydrocarbon accumulation potential in the "RDA" field, which can facilitate more effective and efficient exploration planning.

Keywords— Amplitude Variation with Offset, 3D seismic angle stack, net pay, porosity, reserves.

I. Introduction

Hydrocarbons are energy sources derived from fossil fuels, such as oil and natural gas. According to data from the Ministry of Energy and Mineral Resources (ESDM) in 2023, Indonesia has oil reserves of 2.41 billion barrels (BBO) and gas reserves reaching 35.3 trillion cubic feet (TCF), which are distributed across various regions in Indonesia. However, with the increasing population in Indonesia and the rapid advancement of technology, the demand for energy has surged, necessitating the optimization of hydrocarbon exploration in fields that have been frequently exploited as well as in fields that are rarely or have never been exploited.

In the process of hydrocarbon exploration, the seismic reflection method can be an effective technique to utilize. Seismic reflection can be considered part of exploration seismology, which uses reflected waves to detect the presence or location of hydrocarbons [1]. The principle of this method is to use waves generated by equipment that propagate beneath the Earth's surface; these waves will be reflected or refracted and then captured by receiving components. In exploration seismology, seismic methods are divided into two types: refraction seismic, commonly known as seismic refraction, and reflection seismic,

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commonly known as seismic reflection. The fundamental difference between these two methods lies in the depth that each method can reach. The seismic reflection method utilizes the reflection angle of wave propagation within the ground to explore deep ranges, making it suitable for hydrocarbon exploration [2]. Based on data collection and analysis, seismic reflection methods can be categorized into two types: 2D seismic methods and 3D seismic methods.

The 3D seismic method is regarded as a technique capable of providing a comprehensive and more detailed depiction of subsurface structures compared to the 2D seismic method. This is because, in the 3D seismic method, stratigraphy can also be visualized from beneath the surface, which is not available in the 2D seismic method. Additionally, the 3D seismic method provides extra information on rock parameters recorded along with changes in azimuthal direction from source to receiver (Biondi, 2006). 3D seismic forward modeling can be performed using wave propagation approximation (ray-tracing) or wave equations. The forward modeling approach has several advantages, such as yielding stronger wave equations; however, it also has drawbacks, such as requiring longer computational time, making it more expensive. On the other hand, modeling using wave propagation results in reasoning waves that hit the target and are reflected back to the receiver, which can be used to determine the location of the target seismic signal within the data [3].

One method that can be used to interpret seismic data is the Amplitude Variation with Offset (AVO) method. The working principle of this method utilizes changes in the amplitude of reflected waves obtained from seismic reflection data acquisition relative to the change in distance between the source point and the receiver, referred to as reflection amplitude anomaly [2]. The AVO method can also be considered a form of distance variation from source to receiver due to changes in reflected signal amplitude (offset). As the offset increases, the incidence angle also increases, thus it is often referred to as Amplitude Variation with Angle (AVA). AVO was first introduced by Ostrander in 1984 [4]. The AVO analysis is widely used to identify the location of hydrocarbons. Moreover, this analysis can be utilized to determine reservoir characteristics in the target area. AVO analysis relies on changes in the amplitude of reflected signals in relation to the distance from the wave source to the receiving geophones. The greater the distance between the source and the receiver geophones, the larger the incidence angle becomes [5].

In the process of hydrocarbon exploration, the AVO method is closely related to angle stack data. This is because angle stack data can reduce noise and enhance signal quality, thus providing a clearer depiction of gas presence from various angles during the interpretation process. This demonstrates that the combination of angle stack data and AVO analysis can result in more accurate interpretations when characterizing gas reservoirs [3].

The "RDA" field was selected as the research location because it is one of the gas fields actively exploited since 1967. The "RDA" field spans an area of 75 km x 18 km with a depth reaching 5000 meters. This field has an anticline structure and is dominated by distributary channels and fluvial channels, indicating the potential for a good reservoir. To optimize gas production in the "RDA" field, in addition to determining potential areas, it is essential to determine the number of wells that can be drilled, often referred to as hydrocarbon prognosis wells. To estimate the number of hydrocarbon prognosis wells, it is necessary to understand the hydrocarbon distribution and the probabilistic volume of hydrocarbons in the reservoir at the research location. This can be achieved through AVO analysis [4].

According to research conducted by Abdi (2017), it has been proven that AVO analysis can be used to detect hydrocarbon distribution based on AVO attribute maps, accompanied by AFI (Amplitude Variation with Offset Fluid Inversion) analysis to obtain fluid properties from the rock, resulting in a more accurate interpretation. In his research, Abdi employed AVO and AFI analyses because the results from AVO analysis still had quantitative uncertainties, requiring additional analysis such as AFI to minimize the likelihood of adverse outcomes, such as misinterpretation.

Based on the explanation above and considering the conditions of the "RDA" field located in the "K" Basin, East Kalimantan, which is one of the active gas fields, the potential presence of hydrocarbons can be determined using the AVO method with 3D seismic angle stack data.

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II. Methodology

The research was conducted in the Geophysics Laboratory, Faculty of Science and Mathematics, Diponegoro University, Semarang. The study took place from December 2023 to July 2024. This research utilized two software programs: Petrel 2018, used for processing 3D seismic angle stack data, including the creation of stratigraphic correlations, anomaly picking, multimap generation, identification of potential areas, and well design; and Microsoft Excel, which was used to calculate hydrocarbon reserves. The data used in this research is secondary data from the "RDA" field located centrally in the "K" Basin, East Kalimantan, with a total area of 73,379,641 m².

The data processing in this study began with anomaly picking, which is the process of identifying areas with potential hydrocarbon presence by searching for amplitude anomalies from seismic data obtained earlier to understand the distribution of hydrocarbon anomalies in the research area. In this study, anomaly picking was conducted based on the AVO method applied to 3D seismic angle stack data. Amplitude maps were created for each angle stack data, resulting in six amplitude maps (near-stack, far-stack, ultrafar-stack, full-stack, base-stack, and RMS-stack).

The purpose of creating the multimap was to observe the consistency of previously picked anomalies and to ensure that the anomalies picked were isolated. Classifying the multimap can be seen as a stage that follows multimap creation. This process aims to facilitate the sorting of multilayer maps obtained from the previous stage, allowing for more focused data processing on maps with consistent anomalies across all angle stacks, thereby speeding up the processing. The classification was done by sorting the multimap based on the consistency of hydrocarbon anomalies visible in each stack, aiding in the identification of potential areas. Based on this consistency, the multimap was categorized into two types: full consistency multimap and partial consistency multimap. A full consistency multimap refers to a map where hydrocarbon anomalies are consistent across all stacks (near-stack, far-stack, ultrafar-stack, full-stack, base-stack, and RMS-stack), while a partial consistency multimap refers to one where hydrocarbon anomalies are only consistent in some stacks.

The determination of potential areas was conducted by observing geobodies that cluster and stack within a polygon in a 2D window, created in the multimap generation stage, and subsequently grouping them into several clusters based on the number of geobodies. This step aims to identify areas suitable for drilling, which could be used for hydrocarbon production wells.

Well design is the stage where the well is planned before drilling takes place. The purpose of this step is to optimize hydrocarbon production, which, in this research, focuses on natural gas. This stage involves examining stacked polygons with varying depths, allowing for the creation of a well trajectory that defines the path or direction of the wellbore.

The hydrocarbon reserves calculation in this research was performed using the IGIP (Initial Gas In Place) equation, represented by equation (1).

$$Area \times Net\ pay \times PHIE \times S_g \times \frac{1}{Bg} \times RF = Reserves \quad (1)$$

The area refers to the polygon area that has been previously created, while net pay represents the gas thickness obtained from the amplitude function, which correlates with the net pay from the well located within the respective amplitude. S_g represents gas saturation, $PHIE$ denotes effective porosity derived from the percentage porosity values from the density log, and Bg is the gas formation volume factor, which is calculated by comparing the volume of gas under reservoir conditions with the standard gas conditions. RF refers to the recovery factor, which indicates the percentage of gas that can be extracted to the surface, and *reserves* represent the volume of gas that can be recovered.

III. Discussion

The results of anomaly picking from Z3D seismic data are marked by the presence of bright spots, which indicate the potential presence of sandstone or carbonate rocks. Bright spots represent strong amplitude anomalies with a negative reflection coefficient, suggesting a high potential for hydrocarbon presence. The brighter the color contrast of the bright spot, the greater the probability of hydrocarbons in that area. To distinguish between sandstone and carbonate rocks from the picked bright spot

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anomalies, the indication of blue over red (blue on top of red) is observed. The anomaly picking process was conducted using Z3D seismic data in the form of angle stack data, with far-stack data as the reference, as shown in Figure 1.

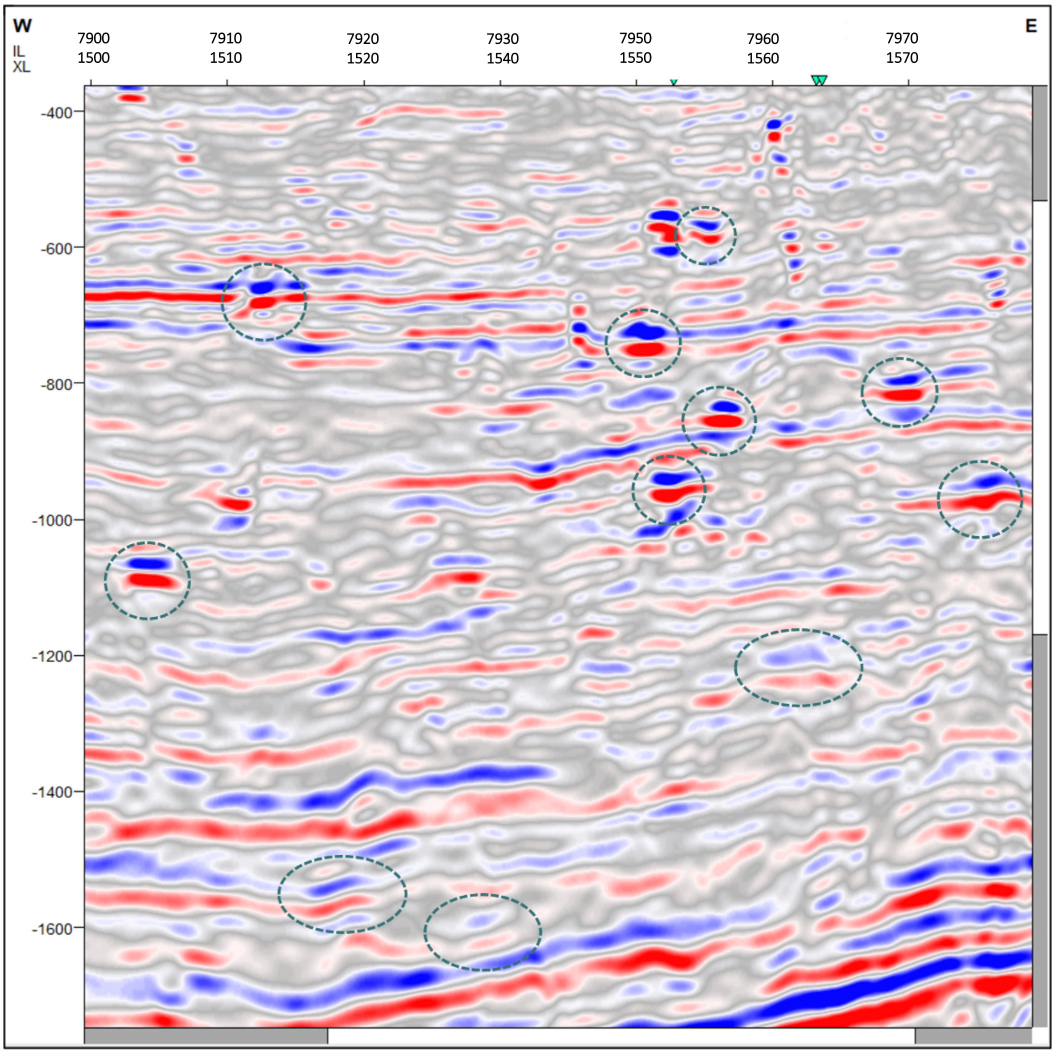

Fig. 1 Identify brightspot anomalies with blue over red color on seismic sections with far-stack data

From the bright spot anomalies visible on the seismic section, indicated by dashed lines, it can be observed that gas anomalies in the research area range from depths of 300 meters to 2000 meters. However, at depths greater than 1000 meters, the amplitude anomalies visible are not bright spots but rather dim spots. This can be assumed to result from the lower seismic signal quality at depths beyond 1000 meters. The marking of amplitude anomalies on the seismic section was performed using Petrel 2018 software, and several amplitude anomalies were identified on the seismic section, indicating the previously determined anomalies, as shown in Figure 2.

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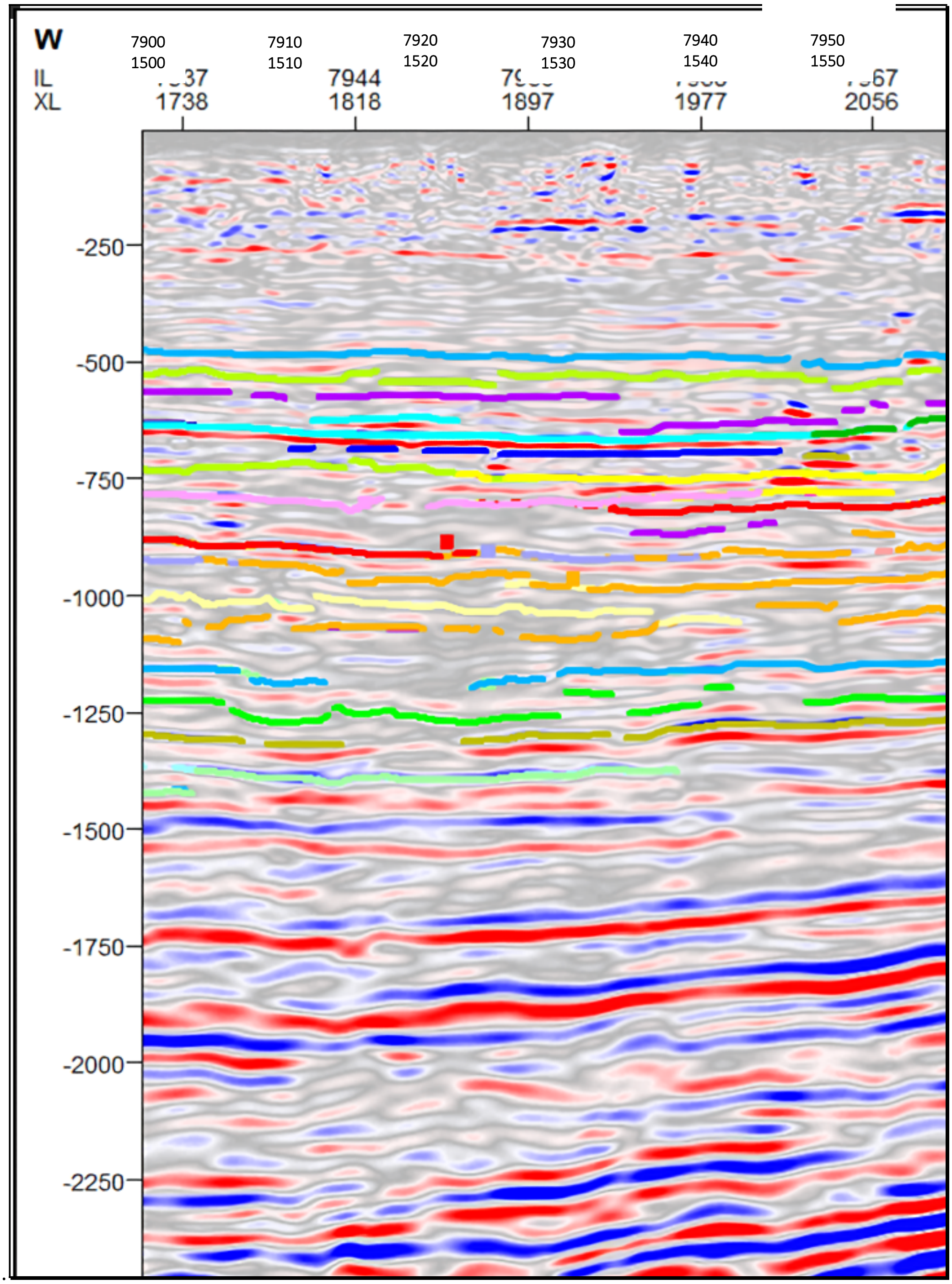

Fig. 2 Picking anomalies with far-stack data as seen in the seismic section

After identifying the amplitude anomalies on the seismic section, the next step is to propagate these amplitude anomalies in the form of an amplitude map to evaluate whether the anomalies are isolated, a characteristic of hydrocarbons. If the amplitude anomalies on the amplitude map appear isolated, polygons are created to match the shape of the anomalies. This step is taken to determine the location of the amplitude anomalies and map the distribution of hydrocarbon anomalies in the study area. For non-isolated amplitude anomalies, polygons are not created, as these anomalies are assumed not to represent hydrocarbons.

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From the process of selecting isolated and non-isolated amplitude anomalies, 354 polygons were identified, representing isolated amplitude anomalies with characteristics similar to hydrocarbon anomalies, as shown in Figure 3.

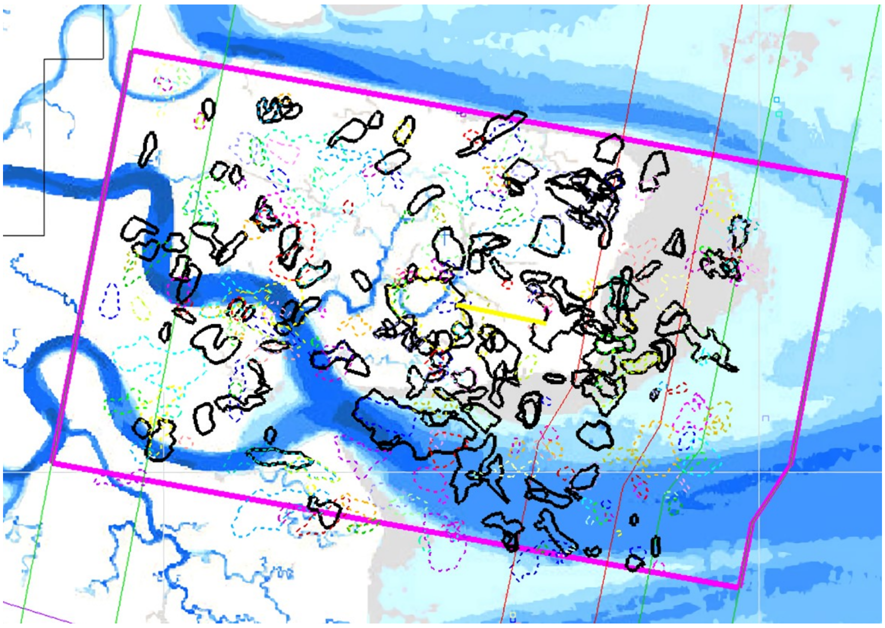

Fig. 3 Polygon geobodies mapping

From the results of the anomaly picking, it can be observed that the majority of the anomalies are located at depths between 501 and 1100 meters. In contrast, there are only a few anomalies at depths of 400 to 500 meters, as this area is classified as shallow and has not been extensively drilled in previous operations.

Multimap can be described as a collection of amplitude maps from various stack types (near-stack, mid-stack, far-stack, ultrafar-stack, full-stack, base-stack, and RMS-stack). From this multimap, the consistency of hydrocarbon anomalies can be observed based on the shape of the anomalies in relation to the polygons, using the polygons in the far-stack as a reference. Out of the 354 polygons indicating hydrocarbon anomalies in the research area obtained from the anomaly picking process, all polygons were propagated into a multimap, resulting in 354 multimaps that will subsequently be classified into two categories based on the consistency of the visible hydrocarbon anomalies. This can be seen in Figure 4, which represents one example of a multimap obtained from the anomaly picking process at a depth of 650 meters.

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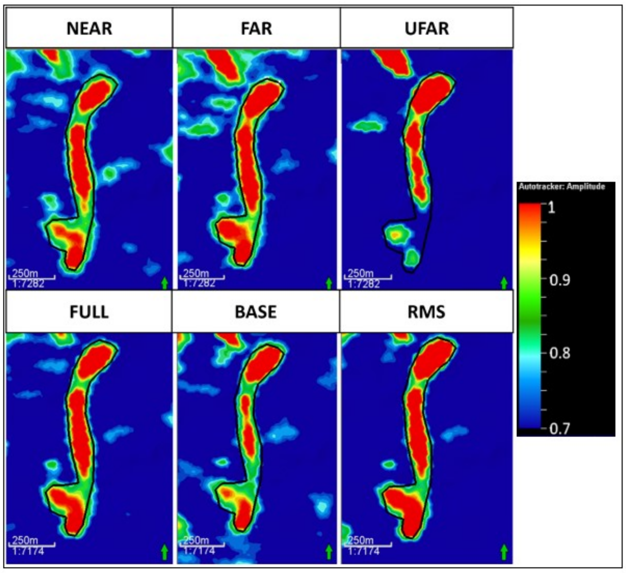

Fig. 4 Multimap example of an anomaly at a depth of 650 meters

From the multimap, it can be observed that the hydrocarbon anomalies visible in each stacking exhibit a consistent shape.

Based on the consistency of the hydrocarbon anomalies observed in each stacking, the multimap is categorized into two types: full consistency multimap and partial consistency multimap. A full consistency multimap is defined as a multimap in which the hydrocarbon anomalies are consistent across all stack types (near-stack, far-stack, ultrafar-stack, full-stack, base-stack, and RMS-stack), as illustrated in Figure 5.

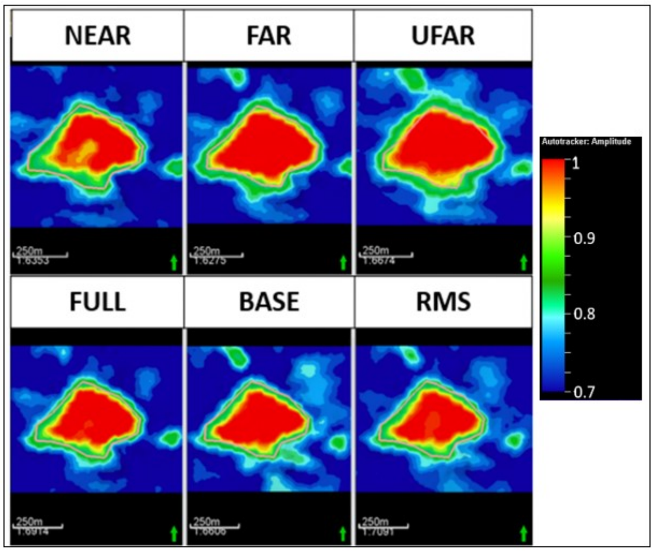

Fig. 5 Example of full consistency multimap

From the multimap, it can be determined that the hydrocarbon anomalies exhibit a consistent shape across each stacking, categorizing them as full consistency anomalies. On the other hand, a partial consistency multimap is characterized by hydrocarbon anomalies that are consistent only in certain stack types, such as being consistent in the far-stack and ultrafar-stack but inconsistent in the base-stack and RMS-stack, as shown in Figure 6.

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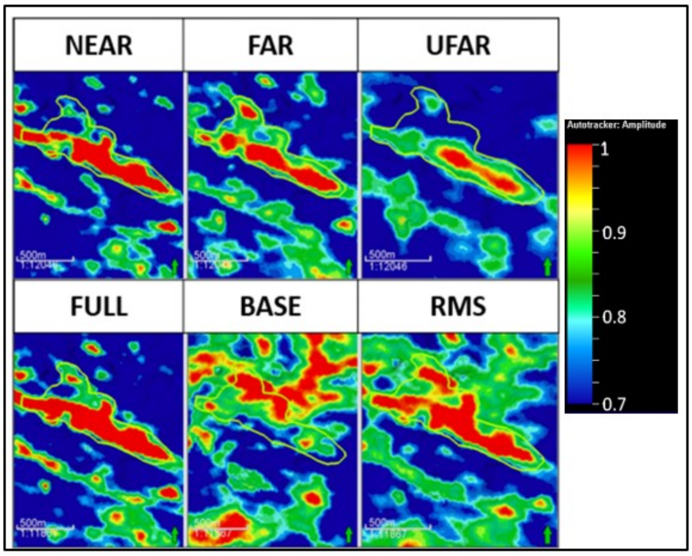

Fig. 6 Example of multimap partial consistency

From the multimap, it can be seen that the hydrocarbon anomaly is not consistent throughout the stacking, so the hydrocarbon anomaly falls into the category of partial consistency.

Out of the 354 multimaps that were previously created, 145 multimaps fall into the category of full consistency multimaps and 209 multimaps fall into the category of partial consistency multimaps. Therefore, it can be concluded that in this research area, there are more hydrocarbon anomalies that are only consistent in some stackings compared to hydrocarbon anomalies that are consistent in all stackings.

In determining potential areas, things that need to be considered are the number of polygon geobodies that gather and stack in one area and the consistency of the hydrocarbon anomaly because the more consistent the visible hydrocarbon anomaly, which indicates that the hydrocarbon anomaly is isolated like the characteristics of hydrocarbons, the higher the probability of hydrocarbons being present. in that area. From the multimap classification process that has been carried out, in determining the potential areas that need to be displayed in the base map, only multimaps are included in the full consistency multimap category which is marked with a black polygon and multimaps are included in the partial consistency category whose anomalies are consistent throughout the stacking except the base stack. and RMS-stack which is marked with a colorful polygon with a dotted line as shown in Figure 7.

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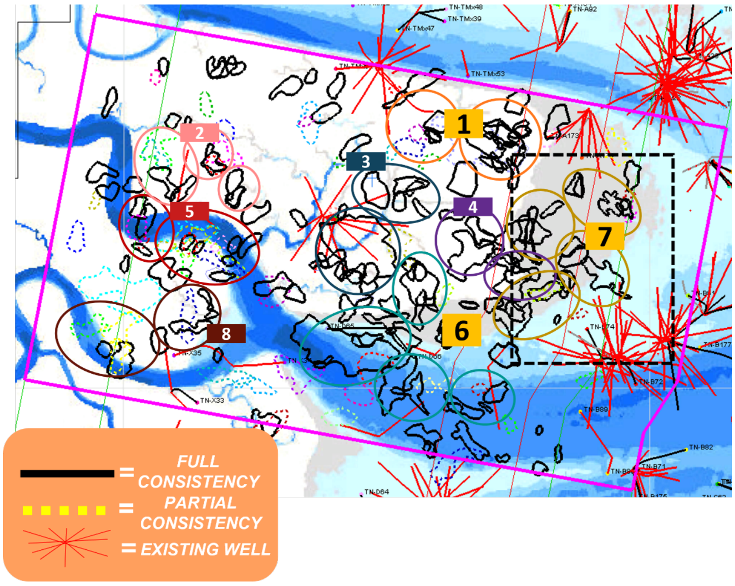

Fig. 7 Areas with potential accumulation of hydrocarbons

From the 354 geobodies that have been previously propagated, it can be seen that the hydrocarbon anomalies are spread quite evenly and we found 8 areas with geobodies that are gathered and stacked as an indication of areas containing hydrocarbons with details of the number of geobodies shown in Table 1.

TABLE I

NUMBER OF GEOBODIES IN AREA WITH POTENTIAL HYDROCARBON ACCUMULATION

Area	Number of Geobodies
1	23
2	13
3	15
4	11

From Table 1 it can be seen that there are three top areas that have more geobodies than other areas, namely area 1, area 2, and area 7. These three areas have a fairly large probability of hydrocarbon presence because in these areas there are many hydrocarbon anomalies. which is included in the full consistency multimap category, so that the hydrocarbon anomalies have high consistency and many hydrocarbon anomalies are stacked or gathered in these three areas.

In this research, the well design process was carried out by ensuring that the well trajectory created had a maximum inclination of 60°-70° and a maximum DLS of 3°/10 m. Therefore, not all targets previously determined from a simple potential area determination process can be carried out in the well trajectory design process. In this research, the well design process was not carried out in all geobodies, but only in several areas where potential areas had previously been determined. From these two processes, 8 areas were obtained that could potentially contain hydrocarbon accumulation and from these 8 areas, 11 possible wells were obtained as shown in Figure. 8.

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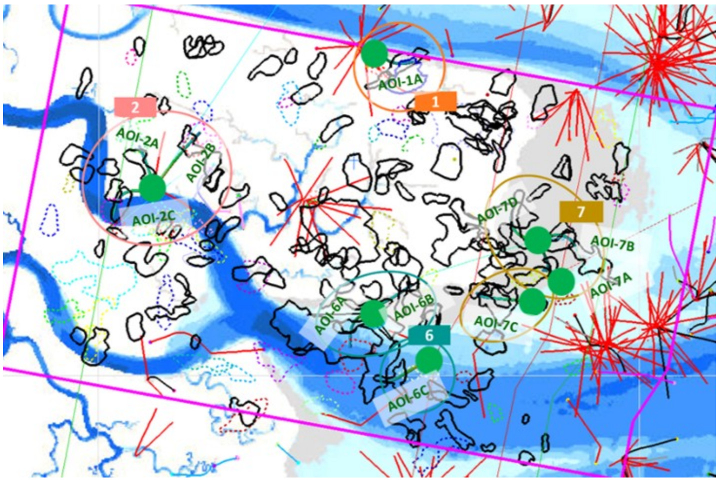

Fig. 8 Possible well 2D map view

From area 1 we get one possible well, in area 2 we get 3 possible wells, in area 6 we get 3 possible wells, and in area 7 we get 4 possible wells. In making the well design, an example was taken from one of the possible wells, namely the AOI-7B well as shown in Figure 9.

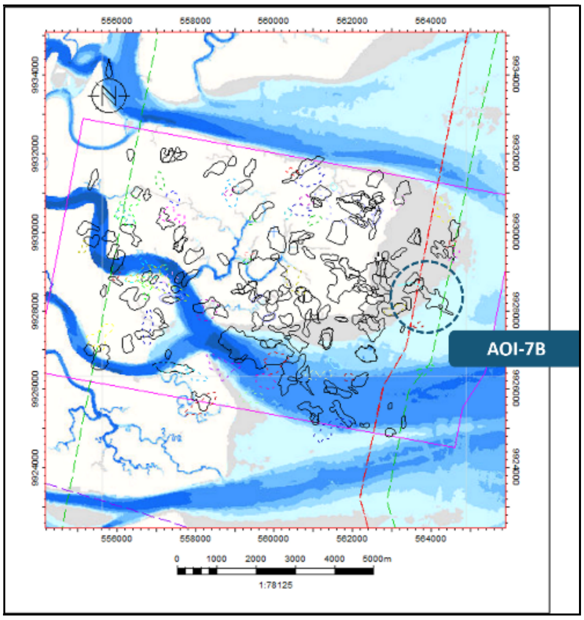

Fig. 9 Well trajectory planning from 2D map

Figure 9 explains one of the target areas where the well design process will be carried out, namely the AOI-7B well area. The AOI-7B well was chosen for the well design process because the anomaly in this area has three geobodies and when viewed from the reserves calculation, this area has a fairly high total reserves value, reaching 0.84 Bcf. Therefore, this area is used as one of the main targets for the well design process. Well trajectory planning made in AOI-7B can be seen in Figure 10.

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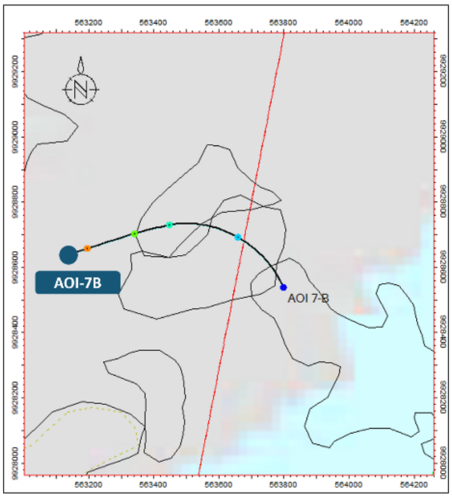

Fig. 10 Example of well trajectory planning for the AOI-7B well on a 2D map from the top view

From Figure 10, it can be seen from the AOI-7B well that there are 3 anomaly targets, all of which are affected by the well trajectory.

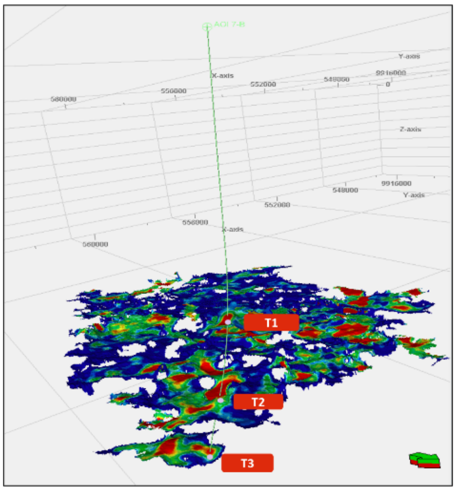

Fig. 11 Example of well trajectory planning for the AOI-7B well on a 3D map from the front view

From Figure 11, it is known that the three hydrocarbons anomaly targets from the AOI-7B well were hit by the well trajectory marked by the green line.

At the hydrocarbon reserves calculation stage, several input data are required, namely area data, net pay, reservoir properties (PHIE or effective porosity, gas saturation (Sg), and rock formation factor (1/Bg)), and recovery factor (RF). Net pay and reservoir properties data are obtained automatically from the Petrel 2018 software through the multimap creation process from the multimap extraction process. This reserves calculation is carried out based on equation (1) using Microsoft Excel software.

From the results of the reserves calculation, it can be seen the value of reserves and net pay resulting from each anomaly target from the 11 possible wells for which the trajectory plan was previously made. The reserves calculation that has been carried out previously needs to be reconfirmed by carrying out a static calculation to crosscheck the net pay obtained with the existing well at the same depth, so that the resulting net pay probability is more accurate and reduces the risk of miscalculations. In this process, one example of the use of static calculations can be seen which was carried out on one of the possible wells, namely on the AOI-7B well as shown in Figure 12.

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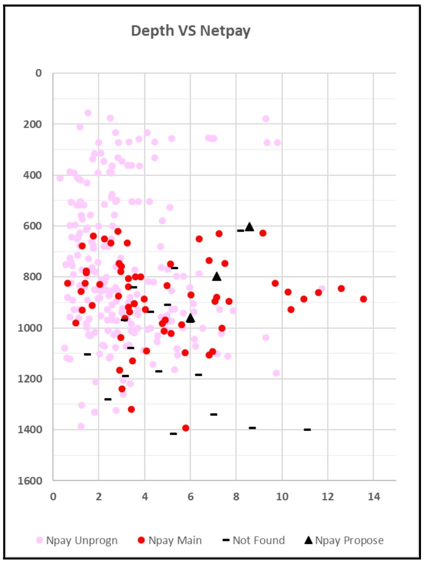

Fig. 12 Depth vs net pay from possible well with existing well from well AOI-7B

Figure 12 explains the comparison between the net pay possible well and the net pay existing well from cloud data of drilling that has been carried out previously at the same depth.

From Figure 12 it can also be seen that there are three net pay propositions for each target in the AOI-7B well. From the results of previously carried out reserves calculations, the results of reserves calculations with various levels of confidence or what are called static calculations are also obtained as shown in Figure 13.

1P

Well Name	Reservoir Name	Target Name	Depth mTVDss	Completion Type	Surface (km 2)	NP average (m)	NP @ Well (m)	Phie (from depth)	Sg (from Phie)	1/Bg	GIIP Mini (Bcf)	RF (%)	Reserves 1P (Bcf)
AOI-7B-CF 1	T1	Main	603	SCON	0.07	6.2	5.7	30.0%	70.7%	57	0.18	44%	0.12
AOI-7B-CF 1	T2	Main	798	SCON	0.11	3.4	4.86	27.6%	66.9%	75	0.18	40%	0.12
AOI-7B-CF 1	T3	Main	959	SCON	0.23	3.4	3.87	25.6%	63.1%	90	0.39	34%	0.23
							14.4			SUM:	0.75		0.60

2P

Well Name	Reservoir Name	Target Name	Depth mTVDss	Completion Type	Surface (km 2)	NP average (m)	NP @ Well (m)	Phie (from depth)	Sg (from Phie)	1/Bg	GIIP 2P (Bcf)	RF (%)	Reserves 2P (Bcf)
AOI-7B-CF 1	T1	Main	603	SCON	0.10	7.1	8.6	33.0%	84.7%	57	0.30	65%	0.20
AOI-7B-CF 1	T2	Main	798	SCON	0.15	4.2	7.1	30.6%	81.5%	75	0.36	60%	0.21
AOI-7B-CF 1	T3	Main	959	SCON	0.32	4.1	6.0	28.6%	78.5%	90	0.79	54%	0.43
							21.7			SUM:	1.45		0.84

3P

Well Name	Reservoir Name	Target Name	Depth mTVDss	Completion Type	Surface (km 2)	NP average (m)	NP @ Well (m)	Phie (from depth)	Sg (from Phie)	1/Bg	GIIP Maxi (Bcf)	RF (%)	Reserves 3P (Bcf)
AOI-7B-CF 1	T1	Main	603	SCON	0.14	8.0	12.7	35.8%	93.2%	57	0.55	70%	0.28
AOI-7B-CF 1	T2	Main	798	SCON	0.19	4.9	10.3	33.4%	90.6%	75	0.71	70%	0.34
AOI-7B-CF 1	T3	Main	959	SCON	0.41	4.9	8.76	31.4%	88.1%	90	1.60	70%	0.74
							31.7			SUM:	2.86		1.13

Fig. 13 Static calculation of the AOI-7B well

Figure 13 explains the results of static calculations for the AOI-7B well. From this static calculation, net pay and reserves calculation results will be obtained with various levels of confidence, namely 1P, 2P, and 3P. In this research, the reference for determining whether a possible well has economic value or not is the result of the 2P reserves calculation. From these calculations, the total net pay value for all anomaly targets in the AOI-7B well is 21.7 m. Apart from that, the total reserves value of all anomaly targets in the AOI-7B well was 0.84 Bcf.

In determining whether a possible well can be said to be an eco well or a well with economic value, what needs to be taken into account is that the total reserves of a possible well must be at least 0.6 Bcf. This is because a well with a production of 0.6

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Bcf is considered economical because it is able to generate sufficient income to cover operational costs and is able to provide a profit.

From 11 possible wells, hydrocarbon reserve calculations were produced as in Table 2.

TABLE III
FINAL RESERVES CALCULATION

Platform	Well	Target	Res (Bcf)	Total Res (Bcf)
PF-1	AOI-2A	T-1	0,07	0,33
		T-2	0,06	
		S-1	0,00	
	AOI-2B	T-1	0,04	0,40
		T-2	0,36	
	AOI-2C	T-1	0,09	0,22
		T-2	0,13	
PF-2	AOI-6A	T-1	0,12	0,35
		T-2	0,05	
		T-3	0,18	
	AOI-6B	T-1	0,10	0,87
		T-2	0,77	
		S-1	0,00	
PF-3	AOI-6C	T-1	0,19	0,31
		T-2	0,11	
		S-1	0,00	
PF-4 PLAN A	AOI-7A PLAN A	T-1	0,11	0,18
		T-2	0,07	
		S-1	0,00	
PF-4 PLAN B	AOI-7A PLAN B	T-1	0,09	0,16
		T-2	0,07	
		S-1	0,00	
	AOI-7B	T-1	0,20	0,84
		T-2	0,21	
		T-3	0,43	
	AOI-7D	T-1	0,42	0,65
		T-2	0,23	
		S-1	0,00	
PF-5	AOI-7C	T-1	0,17	0,49
		T-2	0,26	
		T-3	0,06	
PF-6	AOI-1A	T-1	0,21	0,32
		T-2	0,11	

Table 2 explains the final results of calculating reserves for 11 possible wells. From this table it can be seen that there are three possible wells which are included in the eco well category, namely AOI-6B with total reserves of 0.87 Bcf, AOI-7B with total reserves of 0.84 Bcf, and AOI-7D with total reserves of 0.65 Bcf. Apart from that, from the 11 possible wells, 8 non-eco wells were also found which could be used as case studies for drilling engineers.

IV. CONCLUSION

From the research that has been carried out, it can be seen that in the research area there are areas that accumulate hydrocarbons as indicated by the results of determining simple potential areas which produce 8 main areas that have a probability of hydrocarbon accumulation based on the number of stacked geobodies and the anomalous consistency in the area. Apart from that, from the results of the well design process and calculating reserves or hydrocarbon reserves from the 8 main areas, it was obtained that 11 possible wells had their respective net pay and reserves values which indicated the probability of hydrocarbon accumulation in these areas. In addition, this research produced 11 potential hydrocarbon prognosis wells (possible wells), consisting of 3 potential hydrocarbon prognosis wells (eco wells) which have a high probability (proven), so that a review can be carried out for drilling and 8 potential hydrocarbon prognosis wells (non-eco well) which can be used as a case study for drilling engineers.

From the research that has been carried out, the researcher has suggestions regarding further research, namely that of the 11 potential hydrocarbon prognosis wells that have been obtained from this research, testing can be carried out in stages from one well with comparisons using other methods.

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