9th Biennial International Conference
& Exposition on Petroleum Geophysics

"HYDERABAD 2012"

P-392

Anisotropic parameters for HTI media: Application to land data with orthogonal shooting geometry – An example from India

***N.V.N.Kishore.Pudipeddi*, Dean Clark**, Fugro*

Summary

The presence of fractures in a formation may lead to differences in velocity with azimuth. This phenomenon can lead to deterioration in image quality of the seismic data but may also reveal information about the orientation and intensity of fracture systems. The application of the non- hyperbolic moveout equation for horizontally layered horizontal transverse isotropy HTI media, which was developed by Nizare El Yadari et.al. (Fugro Seismic Imaging Ltd), is demonstrated in an example of orthogonally shot land data from India.

***Keywords**: Azimuthal anisotropy, Automatic velocity picking*

Introduction

A system of fractures embedded in an isotropic media exhibits HTI behavior (Fig-1). Selection of anisotropic parameters at any one event and CMP location is extremely difficult and liable to human bias. Automatic picking uses a coherence measure to fit the NMO curves to the recorded reflection events. Each curve defines a summation trajectory over offset and azimuth. The greater the power of sum the better the alignment of the curve.

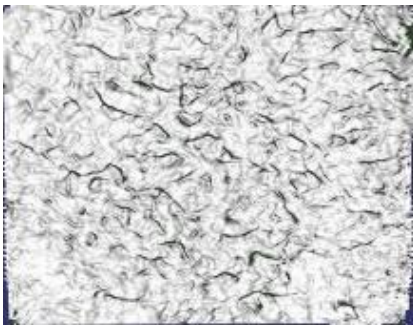

Figure1: Discontinuity cube showing fracture network

Theory

The basis for the P-wave HTI model is tilting the vertical transverse isotropy VTI symmetry axis all the way to horizontal (Fig-2) P-wave reflection travel times in HTI media are conveniently expressed in terms of δ and η as suggested by Tsvankin (2001), where δ and η are the anisotropic parameters in the vertical plane containing the axis of symmetry. The VTI equation originally developed by Alkhalifah and Tsvankin (1995) can be extended to express long-spread P-wave HTI moveout for any source-receiver azimuth β and offset X as

$$T^2(X,\alpha) = T_0^{\,2} + X^2/V^2_{NMO} - 2\,\eta\, X^4/\,V^2_{NMO}\,[T_0^{\,2}\,V^2_{NMO} + (1+2\,\eta)\,X^2] \qquad \text{(eq1)}$$

(Nizare El Yadari et.al, SEG Denver 2010 Annual Meeting.)

where T_0 is the zero-offset time, $V_{NMO} = V_{NMO}(\alpha)$ is the azimuthally varying NMO velocity (i.e., the NMO ellipse), and $\eta = \eta(\alpha)$ is the azimuthally varying anellipticity coefficient as mentioned above. The parameter α is the angle between the NMO ellipse orientation (i.e., the axis of symmetry), denoted by φ, and the source-to-receiver orientation, denoted by β_0, (Fig-3).

Fugro Geoscience India Pvt. Ltd Fugro House D-222/30. MIDC, Nerul, Navi Mumbai-400706 India
kishore.pudipeddi@fugro-fsi.in dean.clark@fugro-fsi.in

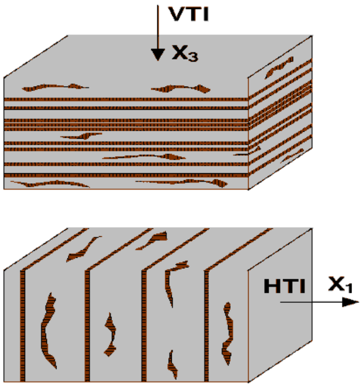

Figure 2: Schematic models of VTI (thin layering) and HTI (vertical fracturing), where HTI is equivalent to the 90◦ rotated VTI model.

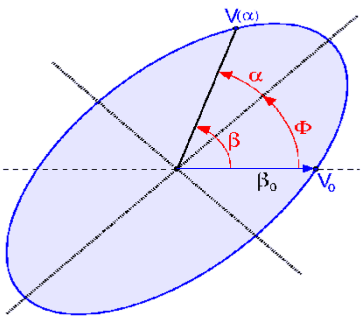

Figure3: NMO ellipse describing the azimuthal velocity model V(α). φ denotes the orientation of the ellipse, β is the source-receiver azimuth, and β_0 is associated with the reference velocity V_0.

Based on the work of Al-Dajani and Tsvankin (1998) Nizare El Yadari et.al (SEG Denver 2010 Annual Meeting.) modified VNMO(α) and η (α) to be expressed in terms of any average source-receiver azimuth β0, reference NMO velocity and reference η, denoted by V0 and η0 respectively

$$V^2_{NMO}(\alpha) = \{[1+2\delta\cos^2(\alpha_0)]/[1+2\delta\cos^2(\alpha)]\}V_0^2 \quad \text{(eq2)}$$

and

$$\eta(\alpha) = \{N(\alpha,\alpha_0)/N(\alpha_0,\alpha_0)\}\eta_0 \quad \text{(eq 3)}$$

where

$$N(\alpha,\alpha_0) = \cos^2(\alpha_0)\cos^2(\alpha)+\sin^2(\alpha_0)\sin^2(\alpha) +\cos^2(\alpha_0)\sin^2(\alpha_0)\cos^2(\alpha)\sin^2(\alpha) \quad \text{(eq 4)}$$

(Nizare El Yadari et.al, SEG Denver 2010 Annual Meeting.)

We have used an azimuthally anisotropic velocity interactive and automatic picking tool, which was developed by using the above relation on multi azimuth land data for correcting the HTI anomalies.

We notice that even adjacent offset traces manifest residual moveout artefacts, the ripples (marked with black circle fig-4A) correlate with the variations in source receiver azimuth as annotated on the display

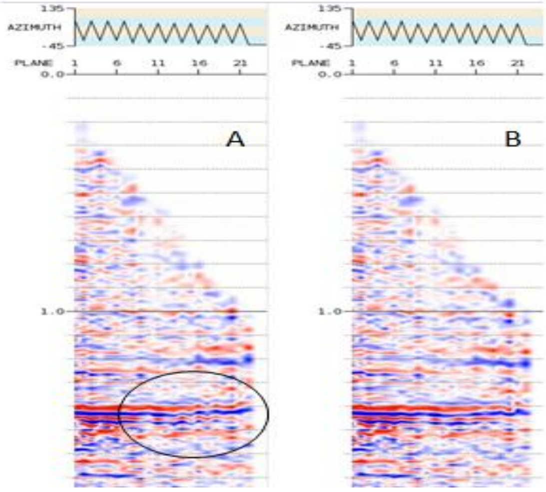

Figure 4: Gather before (A) and after (B) correcting for HTI

The application of 4th order isotropic moveout correction reduces the residual moveout. However, isotropic NMO correction cannot compensate for the short-period ripples (Fig-4A).

To obtain the HTI parameters V0, δ and φ, as a first step, a manual sweep of different constant values of δ (i.e., eccentricity) showed promising results and confirmed the orientation of the axis of symmetry φ. A continuous automatic scan was required to resolve the time-variant behaviour of δ. Once the δ and φ were resolved, the initial RMS velocity was allowed to vary within a corridor of ±10% and the corresponding interval velocity (inverted using the Dix equation) to within ±35%. Fig-4B shows the result of applying a 2nd order HTI-type NMO correction with V0 and δ and φ (Fig-5) derived from the automated scan. The gather is now flatter than the isotropic NMO correction.

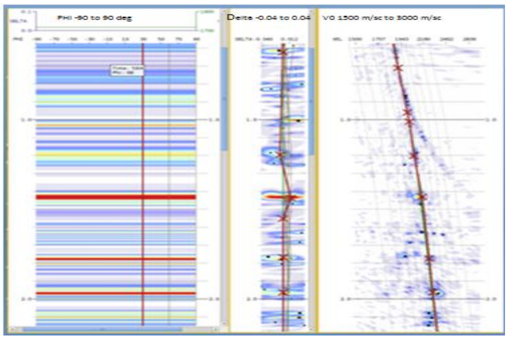

Figure5: Display φ, δ and V0 showing picked HTI

Example – Land survey from India with orthogonal shooting

A land survey from India acquired with an orthogonal shooting pattern was analyzed for azimuthal anisotropy by the method described above and the results were used to update our understanding of the fracture system. It had been noticed that there may be a correlation between hydrocarbon production and fracturing orientation and intensity. The conceptual reservoir model comprises a low permeability system: the volume of hydrocarbon is determined by the matrix porosity and the recovery rate is controlled by the natural 'polygonal' fracture network.

The acquisition survey parameters are given in the Table 1 below.

Shot Spacing	25 meters
Receiver Spacing	25 meters
Shot Line Spacing	300 meters
Receiver Line Spacing	300 meters
Shot Line Azimuth	90 degrees
Receiver Line Azimuth	0 degrees

Table1: Acquisition parameters of the present orthogonal survey

Analysis of the fold with azimuth shows that the data has good coverage in each azimuth sector which is shown in Fig-6.

The advantages of azimuth rich (wide/multi azimuth) 3D data, better imaging, better illumination, and better results in de-multiple, are well know to the industry. With the advancing technology and continuous research, azimuthal processing has became more common for less conventional play types and fractured zones, which benefit from wide azimuth 3D data. (Jaime A. Stein, Robert Wojslaw, The Leading Edge November 2010)

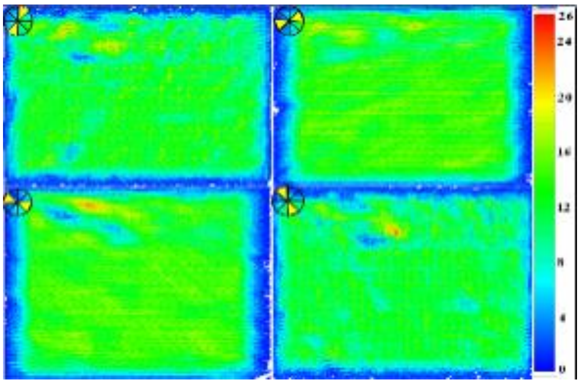

Figure 6: Variation of fold with azimuth. Azimuth sectors are illustrated on top L.H.S. of each fold map

Analyzing data with HTI tools, discontinuity cube, spectral decomposed and color blended volumes increased the ability to map the fracture zones, density & intensity of fracturing and fracture orientation. Figure 7 shows a blended composition of a spectral decomposition attribute with a discontinuity slice at the reservoir interval as well as the polygonal fracture network, a channel feature is also shown in blue meandering from north to south.

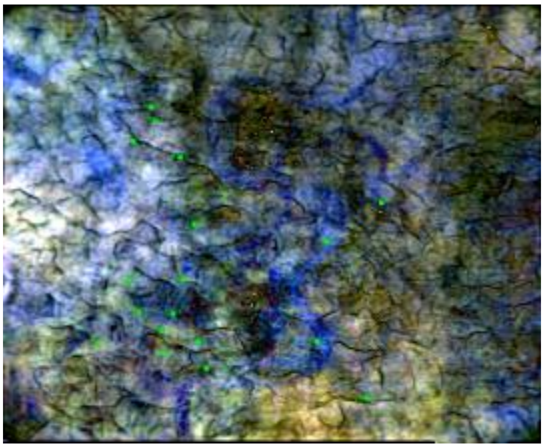

Figure 7: Spectral decomposition showing fracture network (Polygonal fractures) and a channel feature.

The CMP gathers were analyzed for azimuthal anisotropy at discrete locations throughout the volume. At each location, estimates of V0, δ and φ were obtained. The HTI properties could then be used to obtain improved images of the seismic data. Values of φ were very consistent at around 30 degrees and correlate with the fault/fracture alignment implied from the discontinuity cube. The HTI analysis locations with direction arrows denoting φ are shown together in Figure 8.

Figure 8: Map showing overlay of φ on a discontinuity cube showing fracture network.

The addition of properties derived from HTI analysis along with other available geological and geophysical data has allowed us to make some assumptions regarding the development of an effective porosity system.

Conclusions

The improved flatness of gathers after analysis for azimuthal anisotropy reveals that the HTI approach can give more accurate velocity than a simple hyperbolic NMO approach.

Analyzing data with HTI tools in addition to discontinuity cube, spectral decomposed and color blended volumes increases the ability to map the fracture zones, density & intensity of fracturing and fracture orientation.

This example strengthens the application of anisotropic parameters to multi azimuth land data.

Analyzing the data with HTI tools confirmed the interpreted fractures (Fig-8)

Incorporating the axis of symmetry derived from the HTI analysis will help to improve our understanding of the nature of fracture systems.

References

Nizare El Yadari, Richard Winnett, Thomas Hertweck, Kelly Beauglehole, 2010, Automatic velocity and anisotropic parameter analysis for HTI media: Application to marine narrowazimuth data: SEG Denver 2010 Annual Meeting.

Tsvankin, I. 2001, Seismic signatures and analysis of reflection data in anisotropic media: Hand book of Geophysical exploration Volume-29(Elsevier science).

Alkhalifah, T., and I. Tsvankin, 1995,Velocity analysis for transversely isotropic media: Geophysics, 60, 1550–1556, doi:10.1190/1.1443888.

Al-Dajani, A., and I. Tsvankin, 1998, Nonhyperbolic reflection moveout for horizontal transverse isotropy:Geophysics,63,1738–1753, oi:10.1190/1.1444469.

Jaime A. Stein, Robert Wojslaw, Tom Lagston, and Scott Boyer, 2010, Wide-azimuth land processing: Fracture detection using offset vector tile technology:
The Leading Edge November 2010.

Vasconcelos, I., and I. Tsvankin, 2006, Nonhyperbolic moveout inversion of wide-azimuth P-wave data for orthorhombic media: Geophysical Prospecting, 54, no. 5, 535-552.

Al-Dajani, A.,T. Alkhalifah, and F. Morgan, 1999, Reflection moveout inversion in azimuthally anisotropic media: accuracy, limitations and acquisition: Geophysical Prospecting,47,no. 5, 735–756, doi:10.1046/j.1365-2478.1999.00140.x.

Acknowledgments

The authors would like to thank Selan Exploration Technology, Gandhi Nagar India for giving permission to present this work.

The authors would like to thank Russell Harris (Fugro Robertson Limited) and Fugro for permission to present this work.