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Application of target-oriented VVAZ on relatively thin fracture reservoir

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Summary

Velocity variation with azimuth (VVAZ) has become a standard technique to extract fracture signatures from wide azimuth seismic data (WAZ). Zheng (2006) proposed a target-oriented approach to directly invert Thomsen's HTI delta and fracture strike of a HTI medium, but it requires travel times between the top and base of a target horizon. If the target layer becomes thin, the top reflected event interferes with the base event. Little research has been done to fully address the thickness limit and the overburden effect on this inversion. Evaluations of this technique on a number of synthetic HTI models that have various scenarios of HTI-layer thickness and overburden effect conclude that the overburden effect has minimal impact on the inversion for the given synthetic models. The inversion is robust in estimating HTI-anisotropic attributes, even for a relatively thin fracture layer. The application of this inversion on a high-density WAZ data set extracts the HTI anisotropic attributes of a relatively thin reservoir. The HTI anisotropic-magnitude map correlates remarkably well with fracture orientations measured from image logs in areas with high anisotropy.

Introduction

Fracture characterization is a key factor in the optimization of a reservoir production. Understanding the fracture distribution and orientation helps to identify sweet spots, especially for unconventional resources and shale plays. Seismic data provide an indirect measure of fracture attributes. VVAZ is one of the fracture-detection techniques used to relate azimuthal velocity changes to fractures in rocks. The simplest anisotropic model to describe azimuthal variation of velocity, azimuthal anisotropy, is transverse isotropy with a horizontal axis of symmetry (HTI). This model represents a system of parallel vertical cracks embedded in an isotropic medium (Thomsen, 1995; Schoenberg and Sayers, 1995). The azimuthal anisotropy of a HTI model gives a first-order approximation of seismic responses commonly observed in fractured rocks. Zheng (2006) proposed a target-oriented VVAZ approach to directly invert the HTI magnitude and orientation within a fracture layer. It uses differential residual NMO travel times between the top and base of a fracture layer and performs a least-square inversion using travel times from all azimuths and offsets within a CMP gather. Zheng (2008) further demonstrated the pitfalls and tips for this method in analyzing fracture attributes.

Since the target-oriented VVAZ approach requires picking travel times between the top and base of a fracture layer, the questions are how the overburden affects the inversion and how the fracture-layer thickness changes the inversion result. These two critical questions have not been fully assessed in the industry. The present work addresses these issues by using a number of synthetic HTI models to evaluate the overburden effect and to test various scenarios of HTI-layer thickness. We apply it on a high-density WAZ data set to extract HTI anisotropic attributes of a relatively thin fractured reservoir, and correlate fracture orientations measured from image logs with the inverted HTI orientations.

Method

The present work follows closely with the method from Wang (2007). The detailed derivation will not be repeated here. The basic concept is to invert the magnitude of Thomsen's HTI delta (δ) and the orientation of the fracture strike, using differential residual NMO travel times between the top and base of a fracture layer. This method assumes that the derived HTI Thomsen's delta is positive. This assumption is reasonable for many geological settings in which the geology does not change the sign of delta within a survey. If the true sign of delta is negative, the inverted HTI orientation may have a global error of 90^0. To resolve this ambiguity, we need additional information to constrain the inversion. Despite this limitation, this technique works surprisingly well in practice.

Synthetic examples

The HTI model consists of four isotropic layers and two HTI layers (Table 1). Three models are constructed to examine how the thickness of the fracture layer and the overburden affect the inversion result. The thickness of the second HTI layer changes from 2000 to 500 ft to test the limitation of this algorithm. A typical offset gather with NMO correction of three models exhibits the sinusoidal “wobble” across azimuths associated with the influence of the HTI fractures (Figure 1). The limited-offset gathers sorted by azimuth clearly show the typically sinusoid pattern related to the HTI fractures (Figure 2). The top and base of the reflections of the 2000 and 1000 ft model are well separated. But the base reflection of the 500 ft model starts to interfere with the top reflection. This is probably near the thickness limit of this model.

The inversion was performed independently without any layer stripping, by picking the residual NMO travel times separately for the first and second HTI layers. The first HTI layer has no overburden effect, but the second HTI layer has the anisotropic imprint from the first HTI layer. The inverted attributes of the first HTI layer match the true values almost exactly (Table 2). For the second HTI layer, the overburden effect and weak anisotropic assumption used in the algorithm causes the magnitude of inverted δ to deviate slightly from the true value, but they do not affect the inverted fracture orientation. We consider that this target-oriented VVAZ method is robust and reliable to be used in estimating HTI anisotropic attributes.

Wide-azimuth data example

ConocoPhillips acquired a high-density wide-azimuth land 3D seismic survey. The survey was designed to acquire data with dense spatial sampling rich in azimuth and offset for azimuthal analysis. The objective is to identify fractures or “sweet spots” in the reservoir sands. However, these sands are thin and sometimes below seismic resolution. We pay careful attention in the data processing to preserve the azimuthal seismic signatures. The data quality, in general, is reasonably good and the average VVAZ analysis window is about 75 msec. The HTI-magnitude map (Figure 3a) derived from the target-oriented VVAZ yields an anisotropic-anomaly trend that generally follows the regional-geological-fracture trend.

One way to validate the interval VVAZ result is to use fracture orientations measured from image logs to correlate with the inverted HTI orientations. Figure 3b shows a well location of an image log overlaid on the vector display that represents HTI anisotropic magnitude and orientation of the target layer. The anisotropic orientation from the target-oriented VVAZ correlates remarkably well with the fracture orientation measured from the image log in this location.

Conclusions

The synthetic-model evaluations clearly demonstrate that the target-oriented VVAZ inversion has minimal distortion from the overburden effect and can handle a range of fracture-layer thicknesses, even a relatively thin layer. The inversion is robust and reliable in estimating HTI attributes that are closely related to fractures**.** For the wide-azimuth data example, the HTI-attribute map derived from the target-oriented VVAZ generally follows the geological-fracture trend, and the orientations of HTI anomalies from inverted VVAZ correlate remarkably well with the fracture orientations measured from image logs in areas with high anisotropy.

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References

Schoenberg, M., and Colin M. Sayers, 1995, Seismic anisotropy of fractured rock: Geophysics, Vol. 60, No.1, 204-211.

Thomsen L., 1995, Elastic anisotropy due to aligned cracks in porous rock: Geophs. Prosp., 43, 805-830.

Zheng, Y., 2006, Seismic azimuthal anisotropy and fracture analysis from PP reflection data: Ph.D dissertation, The University of Calgary.

Zheng Y., J. Wang, and M. Perz, 2008, Pitfalls and tips for seismic fracture analysis: SEG, Expanded Abstracts, 1531 – 1535.

re detection

Model 1	**Model 2**	**Model 3**
1500’ - isotropic	1500’ - isotropic	1500’ - isotropic
1500’ - isotropic	1500’ - isotropic	1500’ - isotropic
2000’ - HTI	2000’ - HTI	2000’ - HTI
1500’ - isotropic	1500’ - isotropic	1500’ - isotropic
2000’ - HTI	1000’ - HTI	500’ - HTI
Isotropic	Isotropic	Isotropic

Table 1. HTI synthetic models. Each model consists of four isotropic layers and two HTI layers, and second HTI layer thickness varies from 2000 to 500 ft.

1st HTI Thickness ft	Ideal δ	Ideal fracture strike	VVAZ δ	VVAZ fracture strike
2000	0.11	0^{0}	0.11	1^{0}

2nd HTI Thickness ft	Ideal δ	Ideal fracture strike	VVAZ δ	VVAZ fracture strike
2000	0.30	90^{0}	0.34	89.9^{0}
1000	0.30	90^{0}	0.31	89.6^{0}
500	0.30	90^{0}	0.36	89.8^{0}

Table 2. Inversion results of three models. The second HTI layer has the anisotropic imprint from the first HTI layer.

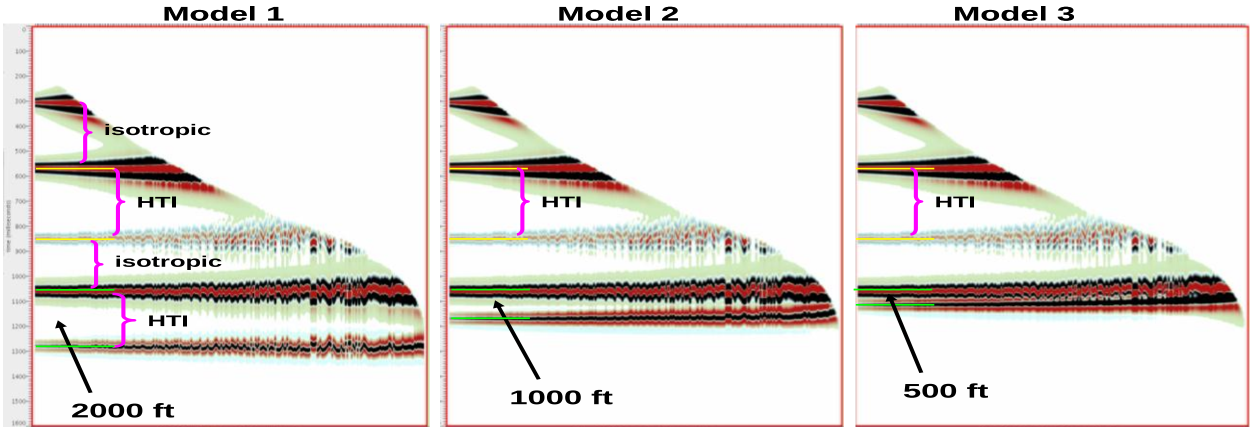

Figure 1. An offset gather with NMO correction of three models, showing the sinusoidal “wobble” across azimuths associated with the influence of the HTI fracture.

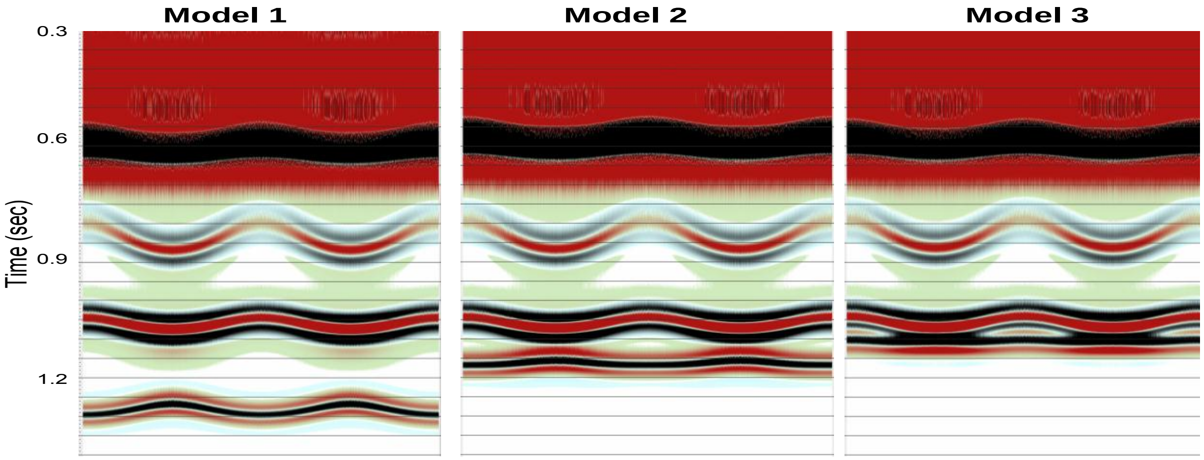

Figure 2. Limited-offset gathers sorted by azimuth with NMO correction of three models, showing the sinusoidal responses across azimuths associated with the HTI fracture.

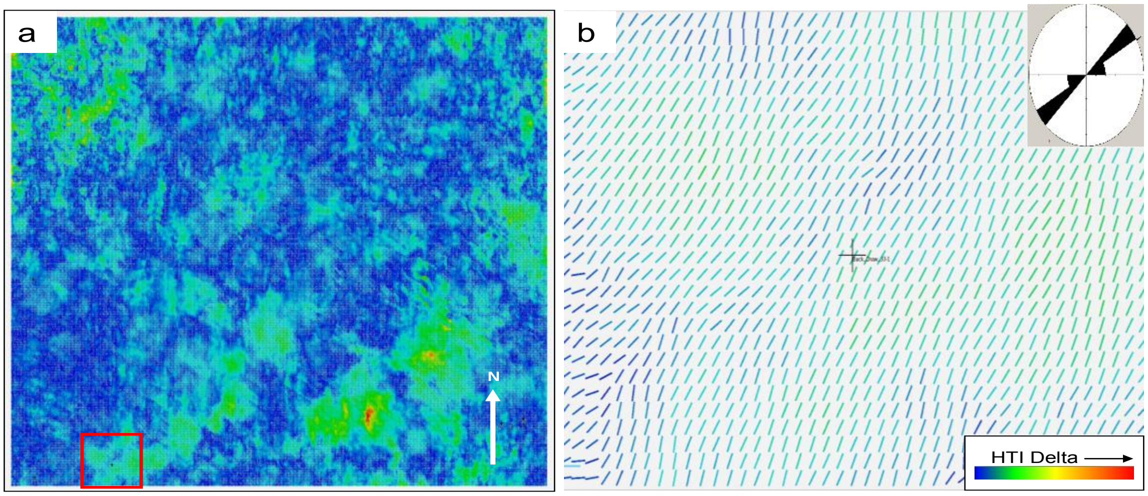

Figure 3. The HTI anisotropic-attribute map: (a) HTI delta map derived from VVAZ, (b) vector display of HTI magnitude and orientation of a selected area (red rectangle box). The cross represents the well location of an image log. The rose diagram from the image log gives the fracture orientations.