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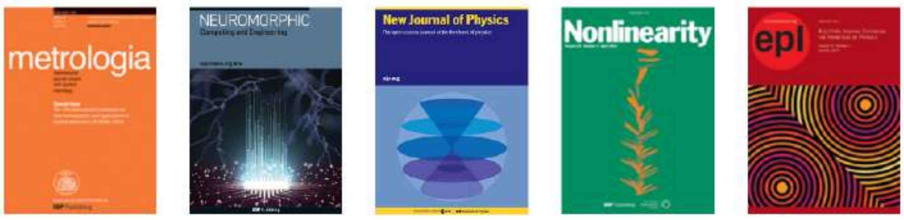

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Reservoir properties prediction using seismic inversion and geostatistical integration

To cite this article: O Dewanto *et al* 2021 *IOP Conf. Ser.: Mater. Sci. Eng.* **1173** 012008

Reservoir properties prediction using seismic inversion and geostatistical integration

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Abstract. Exploration and production in the sand reservoir still have their challenges due to the low porosity and permeability characteristics. This study was conducted to analyse the characteristics of a tight sand reservoir based on a log property distribution map, using acoustic impedance inversion and multi-attribute analysis. Stepwise regression multi-attribute analysis is a method that uses the best attributes to predict the target log by going through a trial and error process. Choosing the right seismic attributes can provide a better depiction of the target zone. This research was conducted to obtain a map of subsurface geological structures, acoustic impedance volumes. Then, we performed a multi-attribute analysis to obtain a prediction of volume log properties such as pseudo gamma-ray, density and porosity using the stepwise regression method. The results of acoustic impedance seismic inversion and stepwise regression multi-attribute analysis shows that the reservoir is a gas with tight sand lithology, which has a range of acoustic impedance values of 15,000 ((ft/s)*(g/cc)) up to 30,000 ((ft/s)*(g/cc)), porosity of 12% to 24%, and the distribution of Sw of 8-13%. The density and porosity maps obtained from the multi-attributes analysis can help in the long-term exploration and production stages. Its aims are to improve primary recovery and tertiary recovery, understanding the stratigraphic traps, and continuity of reservoir layers.

Keywords: qualitative and quantitative analysis, porosity, saturation water, petrophysics

1. Introduction

One of the reservoir characteristics that can be measured by geophysical methods is porosity [1]. Porosity modeling can be obtained through acoustic impedance seismic inversion (IA), using both 2D and 3D seismic data [2]. Seismic inversion IA is a method that can estimate subsurface physical properties in the form of IA values through seismic data as input and well data as control [3]. Seismic data is highly influenced by the bandwidth with a thin layer below the thickness of the tuning resolution which cannot be separated properly. While the well data has high resolution, so it can display the rock layers in detail. The integration of the two can be used to solve the problem of thin layer under tuning thickness, depending on the quality and completeness of the data [4].

The multi-attribute seismic approach can be used to predict well log property data and seismic volume. including porosity [5]. The porosity obtained through the multi-attribute approach is closer to the actual subsurface conditions than using the one-attribute approach (AI) [6]. The objective of a multi-attribute transformation is a linear or nonlinear transformation between the attribute subset and the target log value. The selected subset is determined by the step wise regression process, namely by looking for a larger subset of attributes. The conventional extension of the cross-plot involves the use of convolutional operators to resolve the frequency difference between the target log and the seismic data [7].

AI distribution maps and log property distribution maps (porosity, density, etc.) can be used for reservoir characteristic analysis and reservoir prospect zone location determination. The data generated from the AI inversion process and multi-attribute seismic will later be used to create a porosity distribution in the research area so that it can be used to analyze reservoir characteristics.

2. Methods

2.1. Data

We use seismic data in the form of 3D Post-Stack Time Migration (PSTM) data, which is equipped with an inline of 300 lines running from east-west and an xline that runs from north-south as many as 800 lines, and there are data from 4 wells, namely the ZR-1, ZR-2, ZR-3, and ZR-4 well. This well log data will assist in identifying hydrocarbon zones and lithological characters in the study area. In addition, there is check-shot data in the form of depth with a travel time of Two-Way Time (TWT). In addition, there is also marker data that contains information on the depth of the layers of a rock. In data processing, there are several processes carried out including qualitative and quantitative interpretation, well seismic tie, horizon interpretation, fault interpretation, time structure map creation, time structure map conversion to depth, isopach map creation, initial modeling (initial model), pre-analysis. inversion, AI distribution map, and multi attribute analysis to get seismic volume.

2.2. Geostatistical inversion

Russell (1988) [3] divides the inversion seismic method into two groups, namely pre-stack inversion and post-stack inversion. This research will discuss post-stack inversion related to amplitude inversion, in which this inversion consists of several algorithms such as bandlimited (recursive) inversion, model-based inversion, and sparse-spike inversion.

We tried to increase the conventional inversion seismic constraints such as predicting log AI properties. Attributes in seismic data have a statistical relationship with well log data such as porosity logs [8-11]. So that multi-attribute seismic analysis is also called a term that includes all geostatistical methods that use more than one attribute to predict several physical properties of the earth. Bivariate geo-statistics is clearly the simplest subset of multivariate techniques and standard co-kriging techniques, otherwise known as multivariate geo-statistics. However, in this study we will use a geostatistical method that uses more than two variables. Even so, there are many different methods included in this heading. There are three main subcategories [7]:

a) The expansion of co-kriging includes more than one secondary attribute to predict the main parameter.
b) A method that uses a covariance matrix to predict the parameters of the linear weighted number of input attributes.
c) A method that uses artificial neural networks or nonlinear optimization techniques to combine attributes into the desired parameter estimation.

In this study, the multi-attribute method will be used as in the second point.

3. Results and discussion

3.1. Reservoir zone potential

In the ZR-1 well, the top reservoir layer is at a depth of 4188 ft, and the base reservoir is at a depth of 4425 ft, so that the reservoir thickness indicated to contain hydrocarbons in the ZR-1 well is about 237 ft or about 72 m. Based on the resistivity value in the LLD log, the very high resistivity value in the reservoir layer, with a value of more than 80 ohm-m, indicates that the type of hydrocarbon fluid in the ZR-1 well is a gas.

In the ZR-2 well, the top reservoir layer is at a depth of 4225 ft, while the base reservoir is at a depth of 4540 ft, so that the reservoir thickness in the ZR-2 well is about 315 ft or about 96 m. The type of hydrocarbon fluid in the ZR-2 well is also indicated as gas, because of its high resistivity value, which is more than 80 ohm-m. In the ZR-3 well, the top reservoir layer is at a depth of 3978 ft, while the base reservoir is at a depth of 4258 ft, so that the reservoir thickness in the ZR-2 well is about 280 ft or about 85 meters. The resistance value of the reservoir layer in the ZR-3 well is very high, more than 80 ohm-m, and some layers even reach 2000 ohm-m. This high resistivity value indicates that the type of hydrocarbon in the reservoir in the ZR-3 well is gas. In the ZR-4 well, no reservoir layers were found. Based on the Gamma-Ray (*GR*) log, there are only a few thin layers that have good permeability which are indicated by low *GR* values, namely at the depths of 4473-4486 ft, 4840-4852 ft, 5016-5034 ft and 5168-5199 ft. Although there are several permeable layers, in the ZR-4 well, no cross-section (separation) was found between the RHOB and NPHI logs. Based on the resistivity value in the LLD log, there was no layer that had a high contrast resistance value in a layer that had good permeability, so it can be concluded that in the ZR-4 well there was no prospect layer containing hydrocarbons.

3.2. Sensitivity analysis

Sensitivity analysis is used to obtain the lithological distribution and characteristics of the reservoir or zone of interest. The lithological separation is based on the results of the cross-plot data between p-impedance, gamma ray and porosity. The p-impedance value we get from the multiplication of the p-wave and the density. The cross-plot result of this sensitivity analysis can see the separation between the interest zone which is sandstone and shale lithology. Based on the results of the cross-plot that has been carried out, the separation of sand and shale is considered sensitive because it is able to separate the boundary between sand and shale in the target zone.

From the cross plot between acoustic impedance logs, neutron porosity and gamma ray, it can be seen that high acoustic impedance values are associated with relatively low porosity values, because the lithology of this reservoir is tight sand. In the four wells, the results of the cross-plot analysis were divided into two zones, namely tight sand and shale. The tight sand zone is characterized by high impedance values, low gamma rays, and relatively low porosity. As well as the shale zone has a low impedance value, high gamma ray, and relatively high porosity. The results of this analysis can make it easier to determine the character and reservoir model of the research area. From the results of this cross plot, it is found that the acoustic impedance limit for tight sand in the ZR-1 well and the ZR-2 well is greater than 30,000 ((ft/s)*(g/cc)), while the ZR-3 well and ZR-4 well are more than 27,500 ((ft/s)*(g/cc)).

3.3. Initial model

Initial modeling is performed as a basic model for seismic inversion. This initial model determines whether the inversion result is good or not. The initial model will be used as a control in inversion. If the model results are good, then inversion can be continued. However, if the model does not match the subsurface model, then the model is made again by changing the inversion parameters, such as wavelet, well tie and picking horizon. Based on the results of the model obtained, the reservoir zone has an acoustic impedance value of 15,000 - 35,000 ((ft/s)*(g/cc)).

Table 1 shows the correlation values of the inversion results of the wells ZR-1, ZR-2, ZR-3 and ZR-4. This analysis is carried out to see whether the results of our initial model are correct or not. If the error is small and the correlation between the acoustic impedance value of the log, the initial model and the inversion result are close to 1 then the inversion can be performed. However, if the error is large and the correlation is small, then we have to create a new initial model by updating the wavelet, well tie or picking horizon results.

Table 1. The Correlation Value of ZR-1, ZR-2, ZR-3 and ZR-4 wells inversion results

No	Well	Correlation
1	ZR-1	0.981
2	ZR-2	0.984
3	ZR-3	0.995
4	ZR-4	0.975

The results of the inversion analysis using the model-based method. This analysis was carried out several times until a parameter that was deemed good enough to be applied to inversion was obtained. Analysis can be said to be good if the correlation value is high and the error rate is low. Based on the results of the inversion analysis, the correlation value between the acoustic impedance values of the wells, models and inversions is very good for the four wells, namely the average correlation is 0.983. This value is declared good so that inversion can be done.

3.4. Inversion result analysis

After the initial model has been formed and the error is small, the AI inversion is then carried out according to the inversion AI model that has been made. Acoustic impedance inversion is done by using model-based method after obtaining the best initial model. Inversion is carried out at the boundary of the top reservoir horizon zone to the base reservoir.

Based on Figure 1, the inversion results produce a cross section of the acoustic impedance model and are able to distinguish acoustic impedance zones based on the color and scale of the acoustic impedance values. The zone with the lowest impedance is shown in green and the zone with the highest impedance is shown in purple.

To see the suitability of the inversion AI value with the AI value from the log, a comparison is made on the cross section of the AI inversion result from the log, which can be seen in Figure 1. Based on this comparison, it shows that there is a match between the inversion AI value and the log AI value. For the four wells used, when the AI value from the log shows a low value which is marked in yellow to red in the cross section of the inversion results it shows a low value, as well as a high AI value, so it can be concluded that the inversion results made are very low.

In general, the results of Acoustic Impedance inversion show low values in the target zone, namely the top reservoir and the base reservoir. Where in the targeted sandstone reservoirs in the ZR-1, ZR-2 and ZR-3 wells, the acoustic impedance is in the range of values 15,000 ((ft/s)*(g/cc)) - 30,000 ((ft/s)*(g/cc)) indicated by yellow to red. The low AI value in the reservoir zone is in accordance with the previous sensitivity analysis, that the AI value which is less than 30,000 ((ft/s)*(g/cc)) is a zone containing gas, while the ZR-4 well has a high acoustic impedance value which is more than 30,000 ((ft/s)*(g/cc)). The high AI value in the ZR-4 well is in accordance with the previous petrophysical analysis, that this well does not contain hydrocarbons, so the AI value is relatively high because the lithology in the research area is tight sand.

After inversion is carried out, slicing is carried out in the reservoir zone to see the distribution of AI. The AI slice is carried out at a time of 0 + 50 millisecond below the horizontal top reservoir as shown in Figure 1. It can be seen that the AI distribution value in the area ranges from 8000-30000 ((ft/s)*(g/cc)). However, for the productive reservoir areas, namely in the ZR-1, ZR-2, and ZR-3 wells, there is a low AI value, namely 8000-20000 ((ft/s)*(g/cc)), while for the area in the ZR-4 well has an AI value higher than the productive area, because the well does not contain hydrocarbons.

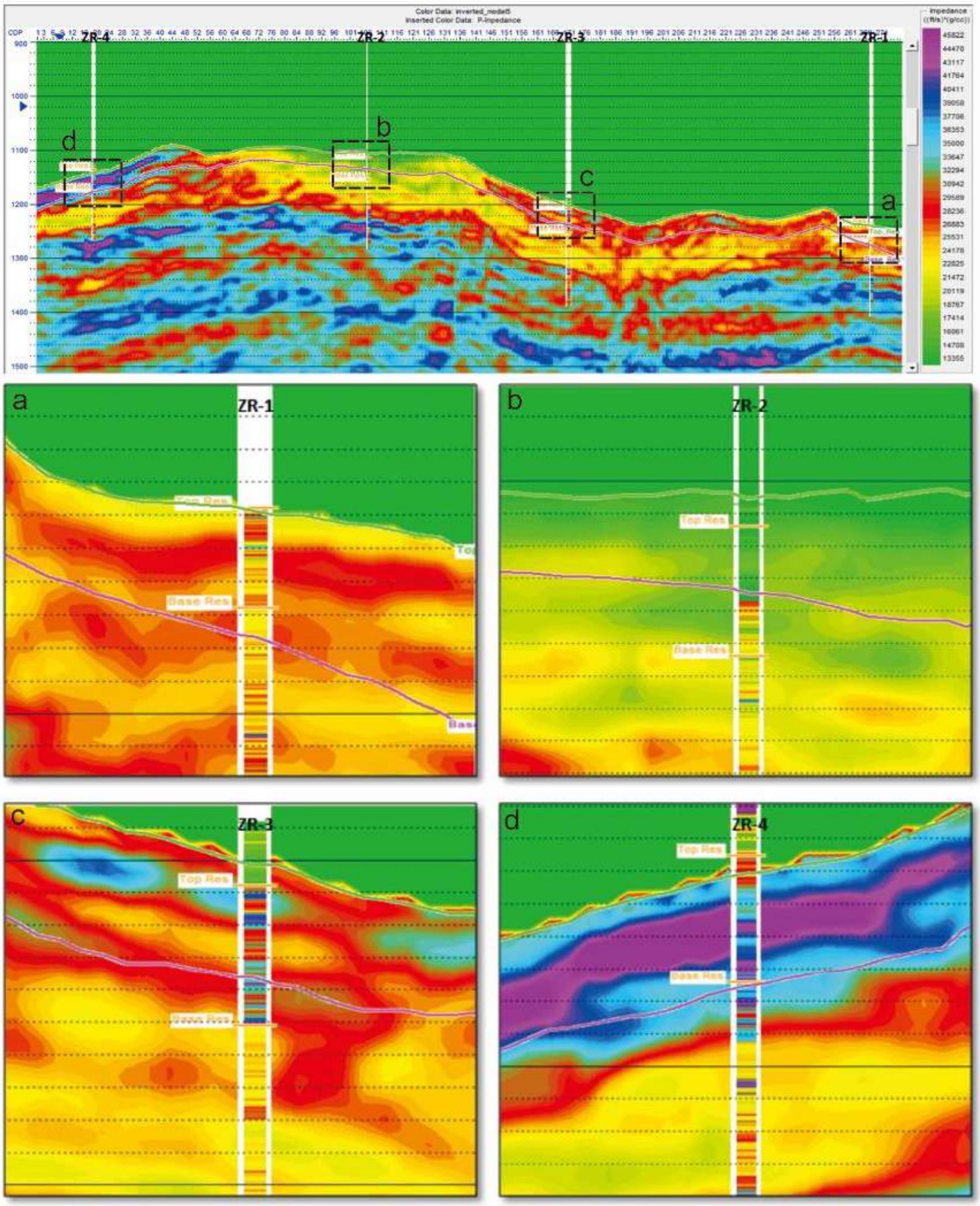

Figure 1. The results of the inversion on the seismic section using a model-based method with details on each well (ZR-1 to ZR-4).

3.5. Properties distribution map

The map of the distribution of porosity is obtained from the equation of the relationship between density and effective porosity in petrophysical analysis. Based on the map of the distribution of porosity in the figure, it can be seen that the value of the porosity in the prospect zone is high, which is around 12-24%.

The map of the distribution of porosity is obtained from the equation of the relationship between density and effective porosity in petrophysical analysis. The effective porosity and density values of the

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petrophysical analysis were plotted to obtain the equation of the relationship between porosity and density. The equation of the relationship between density and porosity obtained in the study area is as shown in Figure 2. From the relationship graph above, it is obtained the equation y = -0.392x + 1.054 and it can be seen that the correlation value is 0.905, this indicates a strong correlation between porosity and density. After obtaining this equation, a porosity distribution map has made. Based on the porosity distribution map in the figure high value prospect zone, which is around 12-24%.

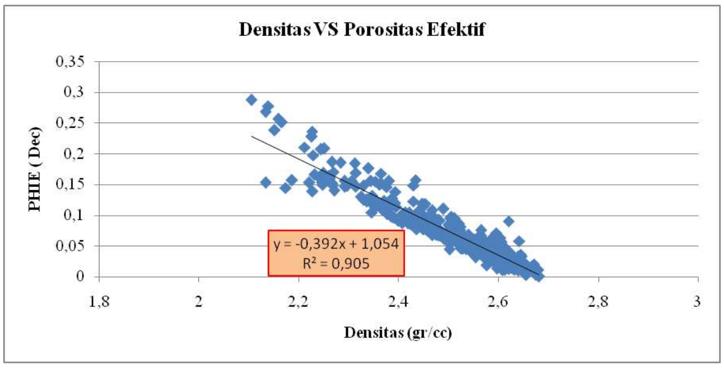

Figure 2. Density and porosity relationship.

The water saturation (*Sw*) value can be obtained from the division between the constant value and the effective porosity. This constant value is obtained from the division between water saturation and effective porosity obtained from log processing. Then the average value of the constant is taken. To get the water saturation value that will be distributed on the map, this constant value is divided by the porosity value resulting from the decrease in AI inversion. Based on the calculation results, the constant value is 0.017. Based on the *Sw* distribution map above, it can be seen that in the prospect area marked with ZR-1, ZR-2 and ZR-3 wells, they have a small *Sw* value, which ranges from 8-13%. This small value indicates that the area is very prospective for containing hydrocarbons, because it has a low water content.

4. Conclusions

The results of the petrophysical analysis show that the ZR-1, ZR-2 and ZR-3 wells have a target zone containing gas hydrocarbons, while the ZR-4 well does not have a prospect zone. The area around the wells ZR-1, ZR-2 and ZR-3 is a prospect area containing gaseous hydrocarbons, which is characterized by the distribution of AI (acoustic impedance) of 15,000 (ft/s)*(g/cc) - 30,000 (ft/s)*(g/cc), the distribution of porosity value is 12-24%, and the distribution of *Sw* is 8-13%.

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