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LITHOLOGY AND RESERVOIR IDENTIFICATION IN THE "EL" WELL, EAST JAVA USING SEISMIC INVERSION

IDENTIFIKASI LITOLOGI DAN ZONA RESERVOIR PADA SUMUR "EL", JAWA TIMUR MENGGUNAKAN INVERSI SEISMIK

Maulana Yusuf Ibrahim[1*], Salma Dita Rysqi Puspita[1], Zhafirah Nurul Syarafina[1], Shaska Ramadhan Zulivandama[2], and Eleonora Agustine[1,3]

[1] Geophysics, Faculty of Mathematics and Natural Sciences, Padjadjaran University, Sumedang 45363, Indonesia

[2] Marine Geological Institute, Jl. Djunjunan No. 236, Husein Sastranegara Bandung 40174

[3] Center for Materials and Earth Engineering studies, Faculty of Mathematics and Natural Sciences, Padjadjaran University, Sumedang, 45363, Indonesia

*Corresponding author: maulana19004@mail.unpad.ac.id

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ABSTRACT: The acoustic impedance inversion seismic method, carried out at the "EL" well in East Java, provides a description of the physical properties of subsurface rocks. This method involves identifying rock layers, lithology types, porosity values, the presence of hydrocarbons, and fluids in the target zone using both well data and integrated seismic data. The data processing included the cross-plotting of acoustic impedance (AI) with gamma ray logs, porosity logs, and resistivity logs. We integrated seismic and well data, picked horizons, and created AI inversion models. The based model inversion technique was used to compare the synthetic model with the seismic data, aiming to obtain an AI value that closely represents the actual model. AI seismic inversion effectively separates lithological boundaries vertically and laterally, based on the selected picking horizon and created model. To enhance understanding of the lithology and hydrocarbon prospect zone in the study area, a cross-plot analysis was used to correlate the seismic inversion model. The results reveal that the study area represents a hydrocarbon prospect zone, with reservoir rocks consist of coral and foram at a depth range of 2320 - 2430 ft.

Keywords: acoustic impedance (AI), seismic inversion, lithology, hydrocarbon prospect zone

ABSTRAK*: Metode seismik inversi impedansi akustik pada sumur "EL", Jawa Timur dapat menunjukkan gambaran sifat fisis batuan bawah permukaan melalui identifikasi lapisan batuan, jenis litologi, nilai porositas, keberadaan hidrokarbon, dan dan fluida pada zona target dari data sumur dan data seismik yang diintegrasikan. Pengolahan dibuat dengan cross plot impedansi akustik (IA) terhadap log gamma ray, log porositas, dan log resistivitas, pengintegrasian data sumur dan data seismik, picking horizon, hingga pembuatan model inversi IA. Based model inversion digunakan untuk membandingkan model sintetik dengan data seismik sehingga didapatkan nilai IA yang mendekati model sebenarnya. Hasil inversi seismik IA dapat memisahkan batas litologi secara vertikal maupun lateral berdasarkan picking horizon dan model yang dibuat. Model inversi seismik kemudian dikorelasikan dengan crosplot sehingga dapat diketahui litologi dan zona prospek hidrokarbon pada daerah penelitian. Hasil inversi seismik menunjukkan bahwa daerah penelitian merupakan zona prospek hidrokarbon dengan batuan reservoir berupa coral dan foram pada kedalaman 2320-2430 ft.*

Kata Kunci: *Impedansi Akustik (IA), seismik inversi, litologi, zona prospek hidrokarbon*

INTRODUCTION

"EL" well is an oil and gas exploration field located in East Java Province near the North Sea. Two crossover lines at the well location are used to identify the reservoir zone. Geologically, the study area is an area composed of several formations including the Ngrayong formation, Tuban formation, and Kujung formation. The Ngrayong Formation originates from the Middle Miocene period with constituent rocks in the form of sandstone, shale, lignite, calcarenite inserts, limestone, and brown carbonate-shale. The Tuban Formation originates from the Early Miocene period which is composed of clay rock, limestone, arenitic limestone inserts, coral, algae, light gray marl, and foram. The Kujung Formation originates from the Oligocene period with layers of brown clay, limestone inserts, hard coral, large foram, layered gray marl, limestone inserts, and algae (Pringgoprawiro, 1983; Triwibowo and Santoso, 2007). Stratigraphy within the study area, especially in the Kujung formation area, has potential as a hydrocarbon prospect azone for locating reserves. Seismic inversion modeling is intended to be able to identify lithology and the existence of reservoirs in the study area (Pratiwi, 2018). The result of seismic inversion model will be correlated with the references used to ensure accurate interpretation and analysis, aligning with the actual conditions of the study area.

Seismic Inversion Method

The seismic inversion method is a geophysical technique used to create a subsurface model by integrating well data with seismic data, which is used as a control and input data (Aina, 2017). The data integration is done using the seismic inversion method of Acoustic Impedance (AI). The AI method provides information about the physical properties of subsurface reservoir rocks through the results of geological cross-sections to identify lithology and the distribution of reservoir distribution in the target area (Putri and Santosa, 2014).

Acoustic impedance (AI) is determined by multiplying the seismic wave velocity with the rock density values. AI is a physical parameter that is affected by lithology, fluid content, porosity, layer depth, pressure, and temperature. This makes AI an essential tool for determining indicators such as lithology types, types of hydrocarbon, rock porosity values, lithology mapping, and distribution of hydrocarbon within the reservoir zone (Pratiwi, 2018).

$$AI = V.\rho \quad \text{……..} \ (1)$$

AI is acoustic impedance ((ft/s).(g/cc)), ρ is rock density (g/cc), and V is seismic wave velocity (ft/s). The AI value indicates the hardness level of a rock, the higher the AI value, the harder the rock will be compressed, while the lower the AI value indicates the softer and more easily compressible rock.

The study uses post-stack data with model-based inversion to obtain a synthetic geological model that represents the actual subsurface model. The synthetic model is then compared with seismic data that is iteratively updated to obtain a match close to seismic data based on error and correlation values (Abigail, 2017).

Inversion Parameters

In the model-based inversion process, the hard constraint method is used by determining the lower and upper values to minimize the error and maximize the correlation. Some other important parameters:

- Single Values, set a single value that is used as an absolute limit to review the suitability of the final result that deviates from the initial estimate. Hard constraints can also be defined as the percentage difference from the initial model (Putri, 2014).
- Average Block Size refers to a one-dimensional unit of time in the model. It represents a series of layers of equations with a thickness measured in milliseconds, controlled by the average block parameter. This model can modify how thick the layer is displayed during the inversion process. The block value will affect the appearance of the data speed structure. Smaller block intervals result in increased time and data resolution in the inversion (Arifien, 2010).
- Prewhitening, is a deconvolution step used to obtain reflection coefficient values by dividing the seismic data with the wavelets. However, the inversion process can become unstable if the result of the seismic data divided by wavelet is zero, or if the bandlimited wavelet itself has zero values. To solve this problem, the wavelet frequency's amplitude can

Table 1. Well logging of hydrocarbon rocks

Hydrocarbon Rocks	Potential identification	Shale/non-shale zone	Density (g/cm³)	Resistivity (Ω.m)	Porosity (%)
Limestone	Reservoir rock, dim spot	Non-shale	1.93 to 2.9(a)	50 – 4 x 10^{2}(e)	0 – 20(c)
Sandstone	Reservoir rock, bright spot	Non-shale	1.61 to 2.76(d)	8 – 4 x 10^{3}(e)	5 – 35(c)
Shale	Cap rock	Shale	1.77 to 3.2(d)	20 – 2 x 10^{3}(e)	0 – 10(c)
Clay	Maturation rock	Non-shale	1.63 to 2.6(d)	1 – 100(e)	40 – 80(b)

(a)Telford et al. (1990); (b)Neuzil (1994); (c)Jasim et al. (2018); (d)Arisona et al. (2018); (e)Ozegin and Okolie (2018) be increased by 1% of its maximum height (Arifien, 2010).

- Number of Iterations relates to the process of creating a model that aims to minimize the error value through iteration. Increasing the number of iterations allows for achieving a smaller error value with reduced errors. While the error value differs between iteration 0 and iteration 10, there are instances where increasing the iteration value does not impact the error value (Arifien, 2010).

Petrophysics

The petrophysical analysis is one of the processes to determine the characteristics of the reservoir. This is done by determining the lithology, porosity, water saturation, and permeability of the subsurface rock layers (Maulana, 2016). Identification is carried out through the type of well logging method on well data. The gamma ray log differentiates between permeable and impermeable layers, the density log and the neutron log calculates the porosity of the rock layers, and the resistivity log determines the water saturation of the rock layers (Maulana, 2016). Petrophysical analysis is used to determine geological formations that can identify potential hydrocarbon zones in the field. The principle of this analysis involves obtaining subsurface data through the process of well logging in drill holes or exploration wells.

Well Logging

In principle, well logging works by recording the response given through a log tool as it enters the well. The recording is based on the differences in physical and fluid properties contained in the rock. This recorded response is then displayed in the form of a curve, which indicates the condition of the rock formation under the well, including lithology and fluid characteristics. These recorded curves are then interpreted to determine reservoir layers such as hydrocarbon or reservoir spreading zones (Aprilia, 2018). Determination of hydrocarbon targets needs to be done in order to identify the depth and the indications of a prospective zone. Table 1 is usually used as a reference for well logging analysis to identify reservoir target zones with rocks and log values for constructing a hydrocarbon system.

METHOD AND MATERIAL

Data

- The seismic data used is 2D post-stack time migration (PSTM) with a sampling rate of 2 ms and normal polarity which is assumed to be data that has gone through the processing step.
- Primary data includes gamma ray logs, resistivity logs, neutron logs (NPHI), and density logs (RHOB) of the "EL" wells 46A line and 59B line in northern sea, East Java.
- Secondary data consists of master log data of the Kujung "EL" formation well in the northern sea of East Java.

Data processing

The steps involved in seismic data processing include the integration of well and seismic data, followed by the construction of an inversion model, which is then analyzed and interpreted. The outcome of data processing is a 2D inversion seismic model, supported by both well data and seismic data from the "EL" well in East Java. Data processing is carried out to determine the hydrocarbon zones based on differences in AI values. The systematic work in this study is divided into several main step including sensitivity analysis, well-to-seismic tie,

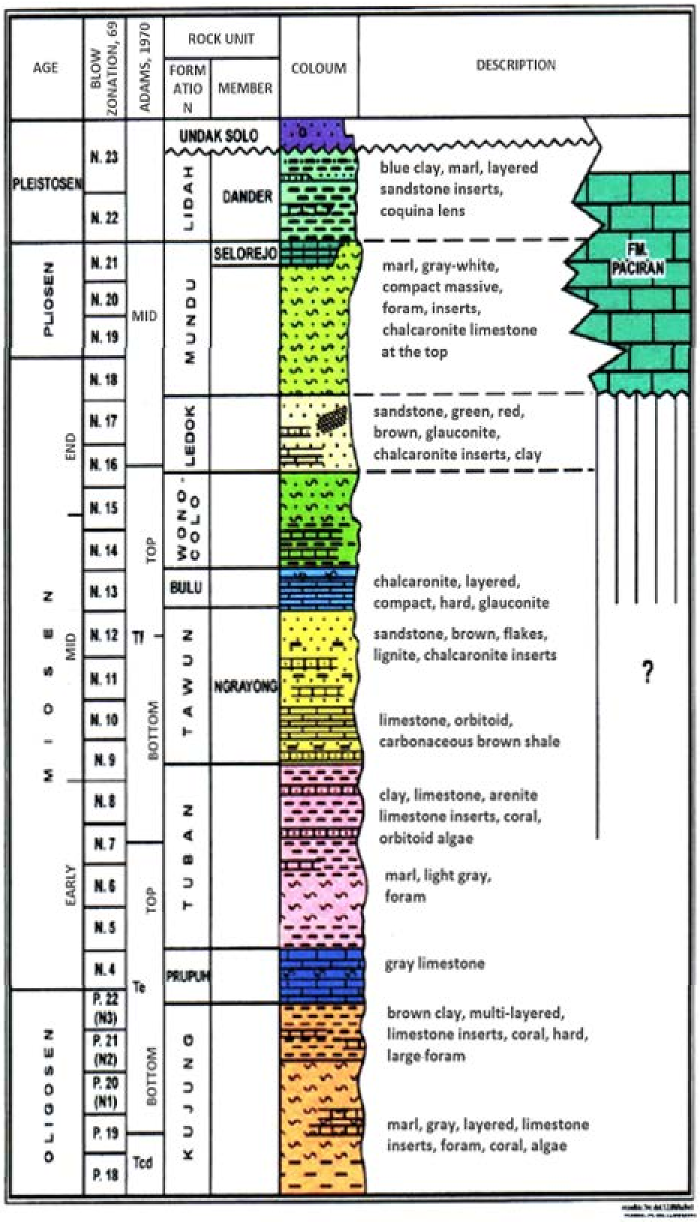


Figure 1. East Java stratigraphic column (Pringgoprawiro, 1983)

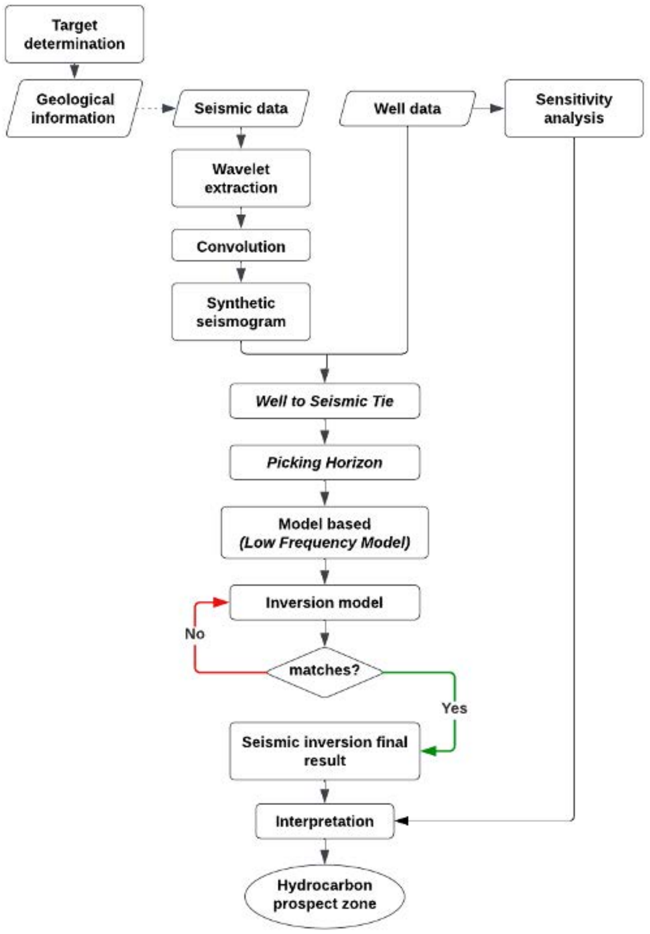


Figure 2. Research Flowchart

picking horizon, synthetic modeling, and the final seismic inversion model. The stages are shown in Figure 2.

During the sensitivity analysis, a cross plot of variables such as gamma ray, porosity, and p-impedance was conducted to observe their correlation with the type of hydrocarbon rock in the "EL" study area. These variables are indicative of the rock content in the area. This stage aids in the interpretation of seismic inversion results once the model has been created.

The well-to-seismic tie is conducted to determine seismic parameters such as phase, polarity, and frequency by binding well data based on depth to seismic data based on time (Abigail, 2017). Binding is carried out on logs used in processing including Gamma Ray (GR) logs, Density logs (RHOB), Neutron Porosity (NPHI) logs and Resistivity logs. In addition, check shot binding is carried out as an adjustment of travel time with depth which is then processed to obtain p-waves for check shot and their corrections.

Picking Horizon is utilized to create a geological cross-sectional model, which is then applied in generating maps by laterally adjusting the seismic data sections, revealing differences and inconsistencies in the sections. The process of picking involves examining the continuity of the cross-sectional layers as the boundaries of each layer.

The purpose of creating of a frequency-based model is to demonstrate the correlation between synthetic sections and bound seismic data sections. The correlation is reviewed based on error values and their corrections. A good model is shown with a small error value and high correction through both hard frequency and soft frequency review.

The final seismic inversion results will be obtained from the suitability of the model with the actual cross section. This will produce filtered colors that align with the selected picked horizons. The results are shown as a colored cross section with a corresponding color bar description indicating rock types based on the impedance value. Based on the obtained results, an interpretation of the impedance value and cross plot is carried out as to reinforce the analysis.

RESULTS AND DISCUSSION

The well data is useful for identifying the initial presumptive targeting of hydrocarbon. Figure 3 presents information on the well data in the Kujung formation. The study area exhibits a permeable (non-shale) layer, as indicated by determinating deflection of the maximum and minimum gamma ray log values in the data. In addition, the cross plot derived from the RHOB log and NPHI log indicates the presence of fluid in the Kujung formation. The resistivity log in the well data shows indications of non-resistive layers, which suggest the presence of non-resistive hydrocarbon with low resistivity values. The non-resistive layer point to the hydrocarbon target zone with a low resistivity (Table 1).

Sensitivity Analysis

Sensitivity analysis through cross plots is aimed at obtaining lithological characteristics and the distribution of reservoir zones or interest zones (Malik et al., 2018). Cross plots were performed on P-Impedance vs Gamma Ray, P-Impedance vs Porosity, and P-Impedance vs Resistivity parameters.

Figure 4 shows plot of the sensitivity analysis of the P-Impedance log to the Gamma Ray log. This cross plot is useful for identifying shale and non-shale lithologies based on the amounts of radioactive elements they contain. The P-Impedance value plays a significant role in determining the hardness or brittleness of rocks. The hardness of a rock can be identified by increasing the p-impedance value (Subakti, 2020), while decreasing the p-impedance value causes the rock to become more brittle. The determination of rock lithology in the GR log is influenced by the intensity of radioactive elements in the form of Uranium (U), Thorium (Th), and Potassium (K) (Budi and Yatini, 2021). The relationship between the

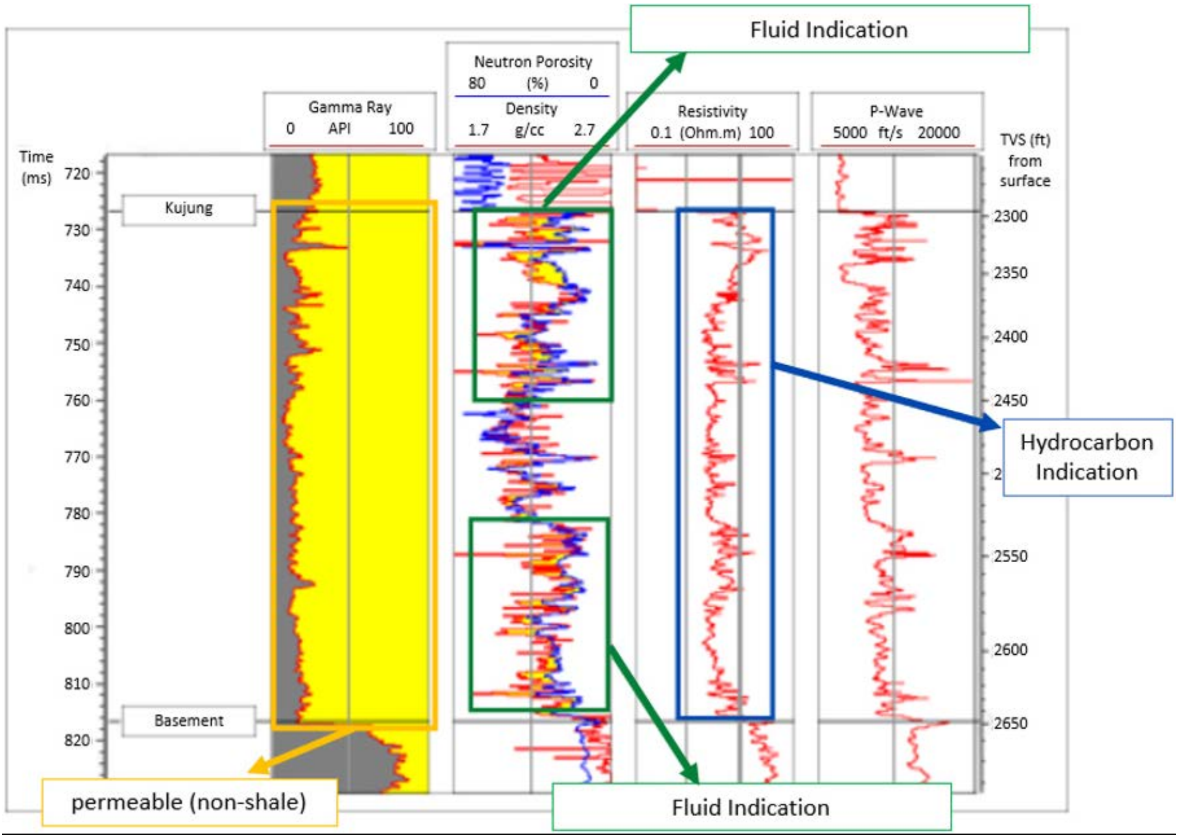


Figure 3. Well data of Kujung formation

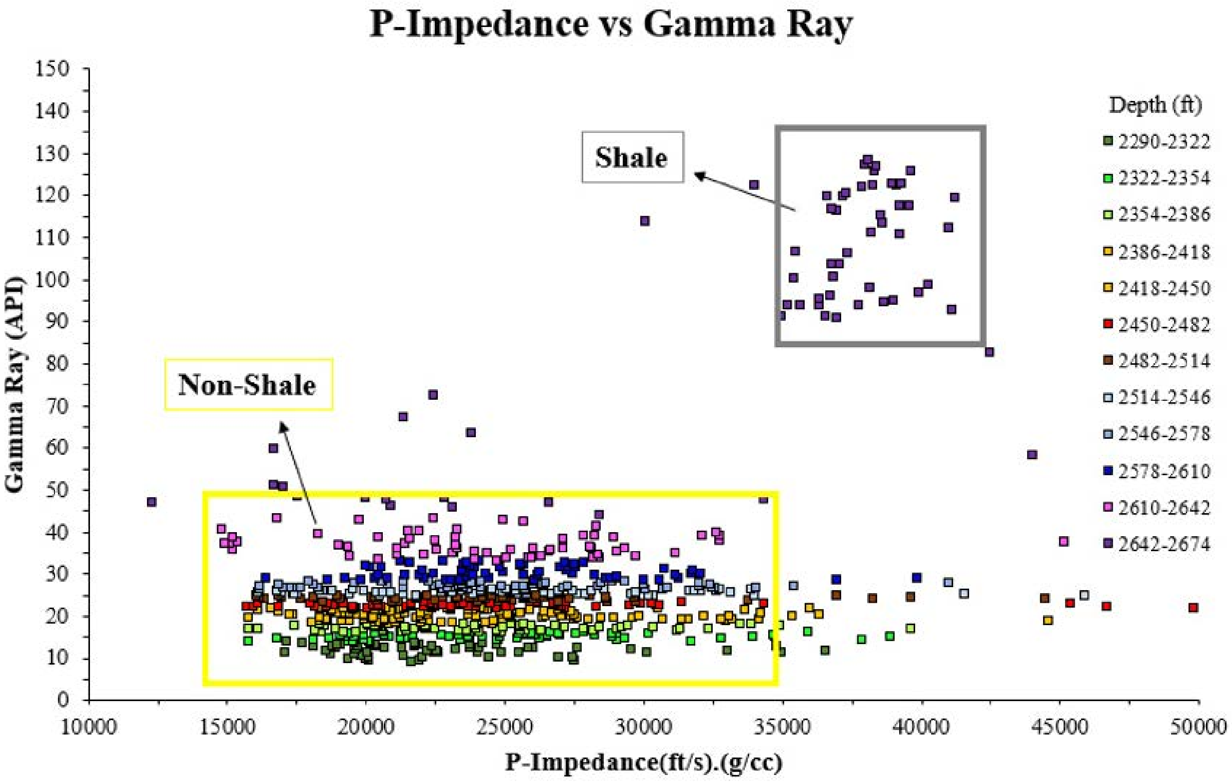


Figure 4. P-Impedance vs. Gamma Ray Cross plot of Kujung formation

intensity of radioactive elements recorded in rocks is directly proportional to the resulting gamma ray value. Rocks containing an abundance of radioactive elements, such as impermeable layers (shale), exhibit high gamma ray values, while permeable layers (non-shale) with fewer radioactive elements have lower gamma ray values. In Figure 5, the p-impedance values are obtained in the range 15000–35000 (ft/s).(g/cc) with a GR value of 10–50 API marked in yellow. This indicates that the rock are brittle with a permeable layer, representing non-shale rock. In addition, a gray area is obtained with a p-impedance values of 35000–42500 (ft/s).(g/cc) and GR values ranging from 90–130 API which is indicated as shale rock.

The reservoir zone can be determined through a cross plot between P-Impedance and Porosity. The cross plot was carried out only in non-shale areas suspected to be potential hydrocarbon prospects (Figure 5). Porosity helps determine the volume of pore space in rocks that can be filled with fluid. The results of the p-impedance to porosity cross plot have an inverse relationship where the lower the p-impedance value, the higher the rock porosity value, so the rock may be filled with more fluid (Hapsari, 2018). Classification of effective porosity indicate a rock's ability to hold or accommodate fluid, where porosity rocks classified excellent if the values more than 25%, verry good at 20-25%, good at 15-20%, fair at 10-15%, poor at 5-10%, and negligible at 0-5% (Koesoemadinata, 1978). The relationship between p-impedance and porosity (Figure 5) shows the presence of porous prospect zones, porous zones, and tight non-prospect zones. The prospect zone on the cross plot is represents an area where the rocks are not too hard and very good porosity, making them suitable for storing fluids. The prospect zone has a P-Impedance values ranging from 15000–18000 (ft/s).(g/cc) and an effective porosity of 22–38%. In contrast, there is a porous zone with harder rocks compared to the porous prospect zone, having p-impedance values from 15000 (ft/s).(g/cc) to 28000 (ft/s).(g/cc) and effective porosity above 20%. The cross plot results also show a tight non-prospect zone with an effective porosity of 0-20% and a p-impedance value ranging from 22200-35000 (ft/s).(g/cc).

The cross plot between P-Impedance and Resistivity log is used to distinguish different rock lithologies in the Kujung formation. Cross plot is carried out on the prospect zone at specific range from 725 ms to 825 ms to simplify the interpretation of hydrocarbon zones according to Table 1. The determination of rock types is based on the effective porosity values which is can show fluid rock quality and accumulation potential in the prospect zone. The measured resistivity value on the log will be identified to determine the nature of the rock and pore fluid through its electrical resistance properties. The presence of fluid with good conductivity in the prospect zone leads to lower measured resistivity values (Aprilia, 2018). Figure 6 displays the results of the P-Impedance vs porosity cross plot which is interpreted into the lithology of rocks that comprise the Kujung formation in the study area. The cross plot allows for classification between the reservoir target, limestone, and clay based on correlations between shale/non-shale zone, porosity, p-impedance, and resistivity parameter values. The reservoir target is characterized as shale zone with good or higher porosity and low resistivity, similar to limestone, but with lower rock hardness. However, the reservoir target has lower rock hardness than limestone, whereas the tight clay characterized as non-shale zone with poor or lower porosity, dominant high resistivity, and harder rock compared to the reservoir target and

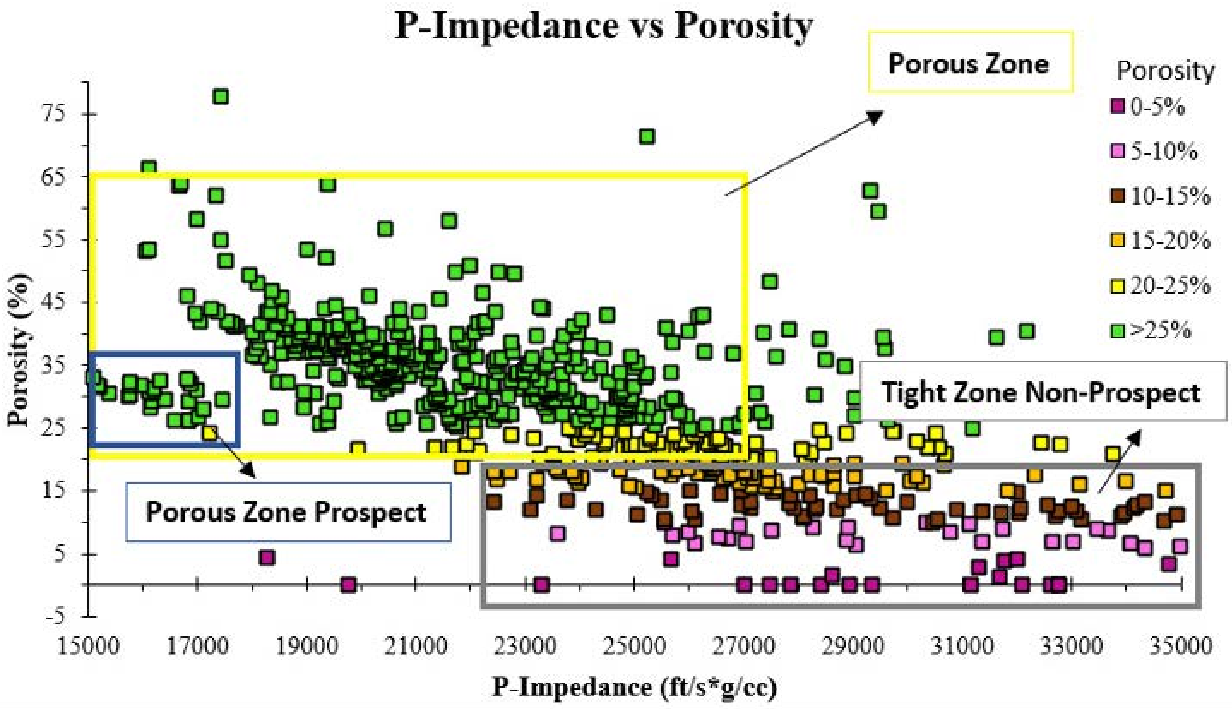


Figure 5. P-Impedance vs. Porosity Cross plot of Kujung formation

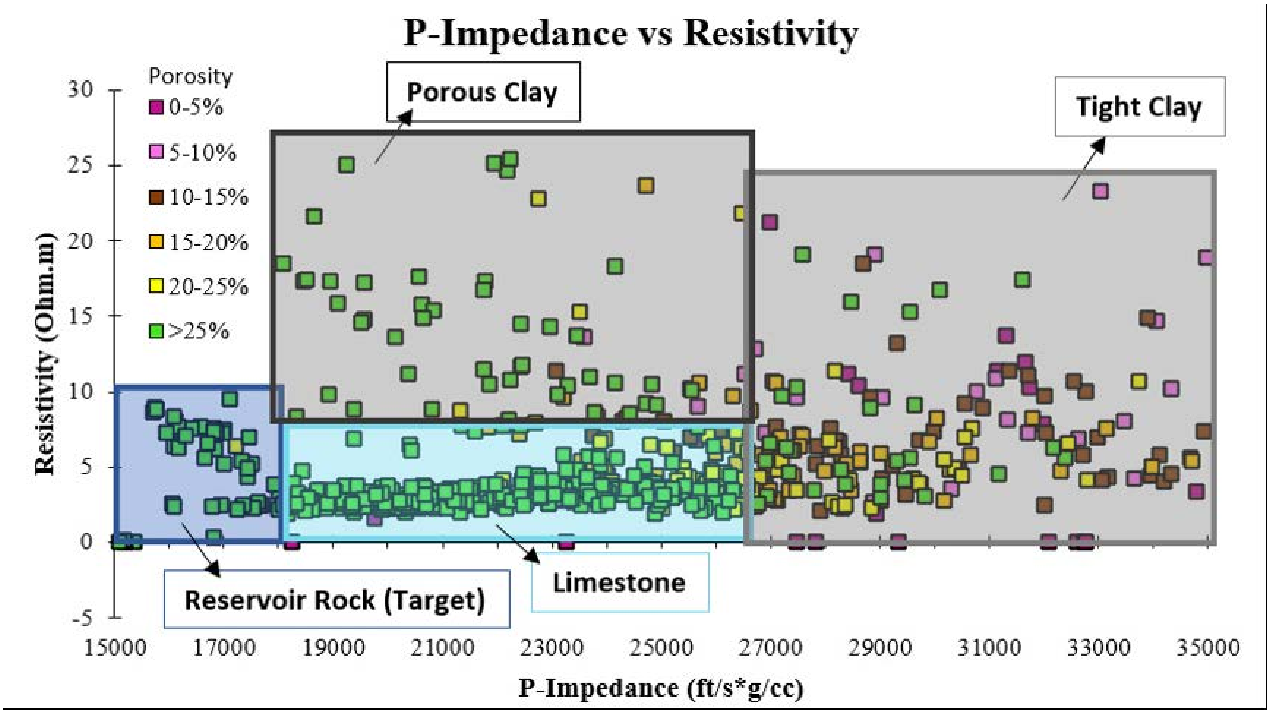


Figure 6. Cross plot of P-impedance vs. Resistivity of Kujung formation at tunning thickness area.

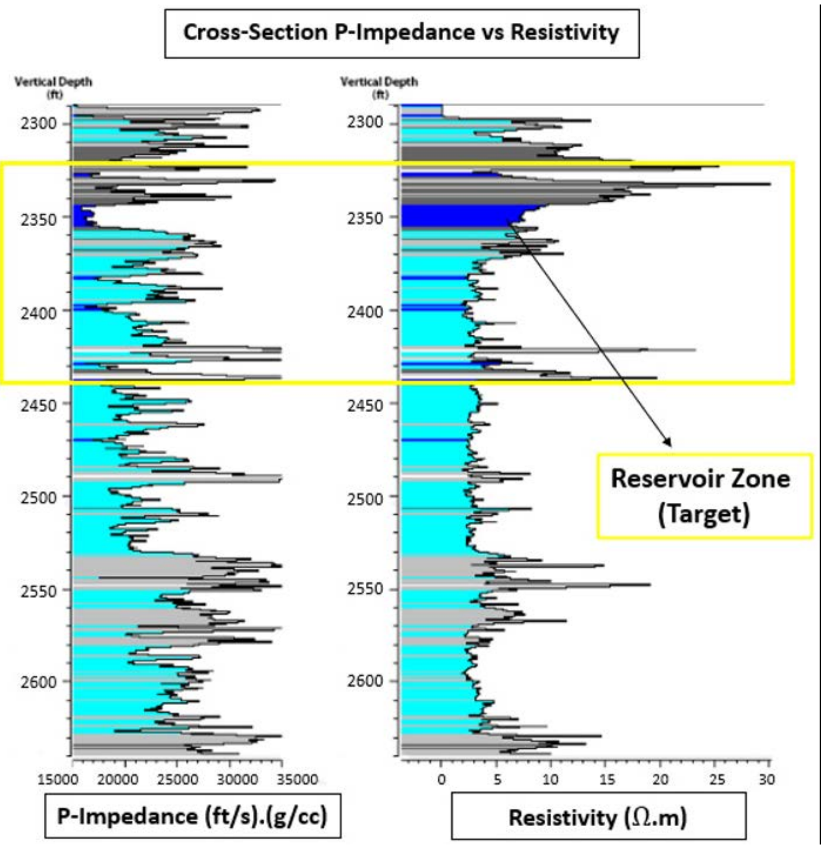


Figure 7. Cross section result of P-Impedance Vs. Resistivity cross plot

limestone. Based on the cross plot results, the lithology of the Kujung formation is composed of reservoir rock, limestone, and clay rocks. The reservoir rock in the cross plot has a resistivity value of 0–10 Ω.m and a P-Impedance of 15000-18000 (ft/s).(g/cc), including porous rock indicated by coral and foram. There are also limestones with a resistivity value of 0–15 Ω.m and a p-impedance of 18000-26500 (ft/s).(g/cc). In addition, the clay lithology is

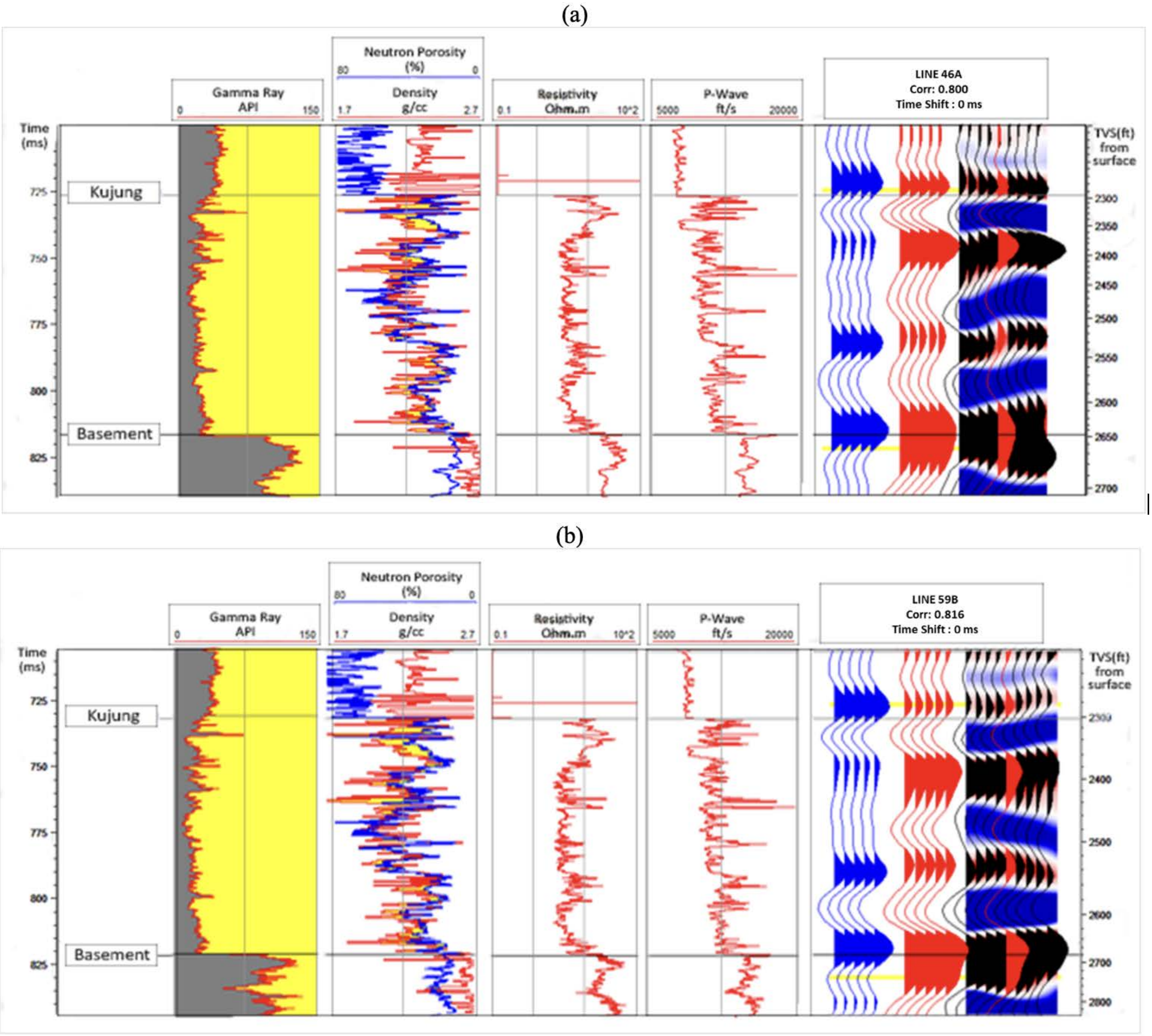


Figure 8. Well seismic result, (a) line 46A; (b) line 59B

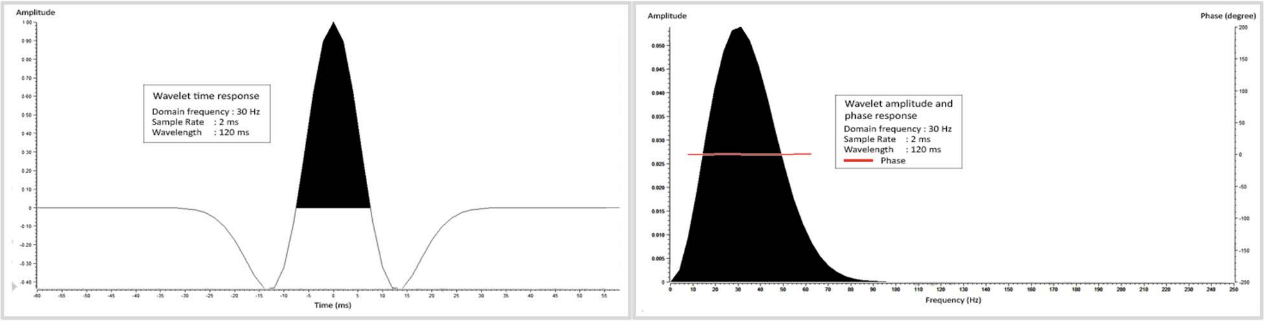


Figure 9. Estimated ricker wavelet with wavelength of 120 ms

divided into porous clay with a resistivity value of 8–26 Ω.m and a p-impedance of 18000–25000 (ft/s).(g/cc), and tight clay with a resistivity value of 0–15 Ω.m and a p-impedance of 25000–35000 (ft/s).(g/cc).

The interpretation results of the cross plot (Figure 6) are presented in Figure 7, showing the well data cross-section to determine the depth of the hydrocarbon prospect zone. The correlation between p-impedance and resistivity based on depth indicate that the reservoir target is at depth range of 2320-2430 ft.

Well to Seismic Tie

The well-to-seismic tie is carried out before the picking horizon stage to enable the integration of time-based seismic data depth-based well data. The correlation values for the well-to-seismic tie in lines 46a (Figure 8a) and 59b (Figure 8b) using wavelet ricker with frequency domain 30 Hz and wavelength 120 ms (Figure 9) are 0.800 and 0.816, respectively.

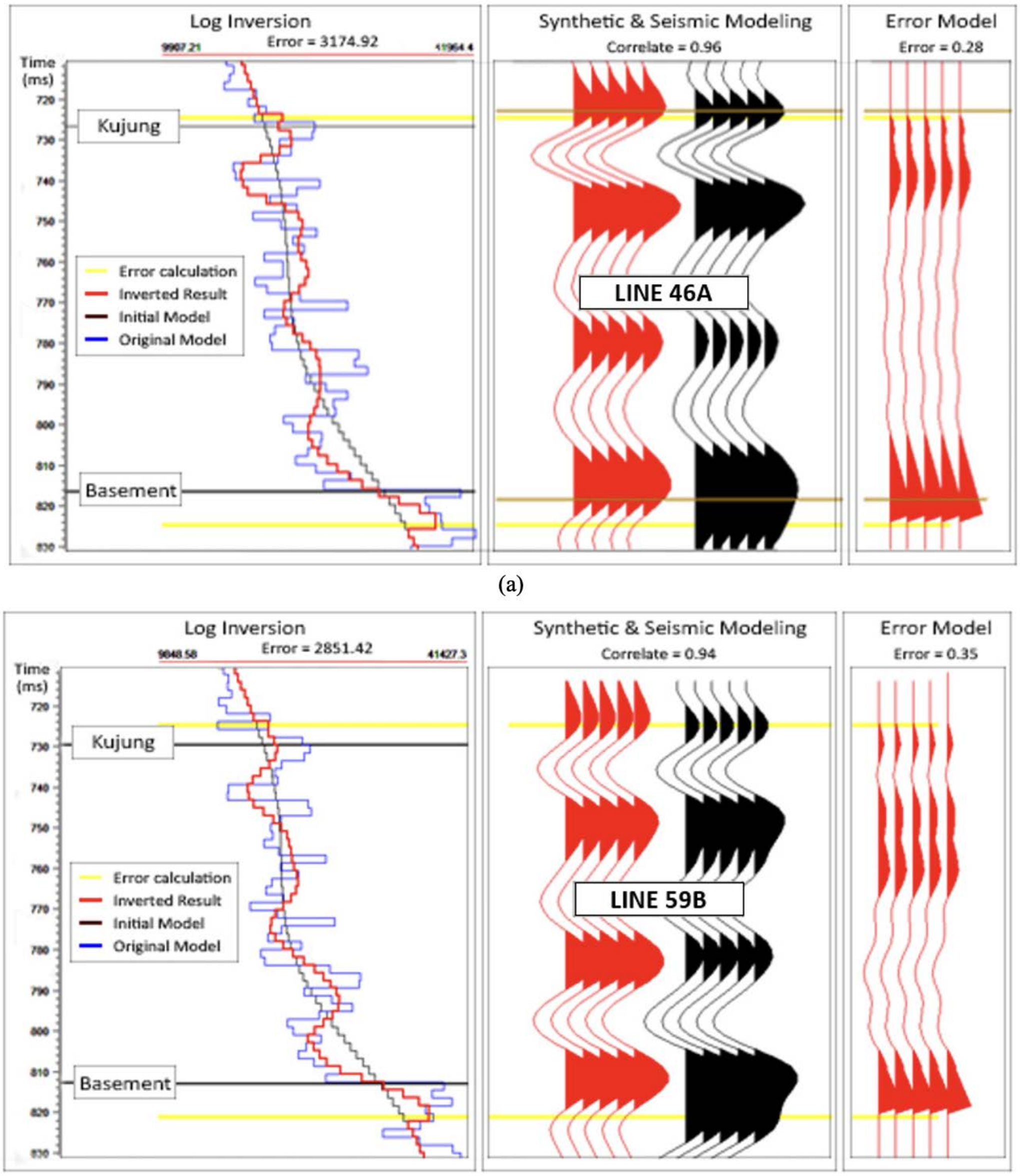
Picking Horizon

Picking the horizon is performed once the horizon of interest has been identified by analyzing the character or polarity changes in the seismic trace. Positive polarity indicates an increase in acoustic impedance, while negative polarity indicates a decrease in acoustic impedance. The horizon is identified as a reflection marking the boundary between two materials with different acoustic properties. The picking of horizons is specifically focused on lines 46A and 59B as part of the seismic inversion processing area.

Seismic inversion model

Model-based inversion processing is used to determine error and correlation values while filtering frequency as tuning thickness. Filtering helps select frequencies within the desired range, enabling the synthetic seismic model to closely resemble actual conditions based on error values and their correlations. In this model, the frequency used for tuning thickness ranges from 725 ms to 825 ms, indicating the reservoir target zone with a minimum thickness of 83.35 ft.

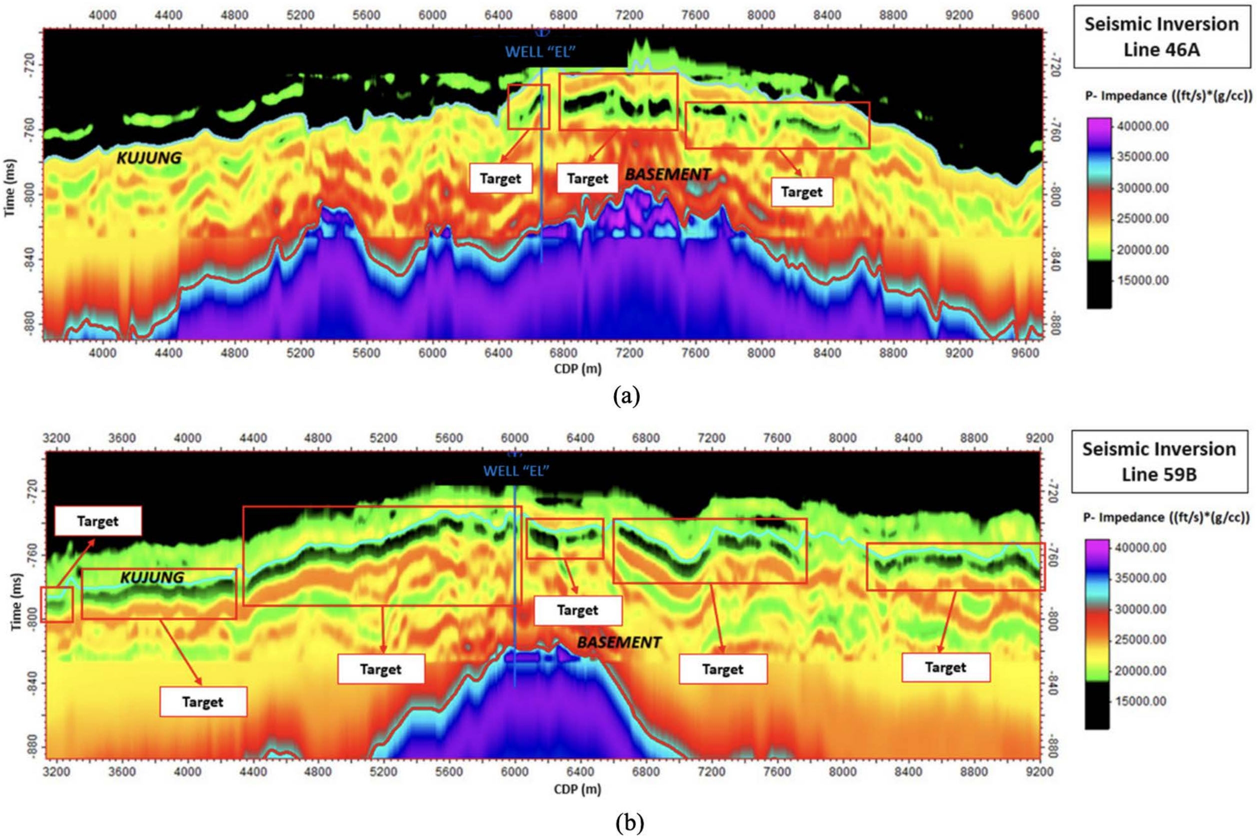
The results of model-based inversion (Figure 10) for lines 46A and 59B show favorable errors and correlations. The initial modeling includes the inversion log model, synthetic and seismic models, and model error values. The inversion log error value is useful for determining the error rate of the inversion log model compared to the actual AI log. Moreover, the correlation between synthetic and seismic modeling proves to identify the compatibility



(a)

(b)

Figure 10. Model-based inversion analysis: (a) line 46A; (b) line 59B



(a)

(b)

Figure 11. Acoustic Impedance Inversion (AI) with an overview of the prospect zone, (a) line 46A; (b) line 59B

between the modeling results (red color) and the actual seismic trace (black). The error model is used to determine the error level of the inversion modeling results. For line 46A (Figure 10a), the log error value was 3174.92, the model error was 0.28, and the correlation was 0.96. For line 59B (Figure 10b), the log error value was 2851.42, the model error was 0.35, and the correlation was 0.94. These values represent an optimal match between the model and the actual seismic trace. The completed model is then subjected to AI seismic inversion to accurately identify reservoir characteristics below the surface.

Seismic inversion AI is strongly influenced by changes in rock density values and seismic wave velocity. These changes will affect the value of the reflection coefficient obtained. The high or low amplitude of the seismic trace shows the value of the reflection coefficient at the layer boundary, as the seismic trace results from a convolution between the reflection coefficient and the wavelet. The amplitude shows the degree of differences in AI values derived from the velocity and rock density of each layer.

The results of AI inversion in the "EL" well, East Java on lines 46A and 59B, reveal the characteristics of the hydrocarbon reservoir in the Kujung formation. The selection is based on the correlation results of P-Impedance with Gamma Ray, Porosity, and Resistivity in the cross plot analysis with acoustic impedance values ranging from 15000–18000 (ft/s).(g/cc), indicating a porous reservoir zone, known as reservoir rock (Figure 4; Figure 5; and Figure 6). The results of seismic inversion can be seen in the distribution of acoustic impedance values (AI) in Figure 11. The character of the reservoir can be identified from the acoustic impedance values in the seismic section. The cross-section shows the inversion results based on the picked and correlated seismic data of the Kujung formation layer with the "EL" well. The P-Impedance values from the inversion results are correlated with cross plot analysis and well data to determine the lithology and characteristics of the hydrocarbon. Correlation results in lines 46A (Figure 11a) and 59B (Figure 11b) are marked in black, distinguishing the rock lithology and fluid content in the formation. The black color represents the prospective zone of hydrocarbon contained in the Kujung Formation. The correlation at well log interpretation (Figure 3), p-impedance cross plot correlation (Figure 4, 5, 6), cross-section p-impedance vs resistivity at tunning thickness (Figure 7), and AI inversion model (Figure 11) show the indication of a hydrocarbon prospect zone in the Kujung formation at a depth of 2320–2430 ft with a P-Impedance value of 15000–18000 (ft/s).(g/cc). The correlation demonstrates the similarities between processing data results and geological regional at Kujung Formation. In addition, the very good effective porosity and low resistivity values suggest that the rock is part of the reservoir rock and has very good fluid storage capabilities. The correlation of well and seismic data shows that the hydrocarbon prospect zone in the Kujung formation is interpreted as a reservoir rock with coral and foram as the other constituent rocks.

CONCLUSIONS

Cross plot analysis of P-impedance, gamma ray, porosity, and resistivity parameters iusing well data allows for the differentiation of shale, non-shale, porous zone, and tight zone layers. This analysis helps in determining the lithology characteristics and distribution of hydrocarbon reservoirs. The lithology of study area composed of shale, clay, limestone, coral, and foram. Seismic inversion AI results obtained from the correlation of well data and seismic data on the Kujung formation reveal the presence of a reservoir prospect zone with coral and foram lithology with impedance value ranging from 15000-18000 (ft/s).(g/cc) at a depth of 2320–2430 ft.

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