Identification of lithology and fluid content using simultaneous inversion in the "IM" field of the North Sumatra Basin

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Abstract. The "IM" field is an oil and gas exploration field located in the North Sumatra Basin. It was previously identified that in this field hydrocarbons were found in the form of gas condensate. This study aims to characterize the reservoir in terms of lithological distribution and fluid content. The research includes carbonate reservoir targets located in Middle Miocene Malacca Limestone. The data used in this study are 3D seismic data and two wells data. The simultaneous inversion method is applied to process data so that research objectives can be achieved. The simultaneous inversion method produces Acoustic Impedance (Zp), Shear Impedance (Zs). The results show that in the gas reservoir the acoustic impedance (Zp) value is around 16542 - 18917 (ft/s*g/cc) and the shear impedance(Zs) is around 8375 (ft/s*g/cc) while in the water reservoir the acoustic impedance (Zp) value is around 21292 - 23667 (ft/s*g/cc) and the shear impedance (Zs) is around 18500-20525 (ft/s*g/cc). The results showed that the reservoir distribution has a North West-South East orientation.

Keywords: Characterization of Carbonate Reservoir, "IM" Field North Sumatra Basin, Simultaneous Inversion.

1. Introduction

Oil and gas are sources of fossil energy that take a long time to be renewed. This is a challenge in itself for the government and related industry players when the public's need for this energy source increases. The large demand for oil and gas has exceeded the number of discoveries of new hydrocarbon reserves [1]. Efforts to find new economic reserves need to be done so that oil and gas production can increase. One of the efforts carried out based on a geological review is to look for the accumulation of hydrocarbons in the stratigraphic trap. This is because currently, the total quantity of hydrocarbon reserves in the structural trap has decreased along with the increase in production activity.

The seismic reflection method in geophysical science is one of the methods that is still considered reliable and is often used in the search for hydrocarbons. This method is carried out in three stages, namely data acquisition, processing, and interpretation [2]. By utilizing the propagation properties of sound waves, this method can describe the subsurface geological conditions, so that the layers containing hydrocarbons can be identified quite well. However, in the interpretation stage, it is still
necessary to integrate well data and further analysis to determine the presence of layers containing these hydrocarbons.

One of the efforts in the seismic data interpretation stage to determine the presence of a layer containing hydrocarbons can be done by characterizing the physical properties of the reservoir. Reservoir characterization is carried out by integrating seismic and well data to separate differences in the presence of rock lithology and fluid content. The purpose of conducting seismic inversion is to describe the subsurface geological conditions by utilizing the seismic data deconvolution process which becomes the input and the well data which becomes the control[3].

Previously, many characteristics of reservoir physical properties have been carried out using the simultaneous inversion method. One of them is research conducted in the northern part of the East Java Basin in the form of carbonates in the Tuban Formation. The simultaneous inversion method in this study is considered successful in identifying lithology and fluid content in the study area. Therefore, this study aims to apply the same method to identify the lithology and fluid content in different areas, namely the North Sumatra Basin.

The "IM" field is one of the oil and gas exploration blocks located in the North Sumatra Basin. The reservoir in this field has carbonate rock lithology. Carbonate reservoirs have a higher degree of uncertainty in determining the presence of hydrocarbons due to the more heterogeneous nature of carbonate rocks[4]. Most of the carbonate rocks are derived from biological materials that are susceptible and complicated to changes in diagenesis leading to changes in mineralogical structure and pore structure[5]. The target to be achieved from this study is to characterize the reservoir in the Middle Miocene Malacca Limestone.

Initially, the inversion technique was applied by using seismic data in the form of a post-stack to produce acoustic impedance. However, acoustic impedance only contains parameters of P wave velocity (Vp) and rock density (ρ) so that it still creates ambiguity in recognizing the effects of lithology and fluid in the reservoir[6]. Then an inversion technique was developed which involved S wave velocity (Vs) [7]. The reason for using the S (Vs) wave in the inversion technique is that the S (Vs) wave is not sensitive to the presence of fluid[8]. While the P wave (Vp) is sensitive to fluid, where the presence of the fluid will affect the P wave velocity (Vp) [9]. As a result, the use of P waves (Vp), S waves (Vs), and density (ρ) are expected to reduce the effects of ambiguity in reservoir characterization.

Then the inversion technique continued to develop with the introduction of a new inversion method using the pre-stack seismic data. This method is known as the simultaneous inversion method [10]. Simultaneous Inversion is widely applied to get the volume of Acoustic Impedance (Zp), Shear Impedance (Zs), and Density (ρ)[11]. This method is very good for mapping the distribution of reservoirs, especially in the separation of lithology and hydrocarbon fluids[12].

Seismic data used in this study, namely Post Stack Time Migration (PSTM) 3D in *.segy format. PSTM data is in the form of partial stack data. The 3D seismic data are about 270 inlines and 720 xlines. Seismic data has azero phase polarity increases acoustic impedance as a negative value. The well data used in this study are two wells, namely Well IM-02 and Well IM-01. The objectives of this study were to obtain a model of acoustic impedance (Zp) and shear impedance (Zs) through the simultaneous inversion method and estimate the distribution of hydrocarbon reservoir areas at the location based on the results of simultaneous inversions.

2. Materials and Method

Data processing includes processing well and seismic data. First, processing the well data in the form of determining the target interval as shown in figure 1. Determining the target interval is done by reading the log data available on both wells. In determining reservoir lithology, gamma-ray logs are used, while estimating the presence of hydrocarbon fluids is done by reading the resistivity log and the neutron-density log. It is known that the "IM" field in the North Sumatra Basin has reservoir lithology in the form of carbonate rocks. Therefore, the determination of the target interval is based on a low
gamma-ray log[13], while to see the presence of hydrocarbon fluids, it can be seen from the high resistivity log value and the presence of a cross between the neutron-density log curves.

Then the well data processing was continued with the analysis of log data sensitivity. The log data cross plot carried out includes the depth of the target interval, namely 3466 - 3852 ft for the Well IM-02 and 3772 - 4289 ft for the Well IM-01. The cross plot was carried out on each of the IM-02 and IM-01 well log data, namely acoustic impedance (Zp) and shear impedance (Zs) with color key log Gamma Ray and Water Saturation.

The cross plot between the acoustic impedance (Zp) and shear impedance(Zs) using the Gamma-Ray log color key shown in figure 2 is to see the sensitivity of the log data in separating the lithological effect, in this case, the carbonate reservoir zone and the non-reservoir zone are to be known. It is shown in Figures 1 and 2 (a&b).

![Figure 1. Determination of the Target Interval for Well IM-02 (a) Well IM-01 (b)](image-url)
The results of the cross plot in figure 2a on the left show three zones, marked with blue, green, and brown colors. The zone marked in blue is thought to be a carbonate reservoir zone with a low gamma-ray value, which is around 17-54 API having an acoustic impedance (Zp) value of 10000-30000 (ft/s*g/cc) and a shear impedance (Zs) value around 7000-20000 (ft/s*g/cc). The position of the target zone, namely the carbonate reservoir is shown in figure 2a on the right, at a depth of about 3460-3860 ft.

The results of the cross plot in figure 2b on the left show two zones, marked in blue and green. The zone marked in blue is thought to be a carbonate reservoir zone with a low gamma-ray value, which is around 15-51 API, has an acoustic impedance (Zp) value of 14000-30000 (ft/s*g/cc) and a shear impedance (Zs) value around 9000-17000 (ft/s*g/cc). The position of the target zone, which is the carbonate reservoir is shown in figure 2b on the right, at a depth of about 3780-4260 ft.

After looking at the lithological zone which is a carbonate reservoir, analyzing the log data sensitivity in the target interval to determine the fluid content. This is carried out a cross plot between the acoustic impedance (Zp) on the X-axis and the shear impedance (Zs) on the Y-axis using the water saturation color key shown in figure 3.
The cross-plot result in figure 3a on the left shows two zones, in red and blue. The zone that the red color is thought to be a carbonate reservoir containing gas with a low water saturation value, which is around 0.02-0.4 with an acoustic impedance (Zp) value of 10500-22000 (ft/s*g/cc) and a shear impedance (Zs) value is around 7000-15000 (ft/s*g/cc). The blue zone which is suspected as the reservoir zone contains water has a data distribution with a high water saturation value, around 0.8-1 with an acoustic impedance (Zp) value of 23000-33500 (ft/s*g/cc) and a shear impedance (Zs) value of 15000-21000 (ft/s*g/cc). In the cross-section of Well IM-02, which can be seen in figure 3a on the right, it is estimated that the carbonate reservoir zone with gas content is at a depth of 3460-3740 ft, while the carbonate reservoir zone with water fluid content is at a depth of about 3740-3920 ft.

The results of the cross plot in figure 3b on the left show a zone which is indicated in blue. This zone is thought to be a carbonate reservoir containing water with a high water saturation value, which is around 0.9125-1, has an acoustic impedance (Zp) value of 18000-40000 (ft/s*g/cc), and a shear impedance (Zs) value is about 8500-22000 (ft/s*g/cc). In the cross-section of Well IM-01, which can be seen in figure 3b to the right, it shows that the carbonate reservoir is saturated with water and is at a depth of about 3780-4300 ft.

After that, the process is carried out by a well to seismic tie. This is important to do because well data and seismic data have different domains, well data is a depth domain while seismic data in the time domain. Before implementing this process, the Check shot Correction must be carried out first to change the well domain to the time domain[14]. Wavelets are an important component in obtaining good information between well data and seismic data.

As shown in figure 4, the wavelet has a phase corresponding to the seismic polarity data. Wavelet extraction was carried out for each angle stack data range. The high frequency of seismic data will disappear as the angle increases (from near to far)[15]. The wavelet is used to well to seismic tie as shown in figure 5. The correlation obtained is 0.731 with a time shift of 0 ms. Then the wavelet is used to produce a low-frequency model. Low-frequency models produce Acoustic Impedance (Zp), Shear Impedance (Zs), and Density (rho).

Before carrying out a simultaneous inversion of the entire seismic volume, it is necessary to do quality control inversion or what is commonly known as pre-inversion analysis. This process is carried out in the zone around the well to control the quality of the final inversion results by changing the parameters so that they have a high enough correlation coefficient between synthetic data and seismic data.

The suitability of the parameters can be determined by transforming Zp, Zs, and the density into ln (Zp), ln (Zs), and ln (D)[16]. The cross plot results in figure 6 show the values of k, kC, m, and mC,
respectively, namely 1.0983; -1.4782; 0.275292; and -1.59271. Meanwhile, the values of ln (Zp), delta ln (Zs), and delta ln (D) are 0.284733; 0.315285; and 0.0580963. These cases are shown in figure 4-7.

**Figure 4.** Extraction of Wavelet Near, Mid, and Far Angle

**Figure 5.** Well Log Correlation

**Figure 6.** Pre-Inversion Analysis Crossplot
3. Results and discussion

The output of simultaneous inversion is the acoustic impedance (Zp) and shear impedance (Zs). The analysis of the results of the inversion was carried out on the Malacca Member Formation. Based on the stratigraphic column (Figure 7.), The Malacca Member Formation includes the Peutu, Bampo, and Parapat Formations. The cross-section of the inversion is focused on Malacca to the Base horizon. The analysis of inversion results, namely acoustic impedance (Zp) and shear impedance (Zs) was carried out in the area around Well IM-01 and Well IM-02.

In the Acoustic Impedance (Zp) section shown in figure 8, to be precise in the area around Well IM-02, under the Malacca horizon, around TWT depth of 1110 ms to 1180 ms, there is a zone that has an acoustic impedance value of around 16542 - 18917 (ft/s*g/cc). At this interval, it has been confirmed that it is a carbonate gas-bearing zone. Then it is also shown from the cross-section, precisely at a depth of around TWT 1180 ms, there is an increase in its acoustic impedance value, which is around 21292 - 23667 (ft/s*g/cc). It is known that at TWT 1180 ms depth is the contact limit for gas and water fluids contained in the reservoir. Meanwhile, in the area around Well IM-01, to be precise in the Malacca horizon, there was also an increase in the impedance value of the upper zone. Where on the Malacca horizon the Acoustic Impedance (Zp) value reaches around 18125 - 18917 (ft/s*g/cc).

There are different types of lithology between the zones above the Malacca horizon and those below it. Then, based on log data analysis, it is known that the Well IM-01, precisely above the Top Malacca horizon, is a shale which has a lower impedance value than carbonate rock. The acoustic impedance (Zp) value in the Well IM-01 area continues to increase with increasing depth. This still shows ambiguity regarding the cause of the increase in the acoustic impedance (Zp) value, due to the influence of lithology that is getting harder or the presence of fluid in the form of water. Therefore, it is necessary to validate the results of the shear impedance (Zs) section.

The area around Well IM-02 in figure 9 is precisely in the Malacca horizon were from the previous analysis it was suspected as part of a carbonate reservoir with a gas content that has a shear impedance (Zs) value of around 8375 (ft/s*g/cc). This value is also higher than the shear impedance (Zs) value in the upper zone which represents the green color which is the non-reservoir zone with the building blocks of sand with an impedance value of about 6350 (ft/s*g/cc). This can be used as validation that the increase in impedance value is due to the construction of lithology. Also, the physical explanation is because carbonate rocks have a higher level of stiffness or rigidity than clastic sedimentary rocks, such as sand and shale. However, the impedance value in the Top Malacca zone which is predicted to contain gas has a lower value than in the carbonate reservoir zone which is suspected of containing...
water with a blue to purple color, where the value reaches 18500-20525 (ft/s*g/cc). It can be shown in Figures 8 and 9.

![Figure 8. Acoustic Impedance (Zp) Inversion Cross Section](image1)

![Figure 9. Shear Impedance (Zs) Inversion Cross Section](image2)

On the map of the amplitude extracted shown in figure 10, it can be seen that the value of the acoustic impedance (Zp) and shear impedance (Zs) for the area around Well IM-01 are greater than in the area around Well IM-02. Geologically, this can be explained in several ways. First, it is known that indeed the carbonate relief or terrain on the Well IM-02 is higher than that of the carbonate terrain at the Well IM-01. Second, the carbonate of the two wells is at different closures. This condition can indicate that the carbonate facies and the depositional environment of each carbonate in Well IM-01 and IM-02 are different. Based on the results of the interpretation, it can be analyzed that the carbonate facies in the Well IM-01 are in the proximal area which has a fairly sloping depositional environment,
while the carbonate facies in the Well IM-02 are formed in the shelf margin environment which is known to have quite a high terrain[18]. This can be seen from the appearance that the carbonate in the Well IM-02 is indeed mounded more than the carbonate in the Well IM-01.

Then after analyzing the environment for carbonate formation in each well, the next explanation that supports the high impedance values of the Well IM-01 compared to IM-02 is the rise and fall of sea level. It has been previously explained that the carbonate terrain of Well IM-02 is higher than that of Well IM-01. Of course, this is also related to the environment in which each carbonate facies is formed. Therefore, what can be explained about the rise and fall of sea level is during the regression phase where the sea level falls then the coastline will move away from the land[19]. When the regression phase occurs, the carbonate in the Well IM-02 at its top will have the potential to be exposed to the surface (appearing partly above sea level). The exposure of the top of the Well IM-02 carbonate to the surface can cause carbonate diagenesis processes to occur, such as dolomitization, leaching, and others. This is also supported by the results of the petrophysical analysis where dolomite minerals were found in Well IM-02 carbonate. This process will cause the carbonate facies in Well IM-02 to experience enhancement porosity. Whereas in the Well IM-01 carbonate facies, which is in the proximal area with lower terrain, the potential for exposure to the surface during regression is very small. So that a process like that experienced by the Well IM-02 carbonate cannot occur. As a result, there is no increase in the porosity value.

After the process of increasing porosity occurs, when the hydrocarbon migration process is running, the hydrocarbon fluid will tend to fill the pores of the rock whose porosity is large[20], in this case, the Well IM-02. The presence of this hydrocarbon fluid causes the impedance value in the Well IM-02 to be lower than the impedance value in the Well IM-01.

Finally, it can be seen that the decrease in impedance value continues to expand to the southeast and east. This is following the boundaries of the North Sumatra Basin that in the eastern part is the Malacca Platform which is an area with very wide carbonate exposure[21]. From the results of this interpretation, it can be estimated that the drilling of Well IM-02 occurred because when viewed from the map, the acoustic impedance distribution tends to fall from the direction of the Well IM-01 to the IM-02, as well as the shear impedance, the event where the acoustic impedance drops but the S impedance remains, it is found in the water zone map to the gas zone, and this becomes interesting. It is shown in figure 10.

![Distribution Map for Acoustic Impedance (Zp) (Left) and Shear Impedance (Right)](image)

Figure 10. Distribution Map for Acoustic Impedance (Zp) (Left) and Shear Impedance (Right)
4. Conclusion
After carrying out all the processes, conclusions can be drawn that refer to the research objectives as follows: The simultaneous inversion method can be applied to characterize the carbonate reservoir in the "IM" Field North Sumatra Basin so that the Acoustic Impedance (Zp) and Shear Impedance (Zs) models are obtained with details on the gas reservoir acoustic impedance (Zp) values of around 16542 - 18917 (ft/s*g/cc) and the shear impedance (Zs) is around 8375 (ft/s*g/cc) while in the water reservoir the acoustic impedance (Zp) is 21292 - 23667 (ft/s*g/cc) and shear impedance (Zs) around 18500-20525 (ft/s*g/cc). It is known that the distribution area of lithology and fluid in the "IM" field of the North Sumatra Basin has a northwest-southeast orientation.

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