Structurally-consistent Interval Velocity Variation with Azimuth

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Summary

Fracture- or stress-induced anisotropy in a Horizontally Transverse Isotropic (HTI) rock can be evaluated by measuring the Velocity Variation with Azimuth (VVAz) response observed in seismic data. The isotropic velocity field is perturbed to estimate the fast and slow velocities, as well as a direction indicative of the vertical fracture orientation. For interpretation, this data needs to be converted from RMS to interval velocities using a generalized Dix inversion (Grechka et al., 1999).

Traditionally, interpreted horizons have been used to delineate the interval zones. In this discussion a technique is presented which uses strong, coherent events on the stacked seismic data to improve the interval velocity derivation. This result has higher VVAz anisotropy resolution, is structurally consistent, and can be smoothed in a 3D sense.

Introduction

A HTI material produces a VVAz response that can be observed on P-wave seismic data. When the data are sorted into Common-Offset, Common-Azimuth (COCA) gathers, a characteristic sinusoidal reflection time pattern is observed (Figure 1a) that corresponds to P-waves traveling parallel (Vfast) and perpendicular (Vslow) to vertical fractures. This can be corrected (Figure 1b) using the azimuthal NMO equation (Contreras et al., 1999):

$$t^2 = t_0^2 + \frac{x^2}{V_{nmo}^2} = t_0^2 + \left(\frac{\cos^2(\phi - \beta)}{V_{slow}^2} + \frac{\sin^2(\phi - \beta)}{V_{fast}^2} \right) x^2$$

$t_0 = zero\ offset\ time\ (sec)$

$x = offset\ (m)$

$t = time\ (sec)$

$V_{nmo} = isotropic\ RMS\ velocity\ (m/s)$

$V_{fast} = anisotropic\ fast\ velocity\ (m/s)$

$V_{slow} = anisotropic\ slow\ velocity\ (m/s)$

$\phi = azimuth\ of\ measurement\ (deg\ rees)$

$\beta = orientation\ of\ symetry\ plane\ (deg\ rees)$

Important anisotropic information can be extracted from the analysis – namely measures of the anisotropic intensity and the fracture orientation:

$$Anisotropic\ Intensity = \frac{(V_{fast} - V_{slow})}{V_{fast}} \qquad V_{fast-azimuth} = \beta + 90 = orientation\ of\ isotropy\ plane$$
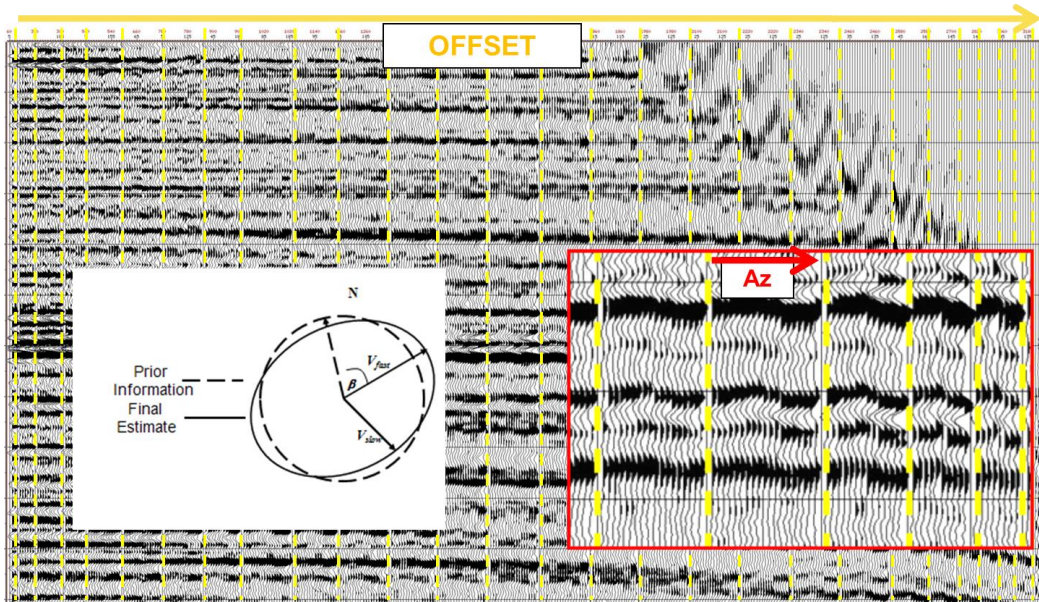
Figure 1a: COCA gather. Sinusoidal feature indicates HTI, where the earlier arrivals correspond to the Vfast velocity and fracture plane of isotropy.
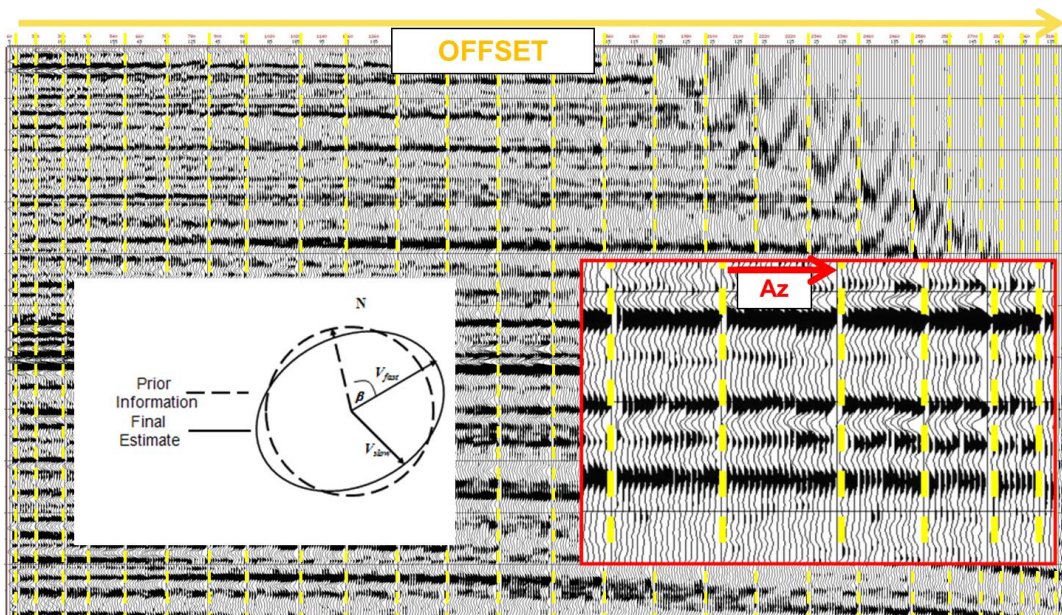

Figure 1b: COCA gather after azimuthal NMO correction

However, at this stage, the VVAz property evaluated is RMS (root mean square) velocity that is cumulative with increasing time. In other words, the anisotropic effects observed on shallow reflections become propagated onto events at later times. To extract meaningful information over a target zone, the RMS information must be converted to interval properties, and this is done through the use of generalized Dix inversion. Traditionally this is carried out by defining the intervals between horizon picks on the seismic stack. A method is proposed that is independent of horizons and instead utilizes small window zones that follow the geologic structure based on the strength of reflection events.

Method

The inputs (RMS Vfast, Vslow, and Vfast-az) can be derived in multiple ways. One way is through orthorhombic velocity analysis (Wang and Wilkinson, 2012) using a Gauss-Seidel method to estimate VTI and HTI corrections. Another way is by using correlation weighted trim statics (Davison, 2011). With this method the static shifts align the seismic events in a CMP gather to a pilot trace. As the isotropic velocities are known, the static values can be shown to correspond to an equivalent elliptic NMO correction. Hence, RMS Vfast, Vslow, and Vfast-az can be determined. Also with this method, the validity of the travel-time fit can be weighted by the correlation of the pilot trace to the gather trace under investigation. For example, if the correlation is very low, then the azimuthal velocity determination is in doubt, and the algorithm will default to an isotropic value where Vfast = Vslow.

For both the interval VVAz analysis methods (horizon and structurally-consistent) the data is input into a generalized Dix inversion to convert to interval properties. The thickness of these intervals is based on the window size. Note that too small a window may result in unrealistic interval velocities when the RMS velocity changes significantly over an interface. The maximum window size is related to the thickness of the target zone.

In the classic method, horizons have been used as the boundaries for the windows. The limitations to using horizons include the isochron size (if too short, the interval velocities become unreasonably large or small), horizon availability (the target event may not be picked with confidence), and the effect of strong reflection events between horizons that dominate the cross-correlations and trim statics values. It is this last limitation that prompted the development of a new analysis method: structurally-consistent interval velocity variation with azimuth.

Structurally-consistent interval VVAz is based on using relatively strong coherent reflections to sample and derive the interval properties. This is accomplished by the use of a skeleton – an event detection scheme that assigns values of 1 to a good event and 0 to noise (Figure 2). Similar to seed-based automatic horizon picking algorithms, the skeleton is constructed over the entire 3D seismic volume using semblance driven correlation weighting.

Temporal interval generalized Dix inversion outputs are mapped onto the existing skeleton points. The Vfast, Vslow, and Vfast-az values are then propagated to the next valid skeleton point. This results in a 3D volume of anisotropic intensity that follows coherent seismic events (Figure 3). As well, in the process of the skeleton construction, inline and crossline dip volumes are generated that may be used to smooth the output in a way that follows the structure, facilitating interpretation.
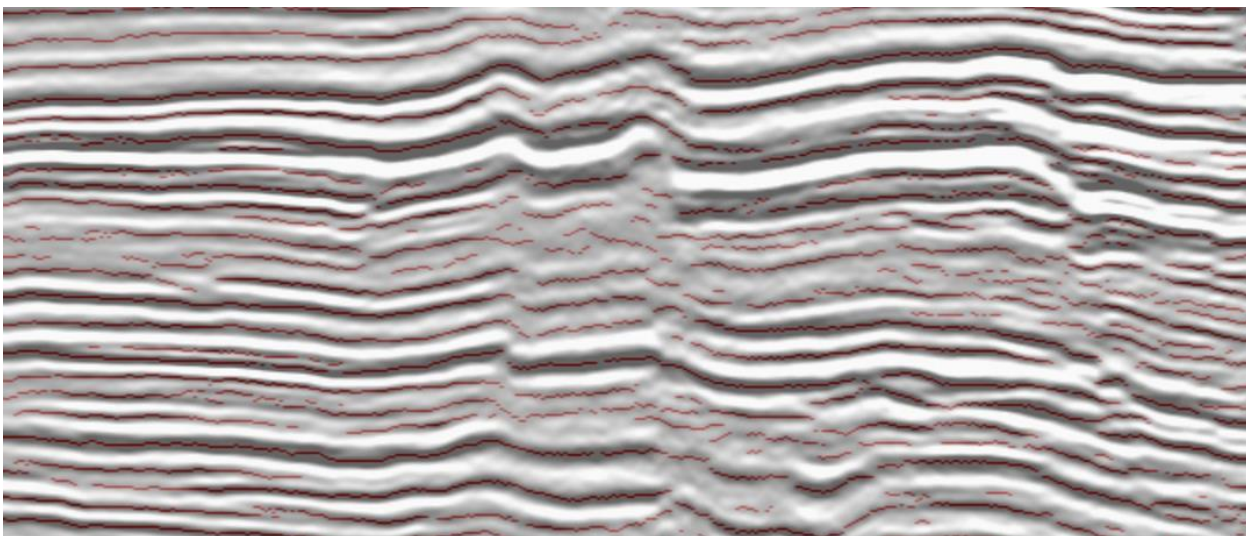

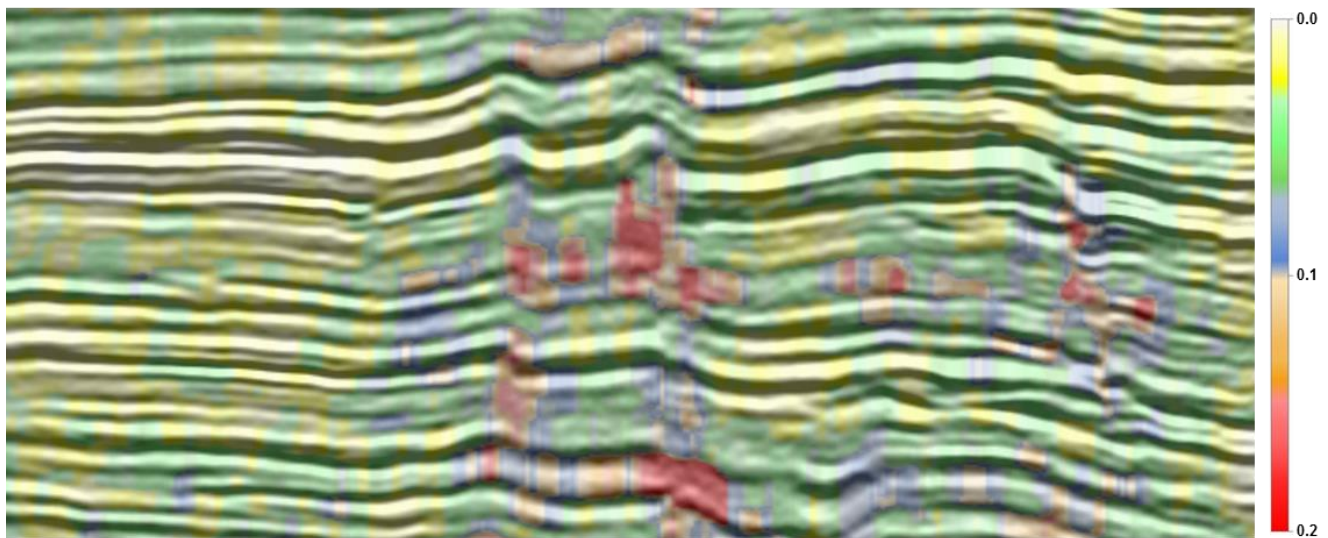**Figure 2**: Skeleton overlain on top of the seismic stack.

Figure 3: Anisotropic intensity from structurally-consistent interval VVAz.

Conclusions

VVAz analysis provides an interpretable volume to detect zones of HTI anisotropy. Conversion of the RMS velocity values to interval properties is done in a structurally-consistent manner, independent of - and not requiring any - picked horizons. A skeleton is constructed based on event-detection in the seismic stack volume, and is then used to create the anisotropic volume, in addition to being used as a dip-consistent smoother. This method has the potential to increase the resolution of the VVAz interval analysis as compared to a horizon-bound technique.

Acknowledgements

References

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