A case study for orthorhombic model building using 5D regularized full azimuth land data

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Summary

We present a case study of the compressional-wave orthorhombic anisotropic (Tsvankin, 1997) model-building for a land area, Kansas, USA. This is a full azimuth (FAZ) dataset that was created by merging two 3D full azimuth surveys, the Wellington and Belle Plaine 3D acquisitions. We apply our 5D regularization technology of antileakage Fourier transform (ALFT) (Xu et al., 2005, 2010; Whiteside, et al., 2014). Our results show that for the orthorhombic anisotropic model building, the merged 5D regularization FAZ data maintains the illumination from both original surveys, minimizes artifacts in the prestack depth migration and fills large survey gaps (Figure 1).

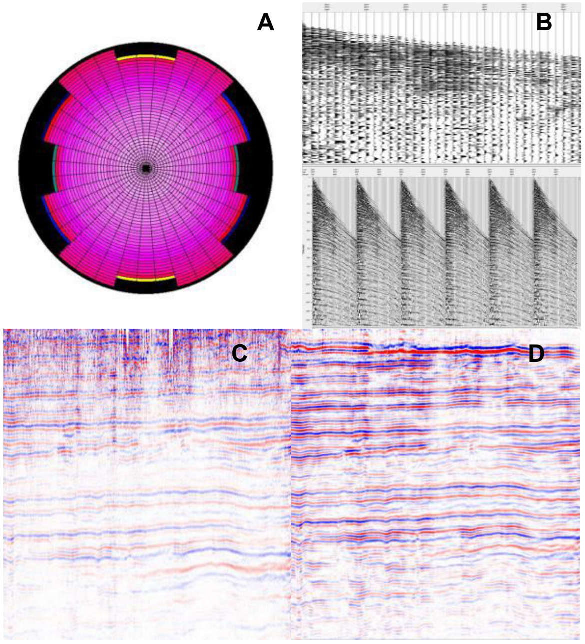

Figure 1: (a) 5D regularization azimuth-coverage diagrams of six azimuth sectors with equal interval of 30°; (b) typical full fold input gathers (top) and 5D regularization (bottom) output azimuth gathers; stacks before (c) and after (d) 5D regularization.

Introduction

In areas with complex geologic structures, wide azimuth (WAZ), multi-WAZ and FAZ surveys are commonly conducted in our industry. Although the illumination is greatly increased, imaging focus is still disappointing with a tilted transverse isotropic (TTI) anisotropic model. When the multiple azimuthal gathers of Kirchhoff pre-stack depth migration (KPSDM) are compared, residual moveout is apparent in some while others are flat. In this situation, with a TTI velocity model, even the multi-TTI models cannot fully describe the local azimuth-related anisotropy.

Under regional tectonic stress, or within salt intrusions, the horizontally layered sedimentary media will deform and create fractures that consist of joint sets and fault sets. These are a combination of three basic faulting patterns: normal, strike-slip and thrust faults. In this realistic state, the fracture-related azimuthal anisotropic character should be accounted for by the anisotropy beyond a simple TTI to build a better and more detailed local anisotropic model.

To better describe complex geological structures that are caused from fractures in the stratigraphic layer media from simple TTI model to more complicated anisotropic model the tilted orthorhombic (T-ORT) model is first choice because T-ORT anisotropy is the simplest symmetric and ideally conditioned description for the fractured TTI anisotropic media where one vertically fractured set, two or three mutually orthogonal fractured sets embedded on the media, which the symmetric axis(es) is(are) parallel to or perpendicular to the symmetric polar of the TTI model within the layered sub-surfaces. To well interpret the different azimuthal datasets, we may build the multiple azimuth-related TTI models. Although there should be only one velocity model at each location within the media. But these multiple azimuth-related TTI models will be essential to derive the optimistic initial orthorhombic model. To fit the all azimuth datasets the orthorhombic tomography should be conducted, and the orthorhombic anisotropic model will be iteratively updated.

5D Data Regularization

Recently the data regularization has been widely used in the seismic processing for merging different acquisitions to create unique regularly sampled dataset and fill the different type gaps in surveys, which preserves the azimuth information for each trace. It can be used as a general tool to merge multiple surveys pre-stack, including, for example, orthogonal wide azimuth surveys, different narrow azimuth surveys, or a combination of the two if the computational cost and runtime are accepted. The 5D regularized full azimuth data will deliver the best illumination of the subsurface and high S/N ratio images in the complex geologic regions as its uniform and isotropic configurations on both sources and receivers can reduce migration artifacts in data. The efficient 5D ALFT regularization technology ensures large-scale surveys are processed cost effectively (Whiteside, et al., 2014). The

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processed dataset preserves the azimuthal illumination from original surveys and fills the large gaps in offsets or surveys. The gathers of the KPSDM from this data keep more accurate azimuth-related anisotropic information compared with that from the conventional input data by using trace weighting schemes, for example, standard fold compensation, and the noise artifacts in the migration gathers and their stacked imaging are obviously mitigated. On the boundary area between the two or more surveys the 5D regularization will output the non-seams datasets. Hence, the 5D regularization dataset is ideal for the orthorhombic anisotropic model building (Figure 1). In this study the 5D regularization data is created by two full azimuth 3D land surveys, the Wellington and Belle Plaine acquisitions located in Sumner County, Kansas, USA in 2013-2014 and 2014, respectively, that covers an area of about 400 square miles.

Orthorhombic Model Building Workflow

It is well known that a P-wave horizontally orthorhombic anisotropic model will be described with a total of seven parameters. These are: isotropic (vertical) velocity ($\boldsymbol{V_0}$); fast velocity orientation ($\boldsymbol{\alpha}$) within the layered subsurface; anisotropic parameters ($\boldsymbol{\delta_f}$ and $\boldsymbol{\varepsilon_f}$) in the fast direction; anisotropic parameters ($\boldsymbol{\delta_s}$ and $\boldsymbol{\varepsilon_s}$) in the slow direction; and anisotropic parameter ($\boldsymbol{\delta_h}$), which contributes to $\boldsymbol{\varepsilon(\phi)}$ of any azimuth $\boldsymbol{\phi}$ within the stratigraphic layer in Thomsen notation (Tsvankin, 1997). When a horizontal layer is tilted the normal direction of the layer subsurface (azimuthal angle $\boldsymbol{\varphi}$ and dip angle $\boldsymbol{\theta}$) is added so that there is a total of nine parameters in a T-ORT model. Generally, for orthorhombic tomography, the isotropic velocity $\boldsymbol{V_0}$ and five anisotropic parameters of $\boldsymbol{\delta_i}$ and $\boldsymbol{\varepsilon_j}$ will be updated to flatten all azimuth gathers. The parameters $\boldsymbol{\delta_f}$ and $\boldsymbol{\delta_s}$ correct the short-offset effect while $\boldsymbol{\varepsilon_f}$ and $\boldsymbol{\varepsilon_s}$ correct the long-offset effect. $\boldsymbol{\delta_h}$ is a judgment for $\boldsymbol{\varepsilon(\phi)}$ between the fast and slow directions.

We describe an efficient workflow for the orthorhombic anisotropic model building (Figure 2). We use multiple azimuth migrations to create the azimuthal TTI anisotropic models by tomography. Then combined the all azimuthal TTI anisotropic parameters we output an initial orthorhombic model. The orthorhombic tomography will iteratively update the previous orthorhombic model (He et al., 2013).

Both the estimation of an initial orthorhombic model and the inversion of orthorhombic tomography require at least three different azimuth datasets. Six azimuthal sectors are necessary to more accurately estimate and update the orthorhombic anisotropic model. Here, we use an even azimuth interval of 30^o (six azimuths of 0^o, 30^o, 60^o, 90^o, 120^o and 150^o) from the 5D regularized FAZ data.

The initial single TTI velocity model is based on the calibrated VTI model of the two survey projects. First, we conduct three passes of conventional TTI tomography to update the isotropic velocity by combining the six azimuthal migration results. Next, we update the anisotropic parameters of delta and epsilon for each azimuth without changing the isotropic velocity. Then we derive the initial orthorhombic model with the six azimuthal anisotropic parameters of delta and epsilon, Finally, a two-pass orthorhombic tomography is applied.

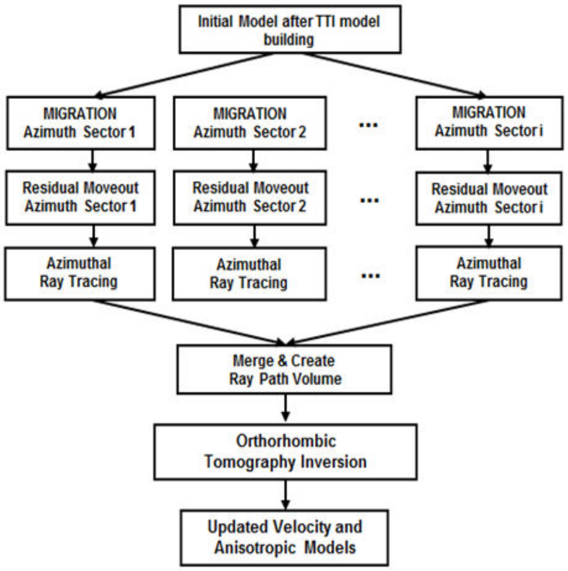

Figure 2: Workflow for orthorhombic model building.

In our model-building process, we use the image-guided tomography method described by Hale, (2009) to update the velocity model. This method constrains the updates that are inverted from the more accurate picking following the seismic structure (Hilburn et al., 2014).

Offset-dependent Picking

The orthorhombic model more accurately describes the detailed and minor anisotropic differences among different azimuths compared to the TTI model. The azimuth-related anisotropy results from the fractures in the stratigraphically layered sediment. Unless we correctly extract the weak anisotropic information from azimuth-dependent migration gathers, it is difficult to accurately estimate and update the orthorhombic model. Obviously, in the weak anisotropic situations to accurately pick residual moveout is vital for the tomographic inversion, especially for an orthorhombic tomographic inversion. In this study we use the newly developed offset-dependent picking technique (Hilburn et al., 2014) as it can track gather events with multiple turning points better than a traditional curvature-based picking. The accurate residual moveout picking can yield updates which more quickly flatten gathers and bring out fine detail in velocity models.

Gather and Image Improvements

Figure 3 demonstrates the six azimuth KPSDM gathers migrated with the initial orthorhombic model and the updated orthorhombic model inverted from a two-pass orthorhombic tomography. The panel on the top shows the six azimuth gathers of the KPSDM with the starting orthorhombic model, where the same events on far offsets are broken or bend up or down on the six azimuth sectors of 0^o, 30^o, 60^o, 90^o, 120^o and 150^o from left to right at depth range from shallow to medium on a CDP location. The bottom panel shows the corresponding azimuth KPSDM gathers migrated with the two-pass updated orthorhombic model. Observably, the breaking and bending down or up of the events on the far offsets in the six azimuth sectors are smoothly linked and flatten partially.

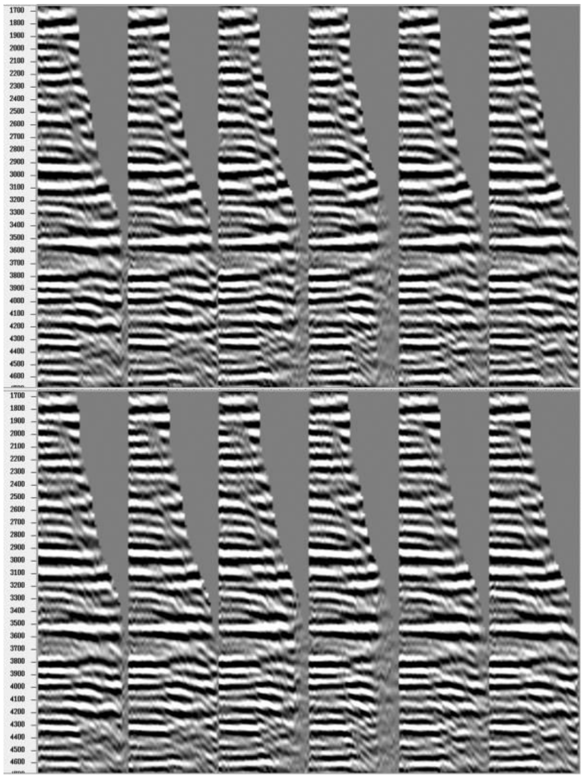

Figure 3: Comparison of six azimuthal gathers (from left to right: 0^o, 30^o, 60^o, 90^o, 120^o and 150^o) before (top) and after (bottom) orthorhombic tomographic updates.

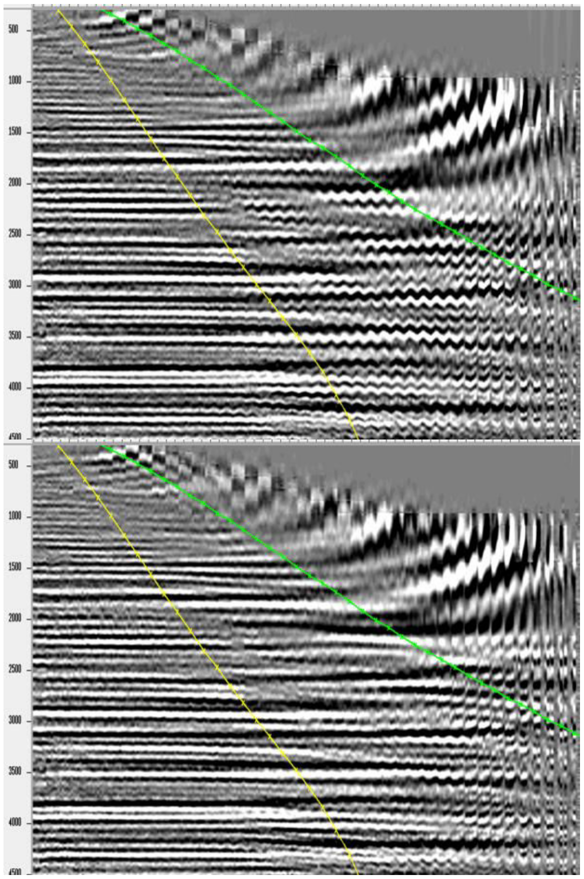

Figure 4: Comparison of nail gathers of six azimuths of 0^o, 30^o, 60^o, 90^o, 120^o and 150^o before (top) and after (bottom) orthorhombic tomographic updates. The yellow and green lines are angle mute lines of 30^o and 60^o respectively.

Figure 4 illustrates the six azimuth KPSDM gathers migrated with the initial orthorhombic model and the updated orthorhombic model inverted from a two-pass orthorhombic tomography in the snail gathers, in which the traces have been ordered based on common offset, common azimuth. It is easy to observe the azimuthal behavior in the event on different azimuths. The top panel shows the snail gathers of the six azimuthal KPSDM migrated with the starting orthorhombic model. The bottom panel shows the corresponding snail gathers migrated with the updated orthorhombic model. The events for small and medium offsets are flat before and after the update of the orthorhombic model, but the same events exhibit sinusoidal residual moveout on the far offsets, with the starting model, and after the model is updated they are more flat.

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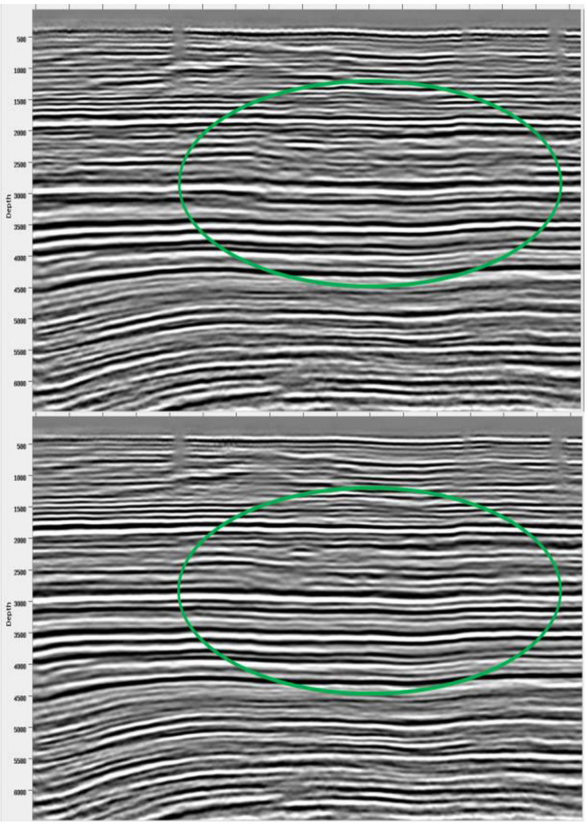

Figure 5: Comparison between KPSDM stacks of six azimuths before (top) and after (bottom) orthorhombic tomographic update.

Figure 5 shows the stacked imaging results from the six azimuth KPSDM gathers before and after the orthorhombic tomographic update. The updated orthorhombic model improves the image focusing by flatting the snail gathers.

Conclusions

Using orthorhombic anisotropic model building our KPSDM orthorhombic tomography approach can efficiently flatten the gathers through model refinement for all azimuths and improve image focusing using a FAZ dataset. Both the azimuthal KPSDM gathers and their stack imaging are obviously improved by using the 5D regularized FAZ datasets for initial orthorhombic model estimation and its tomographic updated model. It is expected that processing with the 5D regularized full azimuth data will provide new opportunities for a more detailed anisotropic description with an orthorhombic anisotropy model or an even more complex anisotropic model. And then they provide better imaging in the complex geologic structures with the better illumination and high S/N ratio.

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