Seismic Anisotropy Modeling from Well Log in Talang Akar Formation, South Sumatra, Indonesia*

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Abstract

Old seismic modeling assume that the seismic wave propagate in the earth have the same value for every directions. In the reality, earth layers are not as ideal as that. It has a very complex structure and waves do not propagate as ideally as isotropic modeling. It propagates with a velocity which varying with the directions. Seismic wave velocity varying with the direction of propagation caused the anisotropy characteristics of rock. Because of that, the petrophysical analysis should consider the anisotropy parameters. The parameters can be aimed from physical characteristics measurement in laboratory and seismic reflection data. In this research, the anisotropy parameters or Thomsen parameters generated from well log data. Those parameters are ε, γ, and δ which known as Thomsen parameters. It represents elastics tensor constant aimed from stress and strain relationship in linear anisotropic medium and solid elastic. Generally, anisotropy characteristics are influenced by clay volume fraction, density, and seismic wave velocity. In this paper, the effect of clay content to the anisotropy analysis in sandstone reservoir is discussed. The case study is in G402 well in the Talang Akar formation in South Sumatra, Indonesia. Anisotropy parameters aimed from the empirical relationship between clay content and body (compressional and shear) wave velocity. The value are $\varepsilon = 0.14$; $\gamma = 0.15$; and $\delta = 0.04$. Those values are less than 0.2 so the well has low anisotropy characteristics. Then, anisotropic AVO (Amplitude Versus Offset) equation is used to extract synthetics seismogram from isotropy and anisotropy model. The different between two models are shown in the synthetics seismogram. The Different of them shows that the anisotropy model give the clearer amplitude, thus providing ease of interpretation and reduce the risk of failure in determining the location of the target zone.

Introduction

The Indonesia energy demand was increased while the production of hydrocarbon decreased. Hydrocarbon is a main energy resource in Indonesia until now. Most oil fields in Indonesia are sandstone reservoirs, and they are old oil fields, which the production decreased. During 2006, the average of oil and gas production in Indonesia was 1.1 million barrels oil per day, where 81% of total production or 894,000 barrels is crude oil. The Indonesia hydrocarbon production has decreased about 32 % since 1996 (IAE, 2007).

The earth model, which used in the seismic data analysis, is isotropic, but in the real condition for most of the rock is anisotropic. By using anisotropy assumption in seismic data analysis, we can get better images in seismic sections, which are more complex and easy to interpret. Anisotropy properties directly related to the structure and composition of rock, from these properties can be determined for the physical properties of rock.

Alkhalifah (1997) introduced that P-wave anisotropy gives more information about the geological structure and delineated the seismic image. Based on the research by Alkhalifah, there are three anisotropic parameters epsilon (ε), delta (δ), and gamma (γ). Li (2006) published his research about the empirical relationship between clay volume and anisotropic parameters. In this paper, we found the difference between isotropic and anisotropic seismic model. We used anisotropic parameters that calculated from clay volume, P-wave velocity, and S-wave velocity, when clay volume was extracted from a gamma ray log. By using the AVO equation using anisotropic parameters, the anisotropic seismic model can be determined.

Talang Akar Formation

The geological history of south Sumatra basin was influence by tectonic activity in Southeast Asia region and controlled by interaction between Indo-Australia plates, Pacific Ocean plate, and the Eurasian plate, which was relatively stable. Currently, the South Sumatra basin is a back arc basin, which is bordered in the northeast by the Sunda shelf. There are Tiga Puluh mount in the northwest and the Bukit Barisan Mountains in the west (Figure 1).

The South Sumatra basin is one of Indonesia's largest petroleum sedimentary basins. The complex sedimentary has an area of about 133,000 km^2 and a thickness of 2,500 m to 5,000 m. The average temperature gradient is about 49°C per km. The study area is located in the South Sumatra province. The Talang Akar Formation (TAF) consists of late stage graben and early post-rift fill and overlies either the Lemat Formation or the pre-Tertiary basement. The TAF was deposited in late Oligocene to early Miocene and consists of fluvial and deltaic sediments that grade basinward into marginal marine sediments. It is divided into two members: the Gritsand Member (GRM) in the lower part and the Transitional Member (TRM) in upper part. The GRM of the transgressive Talang Akar Formation consists of coarse to very coarse sandstone with shale and siltstone intercalations with the thickness reaches 550 m. The TRM consists of shale intercalated with sandstones and coal, that infrequently are intercalated with calcareous sandstones and marine shale (Figure 2). This member was deposited in a littoral to shallow marine environment and reaches 300 m thick (De Coster, 1974; Ginger and Fielding, 2005; Widodo, 2012). The TAF is believed to have potential hydrocarbons in the south Sumatra basin. The value of Total Organic carbon (TOC) is about 36 % with hydrogen Index of 200 to 350 mgHC/g. In this formation, the reservoir rock quality is poor; it has a porosity of 10 to 15 % and permeability about 1 to 50 mD. However, in the sedimentary area which so far from sedimentary source has good reservoir quality. In this area has a porosity of 15-29 % and 100-3,000 mD for permeability.

Thomsen Parameter

The most common measure of P-wave anisotropy is the ratio between the horizontal and vertical P-wave velocities, typically between 1.05 to 1.1 and is often as large as 1.2. Thomsen (1986) introduced a more effective and scientific measure of anisotropy in 1986. He introduced the constants ε, γ, and δ as effective parameters for measuring anisotropy (Elapavuluri et al, 2002). These parameters are valid in the weak anisotropy medium. Li (2006) was introduced that anisotropy parameters affected by the volume fraction of clay, density, value and the directions of the seismic wave. The model is vertical transverse isotropic (VTI). The relationship between Thomsen parameters, clay volume (v clay), and velocity (Vp and Vs) in the clastic sediments is given by (Prahastudi and Bahrie, 2012):

$$\varepsilon = \frac{0.60 * v_{clay} * (V_P - V_{P\ water})}{V_{P\ quartz} - V_{P\ water} - 2.65 * V_{clay}} \tag{1}$$

$$\gamma = \frac{0.67 * v_{clay} * V_S}{V_{S\ quartz} - 2.29 * V_{clay}} \tag{2}$$

$$\delta = 0.32\varepsilon \tag{3}$$

Amplitude Variation with Offset (AVO) Anisotropy

It can be demonstrated that the amplitude character of seismic reflections varies with offset, due to changes in the angle of incidence. The studies are conducted to analyse the behaviour of Amplitude Versus Offset. Zoepprits (1919) showed that the reflection coefficients at different offset and incidence angles are computed. The correct thing to do is to use the full set of Zoepprits equations, but these are awkward to handle (Veeken, 2006).

Thomsen (1986) showed a transversely isotropic term could be added to the equations using his weak anisotropic parameters δ and ε, where $R_{an}(\theta)$ is the anisotropic AVO response and $R_{is}(\theta)$ is the isotropic AVO response. Ruger (1997) based on the Aki and Richard (1980) equation gave the following corrected form of Thomsen's original equation (Shou-Hua, 2008):

$$R_{an}(\theta) = R_{is}(\theta) + \frac{\Delta\delta}{2} \sin^2\theta + \frac{\Delta\varepsilon}{2} \sin^2\theta \tan^2\theta \tag{4}$$

where $\Delta\delta = \delta_2 - \delta_1 \ and \ \Delta\varepsilon = \varepsilon_2 - \varepsilon_1$

$$R_{an}(\theta) = A + \left(B + \frac{\Delta\delta}{2}\right) \sin^2\theta + \left(C + \frac{\Delta\varepsilon}{2}\right) \sin^2\theta \tan^2\theta \tag{5}$$

Method

In this paper, AVO anisotropy is applied to the G402 well located in South Sumatra, Indonesia. Empirical relations were used to calculate the Thomsen parameters with the clay volume data. Clay volume was obtained from the gamma ray log. Vp_{water} is 1.5 km/s; Vs_{quartz} is 4.09 km/s; and Vp_{quartz} is 6.05 km/s. AVO anisotropy modeling was done in order to aim the seismogram synthetics that are more complex from a common modeling which use isotropic modeling. The value of Vp, Vs, density, and Thomsen parameters used as input data in Aki-Richard equation to aim the seismogram synthetics. As a comparison, the seismogram synthetics with isotropic assumption were also calculated. The deviation between anisotropy and isotropy trace calculated so the difference between those modeling could be observed. Generally, the steps of this research are:

1. Extract necessary data (P-wave velocity log, S-wave velocity log, Gamma ray log, and porosity).
2. Clay volume log estimation based on the gamma ray log.
3. Estimate anisotropic coefficients.
4. Compute the seismogram synthetic using Aki-Richard equation based on the anisotropic coefficients.

Result and Discussion

In this paper, Thomsen parameters were calculated based on clay volume and vertical velocity in clastic rock. Each parameters value are ε = 0.14; γ = 0.15; and δ = 0.04 (Figure 3). The value of those parameters are smaller than 0.2 so the well has weak anisotropy characteristics. Figure 3 shows the gamma ray log that has a big range from maximum to minimum value. It is related to the relative low value of clay content. The low value of clay content and anisotropic parameters are consist with the theory that anisotropy affected by clay content. Those values then were used as input for the Aki-Richard equation. The earth model from isotropy and anisotropy was generated with and without the anisotropy parameter based on the Aki-Richard anisotropic model and isotropic model. The uses of anisotropy parameters gives many differences. Anisotropy model has more complex result than isotropic model. It also has clearer amplitude than isotropic model as shown. The deviation is also shown in track 3 of Figure 4. Theoretically, the anisotropy model provides a better result because it considers the parameters with real world conditions than the isotropic model. It considers the velocity which varying with direction while isotropic model assume that the velocity of all directions has similar values. The difference shows that isotropic models provide more opportunity for a misinterpretation, which can give a disadvantage (Figure 4).

Conclusion

Research indicates this well has low anisotropic characteristics based on the Thomsen parameters value (ε = 0.14; γ = 0.15; and δ = 0.04). The offset length was influence by anisotropic characteristic, where the longer offsets have more anisotropic effect. Differences between isotropic and anisotropic model resulted from the Aki-Richards equation observed from seismogram synthetics. The anisotropic modeling provides a better result than isotropic modeling with clearer amplitude. The anisotropic model can improve AVO analysis from amplitude results, which are more complex than the isotropic model.

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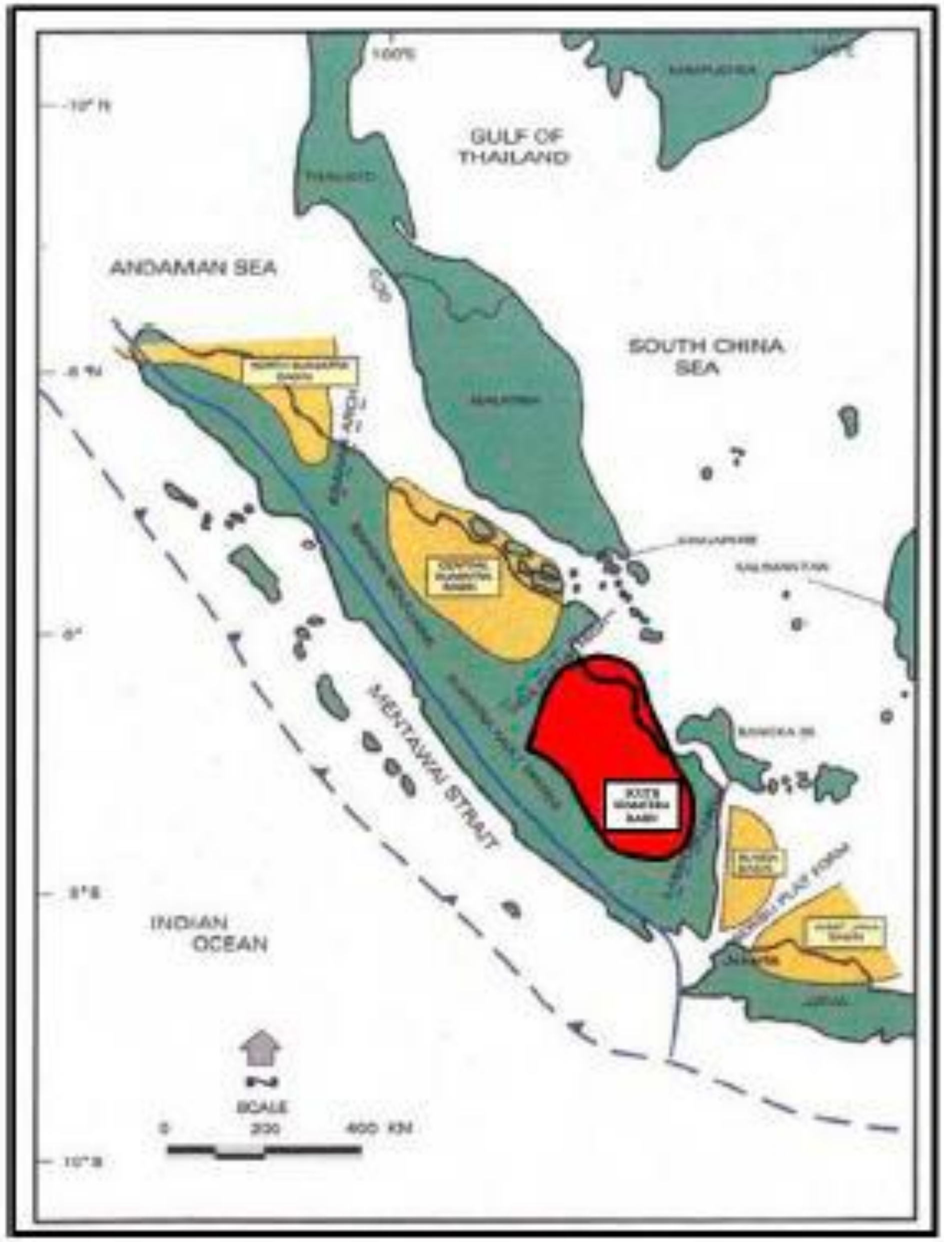

Figure 1. Map of south Sumatra basin location.

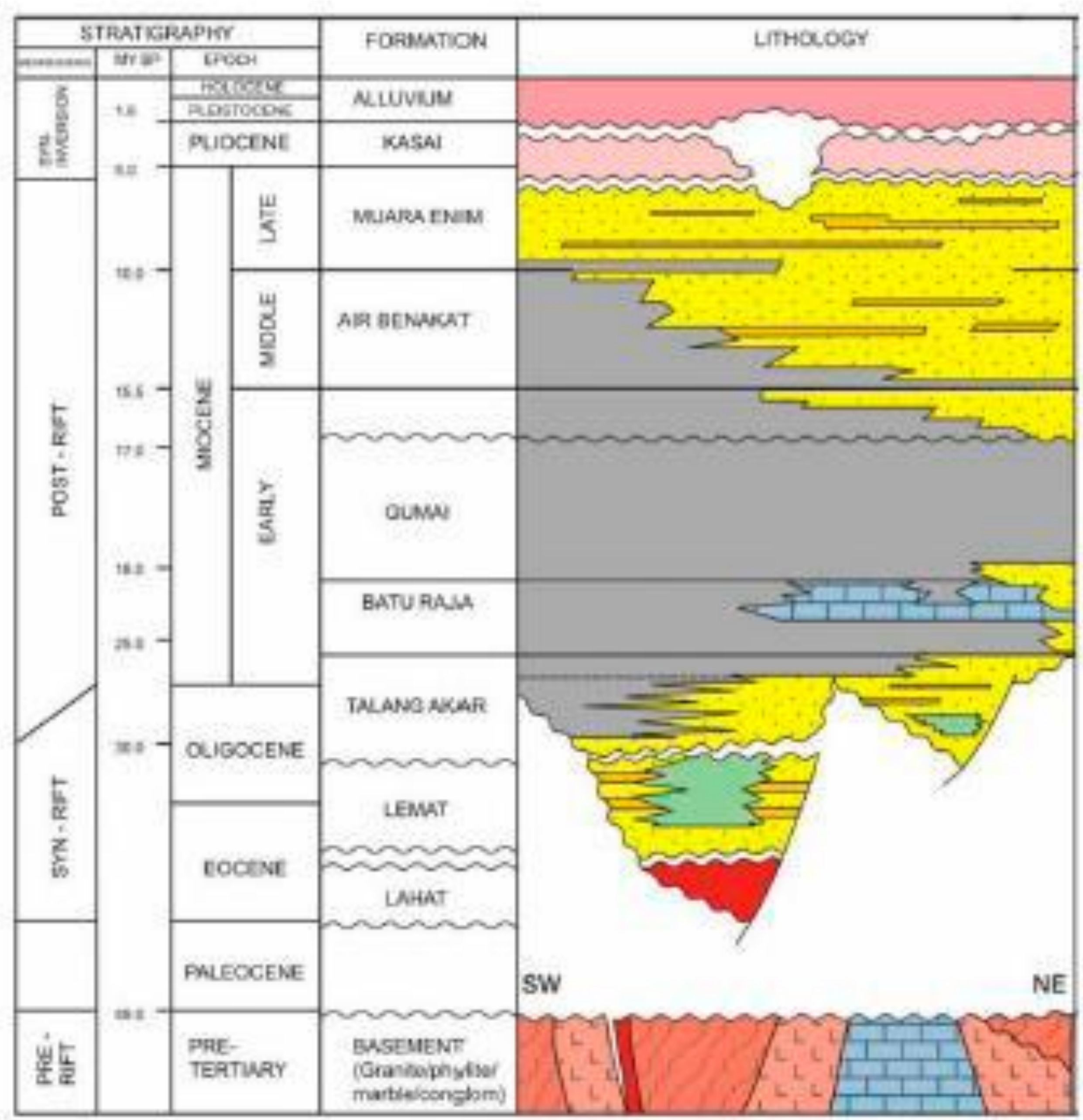

Figure 2. Chronostratigraphy of south Sumatra basin.

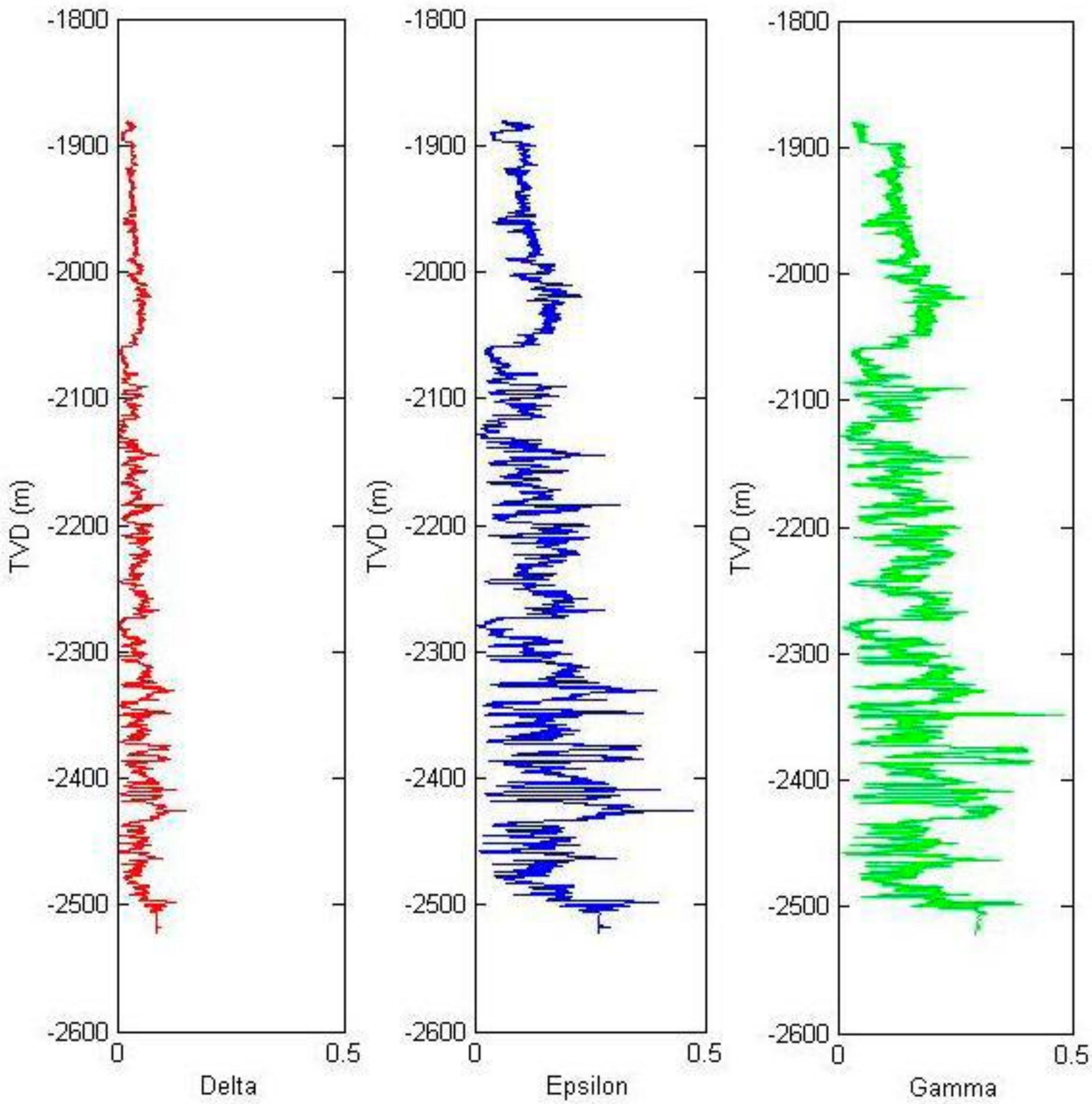

Figure 3. Thomsen Anisotropy Parameters (delta, epsilon, gamma).

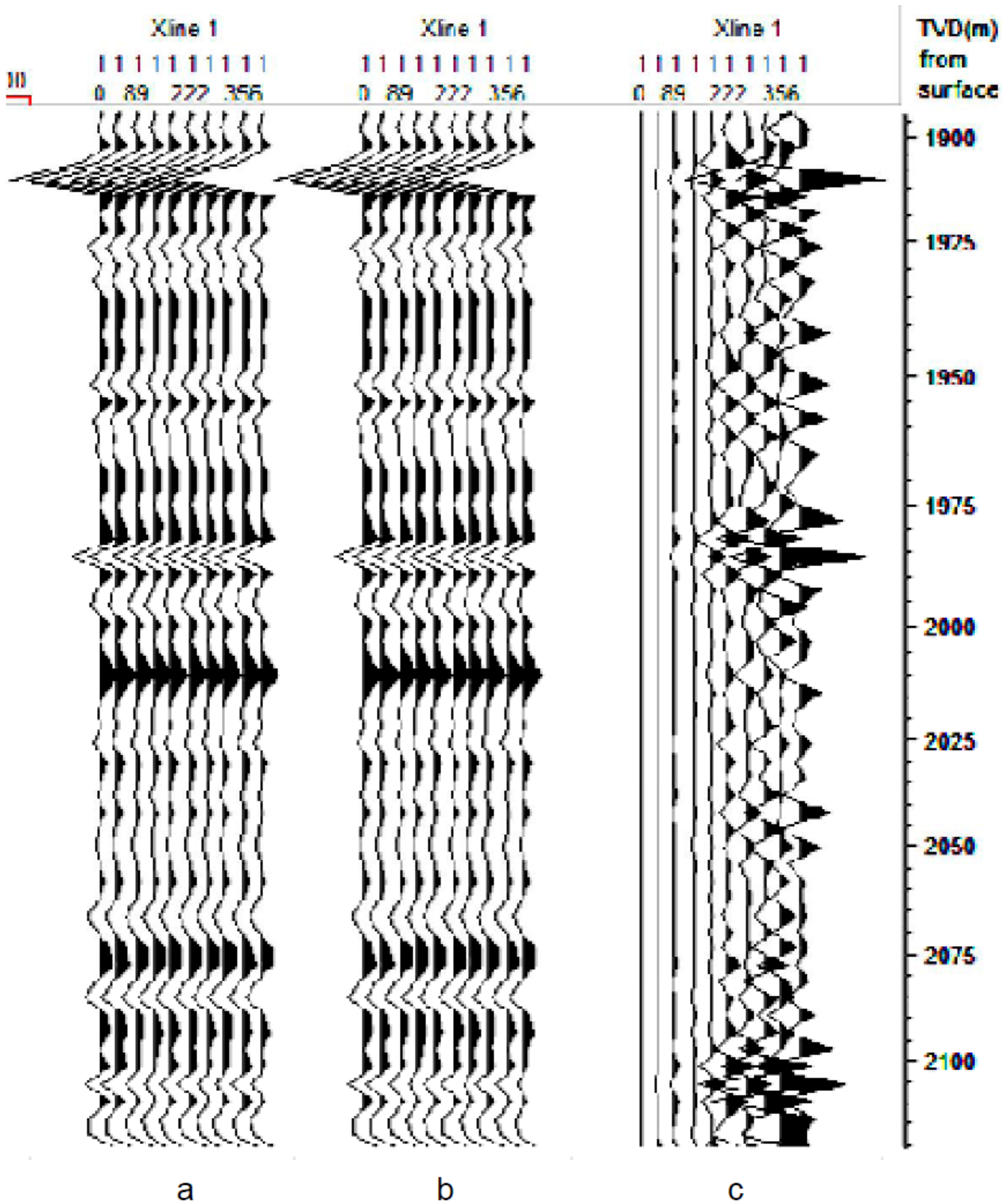

Figure 4. a) Synthetic seismogram with isotropy effect. b) Synthetic seismogram with anisotropy effect. c) Anisotropy - Isotropy.