Prior Analysis in Determination of TI Anisotropy Type through Well-Based Modelling: A Case Study on the Deep Water Environment

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Abstract. The existence of anisotropy phenomena in the subsurface will affect the image quality of seismic data. Hence a prior knowledge of the type of anisotropy is quite essential, especially when dealing with deep water targets. The preliminary result of the anisotropy of the well-based modelling in deep water exploration and development is discussed in this study. Anisotropy types are modelled for Vertical Transverse Isotropy (VTI) and Horizontal Transverse Isotropy (HTI) based on Thomsen Parameters of $\varepsilon$ and $\gamma$. The parameters are obtained from DSI Logging paired with reference $\delta$ value for modelling. Three initial conditions are then analysed. The first assumption is isotropic, in which the P-Wave Velocity, S-Wave Velocity, and Density Log modelled at their in-situ condition. The second and third assumptions are anisotropy models that are VTI and HTI. In terms of HTI, the result shows that the model of CDP Gather in the offset domain has a weak distortion in Amplitude Variation with Azimuth (AVAz). However, another finding shows a relatively strong hockey effect in far offset, which indicates that the target level is a VTI dominated type. It is supported by the geomechanical analysis result in which vertical stress acts as the maximum principal axis while horizontal stress is close to isotropic one. To sum up, this prior anisotropy knowledge obtained based on this study could guide the efficiency guidance in exploring the deep water environment.

1. Introduction

Seismic imaging in an anisotropy media in hydrocarbon exploration is needed. It is because of the fact of the subsurface is anisotropy media. Previous elastic theories that assume rock as an isotropic media is slowly developing into adaptation to the real subsurface phenomenon. The complex geological structure, mineral alignment during sedimentation, and compaction related to overburden are among the
factors triggering anisotropy within rock [1][2]. Transverse Isotropic (TI) is commonly used to simplify the anisotropy in sedimentary rock [3]. TI Anisotropy assumes that a media is isotropic in one direction while anisotropic in its perpendicular plane [4]. It fits the sand/shale lamination reservoir's description representing Vertical Transverse Isotropy (VTI) condition and the fractured clastic reservoir that represents Horizontal Transverse Isotropy (HTI) condition.

The existence of anisotropy in subsurface conditions could influence the subsurface image as captured by seismic reflection data. Both VTI and HTI cases have a different impact on the recorded seismic reflection data [5]. A deep water setting might further enhance its complexity [6]. A thorough exploration planning is necessary to obtain the best data quality for subsurface imaging at a significant depth with the most effective cost. Prior knowledge of TI anisotropy type and degree would be quite essential in deep water exploration. A better understanding of anisotropy will help a lot in the exploration plan to design the acquisition parameter the proper seismic processing flow. It could also become the first clue in development strategies as guidance for the azimuth of directional drilling and maximum offset determination in the seismic 3D acquisition.

2. Methods

Well-based synthetic modeling is a necessary preliminary analysis to further explore or develop decisions in the deep water environment. In the deep water reservoir, Well SAD-4 is part of Sadewa Field discovered in East Kalimantan, drilled to penetrate a clastic reservoir at about 11000ft. Clastic reservoirs evaluated in this research are quartz-rich, moderately to highly porous, fairly compacted, and upper very fine sand to upper fine sand grain size with moderate sorting.

The anisotropy effect is to be modeled to obtain a preliminary understanding of the target's TI Anisotropy type. Parameter ε and γ of Thomsen’s Anisotropy are obtained from DSI Logging paired with reference δ value as the input for well-based synthetic modeling. Thomsen’s Anisotropy Parameter ε and γ range from -0.01 – 0.04 in which considered as weak anisotropy. The δ value refers to the sandstone value of the Typical Thomsen Parameter Value table [7] with adjustment accordingly to the SAD-4 Thomsen’s Anisotropy Parameter magnitude range. Weak anisotropy has a magnitude of ε and δ that less than 0.2 [8].

![Figure 1. A workflow diagram of preliminary TI anisotropy determination through well-based modeling.](image)

Well-based modeling applies three initial conditions of anisotropic assumption in creating the synthetic seismic gather. The first assumption is the Isotropic Media, where the P-Wave Velocity, S-Wave Velocity, and Density Log would be modeled at their in-situ condition. The second assumption is Vertical Transverse Isotropic (VTI), and the third assumption is Horizontal Transverse Isotropy (HTI). Azimuth information is also added to the synthetic modeling. The synthetic seismic is divided into four azimuthal groups centered at N70°, N160°, N250°, and N340°. The modeling result will be sorted into Common Offset Common Azimuth (COCA) and Common Angle Common Azimuth (CACA). The maximum offset of COCA is 7000 meters to provide a sufficient target level coverage, while the ultra-far angle of CACA is 62° following a preliminary angle analysis. These seismic gather sorting allow us to see both the VTI & HTI effect in a single seismic image. Ray tracing technique is applied for the offset to angle mapping of the synthetic seismic gather. We make use of the Sonic Log in SAD-4 as the replacement velocity to perform the tracing from the surface.
In the isotropic assumption, the reflectivity estimation is based on the Zoeppritz equation. It is addressed to ensure a more accurate estimate of the event amplitude of reflection from the target interface compared to the linearized one. In the TI anisotropy assumption, the Schoenberg-Protázio Extension to Anisotropic Zoeppritz Theory is applied. Schoenberg-Protázio extended the Zoeppritz equations to anisotropy by introducing the (2 x 2) block matrices (see Eq. 1), providing the solution to four components of both reflected and transmitted waves [9].

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\begin{align*}
X &= \begin{bmatrix} Vp_{S1} & Vs_{S3} \\ -\rho Vp \Gamma & 2\rho Vs^3 \end{bmatrix}, \\
Y &= \begin{bmatrix} -2\rho VpVp^2 & Vpzs_{3p} & -\rho Vs \Gamma \\ Vpzs_{3p} & Vs_3 & Vs_{1} \end{bmatrix} & (Eq. 1)
\end{align*}
\]

S1 is horizontal slowness, S3p is vertical P-wave slowness, S3s is vertical S-wave slowness, and \( \Gamma \) is equal to \((1 - 2V_s^2S_1^2)\). The synthetic gather is conducted using the Azimuthal Plane Wave technique for the synthetic to have appeared as NMO corrected seismic gather. The synthetic gather of the VTI and HTI of the well-based modeling results are then analyzed. The primary purpose is to better understand anisotropy's nature on seismic reflectivity response. In turn, to understand better relating the TI anisotropy role to the deep water environment.

3. Results

The result of well-based modeling with isotropic assumption using in-situ log condition shows an indication of hockey stick effect at the synthetic gathers seismic far offset. Thomsen’s Anisotropy Parameter value hasn’t been added to the original P-Wave, S-Wave, and Density log data at this in-situ condition.

In terms of HTI, the result showcases that the synthetic Common Offset Common Azimuth seismic gather shows a weak response with minimal distortion in Amplitude Variation with Azimuth (AVAz). Another finding through VTI assumption shows a relatively strong hockey effect in the far offset of the synthetic Common Offset Common Azimuth seismic gather. With additional anisotropy data calculated from Dipole Shear Sonic Imager (DSI) Logging, the hockey stick effect is still present and further enhanced (see Fig. 2a).

However, the strong seismic response on anisotropic is showed by the Common Angle Common Azimuth seismic gather. The hockey stick effect is smoother without any sudden jump in value. The distortion in AVAz is also more pronounced (see Fig. 2b).

4. Discussion

Anisotropy, well-based modelling at the isotropic assumption showcases that the in-situ log data, DTCO, DTSM, RHOB, contains the record of the anisotropic tendency of rocks. It confirms the theory of Li & Pickford [2] stated that most of the rocks are considered weakly anisotropic. The Thomsen’s Anisotropy Parameter of SAD-4 calculated from DSI Logging also falls into the weak anisotropy type with a value of \( \varepsilon \) and \( \gamma \) below 0.2 in magnitude. The use of the anisotropy parameter in the modeling will enhance the anisotropy's effect in the synthetic seismic gather.

Well-based modelling with the HTI assumption shows a weak distortion in AVAz. It could represent a hairline fracture resulting from overburden and compaction commonly found in the clastic sandstone reservoir. The VTI assumption's well-based modelling shows a clear and strong hockey stick effect in the synthetic Common Angle Common Azimuth seismic gather. Analysis into the Pre-SDM seismic gather further confirms this synthetic finding.
This study shows that the well-based modelling concludes that the target level is VTI anisotropy dominated. The work is aligned with Geomechanical MEM Analysis on SAD-4 that stated vertical stress acts as the maximum principal axis. Meanwhile, the magnitude contrast of maximum horizontal stress and minimum horizontal stress is close to the isotropic one.

**Figure 2.** Synthetic seismic gathers result from anisotropy, well-based modeling with in-situ, VTI, and HTI assumption sorted into (a) Common Offset Common Azimuth (b) Common Angle Common Azimuth gather.

5. **Conclusions**
The deep water environment has been posing as a challenge in hydrocarbon exploration. Prior knowledge about the subsurface anisotropy condition would benefit in more sufficient planning of seismic exploration and further development. The well-based modelling could act as a first step in
identifying the anisotropy type before a more comprehensive study is being conducted. The VTI is found in SAD-4 related to the determination of far offset design in the seismic acquisition. This prior anisotropy knowledge obtained from a simple preliminary analysis in the form of well-based synthetic modelling could guide a more efficient exploration in a deep water environment.

References
[1] Liu X 1994 Non-linear elasticity, seismic anisotropy, and petrophysical properties of reservoir rocks PhD Thesis Stanford University, California
[2] Li Y 2002 SEG Technical Program Expanded Abstracts
[3] Saberi M R, Ting J. 2016 First break 34 41-48
[4] Levin F K 1979 Geophysics 44 918-936
[5] Alkhalifah T, Tsvankin I 1995 Geophysics 60 1550-1566
[6] Hall M 2003 CSEG Recorder 28 1-3
[7] Tsvankin I 1997 Geophysics 62 1292-1309
[8] Xiao C 2006 MSc Thesis University of Calgary
[9] Schoenberg M and Protazio J 1992 The Journal of the Acoustical Society of America 88 125-144