Reservoir characterisation using J-attribute as a new attribute to reduce ambiguity in predicting reservoirs

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Abstract. The Amplitude Variation Offset (AVO) technique has often been used to predict the deposition of hydrocarbons. Knott and Zoeppritz developed the AVO method by using values of primary wave velocity \(v_p\), secondary wave velocity \(v_s\) and density. Then, Rutherford and William divide AVO into 4 classes based on intercept and gradient charts. This method is successfully used to predict hydrocarbons. However, in some cases there are still ambiguities and misinterpretations such as those occurring in oil and water which assess large porosity and similar characters, so that in this study required a new AVO attribute proposed by the name J-attribute to study hydrocarbons and use ambiguous in the results interpretation. The J-attribute method is a new method in Indonesia, which has not yet been tried in the Indonesian field so this research wants to prove the working principle of the J-attribute method required to provide maximum results in determining the fluid. This method is carried out in the Fauna Field, which is made in the North Sumatra Basin. The data used in this study 3 wells equipped with markers and log data such as Gamma Ray, SP, Caliper, Neutron Porosity, Density, Resistivity, DT, Photoelectric, and check shot.

1. Introduction
The Amplitude Variation Offset (AVO) technique is commonly used for hydrocarbon prediction. The AVO method is based in principle on the small angle and small contrast approximations of the Zoeppritz Equation. Theoretically, Knott and Zoeppritz developed the AVO method by requiring values of primary wave velocity \(v_p\), secondary wave velocity \(v_s\) and density [1]. Then Rutherford and William divided AVO into four classes based on intercept and gradient graphs. Lately, AVO attribute method could be useful in predicting the presence of hydrocarbons based on the value of the intercept and gradient. This method was successful in most cases, but there were some cases where the results were ambiguous. One example of this case is when the response logs contain water or oil fluids, both of which have large porosity and have similar properties. So, from this case the results obtained often experience errors in interpretation by a geophysicist. So, this research proposes a new attribute called "J" attribute that can be used in predicting hydrocarbons and reducing ambiguity. The J-Attribute method is a new method that has not been widely used in Indonesia, so this research also wants to prove the working principle of the J-attribute method which is expected to provide maximum results in distinguishing fluids. To reduce the ambiguity that occurs in hydrocarbon cases, the J-attribute method can use the Biot-Gassman theory which can later analyze in more detail the difference between fluids containing water or oil.
2. Regional Geology
This research is in the North Sumatra Basin, which is in the western part of the Sunda land with an area of about 60,000 km² of land and offshore. This area has been producing for more than 100 years and is one of the most productive sedimentary basins in Indonesia. Regional Geology of the North Sumatra Basin. The Sumatra Basin is the result of the interaction of two plates, namely the Indian Plate and the Eurasian Plate which causes changes in angle and velocity from one place to another. The North Sumatra Basin is a basin with a back-arc basin type, the structural development of this basin is relative complex. The North Sumatra Basin contains two main sources of sedimentation in the Middle Miocene, from granitic terrain in the Northeast area, namely the Asahan hill area and Peninsula Malaysia towards the West which are intruded by granite and volcanism (Morton, A.C., et al., 1994).

3. Basic Theory

3.1 Amplitude Versus Offset
The Amplitude Versus Offset (AVO) or Amplitude Versus Angle (AVA) method is a method based on changing the value of the reflection signal to the distance or angle from the wave source to the receiver, in this case the greater the distance from the source to the receiver (offset) the angle greater of incidence. It is then possible to connect the seismic amplitude with the angle of reflection and the physical characteristics of the elastic rock in a rock layer using the Zoeppritz equation. The equation in 1919 explained the division of the energy partition of a wave when it hit a layer boundary. In general, where an incident wave touches the boundary of the layer, some of the energy will be reflected and part of it will be transmitted. The angle between the reflected wave and the line perpendicular to the boundary plane (normal line) is called the angle of reflection, while the angle between the transmission wave and the normal line is called the transmission angle. This is in accordance with Snellius's Law that applies to optics [2]. Another equation presented by Shuey [3]. In this case using parameters of wave velocity P (v_p), wave velocity S (v_s) and density (ρ) to calculate the reflection coefficient under normal conditions, the AVO intercept (R0) and the AVO gradient (G), are formulated as follows:

\[ R(\theta) \approx R_0 + G \sin^2 \theta + \frac{1}{2} \frac{\Delta v_p}{v_p} \left( \tan \theta - \sin \theta \right) \]  

Where

\[ R_0 = \frac{1}{2} \left( \frac{\Delta v_p}{v_p} + \frac{\Delta \rho}{\rho} \right) \]  

\[ G = \frac{1}{2} \frac{\Delta v_p}{v_p} - 2 \frac{v_s^2}{v_p} \left( \frac{\Delta \rho}{\rho} + 2 \frac{\Delta v_s}{v_s} \right) \]

3.2 J-Attribute
The J-attribute method is part of the AVO Intercept and Gradient calculation according to Shuey's equation. The value of Jp has similarities with Js, except that Jp occurs in the P wave. When there is a layer of hydrocarbon sand or shale, then the value of Jp will decrease or decrease, while the value of Js will increase. Attribute Js can be defined from the Intercept equation and the AVO gradient as follows [4]:

\[ J_s = 2 \left( \frac{\Delta \rho}{\rho} + 2 \frac{\Delta v_s}{v_s} \right) / (y)^2 \]  

\[ J_p = 2 \left( \frac{\Delta \rho}{\rho} + 2 \frac{\Delta v_p}{v_p} \right) / (y)^2 \]
Where

\[ v_p = \frac{(v_{p2} + v_{p1})}{2} \]  \hspace{1cm} (6)

\[ v_s = \frac{(v_{s2} + v_{s1})}{2} \]  \hspace{1cm} (7)

In the J-attribute equation there is a value of \( \gamma \) which is the value of \( \frac{v_p}{v_s} \) between one layer and another. The value of \( \gamma \) can be calculated from the well data using the Gassman equation. If applied to seismic data, the values of \( v_p, v_s, \rho \) to one layer and another layer cannot be directly searched, so that intercept and gradient values are needed. The Gardner equation relationship can help provide constants that will later function in determining the contrast of \( v_p, v_s \) and \( \rho \).

Then the combination of the intercept, gradient and constant values from the Gardner equation, the contrast values of \( v_p, v_s \) and \( \rho \) are obtained as follows:

\[ \Delta_{v_p} = \frac{2}{1+\alpha} \frac{\Delta v_p}{v_p} R_0 \]  \hspace{1cm} (8)

\[ \Delta \rho = \frac{2\alpha}{1+\alpha} \frac{\Delta \rho}{\rho} R_0 \]  \hspace{1cm} (9)

\[ \Delta_{v_s} = \frac{\gamma^2}{4} G - \frac{\gamma^2 + 4\alpha}{4(1+\alpha)} \frac{\Delta v_s}{v_s} R_0 \]  \hspace{1cm} (10)

Where \( R_0 \) is the AVO intercept and \( G \) is the AVO gradient and \( \alpha \) is a constant obtained from the Gardner equation, then the \( J_s \) value is obtained as follows:

\[ G = \frac{1}{2} \frac{\Delta v_p}{v_p} - J_s \]  \hspace{1cm} (11)

The same is done with the \( J_p \) equation so that the \( J_p \) and \( J_s \) equations are obtained as follows:

\[ J_s = \frac{\alpha}{1+\alpha} R_0 - G \]  \hspace{1cm} (12)

\[ J_p = \frac{4(2+\alpha)}{\gamma(1+\alpha)} R_0 \]  \hspace{1cm} (13)

The \( J_p \) and \( J_s \) values obtained from the above calculations will be rotated against the angle values obtained from the following equation

\[ \theta = tan^{-1} \left[ \frac{J_p(max) - J_p(min)}{J_s(max) - J_s(min)} \right] \]  \hspace{1cm} (14)

The J-attribute is obtained from the calculation of \( J_p \) and \( J_s \) which are rotated against the angle \( \theta \)

\[ J_p' J_s' = J_p J_s \begin{bmatrix} \cos \theta & -J_s sin \theta & J_p sin \theta \cos \theta & J_p sin \theta \cos \theta \end{bmatrix} \]  \hspace{1cm} (15)

\[ J_p' J_s' = J_p \begin{bmatrix} \cos \theta & -J_s \sin \theta & J_p \sin \theta & J_p \sin \theta \cos \theta \end{bmatrix} \]  \hspace{1cm} (16)

Figure 2 is an illustration of the J-attribute before and after rotation to angle (180-\( \alpha \)) with three fluids, namely gas, oil and water. The x-axis is the \( J_p \) value and the y-axis is \( J_s \) while the color bar is the porosity value from 5% to 35% [4].
4. Methodology
The methodology of this research is listed below.

a. Conduct a literature, the collection data (seismic and well data) and the conduct of conditioning data
b. Determine of petrophysics analysis (volume shale, porosity, and water saturation) and then determine of rock fluid saturation with log petrophysics to log vs prediction.
c. Determine of constant $\alpha$ (gander relationship) and rotation angle
d. Interpretation seismic data (fault interpretation and horizon interpretation)
e. Make a time structure maps with gridding method
f. Numerical simulation analysis is performed to see the attribute $j$ using well data and petrophysical value
g. Analysis of J-Attribute and comparing of the result

The software used in this research is as follow.

a. Petrel (interpretation and make a maps)
b. Matlab (Predict Vs log)
c. Geolog (Petrophysic Analysis)
d. Hampson Russel (Well seismic tie)

5. Result and Discussion

5.1 Log vs Prediction
In this study, it is necessary to predict the value of the secondary velocity log. Log Vs can be predicted with the biot-gas theory which is then performed fluid substitution to obtain log Vs.
The first column in the Figure 2 is the log $V_p$ in the x-axis and depth in the y-axis, the second column is the density in the x-axis and depth in the y-axis and the third column is the log $V_s$ in the x-axis and depth in the y-axis. Then in the fourth column is the $V_p / V_s$ Log in the x-axis, the depth in the y-axis and the color key is water saturation. The last column is the Log $V_p$ in the x-axis, log $V_s$ in the y-axis and the color key is the water saturation.

![Figure 2: Predict $V_s$ log in the well, where is the color key is water saturation.](image)

5.2 Numerik Simulation

Numerical simulations are carried out on both wells where one value is taken from the well in the reservoir and its cover, while the values required in the numerical simulation are the values of primary velocity, secondary velocity, porosity, density, and water saturation. Figure 3 is a numerical simulation for two wells.
Figure 3: The numerical simulation for Bango-1 and Bango-2 well.

In the Figure 3, the first column is a numerical simulation before rotation, where the color key is water saturation, in the second column is a numerical simulation after a rotation of 45° with the color key is water saturation, and the third column is a graph where the x-axis is water \( v_p \) (graph Blue) and \( v_p \) of oil (green graph) and the y-axis represents porosity. In the numerical simulation in the Bango-1 well, the \( J_p \) and \( J_s \) graphs after being rotated against the angle
succeeded in distinguishing well between oil and water, but in Bango-2 well this method was not applicable due to the too large cut-off sw value and small porosity. The values of porosity and water saturation have a big effect on the results of this attribute J method.

5.3 Attribute Maps
On the attribute distribution map (Figure 4), it can be seen that before the rotation of the Bango-1 well, there should be an indication of hydrocarbons but it has a very small attribute value, while after rotation the attribute value is much higher than before. In the Bango-1 well, the attribute value is better than the attribute value in the Bango-2 well because the Bango-1 well is in a higher structure than in the Bango-2 well. The J-attribute method as a whole can be applied in distinguishing fluids in this study, but this method still has many drawbacks because this method has not been able to distinguish properly because the cut off value of porosity is below 50% while the cut off value for vshale and water saturation is above 50%, and in this study, the reservoir targets in the Bango-1, Bango2 and Bango-3 wells are so thin that the resolution of the seismic data cannot read this well.

Figure 4: Attribute Maps using seismic data before and after rotation.
Conclusion
First, application of attribute J needs to consider the characteristics of Vshale, porosity and water saturation which is relatively stable. Second, the rotation angle is derived from the rock physics of a specific reservoir. The rotation angle value varies when rock physics configurations are different in a vertical section. Although there are limitations in application like a thickness of reservoir, depth of target, but the J attribute can be used as an efficient tool to supplement the existing attributes in the hydrocarbon prediction. And the last, this research shows that in field in Indonesia (North Sumatra Basin) J-attribute is not applicable to seismic data but is good in well data which is proven in numerical simulations.

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