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The Use of Core & Log Anisotropy Parameters into Seismic Data Processing: A Case Study of Deep-Water Reservoir

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Abstract. The seismic far-offset data plays important role in seismic subsurface imaging and reservoir parameters derivation, however, it is often distorted by the hockey stick effect due to improper correction of the Vertical Transverse Isotropy (VTI) during the seismic velocity analysis. The anisotropy parameter η is needed to properly correct the VTI effect. The anisotropy parameters of ϵ and δ obtained from log and core measurements, can be used to estimate the η values, however, the upscaling effects due to the different frequencies of the wave sources used in the measurements must be carefully taken into account. The objective is to get better understanding on the proper uses of anisotropy parameters in the the velocity analysis of deepwater seismic gather data. To achieve the objective, the anisotropy parameters from ultrasonic core measurements and dipole sonic log were used to model the seismic CDP gathers. The upscaling effects is reflected by the big difference of measured anisotropy values, in which the core measurement value is about 40 times higher than the log measurement value. The CDP gathers modelling results show that, due to the upscaling effect, the log and core-based models show significant differences of far-offset amplitude and hockey sticks responses. The differences can be minimized by scaling-down the log anisotropy values to core anisotropy values by using equations established from core – log anisotropy values cross-plot. The study emphasizes the importances of integrating anisotropy parameters from core and log data to minimize the upscaling effect to get the best η for the VTI correction in seismic velocity analysis.

1. Introduction

Physical property variation for various measurement angles within a medium defines as anisotropy [1]. The variation could be in the form of velocity, density, porosity, and other means of physical properties representing rock heterogeneity conditions. Concerning seismic, velocity is the main parameter that defines anisotropy recorded in the rock formation. [2] describes three unitless parameters that correlate



anisotropy as seismic wave velocity variation within the direction of wave propagation. These parameters are better known as Thomsen's Anisotropy Parameter ϵ , γ , and δ .

Value of V_0 , V_{45} , and V_{90} , ϵ , γ , and δ could be estimated based on the rock formation's velocity data. The measurement is specifically possible only for core plug and dipole logging configuration due to its flexibility in measuring the rock from various directions. Core & log data have a different resolution that leads to a possibility of varying anisotropy magnitude. The more significant the anisotropy magnitude, the bigger the physical properties variation within a rock formation. This logic could lead to a different response in the reflectivity due to the presence of anisotropy.

A deepwater environment has a known special treat regarding the anisotropy condition. The reservoir's depth demands a more extended offset to analyze the anisotropy information stored in the far offset. In the Vertical Transverse Isotropy (VTI) case, the anisotropy affects the long offset of seismic data, forming an artifact known as the hockey stick. Deepwater reservoir further amplifies this effect, requiring a decent length offset to create relevant seismic imaging amidst the anisotropy. The anisotropy correction in VTI media is constructed by evaluating the η based on offset during the velocity analysis. η is a combination of Thomsen's Anisotropy Parameter ϵ and δ heavily associated with long seismic offset. Incorporating anisotropy measurement from core & log as a guide for long offset seismic correction needs to mind the resolution difference brought by the measurement technique.

Delving more into the resolution difference between core & log, we propose to analyze the effect of these differences in the resulted seismic record. This paper intends to showcase the impact of anisotropy value calculated from Ultrasonic Core Measurement & DSI Dipole Sonic Log on long offset seismic in a deepwater environment.

2. Methods

[3] introduced three anisotropic parameters in case of weak anisotropy condition. In the VTI case, Thomsen's Anisotropy Parameter ϵ , γ , and δ are related to velocity variation with incident angle, precisely at 0° , 45° , and 90° . Epsilon is the fractional difference of vertical and horizontal P-wave, which is associated with the long offset effect. Whereas Gamma is related to horizontal & vertical S-Wave, while Delta is influenced by the move-out velocity versus the zero-offset velocity. In a way, as explained by [4], Seismic Anisotropy Eta could be described by Thomsen's Anisotropy Parameters, mainly Epsilon and Delta. These anisotropy values could be calculated from velocity through several means. This research will compare the anisotropy value from Ultrasonic Core Measurement and Dipole Shear Sonic Log. Both of the methods have different hard data as the input and also different resolution as the output. This study aims to better understand the effect of anisotropy value calculated from core & log in long offset seismic reflection through well-based anisotropy modeling.

2.1 Ultrasonic Core Measurement

Ultrasonic Core Measurement application in core data measurement has begun with [5] who used ultrasonic waves to define the relationship between P-Wave, S-Wave, and Poisson's Ratio in dry sedimentary rocks. Since then, the ultrasonic wave is widely known as one method to obtain an elastic and anisotropy parameter from core data. Attempts to compare the result of ultrasonic measurement and sonic log have been conducted to analyze heterogeneity and anisotropy of rocks [6][7]. To estimate the *Eta* based on seismic data, Thomsen's Anisotropy Parameter is being calculated from the core plug using ultrasonic wave and compared the anisotropy value from seismic processing [8].

The core plug data with ultrasonic waves in several directions or angles are used in this study. They are V_{p0} , V_{p45} , V_{p90} as well as V_{s0} and V_{s90} . Each angle represents seismic wave velocity propagation at adjacent, 45 degrees, and perpendicular to the possible anisotropy symmetrical axis. In Vertical Transverse Isotropy, the symmetrical anisotropy axis is perpendicular to the sedimentary layer [9].

2.2 Dipole Shear Sonic Log

Thomsen's Anisotropy Parameter is related to velocity variation within different angles, such as V_0 , V_{45} , and V_{90} . Gamma, which is calculated from Shear Sonic, cannot be obtained from seismic data with a

compressional source and one component geophone. The different angles' velocity could be measured through dipole logging configuration in well-logging acquisition with acoustic log source types. It is applicable for both Sonic Log and Shear Sonic Log.

This research uses DSI Dipole Sonic measurement in cross-dipole configuration to detect the anisotropy and dispersion within the target formation.

2.3 Well-based Modelling with Anisotropy

The degree of anisotropy has various effects on seismic reflection. Well-based synthetic modeling is a preliminary step to analyze further the impact of anisotropy value in long offset seismic. In the Vertical Transverse Isotropy case, anisotropy has a remarkable effect on the far offset of seismic gathering in the form of the hockey stick effect. The reservoir located in a deepwater environment needs a more extended offset to compensate for the more profound depth. The anisotropy analysis in deepwater reservoir should be conducted in seismic data with a long enough offset. Well-based modeling is a way to support further exploration or development decisions in a deepwater environment.

The possible different effect of anisotropy obtained from Ultrasonic Core Measurement and Dipole Sonic Log is to be modeled. The reflectivity calculation of the well-based modeling adopts a Vertical Transverse Isotropy condition. The modeling applies the Zoeppritz equation to ensure a more accurate estimation of the reflection event amplitude from the target interface compared to the linearized one. As for the reflectivity calculation, Schoenberg-Protázio Extension to Anisotropic Zoeppritz Theory is incorporated into the analysis. Schoenberg-Protázio extended the Zoeppritz equations to anisotropy by introducing the (2 x 2) block impedance matrices providing the solution to four components of both reflected and transmitted waves [10]. Azimuthal Plane Wave technique is applied to move out the synthetic gather data for the reflection to appear as NMO corrected seismic gather.

The resulted synthetic gather seismic is sorted into Common Offset Common Azimuth (COCA), Common Angle Common Azimuth (CACA), and Common Offset Vector (COV). The maximum offset to be modeled follows the far offset value of the real seismic data around 6500 meters. The maximum angle of up to 65° is adapted from angle information from the available ultra-far angle seismic. Modeling is conducted for the whole total depth of log data where the P-Wave, S-Wave, and density are known. However, the detailed calculation is focused on the level target on which the core measurement available.

3. Results & Discussions

The well of SAD-4 is located at a deepwater Sadewa Field in East Kalimantan. It is drilled to observe a clastic reservoir at around 11000 ft. The target clastic reservoirs are quartz dominant, moderately highly porous, somewhat compacted, and grain size varies from upper the very fine sand to upper fine sand with moderate sorting. Observation is focused on the reservoir zone of Vertical Transverse Isotropy condition. Synthetic well-based modeling is performed to model the anisotropy effect.

This study aims to analyse the effect of different anisotropy values recorded in seismic gather data. The well-based modeling will cover the following issue—first, synthetic seismic well-based modeling anisotropy from Ultrasonic Core Measurement. Second, synthetic seismic well-based modeling with anisotropy from Dipole Sonic Log. Third, the anisotropy value and data sampling effect on synthetic seismic.

3.1 Seismic well-based modeling with anisotropy from Ultrasonic Core & Dipole Sonic Log

Anisotropy value calculated from Ultrasonic Core Measurement and Dipole Sonic Log has an entirely different value range. The anisotropy from the core plug sample in SAD-4 has value ranged from 0.09 to 1.23. Meanwhile, the anisotropy from the log has value ranged from 0.007 to 0.010. Anisotropy value that close to zero has a similar characteristic of the isotropy one. Figure 1 shows the difference in magnitude between Thomsen's Epsilon and Gamma from both datasets. The anisotropy of the log data is weak to very weak, and the anisotropy of the core plug is moderate to strong.

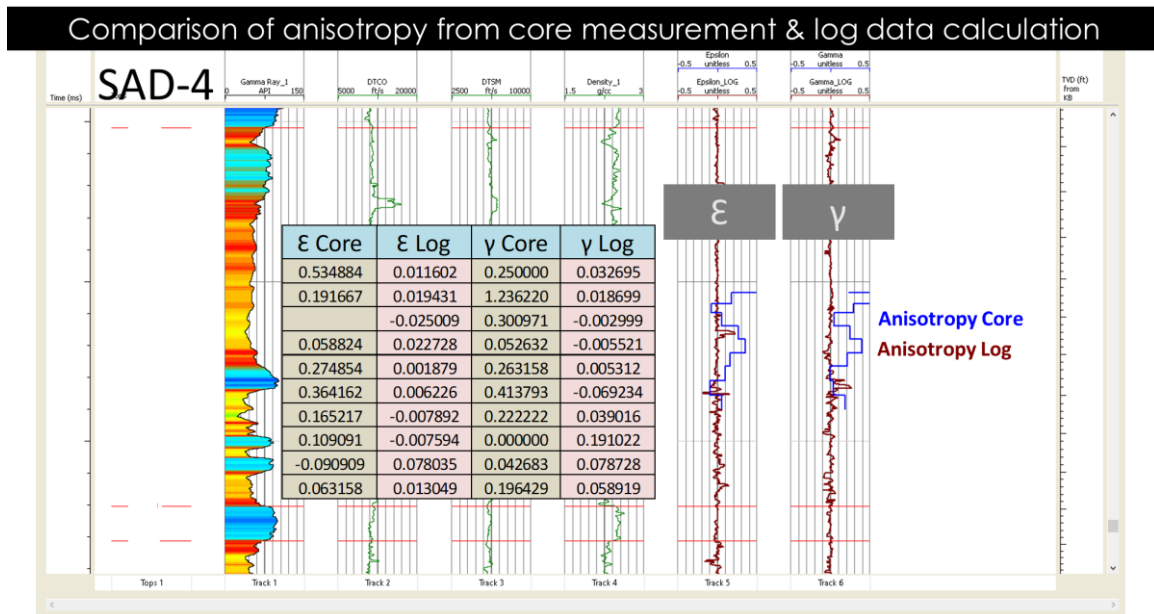


Figure 1. Anisotropy value calculated from Ultra Sonic Measurement (blue) and Dipole Sonic Log (brown) in SAD-4. The detailed analysis of the anisotropy effect is conducted on the level target where the core plug sample is obtained.

In this study, there are three scenarios to be applied in the well-based modeling: The first scenario is modeling using the original log condition as a baseline to its in-situ state. The second scenario is modeling with anisotropy information from Ultrasonic Core Measurement in VTI media. The third scenario is modeling with anisotropy information from Dipole Sonic Log in VTI media. The synthetic gathers seismic resulted from modeling is sorted into Common Angle Common Azimuth gather to better showcased the kick out of hockey stick effect on the long offset reflection.

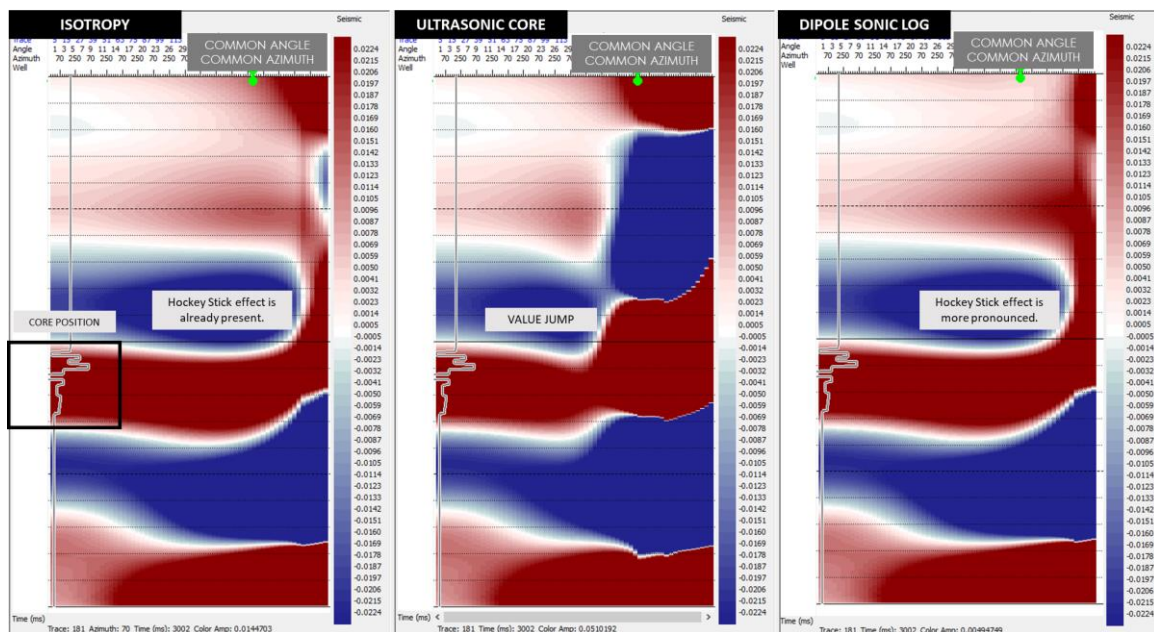


Figure 2. The three scenarios of the synthetic gathers of the well-based modeling result of SAD-4: in-situ log (left), core anisotropy (middle), and log anisotropy (right). The core measurement is conducted around the target, as pointed inside the black box. The synthetic seismic is sorted into Common Angle Common Azimuth gather.

Synthetic gathers seismic from the in-situ log condition of SAD-4 well showcases the hockey stick even before the anisotropy value incorporated into the model. After the anisotropy value integrated into the model, the synthetic gathers seismic still shows the hockey stick effect but with some enhancement on the kick out curving. The synthetic gathers seismic with log anisotropy has a slight enhancement in the kick-out, starting from angle 55° to 65° . In contrast, the original synthetic gathers seismic forms the curving around the angle of 50° . A different result is detected in the core anisotropy; the synthetic gathers seismic shows a value jump as early as 40° before the kick out, starting at the 50° on the long offset (Figure 2). This phenomenon is associated with an anisotropy injection to the model with a reasonably high magnitude level.

Anisotropy magnitude calculated from Dipole Sonic Log is relatively weak compared to the magnitude from Ultrasonic Core Measurement. The implication is that the synthetic gather seismic from log anisotropy tends to be similar to the synthetic gather seismic from in-situ log modeling. The small value of magnitude doesn't have much influence on the seismic reflectivity response.

The synthetic gather model based on the anisotropy that is estimated from Ultrasonic Core Measurement shows a different comparison to the other two in terms of amplitude and reflectivity. The difference in response leads to the possibility of anisotropy magnitude value or irregular data sampling being the factor. To investigate this issue, we come up with another experiment that would be explained later.

3.2 Anisotropy value and data sampling effect on synthetic seismic

There exist two issues that differentiate anisotropy from Ultrasonic Core Measurement and Dipole Sonic Log. They are the range of value and data sampling. The anisotropy from Ultrasonic Core Measurement in SAD-4 has magnitudes 40 times larger than Dipole Sonic Log. The sample is slightly different. Figure 3 shows the illustration of the value difference in Thomsen's Epsilon and Gamma of SAD-4. Furthermore, core plug measurement has a sampling of 9 – 12 ft while the log has a sampling rate of 0.5 ft.

This experiment will explore more about these two factors that influence the seismic response during well-based modeling. The anisotropy value from the log is scaled-up to the anisotropy range value from the core. Likewise, the core's anisotropy value is scaled-down to the anisotropy range value from the log. The scaled-down process in core anisotropy intends to mimic the weaker anisotropy value found in the log. The scaled-up is meant to produce substantial anisotropy with regular sampling. A linear function does the scaling processes derived based on data to data cross plot. Equation (1) represents the scaling function for Epsilon data and Equation (2) represents the scaling function for Gamma.

$$\mathcal{E}_L = -0.0012719\mathcal{E}_C + 0.00182828 \quad (\text{Eq. 1})$$

$$\mathcal{Y}_L = 0.0265119\mathcal{Y}_C + 0.00479782 \quad (\text{Eq. 2})$$

Figure 4(a) shows the synthetic gather seismic resulting from well-based modeling with scaled-down core anisotropy. The value jump phenomenon found in Figure 2 is no longer detected. Overall, the reflector at the target level has similar behavior to synthetic gather seismic with anisotropy from Ultrasonic Core Measurement. On the contrary, the synthetic gathers seismic due to well-based modeling with scaled-up log anisotropy shows an intensive value jump kick out, as shown in Figure 4(b).

These results confirm the previous guess that value range and data sampling modification influence the seismic response on well-based modeling with anisotropy. The bigger or smaller anisotropy value is implied on the synthetic gathers seismic, more specifically on the long offset. The use of the anisotropy parameter based on core and log data in the long offset seismic data gather, the regularization and value normalization are necessary.

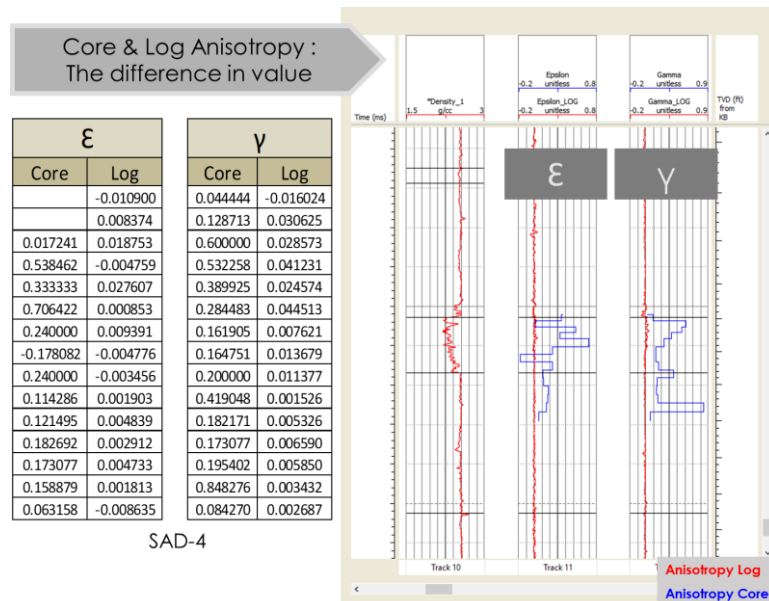


Figure 3. Thomsen’s Epsilon and Gamma from Ultrasonic Core Measurement and Dipole Sonic Log in SAD-4.

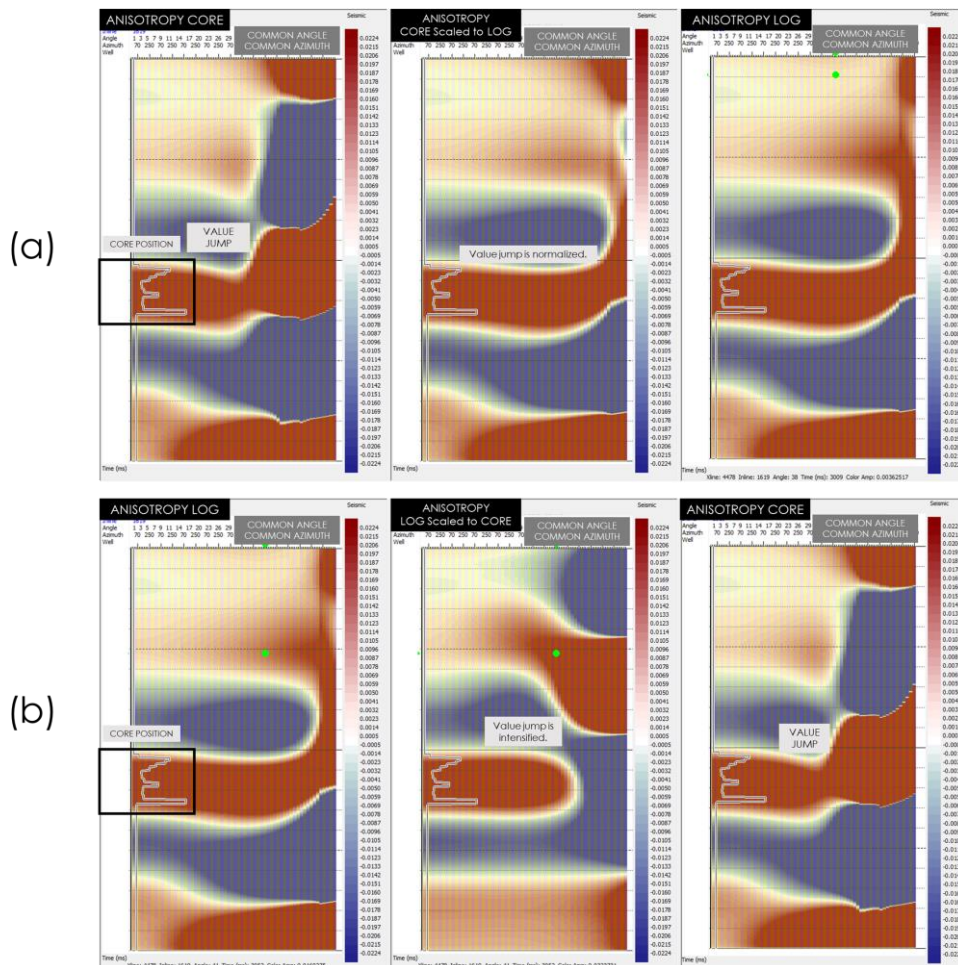


Figure 4. (a) Synthetic gathers seismic result of well-based modeling with core anisotropy scaled into value range of log anisotropy. (b) Synthetic gathers seismic result of well-based modeling with log anisotropy scaled into value ranged from core anisotropy.

4. Conclusions

The deepwater reservoir has been posing a challenge in hydrocarbon exploration. Useful seismic imaging is the primary tool to support a thriving and cost-efficient production. Facing the hockey stick effect as a tribute from Vertical Transverse Isotropy condition, seismic processing needs the right anisotropy parameter Eta (η) for the long offset correction. An elasticity parameter η could be derived from Thomsen's Parameter ϵ and δ . Integrating anisotropy measurement from core & log data has proven to help hand in choosing the best η value. The massive difference in dominant frequency and probably bandwidth of seismic wave source leads to a difference in estimating the anisotropy parameter value between Ultrasonic Core Measurement and Dipole Sonic Log. It could lead to a vague understanding of anisotropy's degree in the same target better. It still needs to find a method for further analysis on transforming the estimation anisotropy parameter value of core and log into the seismic gather data's long offset. In this study, the application of both estimated anisotropy core and log parameters into seismic bandwidth of the long offset data by scaled up or down is made by neglecting the frequency of source or bandwidth dependence effect. The reflection of the weaker anisotropy magnitude shows a similar comparison to the isotropy.

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