Tilted orthorhombic imaging of full-azimuth OBC data offshore Trinidad

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This paper was prepared for presentation during the 14th International Congress of the Brazilian Geophysical Society held in Rio de Janeiro, Brazil, August 3-6, 2015.

Summary

Azimuthal anisotropy in sediments is seen in many areas around the world, usually associated with regional stress and fracturing. With full-azimuth data it is possible to detect and to resolve this anisotropy. In this case study we describe how significant azimuthal anisotropy was found on full-azimuth OBC data from offshore Trinidad, and how orthorhombic velocity model-building and depth imaging was applied to produce superior seismic images.

Introduction

Until quite recently it was common practice to apply isotropic imaging for depth migration projects, but now most projects are performed using TTI anisotropic imaging. This has greatly improved results both in terms of image quality and better well ties. It is now understood that anisotropy is found everywhere, and depth imaging and velocity model building workflows and algorithms have progressed to the point where TTI anisotropy is now standard procedure.

Today's new challenge is azimuthal anisotropy, which is seen on many seismic projects around the world, and which is of great interest because it is often related to fractures and stress. However azimuthal anisotropy is normally ignored during imaging and model building for reasons including:

- The effect of azimuthal anisotropy is normally perceived to be insignificant.
- Wide-azimuth data that can be used to resolve azimuthal anisotropy is not always available.
- Resolution of azimuthal anisotropy in velocity model building adds a great deal of complexity to the velocity model building workflow.

In this paper we describe how significant azimuthal anisotropy was discovered in the Columbus basin, offshore Trinidad, in the course of velocity model building work on the BP Trinidad and Tobago LLC (bpTT) ISS OBC project and how orthorhombic model building and imaging is being applied to produce a superior image.

Trinidad OBC model building and azimuthal anisotropy

The Trinidad OBC project was acquired recently by WesternGeco for bpTT using a high-density full-azimuth acquisition geometry that provides 3000-fold coverage over 900 km². Processing was carried out in Schlumberger's Gatwick DP centre, including velocity model building that started with a model produced by BP using Full Waveform Inversion (FWI).

Four iterations of global CIP tomography were then applied, followed by both Kirchhoff and RTM final TTI imaging. Offset-vector tiles (OVTs) were used during velocity model building to achieve the best possible resolution in the TTI anisotropic velocity updates. Converted wave processing, including TTI velocity model building and depth imaging have also been performed in a 100 km² subarea of the project.

The existence of azimuthal anisotropy became very apparent when an adjacent narrow azimuth survey was merged with the Trinidad OBC data during velocity model building.

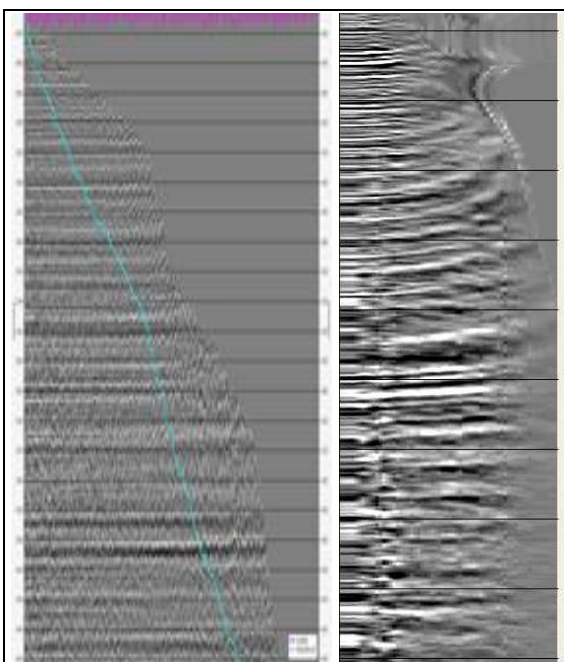

Figure 1 Trinidad OBC OVT CIP gathers (left) and narrow-azimuth CIP gather (right)

Figure 1 shows displays of a single OVT CIP gather from the OBC dataset compared with a nearby gather from the narrow-azimuth dataset migrated using the same velocity model. The migrated gather from the narrow-azimuth survey is obviously overcorrected, indicating that a faster velocity is required. Though events on Trinidad OBC OVT depth gathers were flat on average, jitter on events at longer offsets indicated that azimuthal anisotropy could be a problem.

Other evidence of azimuthal anisotropy came from the converted wave processing on which significant shear wave splitting was found. It was decided to perform an orthorhombic imaging study on the same 100-km² subarea that was covered by the converted wave processing.

Orthorhombic model building

TTI model building was once perceived as being very complicated, with five parameters required for P-wave imaging (Vp0, δ, ε, TTI dip angle θ, and TTI azimuth φ). Orthorhombic model building is significantly more complex, with nine parameters needed (commonly parameterized as Vp0, δ1, δ2, δ3, ε1, ε2, TTI dip angle θ, and TTI azimuth φ, and the rotation direction of the symmetry axes within the azimuthal plane ψ).

There are a number of different ways to derive a model for orthorhombic imaging (Zdraveva et all, 2015). For purposes of this test the initial orthorhombic model was derived using a workflow that has been documented on other orthorhombic imaging projects in the last couple of years. (Shen et al., 2012):

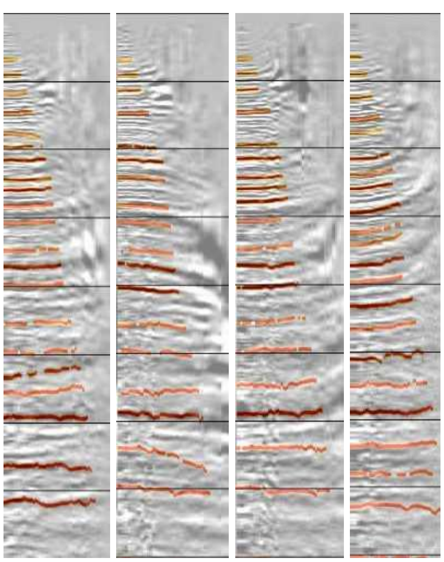

Figure 2 Azimuth sector gathers with tomography input picks overlaid for azimuths (from left to right) 22.5°, 67.5° ,112.5° and 157.5°.

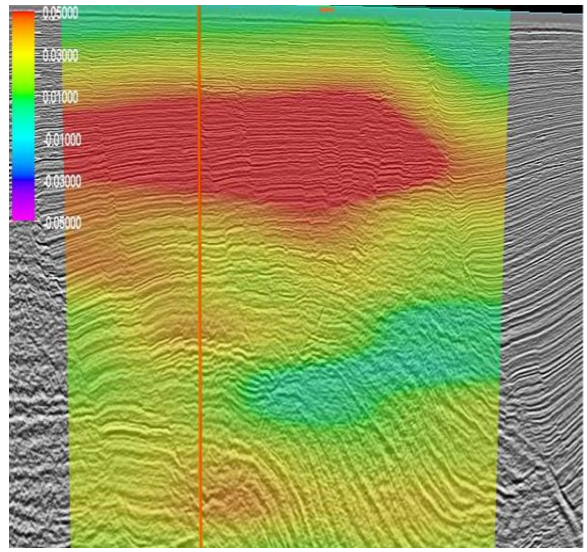

Figure 3 Difference between parameters δ1 and δ2 for initial orthorhombic model.

1. Pick residual moveout on azimuth sector gathers.
2. Perform separate CIP tomography (Woodward et al., 2008) for each azimuth sector updating only epsilon and delta.
3. Convert azimuth sector tomography results to a single orthorhombic model.

Input picks overlaid on gathers are shown in Figure 2 and a section through the initial orthorhombic model is shown in Figure 3. The high values of δ1- δ2 in the shallow section indicate that azimuthal anisotropy is mostly limited to this depth range.

Testing of orthorhombic imaging

Orthorhombic Kirchhoff PSDM (Kainkaryam et al., 2015) was run with the initial orthorhombic velocity model. Figures 4 and 5 show comparisons of TTI and tilted orthorhombic (TOR) depth-migrated results for a line across the test area.

OVT CIP gathers are displayed, sorted to highlight azimuthal effects (spiral gathers). These exhibit significant jitter for larger offsets on the TTI result. This effect is greatly reduced on the TOR gathers with much improved focusing of energy.

There is some jitter remaining on the TOR gathers but these were produced using a preliminary model to allow a fair comparison with TTI imaging. The effect would be further reduced after final TOR model-building. The TOR stack shows better continuity at all levels, especially for higher frequencies. Imaging of complex faulting is also improved.

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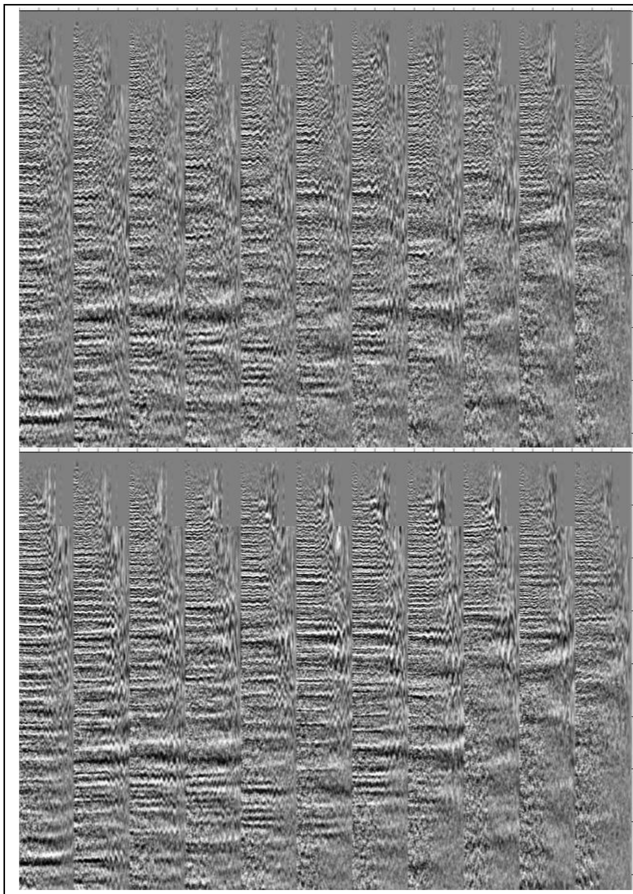

Figure 4 Depth-migrated OVT spiral gathers for TTI (top) and TOR (bottom) imaging.

TTI imaging.

Conclusions

Significant azimuthal anisotropy was found to exist in the Columbus Basin, offshore Trinidad, during the processing of the bpTT OBC survey area, causing serious degradation of TTI depth images. Fortunately, the recently acquired high-density full azimuth OBC data makes it possible to resolve this azimuthal anisotropy.

An orthorhombic model was built with tomographic methods and used to perform tilted orthorhombic (TOR) Kirchhoff PSDM. Output results showed significant improvement over TTI results, though the orthorhombic model used was an initial model produced using azimuth-

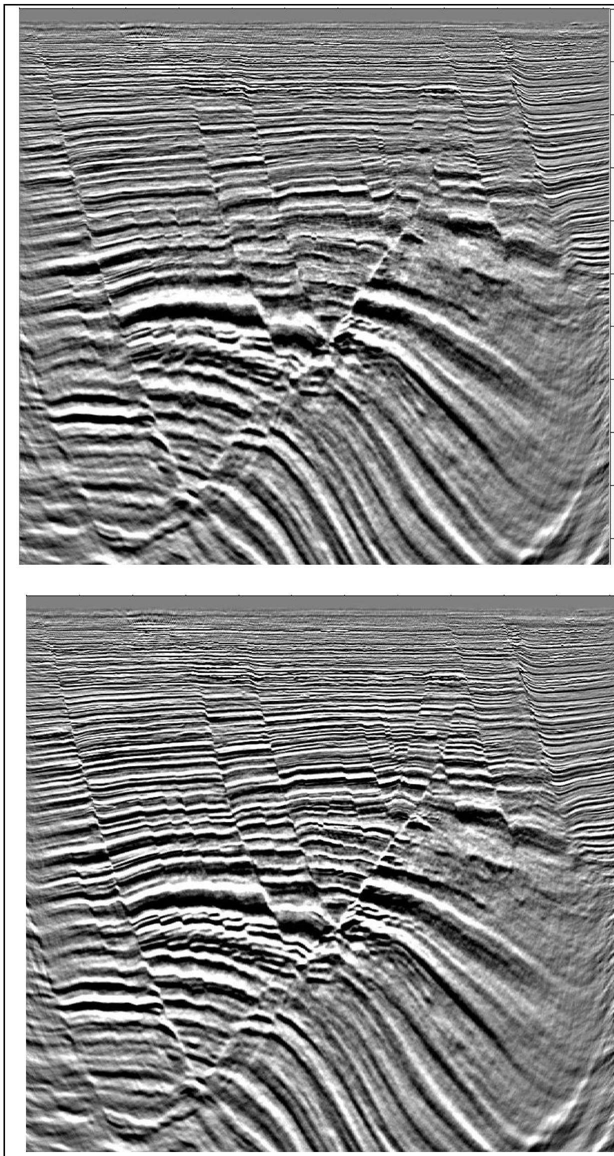

Figure 5 Comparison Kirchhoff PSDM stacks for TTI (top) and TOR (bottom) imaging .

sectored TTI tomography. A better velocity model updated with orthorhombic tomography should give further improvement in the image.

Use of orthorhombic model building and imaging on the Trinidad OBC dataset has produced much better images than was previously possible using TTI imaging, with better resolution and fault definition and more reliable pre-stack seismic attributes. This has the potential to reduce exploration uncertainties, increase confidence in reserves estimation and reduce risk in drilling activities.

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Acknowledgments

Thanks to bpTT and to Schlumberger for permission to present this work. Thanks to the BP and Schlumberger teams who worked on this project, especially Gino Alexander, Neal Zimmermann and Peter Szabo who were responsible for TTI model building