Azimuthal Processing of Vintage Land Seismic Data: Leveraging the Benefits of 5D Interpolation

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Keywords

5D Interpolation, HTI Anisotropy, Orthorhombic Migration

Summary

HTI anisotropy induced by fractures in unconventional reservoirs shows azimuthal variations in amplitude and velocity. Identification of fractures from seismic data requires wide azimuth data acquisition which have cost implications. Due to slump in oil pricing, new acquisitions may be difficult but the legacy 3D volumes may be re-processed with azimuthal workflows taking advantage of higher orders interpolation schemes and add value to exploration at a bare minimum cost. Here we have presented a case study to describe a pragmatic workflow to test and reprocess the vintage 3D with azimuthal consideration. In the present study one of the legacy 3D seismic shot with the orthogonal acquisition geometry, originally acquired for conventional reservoir objectives, have been used for azimuthal processing. The aspect ratio of this dataset indicated its sub-optimal amenability to azimuthal processing. A feasibility study indicated that with 5D interpolation scheme, all required azimuth-offset classes could be populated reliably. The interpolated dataset was divided in six azimuth sectors and migrated; azimuthal moveouts were inverted using NMO equation as described by (Tsvankin 1997; Contreras et al. 1999). V_{fast}, V_{slow} and azimuth of V_{fast} thus calculated were included in Azimuthal sectored Migration. Consequently "Snail gathers" or COCA (common Offset Common Azimuth sorted) gathers exhibiting azimuthal moveout were corrected for HTI anisotropy.

Introduction

The survey has been acquired with an orthogonal geometry designed for the conventional exploration objectives. However fracture characterization in unconventional reservoirs warrant wide azimuth data. Prima facie the selected 3D volume has very scanty azimuthal distribution in offset classes shown in Figure-2, however, 5D interpolation could improve poorly sampled land seismic (Hunt et al. 2008) resulting in significant improvement of Azimuthal AVO estimates. This may produce value added products without going for a new wide azimuth acquisition. A study to analyze the feasibility of azimuthal processing was performed. This study explored the potential use of 5D interpolation to circumvent the deficiencies in azimuth/offset sampling. 5D interpolation has ensured a regular sampling in all azimuths. VTI analysis and Azimuthal velocity analysis were performed to calculate the required parameters for Orthorhombic Migration. The project thus included three key steps: 5D interpolation, Azimuthal velocity analysis and Azimuthal sectored migration.

Survey Geometry

The legacy 3D seismic survey covered an area of approximately 500 square kilometers in a petroliferous basin in onshore India wherein. The acquisition geometry consisted of 10 receiver lines per shot with a source and receiver line interval of 360m each. A split spread with 192 receivers in each receiver line was used. There are big coverage gaps in the data due to a river and a large pond falling in the area. The shot interval and the receiver interval were 60m & 30m respectively, which results in a nominal fold of 40. The survey was shot with explosive source of size 2.5 kg and record length of 8 second.

Processing Sequence

5D Interpolation

Various 5D Interpolation methods available in the industry such as MWNI (Minimum Weighted Norm Interpolation) method by Liu and Sacchi (2004), the ALFT (Anti-leakage Fourier Transform) method by Xu et al. (2005) and the POSC (Projection onto Convex Sets) method by Abma and Kabir (2006), are widely discussed in literature. ALFT based method for interpolation (Poole, 2010) where data is transformed into spatial frequency domain with an irregular Fourier transform and a reverse transform then reconstructs the energy on a target grid was used. Interpolation (in Inline-crossline-azimuth-offset-frequency domains) was done using NMO corrected data for better preservation of amplitude variations with azimuth (Trad, 2008).

Azimuthal Velocity Analysis

Exhibition of elliptic behavior in azimuthal velocity of a horizontal reflector for near vertical incidence in a HTI medium has been first discussed by Tsavankin 1997. Later Contreas et al. 1999 modified the P wave NMO ellipse in the form of Equation 1 as below

$$\frac{1}{V_{NMO}^2} = \frac{\cos^2(\phi - \beta)}{V_{fast}^2} + \frac{\sin^2(\phi - \beta)}{V_{slow}^2}$$

Where ϕ is the Source-Receiver azimuth, β is azimuth of Fast Velocity, V_{fast} and V_{slow} are the semi major and minor axis of NMO ellipse respectively. Different methods have been proposed by various authors for the inversion of this NMO ellipse like Sectoring, Scanning and Surface fitting (summarized by Calvert et al. 2008). We have used surface fitting approach (Davidson et al. 2011), where trim statics is performed between CMP traces and a pilot stack. These trim statics are then inverted in least square sense using the input NMO velocity model. The V_{fast}, V_{slow} and azimuth of Fast velocity thus calculated were used in azimuthal migration.

Azimuthal sectored Migration

Orthorhombic velocity model for P-wave is expressed by V_{fast}, V_{slow}, azimuth of V_{fast} and three anellipticity parameters (η^1, η^2 & η^3) of the symmetry planes. We have derived these parameters using a cascaded approach (analogous to Jenner 2011), where VTI and HTI anisotropic parameters are estimated independently. Initially VTI velocity analysis is performed using all the data considering η as independent of azimuth. Thereafter Azimuthal velocity analysis is performed for V_{fast}, V_{slow} and azimuth of V_{fast}. After incorporating these orthorhombic anisotropic parameters Kirchhoff pre-stack time migration is performed for all azimuth sectors.

Case study

In the feasibility study we have simulated 5D interpolation with different window sizes in all four spatial dimensions. Data has been divided into 12 azimuth sectors of 30^0 each measured clockwise from North as shown in Figure 1 (0^0 to 360^0). However assuming source-receiver reciprocity during interpolation these can be grouped into six azimuth sectors.

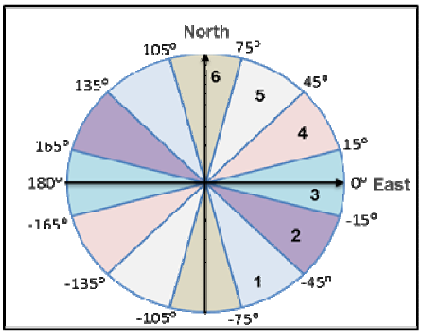

Figure 1. Azimuths are divided into 12 sectors starting from North in clockwise direction. Each sector is of 30^0 width. Taking Source-Receiver reciprocity sectors which ae 180^0 opposite, can be grouped together resulting six sectors.

For 2580m Offset class we have observed that input data was very sparse as shown in Figure 2. Two azimuth sectors and three offset classes each side of the target Azimuth-Offset class were included with a spatial window of 120m along Inline & crossline direction. It was observed (Figure 3) that after 5D interpolation we could get sufficient sampling in all sectors required for azimuthal processing. Input data used in interpolation has been pre-processed for noise attenuation, multiple attenuation and Surface consistent processing. On the pre-processed data 5D Interpolation was then performed in five dimensions - inline, crossline, time, offset and azimuth on NMO-corrected Data. Figure 4 (a) & (b) shows a comparison of the COCA (Common Offset Common Azimuth) gathers with and without interpolation respectively. The improvement in azimuthal distribution for each offset class is clearly evident.

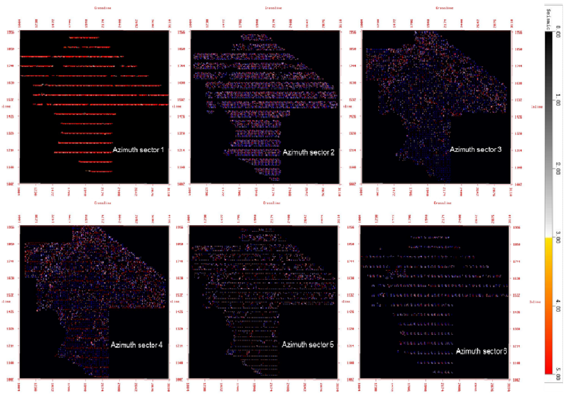

Figure 2. Input data Fold map for Offset 2580m are displayed for six Azimuth sectors. It can be seen that there is very small coverage in sectors 1, 5 & 6; while sectors 2, 3 & 4 have sufficient fold.

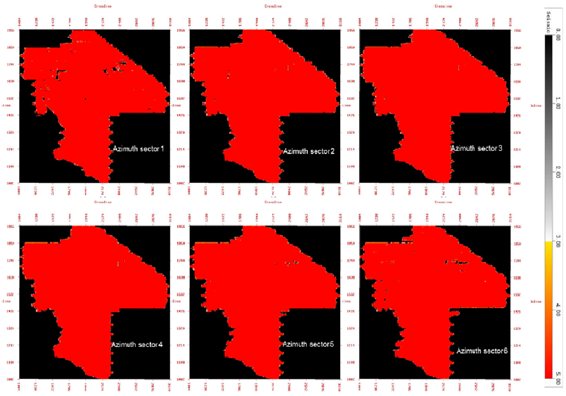

Figure 3. Two azimuth classes and three Offset classes each side of the target Azimuth-Offset class were counted in the simulation. Including traces within 120m in Inline & Crossline direction it is observed that we could get sufficient fold for Azimuthal processing.

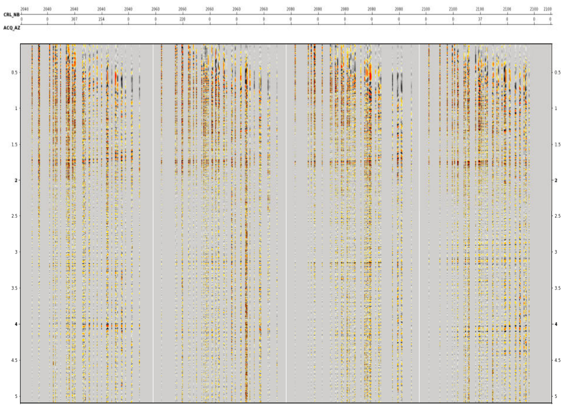

Figure 4(a). Common offset common azimuth (COCA) sorted gathers before Interpolation.

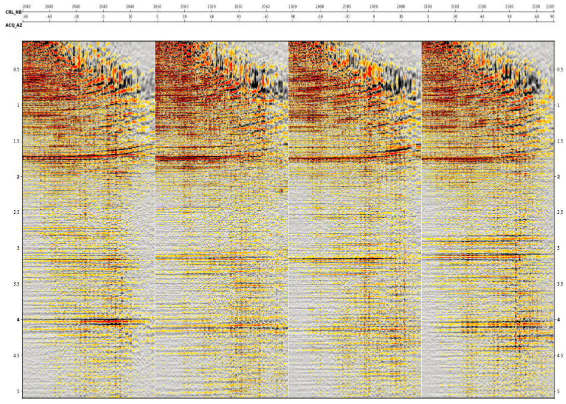

Figure 4(b). Common offset common azimuth (COCA) sorted gathers after 5D Interpolation.

VTI velocity analysis is performed on the conventional seismic data. Data from each of the six azimuth sectors are migrated independently using η and V_{RMS} velocity (VTI). Subsequently Azimuthal velocity analysis was done for HTI anisotropic parameters, V_{fast}, V_{slow} and azimuth of V_{fast} on the COCA gathers. Orthorhombic migration was finally performed utilizing η and HTI anisotropic parameters on each sector. It is to be noted that the η is considered to be independent of azimuth during the orthorhombic migration. Figure 5 (a) & (b) displays COCA gathers with VTI migration and orthorhombic migration respectively. It is noticed that Azimuthal variation in move-out that was present in VTI PSTM gathers has been corrected after orthorhombic PSTM. Six migrated volumes and one composite stack combining all azimuths have been generated. A comparison of conventional PSTM stack and Composite Azimuthal PSTM stack is shown in Figure 6(a) & 6 (b) respectively. Combined stack of Azimuthal PSTM has superior imaging than conventional PSTM stack. Six azimuthal volumes have been successfully used for estimation of fracture density and orientation using azimuthal AVO techniques, however these results are not included in this paper.

Conclusions

Vintage Land seismic datasets may have sub-optimal sampling in offset-azimuth dimensions to be taken up for azimuthal processing. However 5D interpolation has provided an opportunity to make the data

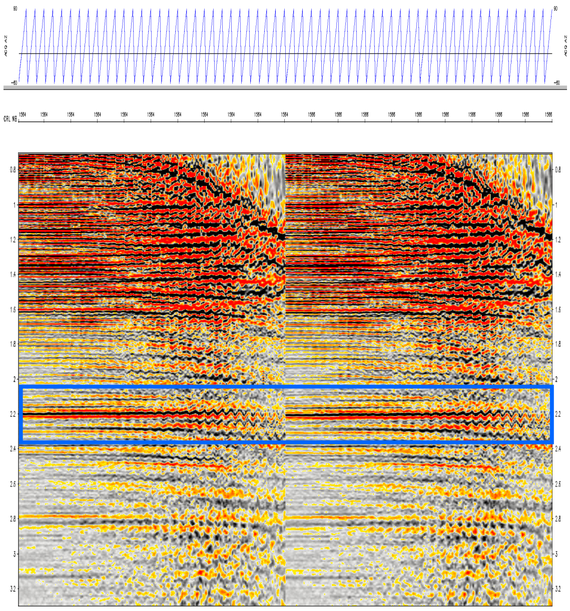

Figure 5 (a). COCA gathers after VTI Migration

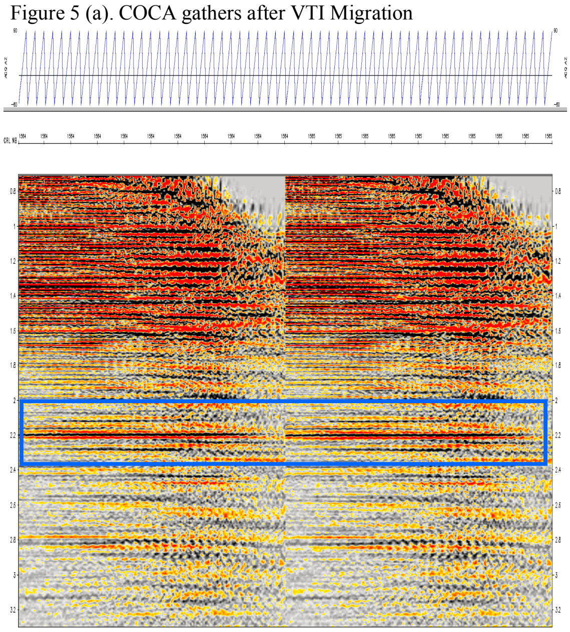

Figure 5 (b). COCA gathers after Orthorhombic Migration. As shown in blue box sinuosity nature has been corrected after Orthorhombic Migration.

amenable for azimuthal processing without specifically investing on multi azimuth acquisition. In present study, through a cascaded approach of VTI and HTI velocity analysis orthorhombic anisotropic parameters were estimated. Orthorhombic Kirchhoff PSTM utilizing the estimated anisotropic information resulted in improved COCA gathers. AVO attributes on the processed data have improved and provided opportunity for use in Fracture identification in the area.

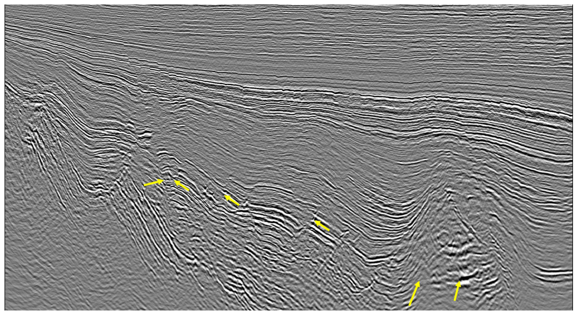

Figure 6 (a). VTI PSTM Stack

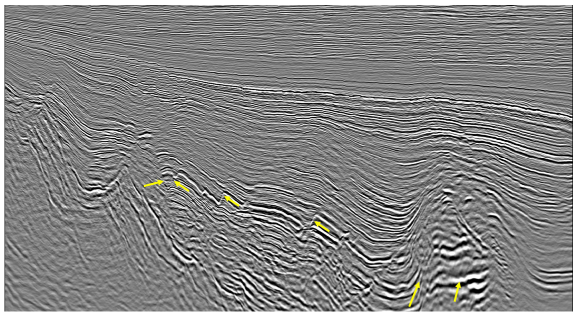

Figure 6 (b). Orthorhombic PSTM Stack- composite

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