Estimation of reservoir lithology in field “A” using modeling of anisotropy parameter

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Abstract. The heterogeneity and anisotropy of rocks in the field is a necessity. Moreover, the existence of clay and carbonate sediment in Indonesia almost dominate the existing oil and gas reservoir. Ironically, the processing of seismic data is still much done by treating reservoir rocks as an isotropic homogeneous medium. Inaccuracies of results, therefore, always haunt the failure of exploration. Hockey stick phenomenon is the result of anisotropic medium that often appears on the far offset. Demand for the implementation of an anisotropic rock medium is now increasing and more important amid the exhaustive oil and gas reserves. NMO correction by using hyperbolic travel time on anisotropic media still displays the phenomenon of hockey stick at the remote offset. Usually this phenomenon will be muted on the processing of seismic data with the approach of isotropic earth models. This will result in the loss of some lithologic information. Therefore, this study was conducted using anisotropic approach to reduce residual moveout for data which has a very long offset. The method is to calculate the anisotropy parameter model of $\eta$ which is controlled by core data. The results of this study showed that the Alkhalifah and Tsvankin method of non-hyperbolic travel time was better in the NMO correction for anisotropy medium with a long offset compared to the method of hyperbolic travel time. In addition, Alkhalifah and Tsvankin method can also estimate the lithology of a reservoir. The value of anisotropy parameter $\eta$ from the equation itself has the same pattern as the gamma ray log. In reservoir, the sand has negative $\eta$ value and shale has positive $\eta$ value.

Keywords: Anisotropy, hockey stick effect, NMO, Alkhalifah method, shale

1. Introduction
Anisotropic phenomenon is a non-uniform seismic velocity occurring in all directions of medium. Different directions, different speed. The phenomenon often occurs in shallow layers as well as at far offsets. Clay’s presence is the main cause of anisotropy phenomenon. In shallow layers, anisotropic phenomena are caused due to high levels of heterogeneity, whereas in far offset, the presence of a thin layer of clay that intersperses the rock medium causes the reservoir to become not homogeneous and makes the wave's alignment a behavior anisotropy.

Seismic exploration with deep targets requires long offsets, but there are often problems with far offset. A number of factors occur when the acquisition of seismic data with a very long offset including in the form of nonhyperbolic moveout record. Very long offset means that the ratio of the offset value to depth ($x/z$) is greater than one at one horizon. Nonhyperbolic moveout is not seen in raw data, but it
will be obvious when hyperbolic moveout at near offset has been removed and there will be a hockey stick phenomenon [1]. The hockey stick effect is a seismic event that curves like a hockey stick shape. The problem is caused by the layer medium in shallow depth, which is generally anisotropic and heterogeneous rock. In an anisotropy medium, the seismic wave will propagate at an unequal pace in all directions. Especially in the direction in which there is shale layer, the seismic wave velocity will be attenuated. This speed weakening will generate hockey stick phenomenon. Therefore, NMO (normal moveout) correction of the hyperbolic method with the isotropic approach cannot be used anymore when the phenomenon occurs. The isotropic approach assumes that seismic waves that travel under the surface of the earth will have the same value in all directions. In reality the earth has a complex structure so that the value of seismic velocities will strongly have velocity variation. Alkhalifah and Tsvankin provide nonhyperbolic moveout equations to overcome the hockey stick phenomenon by giving the correct NMO velocity and eta (η) values [2]. So it is not necessary to do muting on the hockey stick phenomenon as it is done in an isotropic approach which results in the loss of important far offset information [3].

Here, we only focus on the anisotropic effects that occur in the far offset data. We will also use the anisotropic approach using the nonhyperbolic Alkhalifah and Tsvankin’s travel time equation and compare it to the hyperbolic method. Then the anisotropy parameter (η) value obtained from the seismic data will be used to estimate the characteristics of reservoir lithology.

The field “A” is situated in the South Sumatra Basin and it’s located at north of Lematang Normal Fault. The field structure is an asymmetric fault-bend fold trap from Lematang Normal Fault which has a strike almost East-West. As a balance/release of the compression force of the fault, a normal fault is formed which has a relative strike pattern in the North-South direction. Then the normal faults divide the field “A” structure into 4 oil pool compartment sectors [4]. Field “A” is composed of rock formations like basement, Lahat Formation, Talang Akar Formation, Batu Raja Formation, Gumai Formation, Air Benakat Formation, Muara Enim Formation and Tuff Kasai Formation [5].

2. Methods

2.1. NMO correction

NMO correction is defined as the correction of the reflection seismic wave travel time caused by the difference in the arrival time of the reflected wave for each offset with zero offset [6]. The difference in the arrival time of the reflected wave caused by the larger offset change will make the travel time \( t \) curve as the offset function form a hyperbolic curve. The purpose of NMO correction is to eliminate the offset effect on seismic trace in one CDP (common depth point). The reflection curve which used to be hyperbolic will become perpendicular after NMO correction. The two-way travel time of the reflection wave for distance \( x \) \( (t_x) \) is expressed as:

\[
t_x = \sqrt{t_0^2 + \left(\frac{x}{v}\right)^2}
\]

and NMO correction \( (\Delta t_{nmo}) \) is:

\[
\Delta t_{nmo} = t_x - t_0
\]

can be written as:

\[
\Delta t_{nmo} = \sqrt{t_0^2 + \left(\frac{x}{v_{nmo}}\right)^2} - t_0
\]
2.2. Traveltime calculation by Alkhalifah and Tsvankin’s method
Alkhalifah and Tsvankin write an accurate moveout equation for a long offset. The equation is written as [2]:

\[ t^2 = t_0^2 + \frac{x^2}{v_{aniso}^2} - \frac{2\eta x^4}{v_{aniso}^2 [v_0^2 + (1 + 2\eta)x^2]} \]  

(4)

where,

\[ \eta = \frac{\epsilon - \delta}{1 + 2\delta} \]  

(5)

In its development, Alkhalifah and Rampton developed the Alkhalifah and Tsvankin's method to interpret lithology especially sand and shale content in a reservoir [7]. The results show that there is a correlation and similarity pattern between the \( \eta \) curve and the gamma ray log curve (see figure 1). In the gamma ray log the shale content is indicated by the curve deflection to the right. And also on \( \eta \) curves, the shale content is indicated by the curve deflection to the right, and the curves patterns are similar. Since the positive value of \( \eta \) due to an anisotropic medium, the shale content might be represented by and associated with anisotropic reservoir.

3. Results and discussion

3.1. Simulations with syntethic data
Modeling with synthetic data is developed using rock parameters data as shown in table 1 with six horizontal layers, each layer has a P-wave velocity (\( V_P \)) and values of different anisotropic factors epsilon (\( \epsilon \)) and delta (\( \delta \)). The model is created to see the effect of anisotropy parameters when the hyperbolic method is applied to NMO correction. The first layer is made into a layer that is assumed to be an isotropic medium and the second layer to the sixth layer is treated as an anisotropic medium. The anisotropic behavior is affected by the eta factor (\( \eta \)), where the value is the result of equation 5. The CDP gather of the synthetic model is shown in figure 2.

Figure 1. (a) Correlation between gamma ray log and eta (\( \eta \)) curves which have the same pattern, (b) lithological interpretation of shale and sand content estimated from the interval value of \( \eta \) [7].
Table 1. Synthetic data of epsilon $\varepsilon$, delta $\delta$, eta $\eta$, and velocity $V_p$.

| Layer | $\rho$ (g/cm$^3$) | $\varepsilon$ | $\delta$ | $\eta$ | $V_p$ (m/s) |
|-------|------------------|---------------|----------|--------|-------------|
| 1     | 2                | 0.000         | 0.000    | 0.000  | 2000        |
| 2     | 2.2              | 0.100         | 0.056    | 0.040  | 2100        |
| 3     | 2.3              | 0.150         | 0.120    | 0.024  | 2300        |
| 4     | 2.4              | 0.197         | 0.019    | 0.171  | 2500        |
| 5     | 2.5              | 0.430         | 0.230    | 0.137  | 2800        |
| 6     | 2.7              | 0.300         | 0.120    | 0.145  | 3200        |

Figure 2. CDP gather of synthetic model.

3.2. NMO correction using hyperbolic method

To remove the anisotropy effect of hockey stick phenomenon, the both methods of hyperbolic and Alkhalifah and Tsvankin are applied here. The formula that represents both methods has been described in the equation 1–5. Figure 3 is the result of NMO correction using the hyperbolic method for each layer. The first layer with a value of $\eta = 0$ can be ascertained that the reflector will be straight as shown in figure 3a. It is happened because the medium consists of only one layer, so it can be considered as a homogeneous isotropic medium and therefore has no anisotropic factor ($\eta = 0$). Whereas in the second to sixth layer where the medium consists of more than 2 layers of rock so that it is considered as heterogeneous anisotropic medium. There is an anisotropic factor ($\eta$) which affects and occurs in far offset problems in the form of a hockey stick phenomenon. Very long offset at the time of data acquisition will occur non-hyperbolic moveout record. So, the hyperbolic method cannot be used effectively in making NMO corrections. The hyperbolic method can only provide NMO corrections in the near to mid offset only [1]. Figure 3b to figure 3f show the hockey stick phenomenon in the 2nd to 6th layers which dominantly occurs in far offsets.

3.3. NMO correction using Alkhalifah and Tsvankin method

Similar to the hyperbolic method, the result of NMO correction by Alkhalifah and Tsvankin method in which the first layer is also not affected by anisotropic factor ($\eta = 0$). The result becomes straight due to the isotropic medium. However, unlike the hyperbolic method, the NMO results with the Alkhalifah and Tsvankin method are able to eliminate the hockey stick phenomenon that occurs in far offset of second
to sixth layer (see figure 4). So the reflector turns straight. Compared to the NMO results with the hyperbolic method, it can be seen that the anisotropic parameter ($\eta$) is very influential in correcting far offset data. This shows that the Alkhalifah and Tsvankin method are more optimal in overcoming the problems that occur in far offset than the hyperbolic method.

3.4. Application Alkhalifah method to field “A” data

As the Alkhalifah method has much better result in eliminating the anisotropic effect, the method then applied to real field “A” data. The implementation is more focused on estimating lithology using the anisotropy parameter ($\eta$) value of the Alkhalifah’s method. The $\eta$ parameter is searched via semblance analysis process. The process is done to select the speed ($v$) and the parameter of anisotropy $\eta$ which apply the travel time of Alkhalifah shown in equation 4 and equation 5. The results of semblance process can be said to be good when the seismic event becomes straight (flat) after NMO correction by travel time of Alkhalifah equation. The obtained anisotropy parameter ($\eta$) value, then correlated with and verified by the gamma ray log from the well data. The data used in this study is only 1 CDP which is located right in the well. This study uses land seismic data that has been processed to the preprocessing stage. Offsets ranging from 395 m to 2809 m as it can be seen in figure 5.

3.5. NMO correction using Alkhalifah and Tsvankin method

Figure 6 shows CDP gather from the “A” field data before and after the NMO correction process using the Alkhalifah and Tsvankin method. After NMO correction the reflector is in zero offset position. Semblance analysis is done before the NMO process. From the semblance analysis process, the VNMO and $\eta$ values for each target reflector are automatically obtained. The values are generated by implementing the equation 4 and equation 5. The obtained $\eta$ value is then plotted in the $\eta$ interval curve and correlated with gamma ray log data on the existing well data.

![Figure 3. NMO correction results with the hyperbolic method in the (a) first, (b) second, (c) third, (d) fourth, (e) fifth and (f) sixth layer.](image-url)
Figure 4. NMO correction results with the Alkhalifah and Tsvankin’s method in the (a) first, (b) second, (c) third, (d) fourth, (e) fifth and (f) sixth layer. The hockey sticks phenomena at far offset can be eliminated.

Figure 5. Seismic data of field “A”.

3.6. Estimation of reservoir lithology using anisotropy parameter ($\eta$) value

From the results of previous studies, the reservoir target was in 1717 ms to 1721 ms. So that the process of estimating the field “A” reservoir lithology is also focused on the depth. The target reservoir is sand gas saturated with a thickness of about 10 m (figure 7).

In the gamma ray log (figure 7) the reservoir sand at a depth of 1717 ms to 1721 ms has a low gamma ray value with a curve deflection to the left. The small shale value on the gamma ray is associated with
the anisotropy parameter ($\eta$) curve which has a negative value. This shows that the sand layer in this field is isotropic because it has no fracture and does not contain clay as Wang said [8]. From the results of well analysis, it was found that there was shale at the top and bottom of the reservoir. In gamma ray logs, shale is given a blue color (see figure 7). The shale value in the gamma ray log has a large value with the curve deflection to the right. The pattern of increasing shale values is also illustrated by the anisotropy parameter ($\eta$) curve which gives a positive value for shale because it is anisotropic.

![Figure 6. NMO correction (a) before and (b) after using Alkhalifah and Tsvankin method.](image)

![Figure 7. Reservoir figure out in log data.](image)
This is similar to what Wang said that intrinsic anisotropy occurs in shale [8]. Figure 8 shows the correlation between the anisotropy parameter ($\eta$) curve and the smoothed gamma ray log in interested range of field “A”. Both curves have similar patterns. So that the anisotropy parameter ($\eta$) value can be used to describe lithology.

4. Conclusion
From the results of this study it can be concluded that NMO correction using the Alkhalifah and Tsvankin method better than the hyperbolic method. In addition, the anisotropy parameter ($\eta$) curve has the same pattern as gamma ray log, the high $\eta$ value most likely associated with shale, and the low value of $\eta$ believed represents sand sediment. Therefore, it can be used to discriminate sand from the shale. field "A" reservoir in this study area consists of sand layers with negative $\eta$ value and shale with positive $\eta$ value.

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