Fracture detection and reservoir characterization through high resolution orthorhombic tomography for unconventional plays

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Summary:

Orthorhombic processing can be leveraged to yield a wealth of information beyond the expected imaging improvements. The nature of this information provides straightforward opportunities for correlation with fractures and other reservoir properties, to ensure optimal production in unconventional plays. The use of high resolution orthorhombic processing can increase the value and usefulness of new and existing seismic surveys, by providing a variety of interpretable products through the model building process. A test project in a popular unconventional play demonstrates good correlation between the derived orthorhombic model and information from previous studies of the area.

Introduction:

Recently, the seismic industry has begun to move beyond tilted transverse isotropy (TTI) as the industry standard anisotropic model definition (Hilburn et al., 2017). The use of tilted orthorhombic models, while still far from ubiquitous, has become common, and is increasingly required by clients seeking the best possible imaging and geological attribute characterization. While the push toward imaging refinement was the primary motivation in expanding the model space beyond TTI, there are a number of ways in which orthorhombic processing can provide useful information, beyond improved imaging. Geologically reasonable orthorhombic models can yield a wealth of information regarding rock properties and reservoir characteristics which can be leveraged in many ways to gain additional understanding of the survey region.

Orthorhombic processing, with the intent of producing interpretable model volumes, is particularly useful for onshore projects in unconventional plays, as 3D land projects typically have full azimuthal coverage. In these areas, large and small scale fracture characterization can be vital to optimizing hydrocarbon production and planning of future offset or infill wells. Since organized fracture systems are also expected to give rise to orthorhombic anisotropy (Tsvankin et al., 2010), areas showing significant azimuthal velocity variations may often be correlated with preferential fracture orientation, which can help guide drilling decisions.

A test project area in south central Texas shows good correlation between a priori knowledge of fracture orientation and density to high resolution orthorhombic tomography results. This project demonstrates the ways in which orthorhombic processing can yield additional useful results beyond the usual imaging benefits, by considering the models themselves as interpretable products which can significantly improve the impact of the overall suite of processing results.

Theory and Method:

The recommended orthorhombic tomography job flow follows directly from the finalized TTI model (Tiwari et al., 2015). Following TTI model building, azimuthally independent migration and TTI tomography are performed to provide an update to the usual anisotropic parameters ε and δ in each azimuthal direction of interest. These results are then fit to an approximate ellipse to provide the direction of the fast velocity at each grid point, which will remain invariant for the remainder of the project, as well as initial estimates of the orthorhombic parameters ε_1, ε_2, δ_1, δ_2, and δ_3 (Tsvankin, 1997). As is typical for tilted model spaces, the azimuthal and tilt angles, φ and θ, are determined by measuring the dip on the most recent stacked migration image. The orthorhombic parameters are then updated through a tomographic scheme utilizing the most advanced tools to ensure geological plausibility and optimal gather flattening. Nonparameterized moveout picking captures complex details of the input gathers, to allow the tomographic engine to correct small differences in moveout between azimuthal bins. Then, the image-guided tomographic inversion intelligently interpolates and smooths the update grids iteratively, encouraging adherence to observed geological structure (Hilburn et al., 2014).

Ensuring that the process to generate results is sufficiently advanced to provide the required accuracy is vital, but it is equally important to consider methods to check and verify that the obtained results are plausible. It is well known that anisotropic tomographic solutions can be very ill-conditioned and uncertain, and the orthorhombic model space has a very large number of parameters to define, making model building an extremely ill-posed problem (Hilburn et al., 2017). Fortunately, there are several checks that can be imposed to ensure that the physicality of the solution is reasonable for the situation. Tsvankin et al.

(2010) note that arbitrarily oriented series of fractures are known to yield approximately orthorhombic anisotropy, through theoretical and numerical studies. Fractures expected to cause azimuthal anisotropy are likely to be much smaller than seismic scales are able to resolve, but we can leverage the fact that smaller scale fracturing is expected to be associated with larger, major faults in the region. To make use of this knowledge, a technique of automatically detecting and isolating faults from a stacked image is needed. Hale (2009) presents a methodology to construct structural tensors from an image. One component of this process is scanning for structure-oriented semblance. Specifically, one of the semblance volumes calculated highlights coherent structures which interrupt events in the dominant direction, making it ideal for extracting fault information in sedimentary layers. This volume can be used to give a macroscopic view of faulting in the region, for correlation to the azimuthal direction of fastest propagation. Techniques such as this are vital to properly apply orthorhombic updates, helping create a more well-constrained and certain model space.

Examples:

The included examples are extracted from a 3D PSDM onshore test project in south central Texas, primarily located in Lee County, which is part of the popular Eagle Ford shale play. Producing reservoirs in this area include the Austin Chalk, Eagle Ford Shale, and Buda formations, at depths from about 7,000 to 10,000 feet. Figure 1 shows representative depth and vertical slices for this survey, with three horizons of interest plotted, which will be examined further. Also depicted on the depth slice is the generally accepted dominant direction of fracturing in this area (Haymond, 1991; Li and Mueller, 1997).

While in most projects, the flatness of the gathers is the desired outcome to ensure the best image focusing, for this project gathers are primarily used to confirm the validity of the anisotropic model. Figure 2 shows common offset common azimuth (COCA) gathers before and after orthorhombic model building. The reduction of mid to far offset undulations in COCA gathers by updates in the orthorhombic model suggests that the fast direction has been defined correctly, and the azimuthal anisotropy is being correctly considered. Additional iterations of orthorhombic tomography will lead to convergence of the model, and flat COCA gathers.

Figures 3, 4, and 5 show the structure-oriented semblance calculated at the Pecan Gap, Austin, and Buda horizons, respectively. Overlaid on each semblance plot are vectors whose directionality corresponds to the fast velocity direction at that grid point. The color and length of the overlaid vectors represent the magnitude of the orthorhombic anisotropy. The features shown in the structure-oriented semblance are likely to be large scale faults through the region. Assuming that small scale fracturing will correlate with faults, the faults should also then correlate well with the fast velocity direction, where anisotropy is considerable. In general, for high degrees of azimuthal anisotropy, the dominant fast direction is NE-SW, matching very well with the accepted fracture direction shown in Figure 1. In the central sections of the slice, the faults shown also correspond well with the fast direction, for areas of high anisotropy. On the NW and SE sides of the slices, the velocity becomes more chaotic, with the semblance suggesting that the faulting becomes less ordered and more complex. On a macroscopic scale then, the results of the orthorhombic tomographic solution agree with theory and known fracture orientation in the region.

Conclusions:

One of the primary ways to easily increase the value of processing projects is by finding new and unique ways to utilize existing data. Orthorhombic tomography can be used to improve an image, providing the best possible gather flattening through model refinement. To take this one step further, characterizing azimuthal velocity variations can also provide the possibility of new deliverable products, which significantly enhance the usefulness of a processing project. By applying the knowledge that fracture orientation and fracture density should relate to the directionality and strength of azimuthal anisotropy, respectively, maps of dominant fracture systems can be created. These products can be particularly useful in unconventional plays, where fracture characterization is vital to ensure optimal hydrocarbon production. A test project area shows good correlation between tomographically-derived fracture information and a priori knowledge about the area of interest. Furthermore, the tomographic solution correlates well with dominant faults extracted from the stack in a structure-oriented semblance volume. Together, these suggest that similar future projects may benefit as much from deliverable model volumes as from the final imaging product.

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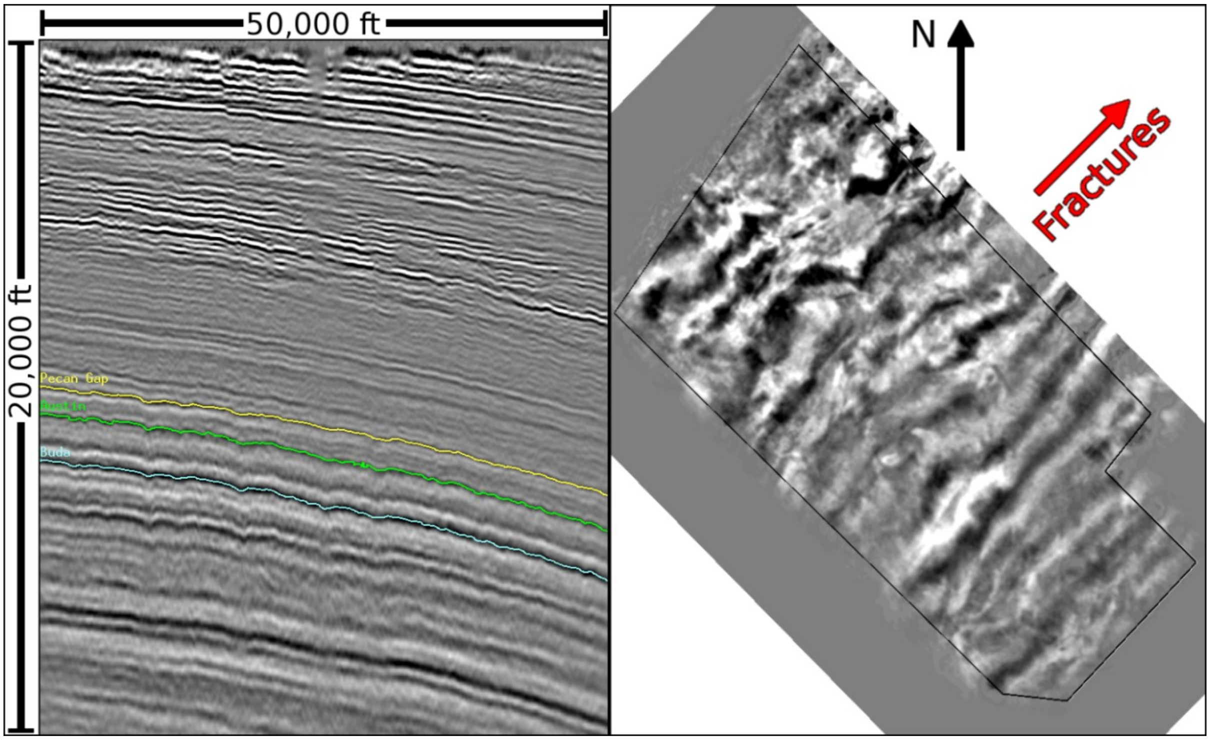

Figure 1: Stacked image vertical slice (left) and depth slice at 3,000 ft (right) for the project area. Seismic data is the proprietary property of Seitel, Inc.

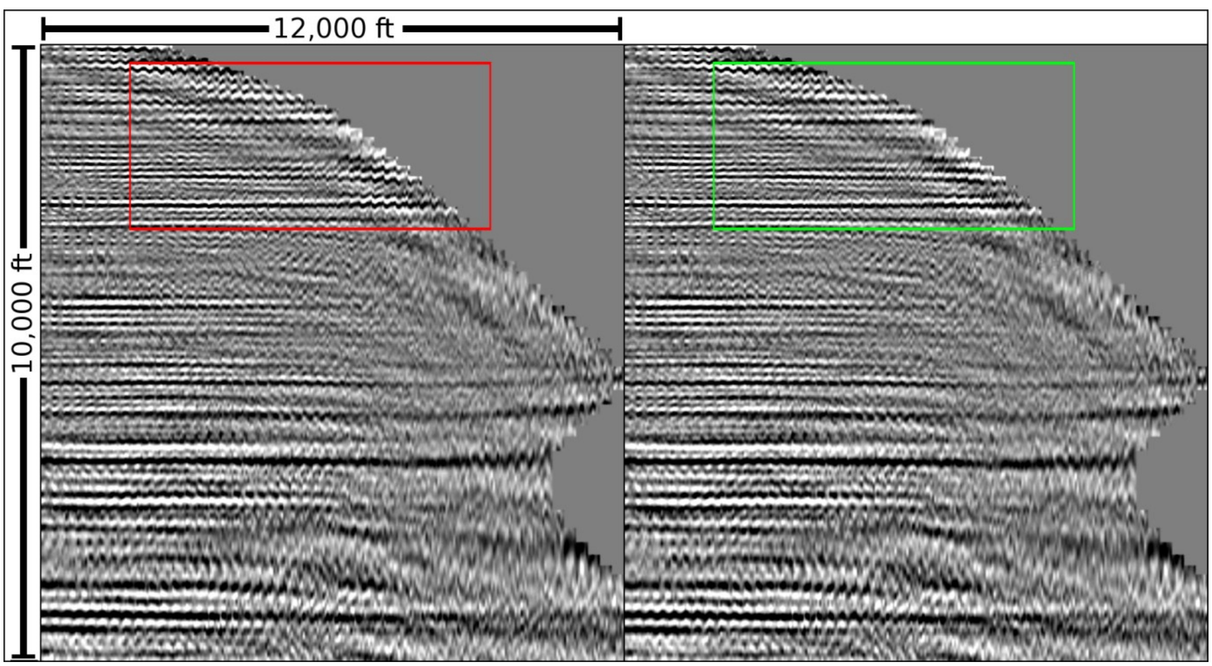

Figure 2: Common offset common azimuth gathers before (left) and after (right) initial orthorhombic model building. The reduction in mid to far offset undulations suggests proper fitting of the fast velocity direction. Seismic data is the proprietary product of Seitel, Inc.

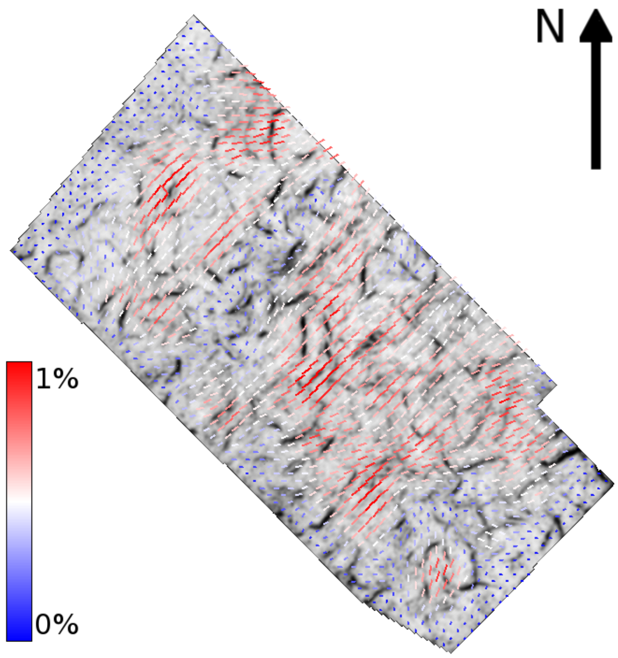

Figure 3: Structure-oriented semblance plot calculated at the Pecan Gap horizon, overlaid with vectors displaying the fast velocity orientation. Dark areas of the structure-oriented semblance are events which interrupt coherent layering; in this case, this highlights the area's fault systems. Vector colors and lengths show the degree of orthorhombic anisotropy, from zero (blue) to one (red) percent, when comparing the fast direction velocity to the slow direction velocity.

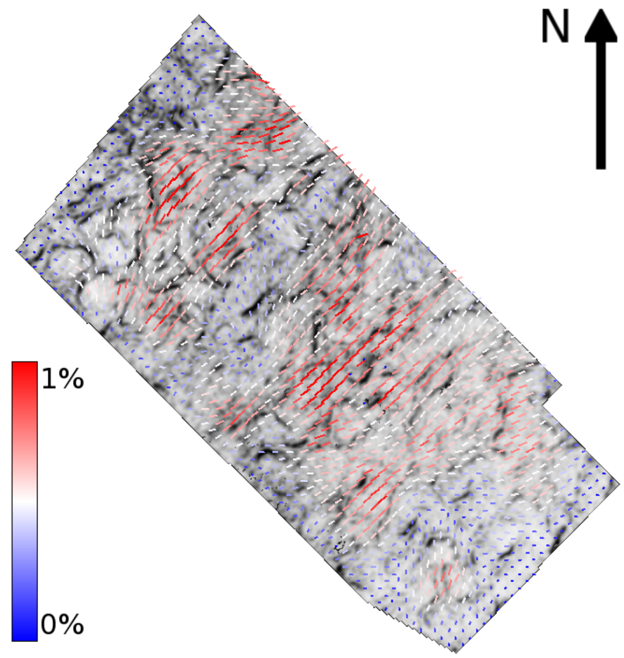

Figure 4: Semblance and vectors for the Austin Chalk horizon, as with Figure 3.

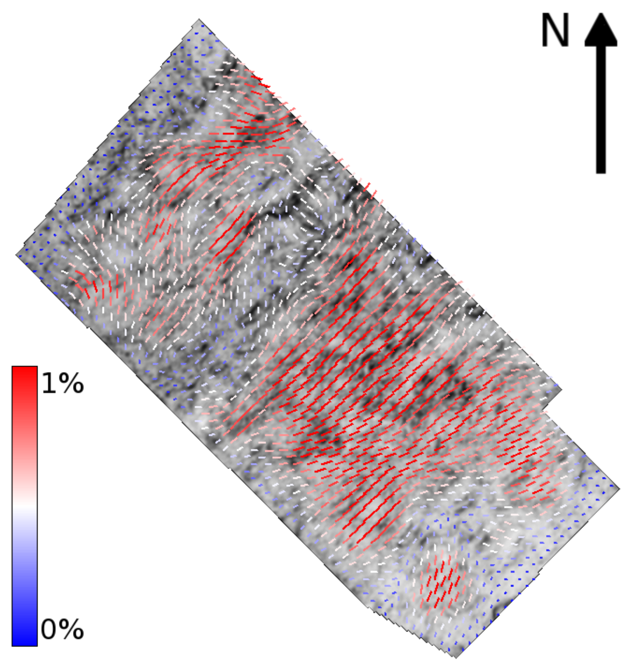

Figure 5: Semblance and vectors for the Buda horizon, as with Figure 3.

EDITED REFERENCES

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