Reservoir Characterization with Acoustic Impedance Inversion and Multi attribute Method on “Essen” Field, Talang Akar Formation, Sub-Ciputat Basin, North West Java

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Abstract. Acoustic impedance and multi-attribute seismic inversion seismic are a number of seismic methods that can be used to map sandstone reservoir distribution. Using this method, we can separate the sandstone and shale in the Talang Akar Formation found on the “Essen” Field, Ciputat Sub-Basin. Both of these methods will be compared with each other in order to get more valid results in sandstone reservoir mapping. The inversion method used in this study is a model-based method. While the multi-attribute method used is the neural network in mapping gamma-ray volume, shale volume, and porosity. The inversion results are not able to image the sandstone distribution good enough because the range is too large and there is overlapping on the acoustic impedance values of sandstones with ranges (8000-12000) (m/s)*(g/cc). The results of the gamma-ray multi-attribute, shale volume and porosity, have been shown to consistently show the distribution of sandstones that have a trend in the distribution of NW-SE reservoir zones. From the results of the analysis there are several potential areas that have the potential to become the next development area, namely the distribution of sandstones in the northern part with high effective porosity, and good seals; In the south with a large volume of sandstones; as well as the distribution formed on the channel surrounding the fault.

1. Introduction

In hydrocarbon exploration, seismic reflection is the main method used nowadays. The widely used seismic method can provide a geological structure and bottom surface coating with high detail and accuracy. In addition, penetration power is also very suitable to see the potential for adequate hydrocarbons [7]. In order to be able to increase the success ratio in drilling, reservoir characterization needs to be done, i.e. further analysis not only in the reflector field but also in its rock properties.

One effort that can be made to characterize the reservoir is the use of the inversion method. The inversion method enables us to transform seismic amplitude into a seismic attribute called Acoustic Impedance. Seismic inversion can provide a description of the fluid and lithology of the reservoir [8].

For a better reservoir characterization, a multi-attribute analysis might be necessary. Multi-attribute analysis, in this case, adopts a statistical approach that uses more than one attribute for the prediction of several physical properties of the earth [1]. It is expected that a good lateral resolution can be obtained while identifying the distribution of the existing rocks.
2. Regional Geology
According to Padmosukismo [2], the North West Java Basin regionally is a back-arc system located between the Sunda Microplates and the Indian-Australian plate supports. The North West Java Basin is affected by a block faulting system that runs north-south. This north-south trending fault system divides the North West Java Basin into a graben or several sub-basins from west to east, namely the Ciputat sub-basin, the Pasir Putih sub-basin and the Jatibarang sub-basin. Each sub-basin is separated by height (the block rises from the fault) as shown in Figure 1.

![Figure 1: Regional geology of the North West Java Basin (Martodjojo, op. Cit. Nopyansyah, 2007)](image1)

Sedimentation in The North West Java Basin has a range of ages from the Middle Eocene to the Quaternary. The oldest deposit is in the Middle Eocene, namely in the Jatibarang Formation which was deposited unconformably on the Rock Base. The regional stratigraphy sequences from the oldest to the youngest are Batuan Base, Jatibarang Formation, Lower Cibulakan Formation (Talang Akar, Baturaja), Upper Cibulakan Formation (Massive, Main, Pre-Parigi), Parigi Formation and Cisubuh Formation, as illustrated in Figure 2.

![Figure 2: Stratigraphic Columns of the North West Java Basin (Arpandi and Padmosukismo, 1975)](image2)

3. Data & Method

3.1. Data
The data used in this study are seismic and well data. Seismic data used in this study are post-stack time migration with 972 (861-1832) inline numbers, 904 (5001-5904) cross line numbers, with a sampling rate of 2ms with zero phases. This is determined based on the reflection coefficient on the boundary
between layers in the well data, where the increase in the acoustic impedance is shown as the peak in the seismic. The good data used in this study are PDM-1, PDM-2, and PDM-4, where each well has a variety of log data that will be used in this study, among them are gamma-ray, neutron porosity, density, sonic and check shots data.

3.2. Method
In this study, two methods will be used namely post-stack seismic inversion, and multi-attribute analysis. The seismic inversion method is basically a process of transforming seismic amplitude value to impedance value. This is done by deconvolution process which transforms seismic traces to earth reflectivity. The post-stack seismic inversion methods use stacked (zero-offset) seismic data to produce images of the AI in depth or time. AI is one of the rock-physics parameters, which is influenced by the type of lithology, porosity, fluid content, depth, pressure and temperature.

An updated approach to inversion is a model-based inversion where an initial low-frequency model is modified iteratively to give the best fit to seismic data. It avoids the problems of recursive inversion by iteratively changing a model to give a least-squares fit to the seismic data [5]. The main step in the inversion procedure includes the data preparation and data input into the software, calibration by tying well logs to the seismic data, estimation of the wavelet, generation of a low resolution initial model, inversion analysis, and inversion.

Multi-attribute seismic analysis is one of the statistical methods using more than one attribute to predict multiple physical properties of the earth. In this analysis, the relationship between logs and seismic data at the location of wells is sought and then uses these relationships to predict or estimate the volume of the log property at all locations in the seismic volume [4]. Statistics in reservoir characteristics are used to estimate and simulate the relationship of variable spacing to the desired value at locations that do not have measurable sample data. This is based on the fact that it often occurs in nature that the measurement of a variable in an adjacent area is the same.

4. Result and Discussion

4.1. Log Analysis & Cross-plot
The first step taken at this stage is to determine the formation boundaries and correlate them by making a top and bottom markers for each well. After that, the type of layer is identified.

![Figure 3: Target zone quick-look on PDM-01, PDM-03, and PDM-04 well](image)

From Figure 3 above the sandstone, a layer is shown in yellow, the carbonate layer is shown in blue and the shale layer is shown in green. The interesting zone is bounded by TAF (Talang Akar Formation) and JTB (Jatibarang Formation) markers. Cross plot that has been carried out including p-impedance -
gamma ray which is used to see whether the results of the acoustic impedance inversion, can later separate the layers of sandstone and shale.

![Figure 4: Cross plot Analysis: Acoustic Impedance – Gamma Ray](image)

In Figure 4, it can be seen that sandstones with shale are quite separable even though there is some overlapping. From the gamma-ray cross plot analysis, there are 4 zones that can be separated. The area circled in red is coal, the blue area is the shale layer, while yellow is a sand layer characterized by gamma-ray values lower than shale (<75 API), and has a concentration of P-Impedance values between 8500 - 12000 (m / s) * (g / cc). The last zone which is purple is the carbonate layer.

4.2. Acoustic Impedance Inversion Result

In conducting inversion analysis, the first thing to do after the well-tie is to make an initial model. The initial model is a model made based on the results of the good tie & picking horizon. The frequency parameter used is high cut with frequencies ranging from 10/15 Hz. After that, the inversion result is conducted in the area of interest. The result is using 60% upper and lower hard constraint, with average block size 0ms, pre-whitening 1%, and 10 times iteration. Here is the impedance inversion result is shown in Figure 5.

![Figure 5: Impedance Inversion Result](image)

Based on the previous cross plot analysis, sandstone (gamma-ray > 75 API), apparently has a P-impedance value that is wide, which is between 5000-12000 (m / s) * (g / cc). However, by referring to the higher concentration of the P-impedance values in the sandstone layer, it can be assumed that the value tends to fall in the number 8500-12000 (m / s) * (g / cc), which indicates that the sandstone layer in the "Essen" field is probably compacted.
After that, the slicing is performed on the volume of inversion based on the model. The slicing parameter used is in accordance with the results of the interpretation in the previous log analysis, which is to do the slicing by averaging the amplitude values that exist along with the TAF -35 ms marker. While referring to the results of the cross plot, it can be seen that the sandstone layer will show p-impedance values ranging between 8500-12000 (m / s) * (g / cc), while the shale layer has a lower acoustic impedance value. As for the coal seams in this formation, they are considered negligible and will not damage the desired results. That is because the coal layer in this formation is a very thin layer.

By comparing the results of the slicing inversion with the seismic map slicing in Figure 10a, we can see that the sandstone reservoir is concentrated on the basin area shown on the black line circle. In the results of slicing inversion, it is seen that the spread of sandstone reservoirs is in several areas: in the north, south, and there is also a spread around the fault.

However, the slice resulting from this inversion has not been able to clearly and surely give the spread of sandstones, due to the wide range of acoustic impedance values in sandstones and overlapping with other rock types as we saw in the previous crossplot analysis. To help clarify the distribution of sandstone, multi-attribute analysis is necessary.

4.3. Multiattribute analysis result

In this analysis, an important parameter to be considered is the maximum number of attributes to use. In this study, the author uses the Emerge module of HRS software to look for groups of attributes that can be combined to predict targets. This is done by the process called step-wise regression. This means that the first search is determined by a single attribute from the list that predicts best by itself. The criterion for evaluating predictions is an RMS (root mean square) error. In other words, Emerge tries every attribute, calculates RMS errors, and determines the best single attribute as the attribute with the lowest error. After finding the single best attribute, Emerge looks for the best attribute pair, assuming that one of the pairs is the single attribute that has just been discovered. Once again this is done by trial and error, solving the system of equations as many attributes to be paired.

4.3.1. Vshale multiattribute result

| Final Attribute | Training Error | Validation Error |
|-----------------|----------------|-------------------|
| 1. Inverted Zp p2 | 19.298667 | 21.063429 |
| 2. Filter 15/20-25/30 | 18.307896 | 20.478709 |
| 3. Filter 25/30-35/40 | 17.704730 | 20.157714 |
| 4. Derivative | 16.769289 | 19.632022 |
| 5. Integrated Absolute Amplitude | 16.206346 | 15.418142 |
| 6. Time | 16.159779 | 19.334331 |
| 7. Quadrature Trace | 15.603501 | 15.745090 |
| 8. Filter 35/45-45/50 | 15.411449 | 15.423565 |
| 9. Amplitude Weighted Phase | 15.209735 | 10.148041 |

Figure 6: List of the attribute used in predicting shale volume values as well as error graphics and error validation
Figure 7: Similarities of trends and crossplot results between predicted Volume Shale and actual Volume Shale

From the results of the analysis in Figure 6, we can see that 5 attributes at once will give the best result because it provides the best validation and error. We can also see from Figure 7 that the correlation result is 0.92 with an error of 9.8%. From these results, it can be assumed that the multi-attribute seismic method is good enough to be validated and justified in characterizing the reservoir zone.

In Figure 10b, we can see that the low shale volume in the area indicates that it contains little shale in the zone and is good for the reservoir zone. From the shale volume parameter, it can be assumed that the presence of sandstones is indicated by a vshale value below 54%. Because the shale volume parameter is directly proportional to how much the shale content if the shale volume value is higher, it also means that the area of lithology contains a lot of shales [2].

Shale volume below 54% are considered as an indication of sandstones shown in green-yellow-red color. Based on this map of shale volume attributes, the trend of sandstone distribution leads to the NW-SE, and is spread in the lowlands of the south, highlands in the north, and there are also spread around the fault.

4.3.2. Effective Porosity Multi-attribute Results

Figure 8: List of the attribute used in predicting porosity values as well as error graphics and error validation
Figure 9: Similarities of trends and cross plot results between predicted Porosity and actual Porosity

From the result above in Figure 8, we can see that effective porosity results provide sufficient results to be able to provide log predictions. The author decides to use up to three attributes because if added 4 attributes the validation results will be reduced. From Figure 9 we can see the correlation results obtained are 0.78 with an error of 4.07%. Cross plot results and similarity results of trends provide sufficient results.

The porosity map in Figure 10c was obtained after a multi-attribute analysis. It can be assumed that the sand porosity value ranged from 8.7-13% which is marked as color blue to purple (good enough) [5]. Based on the results, it can be concluded that the sandstone in this area is dominated by compacted sandstone. Areas that have high porosity values will be ideal as reservoirs because hydrocarbon fluids will enter the reservoir through rock pores and will be trapped in the reservoir if the reservoir is surrounded or limited by impermeable rocks such as shale [5]. It can also be seen that the area suspected to be a sandstone is flanked or surrounded by impermeable rocks so that reservoirs can form.

It can be seen that sandstone distribution based on the porosity map leads to NW-SE along with the normal fault in the SE direction, and also gather a lot in the low closure which is indicated by the red circle boundary.
4.3.3. **Interpretations from inversion and multiattribute slicing maps**

![Image](image_url)

**Figure 10:** a) Impedance Inversion Slicing b) multi-attribute slicing of shale volume c) multi-attribute slicing of effective porosity all at an altitude of 35 ms above the Jatibarang horizon.

We can see from the inversion slicing map (**Figure 10a**) that the sandstone reservoir is consistently concentrated in several locations. We can see several concentration on the faults as shown in numbers 4 and 5. In the northern part shown by numbers 1, 2 and 3, we can see the spread of deltaic fluvial sandstones that may originate from a source in the northern part of the map. This is appropriate when compared to the Jatibarang horizon map because fluvial deltaic is in the highlands. At numbers 4 & 6 there are several sandstone distributions that may originate from sources on the southeast, while at number 7 there are also sandstone distributions that may originate from sources on the western part, but this needs to be confirmed again due to limited seismic data that is owned. In areas marked on numbers 4 & 5, it is seen that it forms a channel or river which is possibly an ancient river that is controlled by a fault but has not been connected/disconnected with the source due to deposition of sediment.

However, the slice resulting from this inversion has not been able to clearly and surely give the spread of sandstones, due to the wide range of acoustic impedance values in sandstones and overlapping with other rock types as we saw in the previous crossplot analysis. To help clarify the distribution of sandstone, multi-attribute analysis is needed.
If you look at the vshale multi-attribute map (Figure 10b), there is consistency of sandstones distribution as obtained from the seismic inversion map. With numbers 1, 2, and 3 in the form of deltaic fluvial. In area number 6 on the vshale (Figure 10b), and porosity map (Figure 10c), it can be seen more clearly that there is a distribution of sandstones that may have resulted from sources in the southeast. In the area No. 5 it is possible that a shallow marine deposition that flows from the north may emerge, resulting in thinner and less continuous sand. Area Number 7 appeared to be controlled by faults which are shown on the jatibarang horizon map. Numbers 4 and 5 on the vshale map (Figure 10b) appear to have low values and forms a channel. It is assumed that the river may be controlled by a fault that leads north-west so it looks curved around the fault. But on the porosity map (Figure 10c), areas number 5 and 3 have a porosity result that is not too good, so that it may be taken into consideration for future decisions. The results of the multi-attribute analysis are proven to validate the results of seismic inversion. The main structure in this field is a high closure and 2 normal faults in the south. Reservoir traps contained in the "Essen" field are structural and stratigraphic traps where fault, fracture, fold, and stratigraphy affect the sandstone distribution.

From the results of the analysis, there are several potential areas that may be considered to be the next drilling area. First is on the north with the deltaic fluvial depositional environment, a fairly high effective porosity, and closed with shale, so there is good potential for reservoirs. The second area which is quite potential is in the southern part where there is a large sandstone distribution area. However, there is a lack of seal from shale, so the possibility of leakage/migration is quite high. The third area which may have the highest risk is the area around the fault where there is good distribution and seal, but it has a tighter sand content.

5. Conclusions

From this study, we can conclude that the Acoustic Impedance inversion method is less effective in distinguishing lithology because the range is too large and the existing overlapping on the value of the acoustic impedance, so that the lithology of the sandstone cannot be dissipated. The multi-attribute analysis provides the distribution of shale volume values with a range of values <0.54%, and porosity values ranging from 8.7 to 13% (porosity is good enough). The application of the multi-attribute method to the "Essen" field gives the trend of hydrocarbon reservoir zone distribution in the NW-SE (South West-North East) direction and converges on the low closure and fault area. There are several areas that have the potential to become the next drilling area, namely the distribution of sandstones in the north with good porosity and seals, In the south with a large volume of sandstones, as well as the distribution that forms in the channel surrounding the fault.

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