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Spatio-temporal Distribution of the Conglomerate Reservoir of Jatibarang Formation, Melandong Field, North West Java Basin, Indonesia

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Abstract

Subsurface mapping of the distribution of the reservoir is essential to be conducted in order to minimize many risks, such as financial losses, and also to increase profit from hydrocarbon production. This research was conducted on the Jatibarang conglomerate reservoir in Melandong Field, North West Java Basin, Indonesia. There are three objectives of this study which are to perform elastic impedance (EI) seismic inversion using available 3D seismic data, to determine the most suitable elastic impedance angle for the data, and to map the spatio-temporal distribution of the Jatibarang Formation reservoir in the Melandong field, North West Java basin, Indonesia. EI inversion was selected for this study using the inversion angle ranging from the near stack (5º-15º) to the far stack (20º-30º). Results from this study show that EI seismic inversion can help in detecting the distribution of the lithology and hydrocarbon within the target zone. Angle 5º is considered as the best EI angle for the studied data as indicated by a correlation value of 0.65. Moreover, EI angles 15º and 10º are less reliable as shown by their correlation value of 0.6 and 0.56, respectively. These results are expected to provide some new insights into the distribution of the Jatibarang reservoir, and help in exploration, exploitation, and development of oil and gas fields in Melandong Field, North West Java Basin, Indonesia.

Introduction

Seismic inversion is a subsurface geological modeling technique using seismic data as input and well data as control. This method helps map the distribution of sub-surface reservoirs and identify fluid and hydrocarbon reservoirs to increase oil and gas production and minimize production risks. This research used the data from the Melandong Field, part of the

North West Java Basin. This area is known as the main field producing hydrocarbon in the operational area of PT. Pertamina EP Java Region. The North West Java Basin is located in northwestern Java and extends off the north coast of Java. This basin is bounded in the south by the Bogor Basin, to the northwest by the Seribu Platform, to the north by the Arjuna Basin, and to the east by the Karimun Java Arc [Fig.1; 1].

Melandong Field is about 15 km west of Pamanukan, West Java. Structurally, it is in the Cipunegara Low graben (sub-Cipunegara Basin, North West Java Basin) [2]. The graben system is located between the Pamanukan-Bojongraong High trend and Kandanghaur-Gantar High trend. Based on the sub-basin division, Melandong Field is grouped as part of the Jatibarang sub-basin [3].

The Jatibarang Formation is composed of early syn-rift deposits, particularly in the central and eastern parts of the North West Java basin. In the western part of the basin (Tambun-Rengasdengklok area), the Jatibarang formation has a thin layer thickness. The lower part of the formation consists of tuff interbedded with lava (flows), while the upper part consists of sandstones and conglomerate rock. This research, however, focused on the conglomerate rock of the Jatibarang Formation.

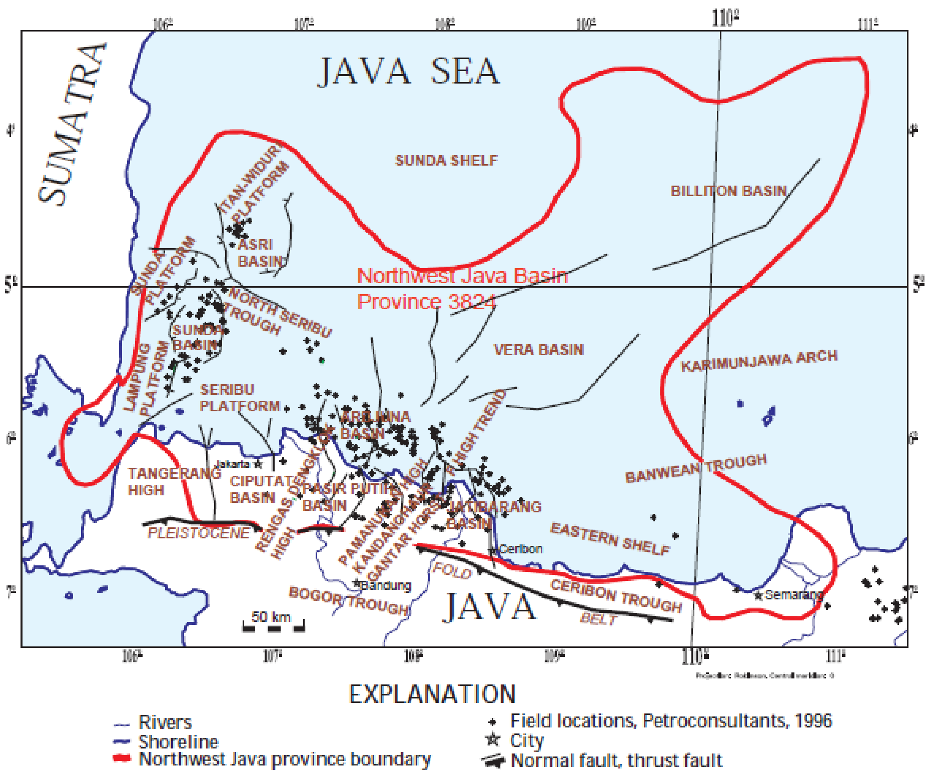

Figure 1. The location of the research area is located in the Melandong Field, North West Java Basin, Indonesia [1]

There are three objectives of this study: (1) to perform an elastic impedance seismic inversion using 3D seismic data; (2) to determine the most suitable elastic impedance angle for the data; and (3) to map the spatio-temporal distribution of the Jatibarang Formation reservoir in the Melandong field, North West Java basin, Indonesia. It is expected that this study can provide some new insights into the exploration, exploitation, and development of oil and gas fields in the North West Java Basin, particularly that targeted the Jatibarang Formation reservoir.

Methods

This study was carried out using seismic reflection data. Seismic reflection is a method that propagates acoustic waves generated from wave sources such as dynamite, vibration, hammers, and others, then recorded by a geophone or hydrophone. Waves propagate in all directions and reflect or refract into the earth when propagating in different layers.

The three-dimensional (3D) seismic data used in this study consist of pre-stack time migration (PSTM) and common reflection point (CRP) data. These data consist of inline 1700-1840 with the inline interval of 25 m, crosslines 7255-7400 with crossline interval of 25 m, and time intervals between 0-3000 ms with a sampling rate of 2 ms.

Amplitude versus offset (AVO) analysis was also conducted for this research, and this analysis aims to determines the differences in reservoir fluids and lithology. This AVO analysis requires CRP gather seismic data in order to obtain seismic reflectivity. The AVO graph is also helpful in determining the class of AVO anomalies based on the relationship between the reflected signal amplitude and the angle of incidence of the seismic waves. Another data is wireline logging from M-01 well. The data consists of gamma-ray logs (GR), P wave velocity logs (Vp), S wave velocity logs (Vs), neutron porosity logs (NPHI), bulk density logs (RhoB), elastic impedance logs (EI), time-depth curves, and well marker information.

The data processing method is seismic elastic impedance inversion (EI) [4]. The Software applied is Vanguard; while picking the horizon and seismic-tie wells, use Seisearth Software. Develop The Elastic Impedance (EI) method to generalize acoustic impedance for several incident angles [5]. Elastic Impedance (EI) is derived from linearizing the Zoeppritz equation [6], defined as a function equal to the acoustic impedance for a specific incident angle [7]. The derivation of the elastic impedance formula, i.e.:

$$R(\theta) = \frac{EI_2 - EI_1}{EI_1 + EI_2} \qquad (1)$$

Equation (1) is a function of elastic impedance. The minor impedance change formula is :

$$R(\theta) \approx \frac{1}{2}\frac{\Delta EI}{EI} \approx \frac{1}{2}\Delta \ln(EI) \qquad (2)$$

Substitution of equation (2) into the Aki and Richard (1980) is

$$\frac{1}{2}\Delta\ln(EI)=\frac{1}{2}\left(\frac{\Delta v_p}{v_p}+\frac{\Delta\rho}{\rho}\right)+\left(2\frac{\Delta v_p}{v_p}-2\frac{v_s^2}{v_p^2}\frac{\Delta v_s}{v_s}-2\frac{v_s^2}{v_p^2}\frac{\Delta\rho}{\rho}\right)\sin^2\theta+\frac{1}{2}\frac{\Delta v_p}{v_p}\sin^2\theta\tan^2\theta \quad (3)$$

$K=\frac{v_s^2}{v_p^2}$ that the equation is:

$$\frac{1}{2}\Delta\ln(EI)=\frac{1}{2}\left(\frac{\Delta v_p}{v_p}(1+\sin^2\theta)+\frac{\Delta\rho}{\rho}(1-4K\sin^2\theta)\right)-\frac{\Delta v_s}{v_s}8K\sin^2\theta+\frac{\Delta v_p}{v_p}\sin^2\theta\tan^2\theta \quad (4)$$

Because of $\sin^2\theta\tan^2\theta=\tan^2\theta-\sin^2\theta$ and substituted to $\Delta\ln x$ for $\Delta x/x$, so:

$$\Delta\ln(EI)=\Delta\ln(v_p)(1+\tan^2\theta)+\Delta\ln(\rho)(1-4K\sin^2\theta)-\Delta\ln(v_s)8K\sin^2\theta \quad (5)$$

K is constant, then equation (5) can be formulated :

$$\Delta\ln(EI)=\Delta\ln(v_p)^{(1+\tan^2\theta)}+\Delta\ln(\rho)^{(1-4K\sin^2\theta)}-\Delta\ln(v_s)^{8K\sin^2\theta} \quad (6)$$

$$\Delta\ln(EI)=\Delta\ln\left(v_p^{(1+\tan^2\theta)}+\rho^{(1-4K\sin^2\theta)}-v_s^{8K\sin^2\theta}\right) \quad (7)$$

By integrating and exponentiating equation (7), then the equation is:

$$EI(\theta)=V_P^{(1+\tan^2\theta)}V_S^{(-8K\sin^2\theta)}\rho^{(1-4K\sin^2\theta)} \quad (8)$$

For angle >30^o, tan^{2}θ = sin^{2}θ, then the EI equation is :

$$EI(\theta)=V_P^{(1+\sin^2\theta)}V_S^{(-8K\sin^2\theta)}\rho^{(1-4K\sin^2\theta)} \quad (9)$$

If θ = 0^o, then the equation is :

EI (0^o) = AI = Vp.ρ (10)

Result and Discussion

Wireline logging data analysis

The conglomerate rock, the reservoir zone, is at a depth of 3045 m - 3065 m. The gamma-ray log can distinguish lithology based on the content of Uranium, Thorium, and Potassium element in each rock that emits these radioactive elements. Further, the gamma-ray logs record radiant energy pulses from these elements.

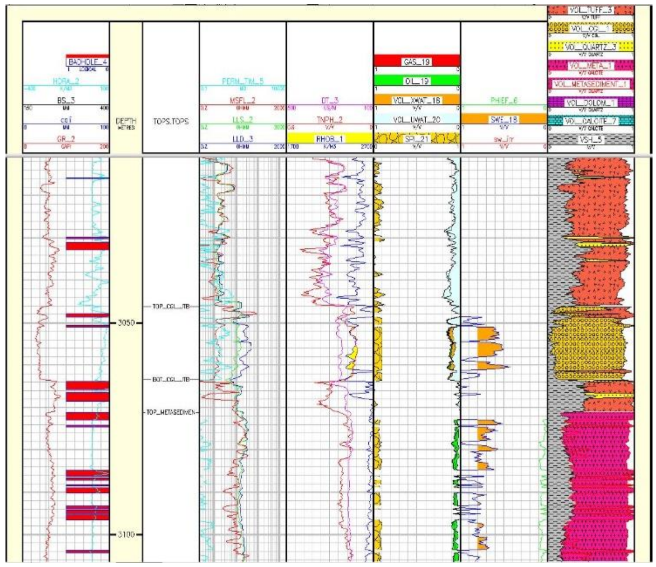

Figure 2. Well-log analysis data displays conglomerate lithology and the potential presence of hydrocarbons in the research target zone (3045-3065 m).

Claystone has a high content of Uranium, Thorium, and Potassium. Meanwhile, sandstone, conglomerate, limestone, and dolomite contain fewer radioactive elements than claystone [8] and [9]. The target zone (3045 m - 3065 m) has a low GR log exhibiting the presence of conglomerate rocks (the results of petrophysical analysis). While the other depth has a high GR log, indicating claystone.

Hydrocarbon interpretation at 3045 m - 3065 m is based on the MSFL 3 and LLD logs (Fig.2; Column 2). The MSFL 3 log measures rock resistivity around the drill hole, which is still affected by the drilling mud. Meanwhile, the LLD log measures the resistivity that is not affected. The separation between the two logs indicates differences in resistivity.

In addition, the neutron porosity and bulk density log relate to the rock's hydrogen content. When hydrocarbons replace hydrogen, the neutron porosity and bulk-density logs are low (Fig 2; Column 3). Otherwise, the bulk density log will be high if the rock contains water because water density exceeds oil and gas ([9] and [10]).

Based on these results, we conclude that at a depth of 3045 m - 3065 m is a porous rock. Further, the cutting data presents that the lithology is conglomerate rocks [3]. Because the rock is porous and permeable, it potentially becomes high-quality hydrocarbon reservoir layers.

Amplitude Versus Offset Analysis

Amplitude versus offset (AVO) analysis aims to observe an anomaly in the presence of hydrocarbons and determine the AVO class. The determination of the class is helpful in the process of analyzing the results of inversion.

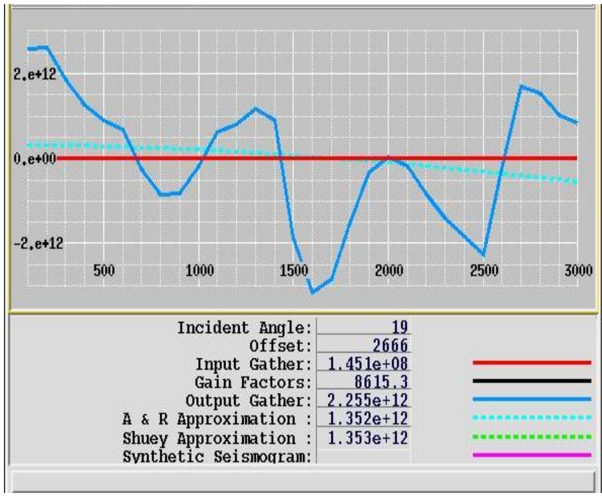

Figure 3. Amplitude versus Offset curve. It can be seen that there is a phase change from near offset to far offset, and it is AVO class IIp.

The AVO graph displays (Fig.3) the AVO anomaly in well M-01 horizon DST-02, which indicates hydrocarbons. The observed anomaly is a change in amplitude with increasing offset (angle). The initial amplitude, which is positive, gets more decrease until at a certain angle. Then, as the offset increases, the amplitude becomes more negative, and the trend changes. This amplitude response to the angle is referred to as the phase change. The difference in amplitude value represents that the DST-02 zone is AVO class IIp. It supports the interpretation that the target zone contains hydrocarbons.

Seismic Analysis

The research target zone (DST-02, 3045-3065 m) comprises conglomerate rocks as reservoir hydrocarbons (Fig.2). Before the elastic impedance inversion process, sensitivity analysis is carried out by cross-plot and cross-section of the elastic impedance log (5^o-30^o angle) with Gamma-Ray log to observe how sensitive these parameters are in differentiating lithology. These cross-plots and cross-sections apply the Gamma-Ray log because it helps separate lithology.

Comparison of cross-plot and cross-section results between EI near stack angles (5^o-15^o) and far stack (20^o-30^o) exhibits that EI near stack is better at separating conglomerate lithology from claystone, characterized by minimal data overlap (Fig.4-5).

At 5^o angle elastic impedance, the cut-off is 8100 ((m/s)2*(Gr/cc)). EI >8100 ((m/s)2*(Gr/cc)) is a conglomerate lithology that is porous and contains hydrocarbons, while an EI <8100 is claystone. At a 10^o angle elastic impedance, the cut-off is 6600 ((m/s)2*(Gr/cc)). EI >6600 ((m/s)2*(Gr/cc)) is a conglomerate lithology, while an EI <6600 is claystone. Further, at a 15^o angle elastic impedance, the cut-off is 5000 ((m/s)2*(Gr/cc)). EI >5000 ((m/s)2*(Gr/cc)) is a conglomerate lithology, while an EI <5000 is claystone. Based on this comparison, the authors decided to use elastic impedance seismic inversion with an angle of 5^o-15^o (near stack) because it will provide better results.

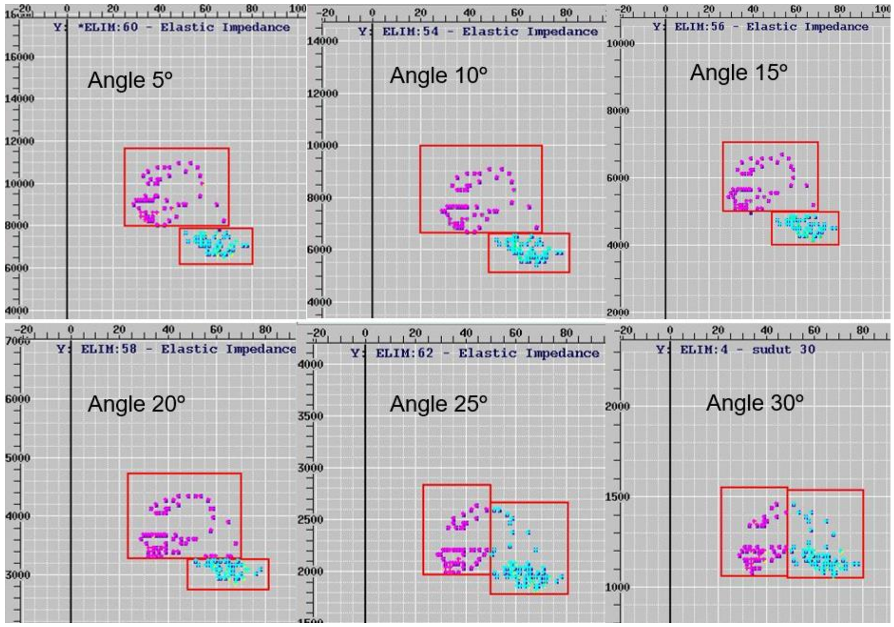

Figure 4. The results of the elastic impedance cross plot with gamma-ray using angles varying from 5-30°.

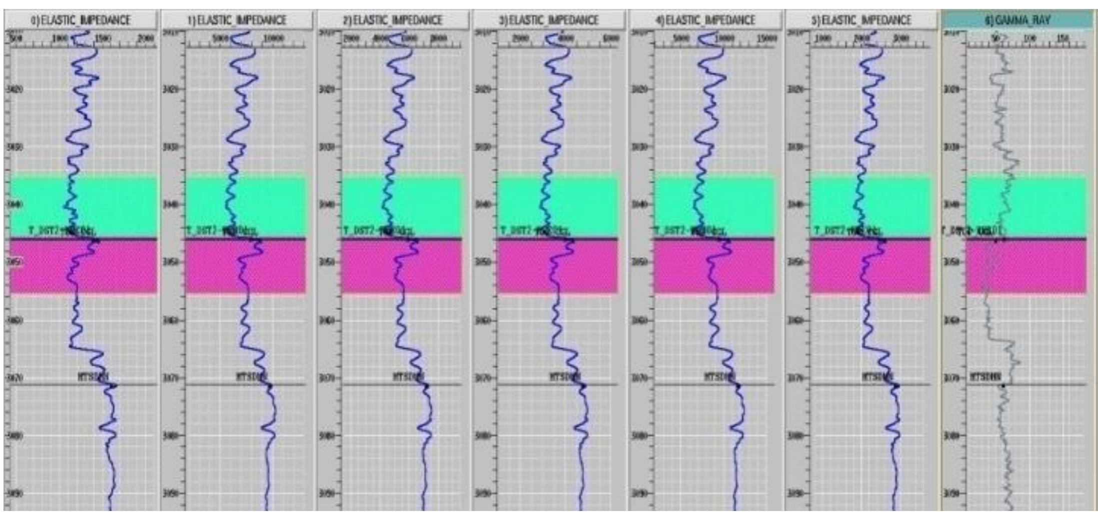

Figure 5. Cross-section results of the EI log at an angle of 5°-30° with the Gamma Ray log.

The well-seismic tie aims to combine and convert well-log data (meter units) into seismic data (time units) (Fig.6.A). The results are excellent, with a correlation value of 0.8 (Fig.6.B). This result is consistent with similar research from Niger Delta field of Africa, which also show the correlation coefficient of >0.8 [11]. Moreover, the tuning thickness analysis is to see the level of vertical seismic resolution that can still be used to distinguish lithology. The tuning thickness is defined as ¼ wavelength (108 m), so a tuning thickness of 27.1 m is obtained (the result of 108/4). The thickness of the target zone conglomerate is 20 m, which indicates that the thickness of the target zone < tuning thickness so that the resulting seismic vertical resolution will be medium-good quality.

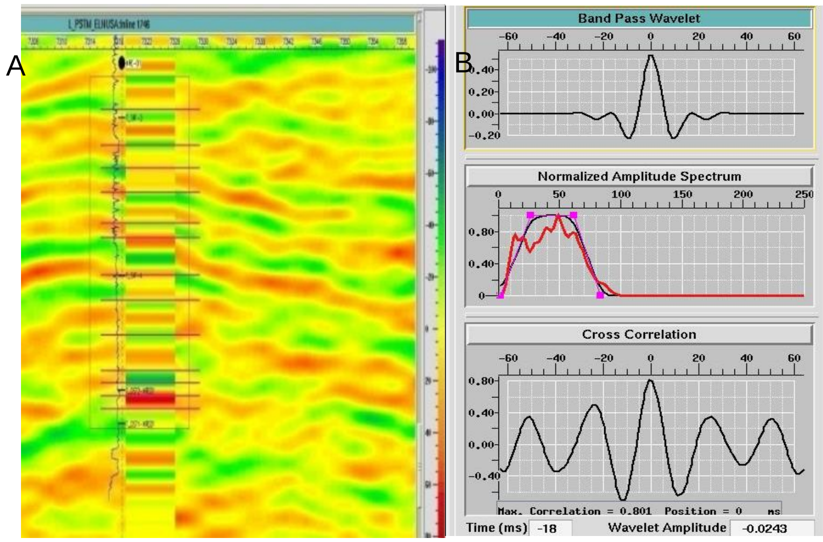

Figure 6. (A) the seismic tie well results with check shot data, and (B) the seismic tie wavelet well extraction results with a correlation value of 0.8.

Slicing is carried out with a thickness starting from 20 ms above the DST-02 horizon to 4 ms below it. Light blue color = conglomerate reservoir, dark blue color = claystone. Figure 7 is the result of inversion. Conglomerate rock reservoirs that are porous and contain hydrocarbons have EI (5^o) ranging from 8100-10700 ((m/s)2*(Gr/cc)) (green layer). In comparison, cross-plot analysis results in the EI (5^o) of the conglomerate rock reservoir ranges from 8100–11000 ((m/s)2*(Gr/cc)). The EI of claystone that overlies the conglomerate layer is 6200 - 8100 ((m/s)2*(Gr/cc), while its cross-plot analysis results in the EI (5) ranges from 6500 -8100 ((m/s)2*(Gr/cc)). The difference between the inversion results and the well data is due to the significant attenuation effect of the frequencies in the seismic data. Although different, the impedance value of the target area in well data can be approximated at a particular value.

Figure 7-8 show the results of seismic inversion of elastic impedance angle 5-15 inline 1746. Conglomerate reservoirs are seen in majority of the study area (Fig.7-8). The different reservoir distribution results from different EI angles. The inversion results are calibrated by correlating the log EI inversion and the log EI derived from the main log. The results are: the EI log for a 5^o angle is 0.65, a 10^o angle is 0.56, and a 15^o angle is 0.6. An EI angle of 5^o is the most suitable elastic impedance angle for mapping the distribution of conglomerate rocks containing hydrocarbons. The distribution of conglomerate and hydrocarbon rocks (reservoir zone) resembles a channel. However, it still needs to be determined due to limited well and seismic data. Therefore, additional seismic data is necessary for a broader area to decide whether or not it is a channel.

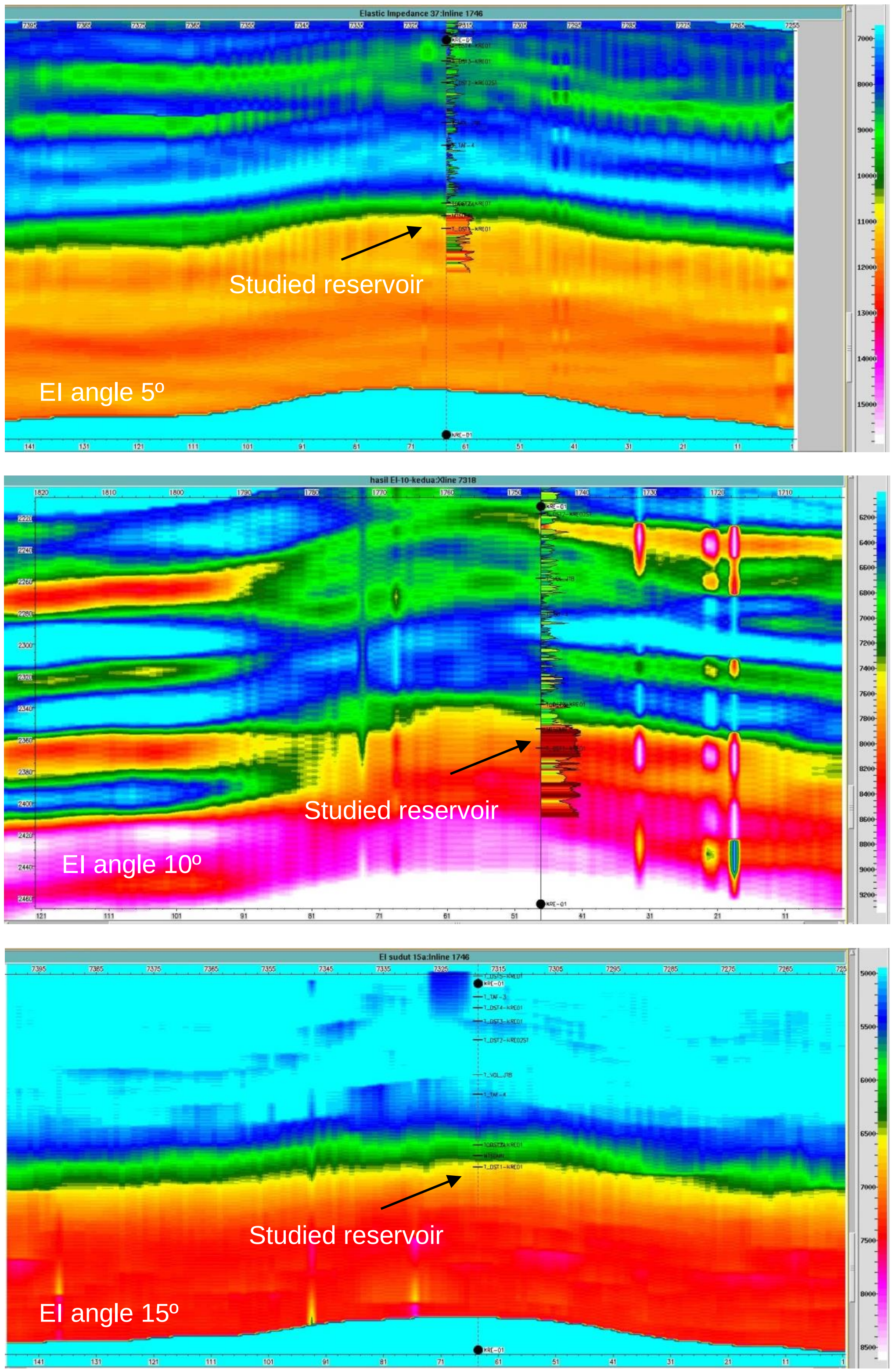

Figure 7. Vertical section of the elastic impedance at an angle of 5º-15º on 1746 inline.

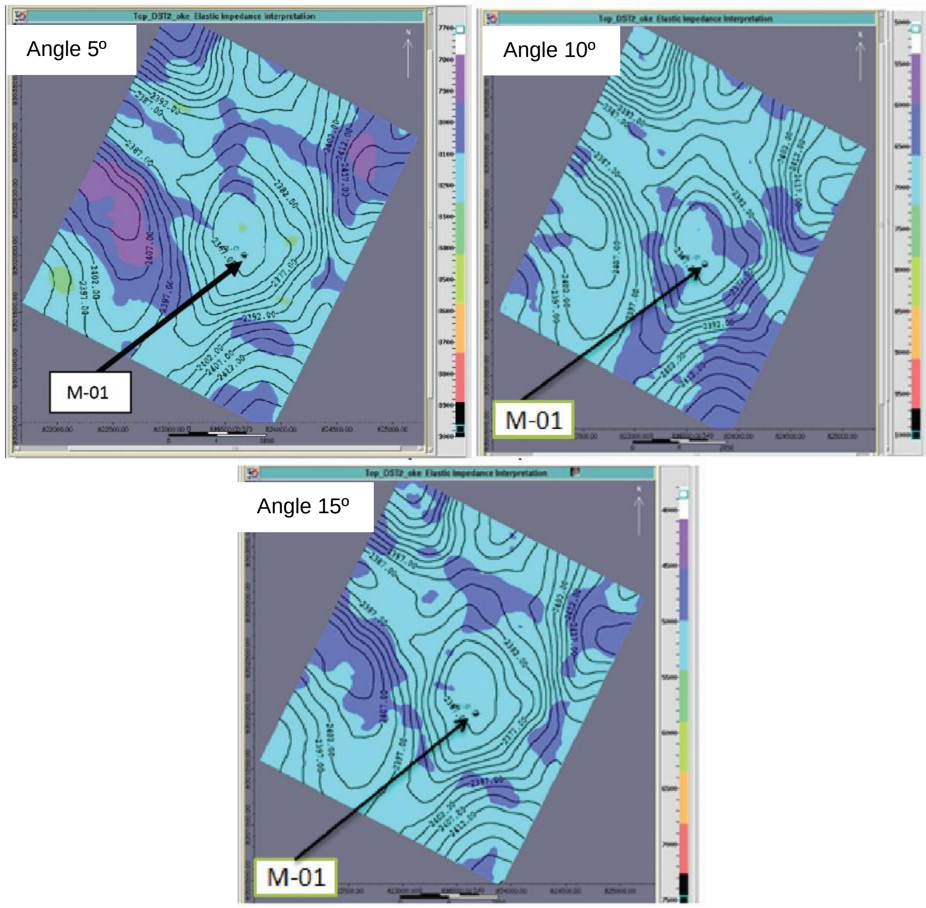

Figure 8. Slicing map resulting from elastic impedance inversion with angles varying from 5º-15º.

Figure 8 presents a 5º EI inversion slicing map with thicknesses ranging from 20ms above the DST-02 horizon to 4ms below it. The distribution of conglomerate lithology, which is porous and contains hydrocarbons, is presented in light blue with EI values of 5º angles ranging from 8100–8250 ((m/s)2*(Gr/cc)). In comparison, the distribution of clay is presented in dark blue with a range of EI 7000– 8100 ((m/s)2*(Gr/cc)).

Whereas for the EI angle of 10º (Fig.8), the conglomerate rock is presented in light blue with a value range of 6600-7800 ((m/s)2*(Gr/cc)) while claystone values range from 6000- 6600 ((m/s)2*(Gr/cc)). As well, for an EI angle of 15º, the conglomerate rock is displayed in light blue with an EI value of 5000-6000 ((m/s)2*(Gr/cc)), and claystone is shown with a value of 4500-5000 ((m/s)2*(Gr/cc)). These EI results are similar to the results from LMR seismic inversion conducted by [12] using the same dataset, and this suggests that findings of this study are highly reliable. Moreover, similar EI study conducted by [13] also show similar results, where the inverted EI results follow the results from well log curves satisfactorily,

Conclusion

Based on the wireline logging data analysis, porous and permeable conglomerate rocks are present in the target zone. The results of the amplitude versus offset (AVO) analysis show the presence of an AVO class IIp anomaly, which indicates the presence of hydrocarbons within the study area. Moreover, the EI inversion results exhibit that elastic impedance seismic inversion can be used to help detecting and mapping of the distribution of conglomerate rock reservoirs with a reliable and acceptable level of accuracy. The best elastic impedance inversion (EI) results in differentiating lithology and mapping the distribution of conglomerate rock are given by EI angle 5^o, with an accuracy of 0.65. Meanwhile, the EI inversion results at angle 10^o and 15^o provide lower-quality inversion results with respective accuracy levels of 0.56 and 0.60.

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