Incorporation of Geology, Wells, and Rock Physics into Anisotropy Estimation for Seismic Depth Imaging Enables "True Earth Model"*

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Abstract

Subsequent to our previous paper on indicating anisotropy from well-seismic mistie analyses (Bui et al., 2010), we present a practical workflow to estimate anisotropy for seismic depth imaging. As is well known, seismic velocity is a very important variable that can result in the lateral and vertical mispositioning of reservoir targets. Likely, it was thought that, if the depth-migrated velocity was wrong, seismic anisotropic functions (Thomsen's delta and epsilon) were also wrong in a vertical transverse isotropic (VTI) case. In fact, the Thomsen's delta and epsilon functions help to flatten the gathers, but the depth still may be wrong at zero offset because the most important parameter that can cause the wrong depth is the vertical seismic velocity used in migration. To create the correct migrated seismic velocity model, we must clarify the right workflow.

A variety of methods exist to estimate anisotropy for seismic depth imaging. The global function of anisotropy is no longer valid, especially in complex areas. In this paper, we present our practical workflow to incorporate rock physics from well and geological information such as checkshot, calibrated sonic and geological markers to estimate anisotropy from surface seismic data at a well location by using a 1D raytracing method. This step is very important to tie the seismic events with the well markers into correct depth as well as to flatten the common image-point (CIP) gathers. Subsequently, we performed local well tomography to upscale into 3D at the well location. Finally, anisotropic functions were propagated along the interpreted seismic horizons using a proprietary steering filter tool. This approach has been applied in 400 OCS Blocks in the Green Canyon area of the Gulf of Mexico. The main steps are: 1) indicate anisotropy from well-to-seismic mistie analyses, 2) perform rock physics and petrophysical analyses ray tracing to correct seismic velocity at well location, 3) run 1D ray tracing with updated seismic velocity from the previous step with gather flatness by

updating the anisotropic functions, 4) propagate the properties field along interpreted seismic horizons, 5) incorporate the dips and azimuth to generate a new seismic velocity model as initial input for tomography, then prior to depth migration, 6) perform seismic-well tie to compare how we can improve with tilted transverse isotropy (TTI).

Case Study

The well under consideration is located in the Green Canyon area in the Gulf of Mexico. The study area covers approximately 400 Minerals Management Service lease blocks with a large number of Pliocene- Pleistocene minibasins and subsalt Miocene- and Wilcox-aged discoveries. The area is dominated by the interaction of salt and sediments, resulting in very steep dips at the salt flanks that may cause difficulties in seismic depth imaging. A total of 17 wells were used for anisotropy estimation. Figure 1 shows a depthmigrated seismic section through the well, where we performed the workflow for seismic anisotropy estimation. This well is vertical and penetrated 17,000 ft in a minibasin (see Figure 1 for location).

Well Data Conditioning and Rock Physics Analyses

The well data were edited to remove the spikes, noise, or bad trend of data and to fill in the gaps in the compressional sonic and density logs. The checkshot was used to calibrate the sonic logs, especially at the shallow section of the well. The pseudoden standard Gardner equation is from a gamma ray log (Gardner, 1974). Subsequently, we performed well seismic calibration for mistie analyses to indicate anisotropy (Bui et al., 2010). The mistie in depth was taken into a 1D ray-tracing model later to correct the seismic velocity and anisotropy at the well location.

Anisotropy Estimation

Figure 2 shows the initial model and the inputs for anisotropy estimation at the well location. Looking at the deepest marker in the well, we observed that the mistie is at approximately 400 ft as indicated from depth mistie analyses in synthetics (Bui et al., 2010), although the original depth is still flat (the last right panel in Figure 2). We will see how the depth can be corrected in a 1D ray model. To correct to the right depth, we must find a way in the first panel in Figure 2. The most critical parameter that can cause the depth change at zero offset is seismic velocity using depth migration. Therefore, it is very important to update the seismic before anisotropy estimation. The comparison in the second panel in Figure 2 indicates the deviation of the seismic velocity (red) from the smoothed well velocity (blue). The petrophysical and rock physics analyses help to correct the seismic velocity at the well location to be consistent with the well velocity (Bui et al., 2010). After correcting the seismic velocity, the depth mistie decreased, just as the drift curve on the first left panel in Figure 3 was reduced significantly.

However, the model depth gather in the fourth panel (Figure 3) is not flat. Subsequently, we must estimate and update the anisotropic parameters. Firstly, we perform 1D ray tracing to estimate Thomsen's δ to flatten the model gather at near and middle offsets. Secondly, Thomsen's ε was estimated by flattening the model gather at the far offset (Thomsen, 1986). Figure 4 shows the final model from 1D ray tracing with updated seismic velocity and Thomsen's anisotropic functions δ and ε. From a 1D raytracing model at the well location, we are not only able to improve the well-seismic tie into the right depth by updating seismic velocity model, but also keep the CIP gather flat. The next step is to perform local well tomography for 3D update at the well location (Bakulin et al., 2009).

3D Anisotropic Model Update

1D ray tracing was performed in all the wells in the study area to tie the seismic events to the right depth in agreement with the geological markers at the well location. The next step is to populate the derived anisotropic functions in all of the study area. As mentioned above, using the well and geology information to calibrate the seismic data closely to the "ground truth", we used interpreted seismic horizons with a steering filter to populate the model. The extrapolation was conducted with an interpretation-to-imaging multiwell analysis workflow (MWA) to build velocity models. The new MWA workflows use multiple wells and seismic velocity models to compute volumes for Thomsen epsilon and delta, update seismic velocity, and correct depth. These workflows are not limited to single wells and also consider lateral anisotropic variation. Figure 5 shows the δ anisotropy field update in the study area overlaid on the seismic data. The variation of the δ anisotropy field shows agreement with the geological structure interpreted in the seismicdata. The updated anisotropic property field and the seismic velocity from MWA will be used as the initial model in a tomography workflow with dip and azimuth to generate an optimized tilted transverse isotropy (TTI) anisotropic velocity field for depth migration. Figure 6 shows the seismic-well tie in between VTI and TTI depth migrated data. The color displays the sediment flood velocity. The seismic-well tie improved significantly with the TTI Kirchhoff migration and came very close to the well makers.

Conclusions

Integrating well data, rock physics, and geology into anisotropy estimation for anisotropic seismic velocity model building plays a very important role in depth imaging. We showed a practical workflow to improve the well-seismic tie in depth as well as to retain the gather flatness. The updated seismic velocity and anisotropic models from our workflow show very significant improvement in depth correction at each well location, bringing the seismic depth images close to "true earth". The accuracy of the anisotropic seismic velocity model, as well as the geological consistence of depth-migrated seismic images, always depends on the input data and geological understanding. Therefore, we must continuously update the model with supplemental data or geological information.

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References

Bakulin, A., M. Woodward, D. Nichols, K. Osypov, and O. Zdraveva, 2009, Localized anisotropic tomography with well information in VTI media: 79th Annual International Meeting, SEG, Expanded Abstracts, p. 221-225.

Bui, H., P-H.D. Ng, J. Durrani, D. Becker, and M. Smith, 2010, Well-Seismic Tie in the Sub-Salt Wells, Deep-water Area in the Gulf of Mexico: A Valuable Indicator of Anisotropy: AAPG International Conference and Exhibition, Calgary, Canada, 12-15 September 2010. AAPG Search and Discovery abstract #90108, Web accessed 24 October 2011, http://www.searchanddiscovery.com/abstracts/pdf/2010/intl/abstracts/ndx_bui.pdf

Bui, H., P-H.D. Ng, D. Becker, J. Zhou, and M. Smith, 2010, Well-to-seismic mistie: A valuable indicator of seismic anisotropy for subsalt velocity model update. A case study in a deviated subsalt well in the deepwater Gulf of Mexico: SEG International Exposition and 80th Annual Meeting, 17-22 October 2010, Expanded Abstracts, p. 302-306.

Gardner, G.H.F., L.W. Gardner, and A.R. Gregory, 1974, Formation velocity and density -- the diagnostic basics for stratigraphic traps: Geophysics, v. 39, p. 770-780.

Thomsen, L., 1986, Weak elastic anisotropy: Geophysics, v. 51/10, p. 1954-1966.

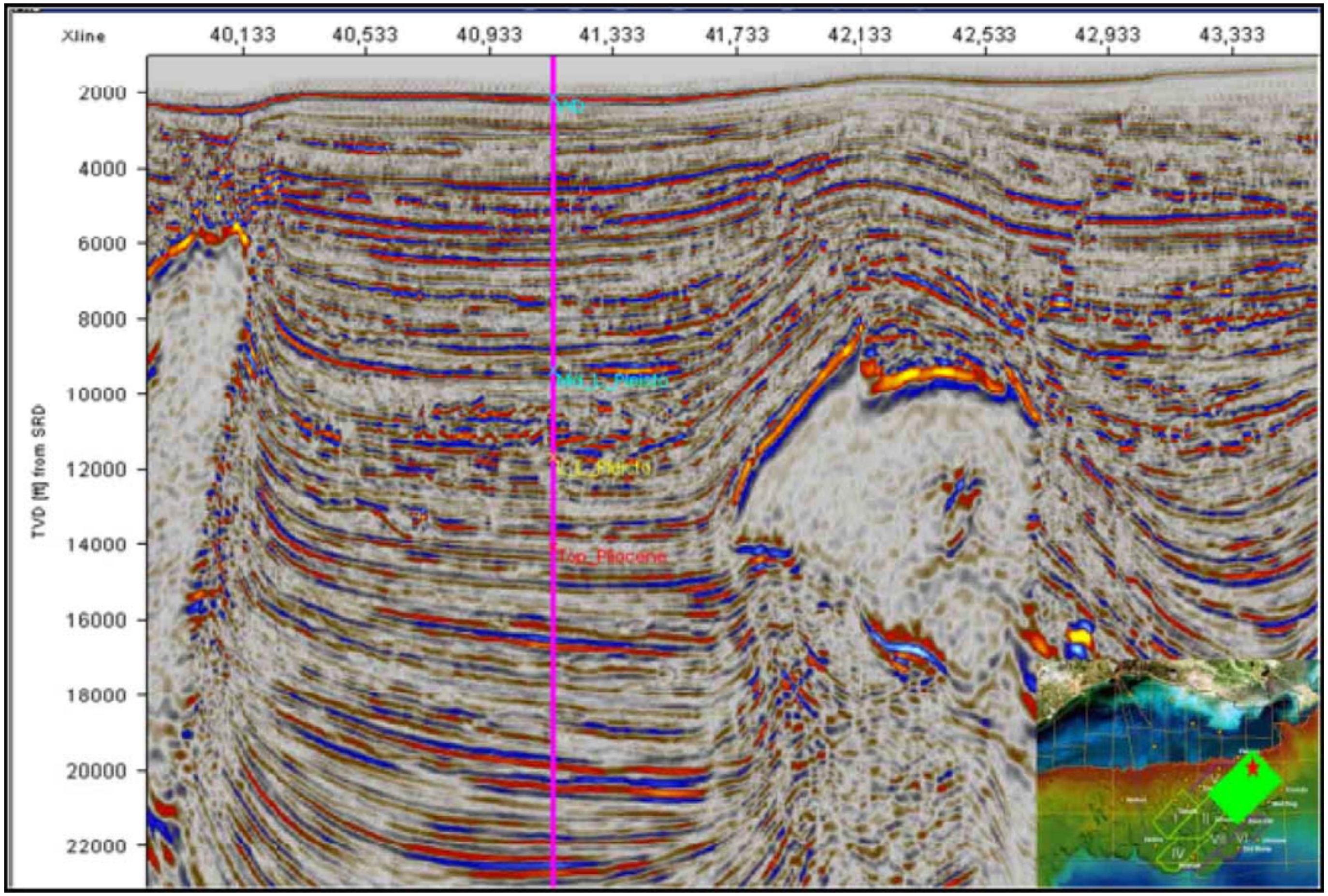

Figure 1. A depth-migrated seismic section though the well. The location of the well in the study area is shown on the map.

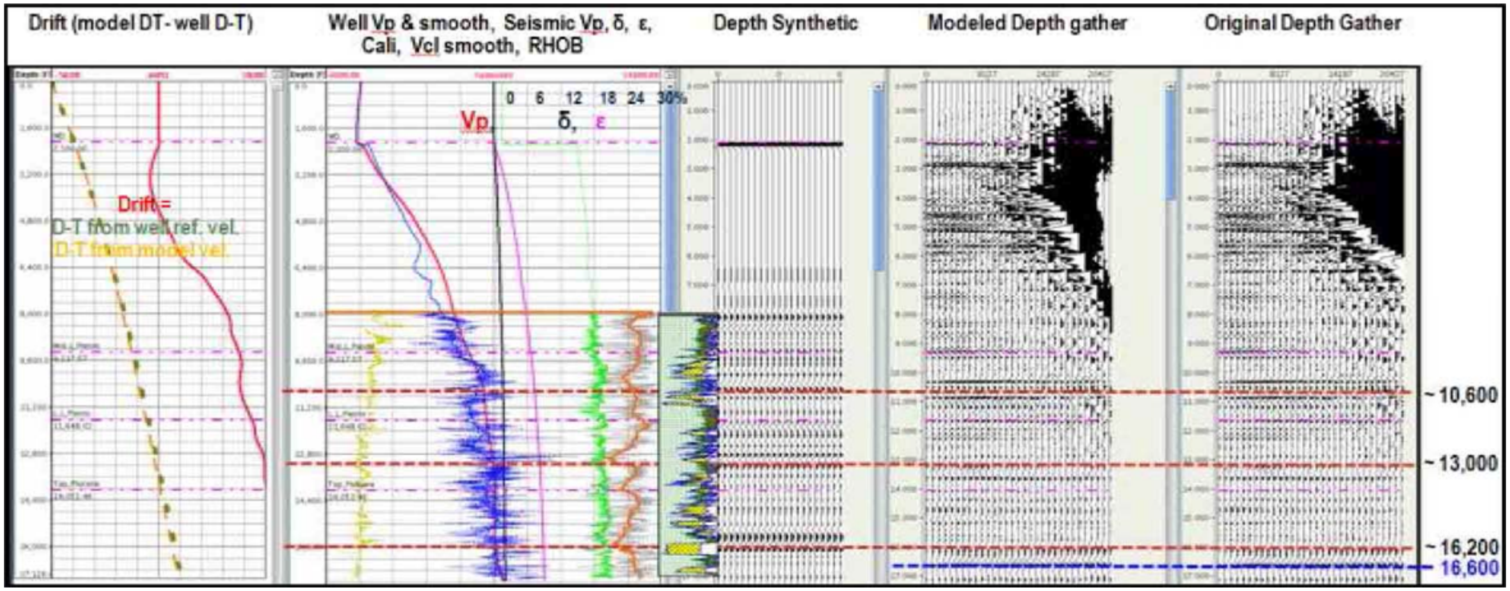

Figure 2. The initial model and inputs for a 1D ray-tracing model at the well location for anisotropy estimation. The first panel is the drift curve (in red color) showing the large difference of the time-depth curve using well velocity and initial migrated seismic velocity. The second panel shows the initial seismic velocity (red), smoothed well velocity (blue), initial Thomsen's δ (black), and ε (purple).

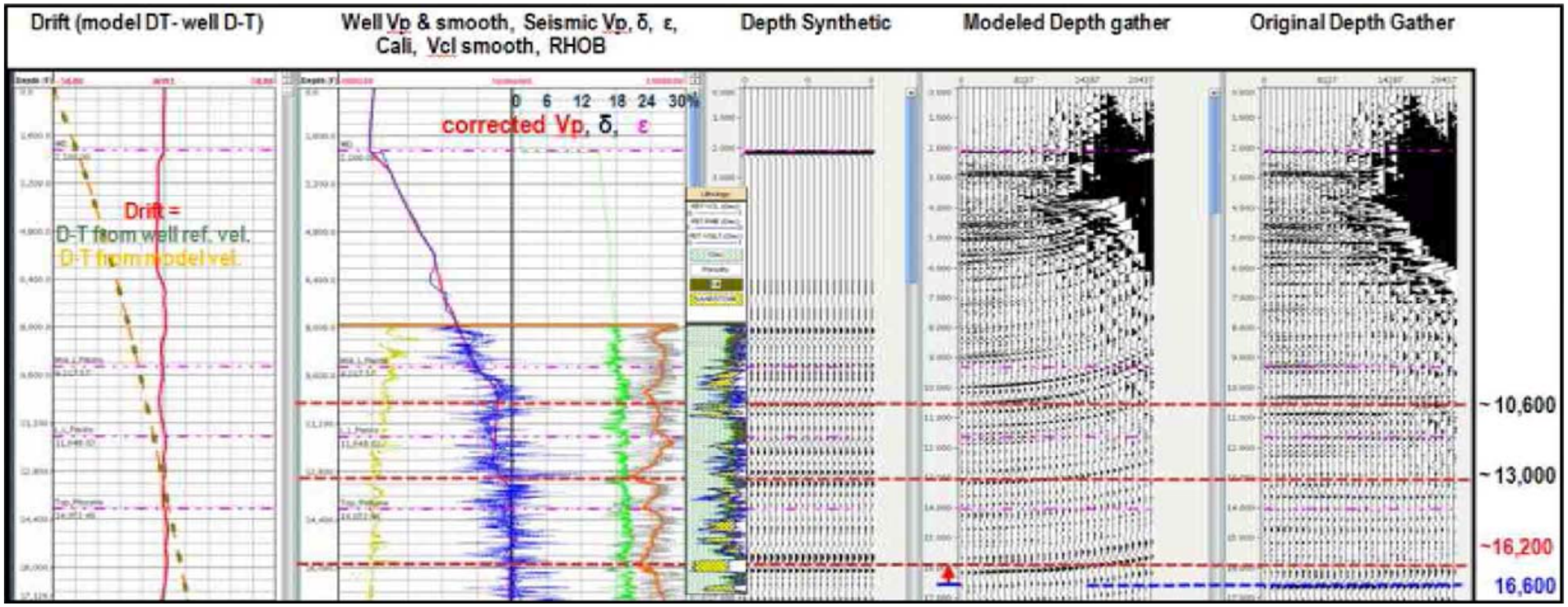

Figure 3. Illustration of seismic velocity correction to correct the depth (400 ft) before anisotropy estimation. Hence, the drift curve is reduced to almost zero. However, the gather is not flat. We need to apply anisotropy correction to flatten the gather.

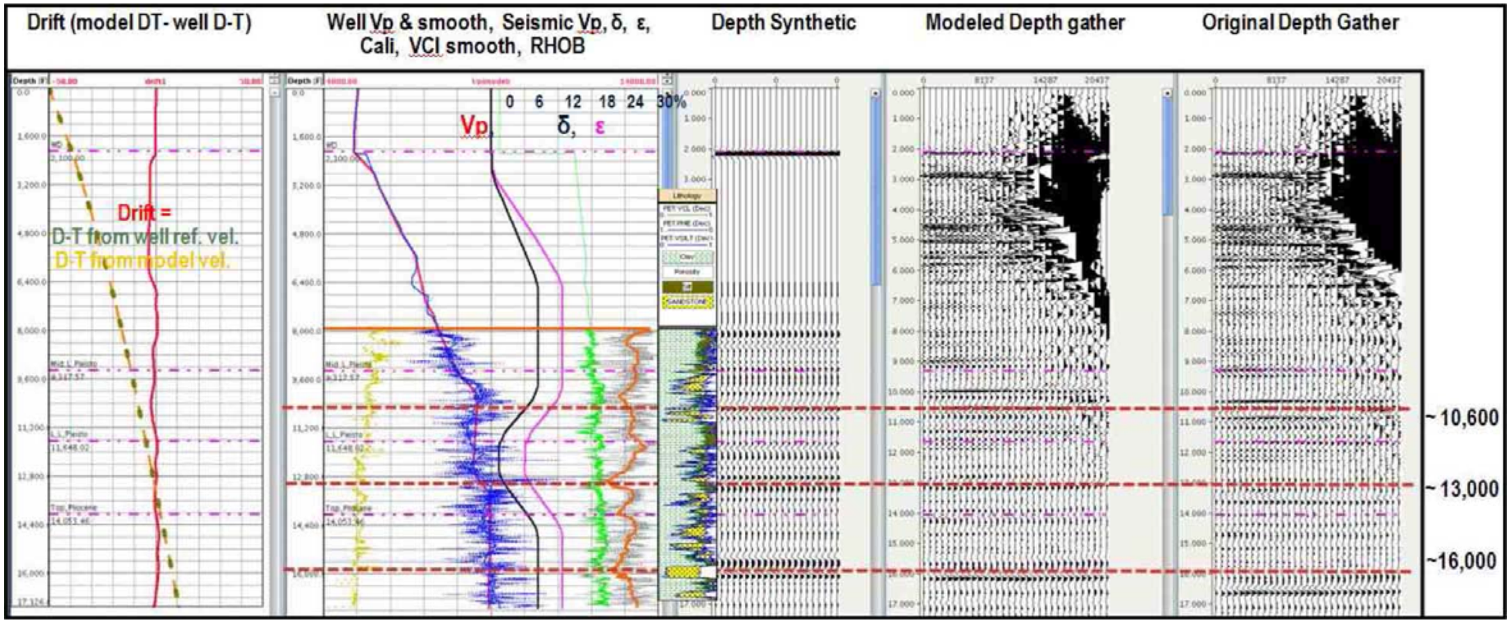

Figure 4. Final update of seismic velocity and anisotropy at the well location from a 1D ray-tracing model. In the second panel, the red is updated seismic velocity, and black and purple are Thomsen's δ and ε, respectively.

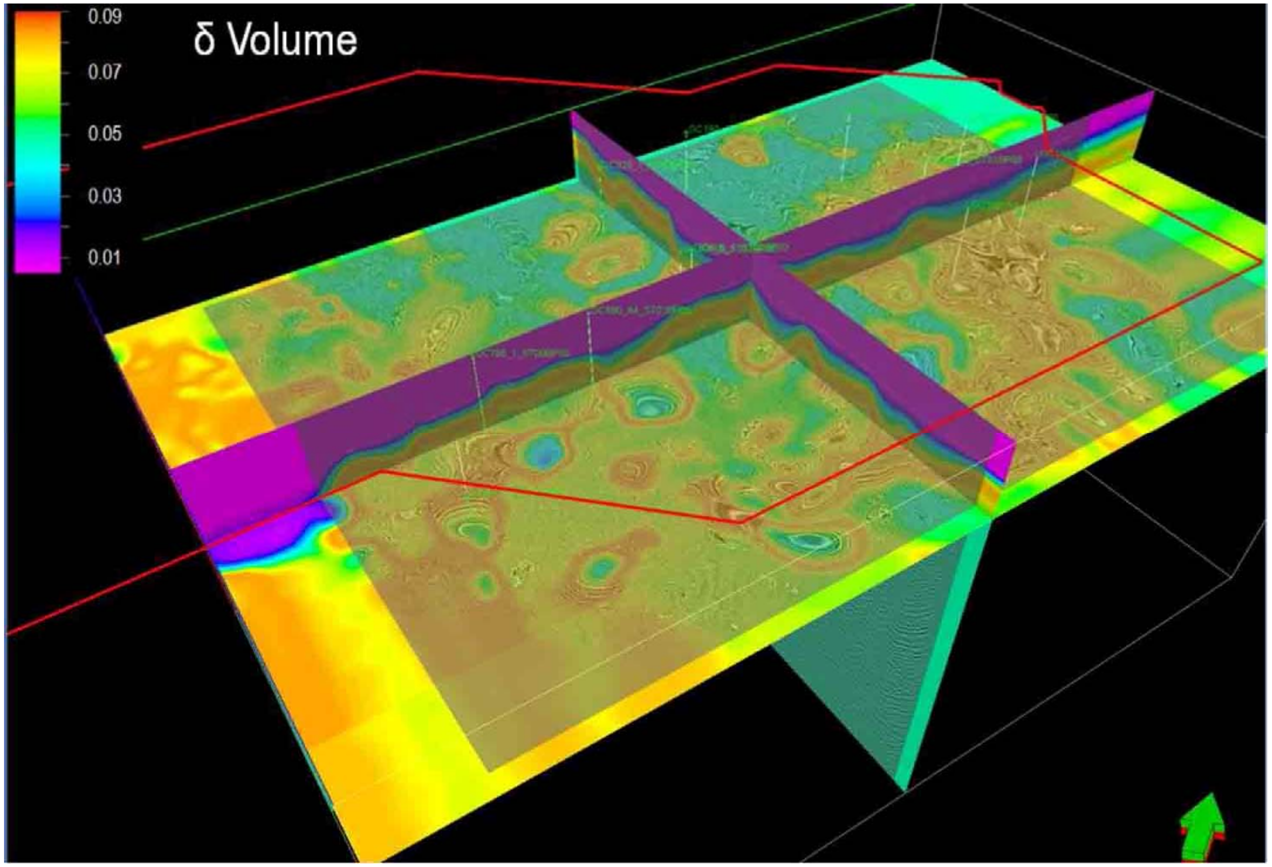

Figure 5. Thomsen's δ anisotropy field in the study area using the well and geological information that has been used for migration.

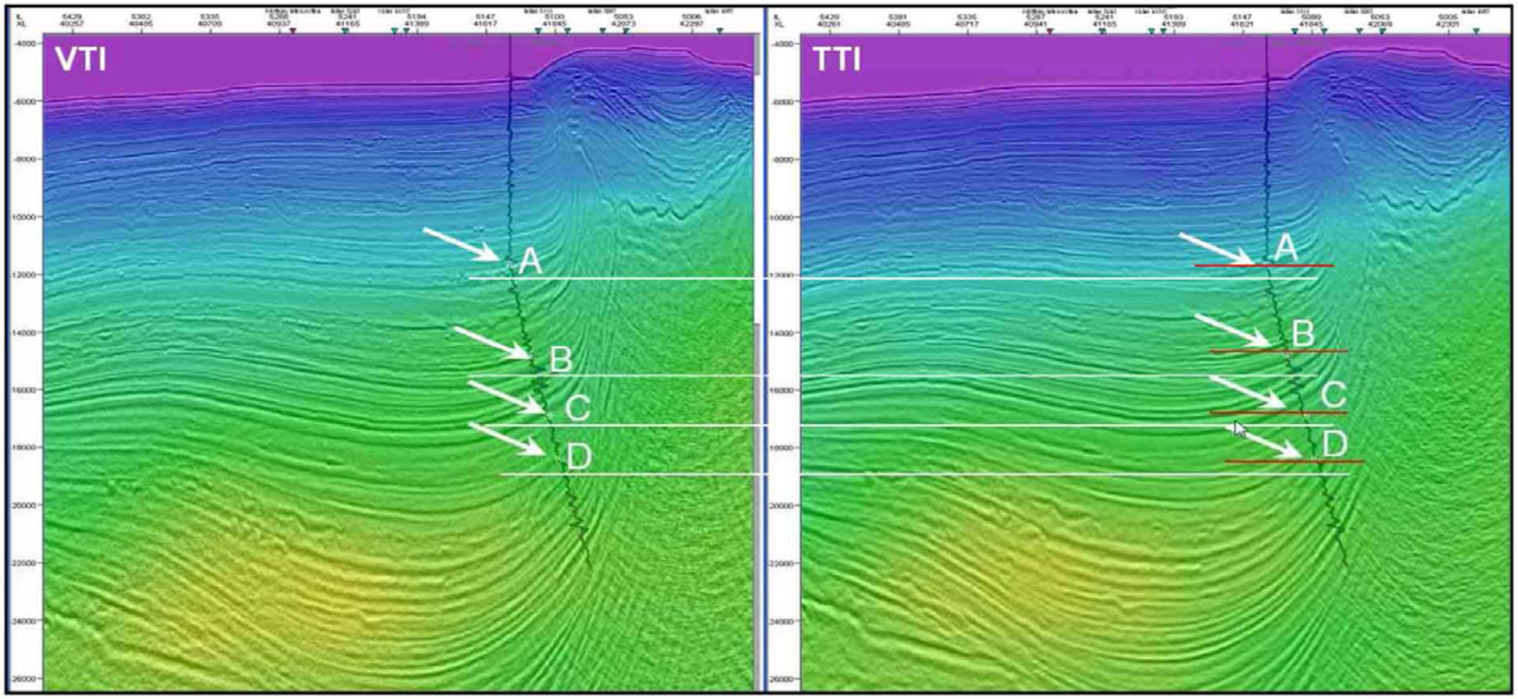

Figure 6. The seismic-well tie analyses between the VTI and TTI model after migration. The color scale shows the sediment flood velocity. The tie between well and seismic has been improved significantly. The white lines show the original positions of the seismic events with VTI. The red lines show the positions by using TTI model that are very close to the well markers (A, B, C, D).