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Dual WAZ Processing and Orthorhombic Imaging - A Case Study in Mississippi Canyon, Gulf of Mexico

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Summary

Dual WAZ and tilted orthorhombic anisotropy model building and imaging has approved to provide a more geologic conforming high resolution velocity models, give a better illumination and flatten the common imaging gathers for all azimuths, and improve the CIG flatness and enhance seismic continuity. In this paper we will present wide azimuthal orthorhombic anisotropy model building workflow and multiazimuth modelling for orthogonal WAZ, compare the TORT initial and final models in depth sections and slices, and show some examples of final TORT seismic imaging and CIG comparison to demonstrate the orthorhombic anisotropy modelling improves the CIG flatness across the different azimuths.

Introduction

Seismic anisotropy is the dependence of seismic velocity on the wave propagation direction, which often leads to the velocity along the sedimentary bedding layers being different from that in the polar axis or azimuthal direction. This variation needs to be taken into account in order to better define the models, and flatten the common image gathers (CIGs) in seismic prestack imaging.

The most commonly modelled anisotropic scenarios in the Gulf of Mexico are horizontal layers with a perpendicular axis of symmetry - vertical transverse isotropy (VTI), tilted transverse isotropy (TTI), and fracture embedded tilted orthorhombic anisotropy (TORT).

In a VTI sedimentary environment, the horizontal velocity is usually faster than that along the vertical direction, where the anisotropy delta/epsilon parameters are introduced to better tie the vertical velocity with the checkshots. However if rock layers are tilted, the VTI assumption is not adequate to describe the additional effects due to dip. When the dipping parameters are added to the VTI modelling and imaging, it is categorized as a TTI problem. If fractures, faults or stress are present in the thin layers, the seismic velocity will be deviated from that in other directions, making the seismic velocity vary at different azimuthal directions. The velocity parallel to the fractures tends to be greater than that in the perpendicular direction. To handle these complex velocity variations, four extra anisotropy parameters have been introduced to solve this TORT problem (Tsvankin, 1997, Figure 1).

In this paper we will present a wide azimuthal (WAZ) orthorhombic anisotropic model building workflow and multiazimuth modelling for orthogonal WAZ, compare the TORT initial and final models in depth sections and slices, and show some examples of seismic imaging stack and azimuthal gathers from TTI and TORT.

Method and workflow

To build and update the orthorhombic modelling and better image the seismic events with wide azimuth data (WAZ) input, a procedure and workflow has been proposed and implemented in TGS (He et al., 2013; Tiwari et al., 2015), in which the WAZ input data are split into multi-azimuthal sectors, and TTI prestack migration and imaged-guided tomography (Hilburn et al., 2014) is performed to update velocity, delta, epsilon and dipping fields at each sector. After several iterations of migration and tomography, most CIGs are well flattened for all azimuths.

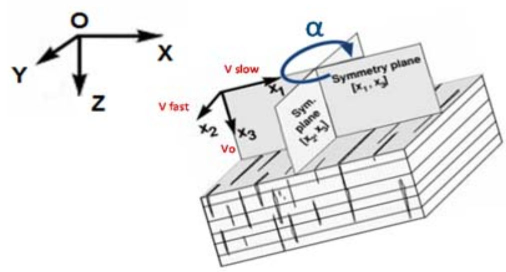

Figure 1 *Tilted orthorhombic anisotropic medium with three orthorhombic symmetry planes: 9 anisotropic parameters, V_0, δ_1 and ε_1 in the $x_2\,x_3$ plane – fast velocity, δ_2 and ε_2 in the $x_1\,x_3$ plane – slow velocity; δ_3 in the $x_1\,x_2$ plane; θ, φ represent normal vector of the symmetric axis; α represents azimuthal rotation of the fast velocity. (Tsvankin, 1997)*

Starting with the best TTI models, the initial nine orthorhombic parameters (V_0, δ_1, δ_2, δ_3, ε_1, ε_2, θ, φ, α) (Tsvankin, 1997, Figure 1) are derived by fitting all TTI deltas and epsilons to an approximate ellipse (Li, 2012), where V_0, θ, φ are directly taken from the TTI model, (δ_1, ε_1), (δ_2, ε_2) are the anisotropy parameters in the symmetry planes (x_2-x_3), and (x_1-x_3) respectively; δ_3 is the anisotropy parameter in (x_1-x_2), which measures the transition between fast and slow velocities; α is the azimuth angle. By introducing four additional anisotropic parameters compared with TTI, the TORT method is able to define the medium velocity variations between azimuths, and improve the subsurface imaging continuity by flattening the CIGs for all azimuths.

For the synthetic data example presented by He et al., 2013, the VTI model is not sufficient to flatten the CIGs for all azimuths where the fractures are present. Some azimuthal gathers need slower velocities, while others require faster velocities at the same location due to azimuthal differences. With orthorhombic modelling and imaging, all the CIGs at each azimuth are better flattened and prestack images are more coherent.

In the TORT model tomography workflow (illustrated in Figure 2), the TORT prestack migration, CIGs curvature picking, and ray tracing are independently implemented for each azimuth, and then jointly invert to update the models. During the inversion the structure-oriented tensors (Hilburn et al., 2014) are used to constrain the update based on the directionality and continuity of the reflectors, which enhances the seismic coherences and the fault boundaries in the imaging.

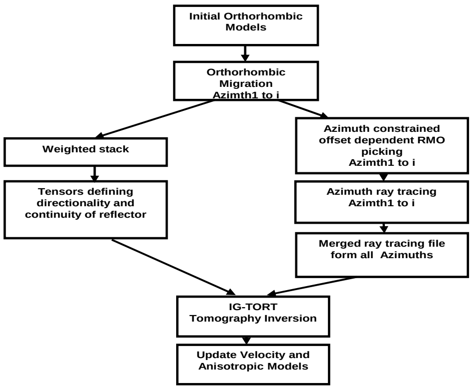

Figure 2 *Tilted orthorhombic model building workflow. TORT prestack migration, CIGs curvature picking, and ray tracing are done independently for each azimuth, and then combined for a single inversion with structural tensors.*

Tilted orthorhombic modelling

The input data is composed of two WAZ surveys, Declaration and Justice in the Mississippi Canyon of the Gulf of Mexico with perpendicular acquisition shooting direction, and Declaration survey is on top of Justice.

After three iterations of multiazimuth TTI prestack imaging and tomographic model updates, and four iterations of multiazimuth TORT modelling with the image guided tomography, the results are shown in Figure 3. Figure 3(a) is the initial orthorhombic model overlaid on initial stack image, and Figure 3(b) is the final orthorhombic model overlaid on final stack image. It's observed that the TORT model is much more compliant with geologic structures and much higher resolution, and the seismic stacks are more coherent through the whole section.

Furthermore, depth slices of the models are compared (in Figure 4). Figure 4(a) shows a depth slice of the initial TORT model after TTI tomography, and Figure 4(b) is the depth slice of the final orthorhombic model. The TORT model conforms much better to the geology and provides more detail.

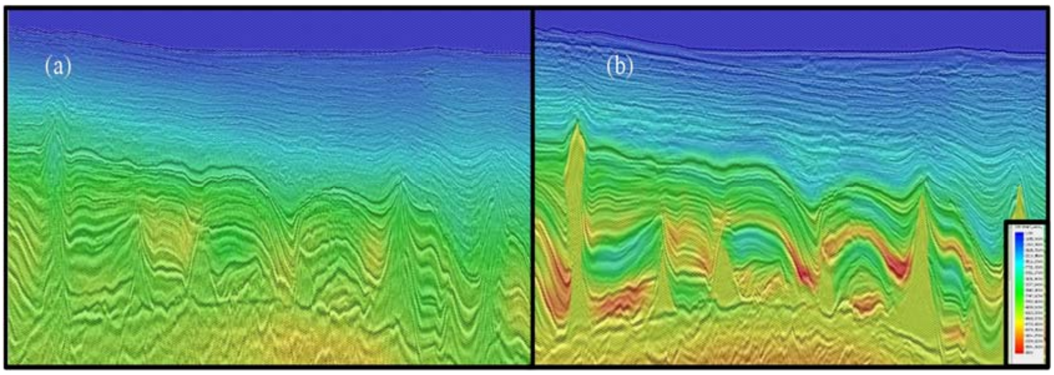

Figure 3 *TORT initial and final models and images, (a) initial orthorhombic model after the final TTI tomography; (b) final orthorhombic model after four iteration multi-azimuth image guided tomography. The TORT final model is much more compliant with geologic structures, and the seismic images are more coherent and resolved.*

In addition we compute the azimuths of the fast velocity corresponding to the preferential direction of fracturing. When they are plotted on top of the depth slice of the salt model, it can be seen that the velocity along the salt radius direction tends to be faster than that in tangent direction. The green arrows as shown in Figure 5 display the direction of the fast velocity around the salt bodies.

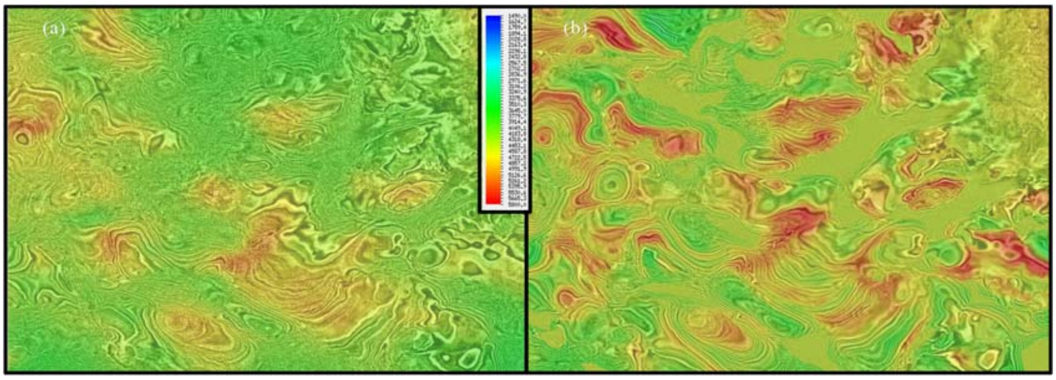

Figure 4 *TORT initial velocity and final model depth slices, (a) A depth slice of initial orthorhombic velocity; (b) A depth slice of final orthorhombic velocity. The TORT final velocity conforms much better with geology.*

Imaging examples

After the suprasalt orthorhombic modelling is complete, the subsalt area is updated with Common Offset RTM (COR) gather tomography (Rodriguez et al., 2016), and then the final prestack imaging is performed. Figure 7 shows the final TORT RTM stack image compared with the TTI RTM result. The faults and detailed features under the overhang and deep carbonate areas indicated by the arrows are imaged much more clearly and geologically conformed. To further demonstrate that TORT modelling not only solves the polar anisotropy but also handles the azimuth-dependent anisotropy correctly, the azimuthal gathers are displayed in Figure 6. CIG flatness is much improved for all azimuths when the proper TORT model is used.

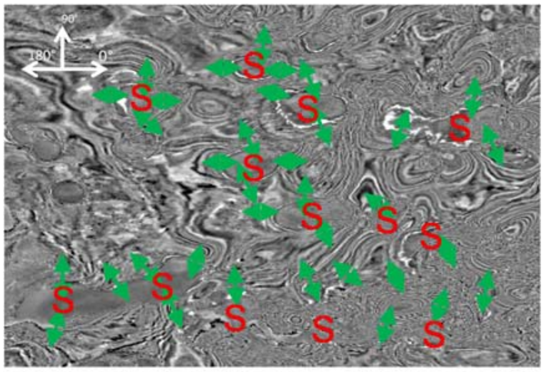

Figure 5 *Azimuthal vectors in green arrows of the fast velocity overlaying on top of velocity model slice. Along the salt radius direction the velocity is faster than that in tangent direction because of the stress changes. S represents the Salt body.*

Conclusions

Tilted orthorhombic image-guided tomography and imaging with multiazimuth input datasets better flattens the CIGs for all azimuths, and provides a more geologically conformed high resolution model. The orthorhombic model has been verified by that the fast propagation direction radiates away from salt domes. These enhancements to current anisotropic models help ensure image continuity and resolution even in the most complex scenarios.

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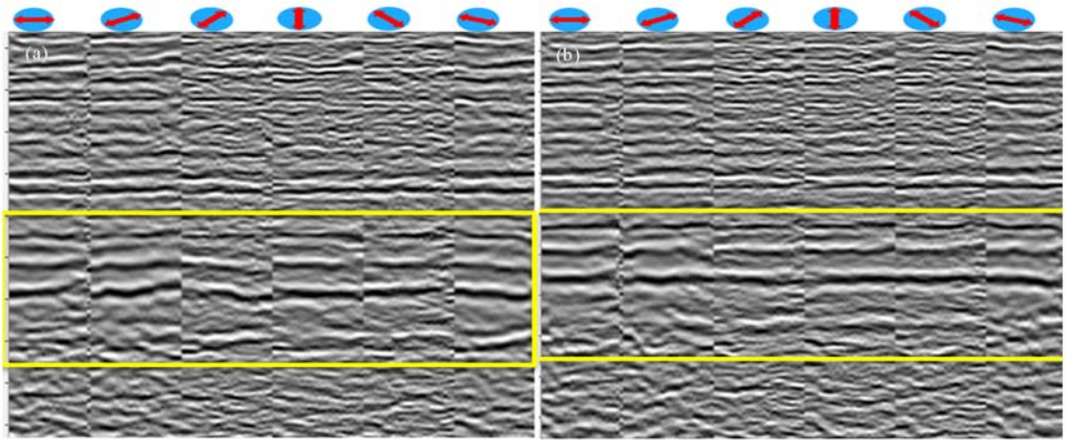

Figure 6 *Comparison of TTI and TORT CIG gathers from six azimuths at the same location, each gather represents one azimuthal CIG, there are total six azimuths from 0 to 150 degree. (a) is from TTI. (b) is from TORT. The gather residual moveout due to azimuthal anisotropy is much improved with orthorhombic modelling and imaging.*

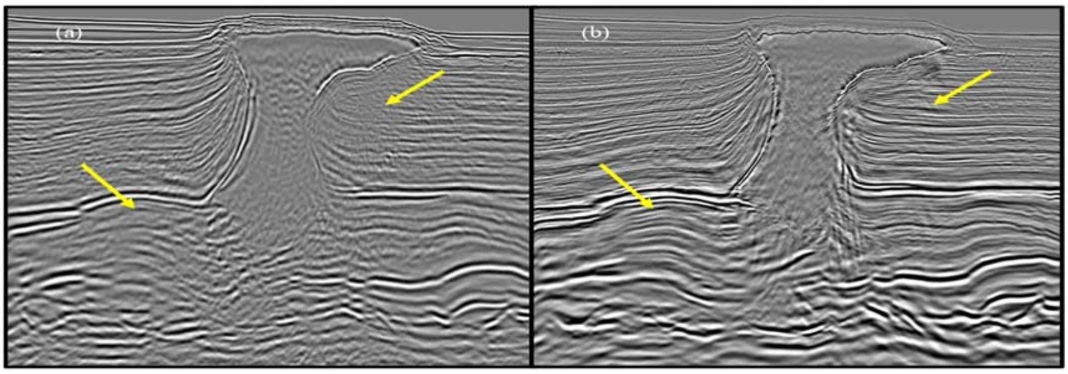

Figure 7 *Legacy TTI RTM and TORT RTM stacks, (a) is the legacy TTI RTM, (b) is multiazimuth TORT final RTM. The TORT images in the overhang area and deep portion are much better.*

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