Acquisition requirements for COV migration and azimuthal AVO

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Summary

Azimuthal attributes such as azimuthal AVO or azimuthal velocity analysis are important tools to estimate fractures in tight reservoirs. In order to perform these analyses prestack migrated gathers which retain both the offset and azimuth information must be generated. One way of achieving this goal is to perform common offset migration. The question arises though how finely sampled must the data be in order to obtain reliable azimuthal AVO parameter estimates with this input. This paper presents a modeling study to demonstrate a methodology to answer this question. The major conclusion is that for the example examined in this paper the source and receiver line interval is too coarse to predict AVAZ parameters reliably. The acquisition parameters used in this paper are typical of the Western Canadian Sedimentary Basin so this conclusion is probably more general. This suggests that seismic data shot with the goal of estimating fractured reservoirs using azimuthal attributes should employ tighter source and receiver line intervals. This is becoming more cost effective with the advent of simultaneous sources and higher channel counts. Alternatively, 5D prestack interpolation may be performed to achieve the same goal but at a loss of spatial resolution.

Introduction

Hunt et al. (2010) demonstrates quantitatively that azimuthal attributes such as azimuthal AVO (AVAZ) and azimuthal velocity (VVAZ) analyses can be used to accurately predict fractures. Ideally the input to these analyses should be prestack migrated image gathers. This follows from work of Mosher et al. (1996) who demonstrated that prestack migration improves AVO analysis. Further, prestack time migration (PSTM) removes the dip dependency from velocity analysis, a prerequisite to azimuthal velocity analysis. In order to perform these prestack azimuthal attribute analyses the azimuth needs to be preserved as part of the PSTM. Forming Common Offset Vector (COV) cubes (Cary, 1999; Vermeer, 2002) and then migrating these cubes is one technique that preserves this information. Li (2008) gives an excellent tutorial describing the method.

One of the key concepts behind the method is that migration outputs offset bins defined by both an x- and y-coordinate. The (x,y) bin center defines a vector whose magnitude is offset and direction is azimuth. These bins are called Offset Vector Tiles (OVT). Assuming an orthogonal geometry, with source lines along the y-axis, the size of the OVT is two times the source line interval (SLI) in the x-direction and two times the receiver line interval (RLI) in the y-direction. For typical land geometries in the Western Canadian Sedimentary Basin (WCSB) these OVT's can be easily over 1000 m in each direction.

Large OVT bin size leads to theoretical error in the azimuthal attribute analysis. This arises from the fact that the true azimuth defined by the source-receiver geometry is different than the azimuth defined by the OVT bin center. This difference can lead to AVAZ parameter estimate errors. The size of this error increases as the OVT bin size /line spacing increases so the natural question to ask is, how finely sampled must the source and receiver line spacing be to generate reliable AVAZ estimates? The answer to this must depend on the geologic objectives since the SLI and RLI are chosen to image both the shallowest reflector of interest and the target zone, thus these parameters depend on the depth of the target. To answer the above question a modeling study was performed based on parameters similar to those used by Hunt et al. (2010).

The 3D seismic acquisition in this case is an orthogonal geometry with the target zone around 1.5 seconds. Synthetic seismic data were generated using a convolutional modeling scheme with reflectivity being generated using the near offset Ruger (2002) equation and the azimuths calculated from the actual source and receiver locations. The near offset Ruger equation is also used by the AVAZ inversion, and thus the reflectivity modeling assumptions are consistent and as such are not a source of theoretical error. However, the AVAZ inversion uses the azimuths defined by the OVT bin centers. Since the OVT may be quite large there can be significant differences between the azimuth calculations. The goal of this paper is to quantify this error and determine what the maximum source and receiver line spacing may be to reliably predict fractures.

Modeling study

The geometry of this dataset is illustrated in Figure 1. The red stars represent shot locations with a source interval (SI) of 60 m and a SLI of 600 m. The receivers are indicated by blue boxes similarly spaced with a receiver interval (RI) of 60m and a RLI of 600 m. The green dots in Figure 1 are the CDP locations for all the source receiver combinations calculated for the cross-spread defined by the source line and receiver line identified by the blue arrows. The black dots are the OVT bin centers.

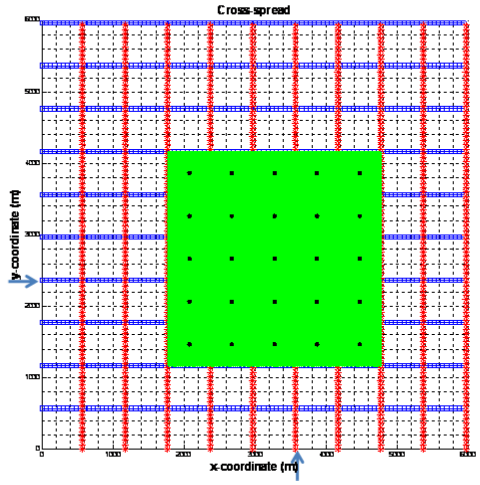

Figure 1: Acquisition geometry of model dataset. Shots in red, receivers in blue, green dots are CDP locations for cross-spread defined by source and receiver line highlighted by arrows. Offset vector tile bin centers shown by black dots.

Figure 2a shows the azimuth calculated from the actual source receiver coordinates for one of the nearest COV's for this geometry. The azimuth of the bin center of this COV is 135 degrees. Note that there is significant scatter of the actual azimuths around 135 degrees. This is highlighted by Figure 2b which shows the difference between the actual azimuth and the azimuth calculated based on the bin center. This difference in azimuth leads to errors in the azimuthal AVO inversion.

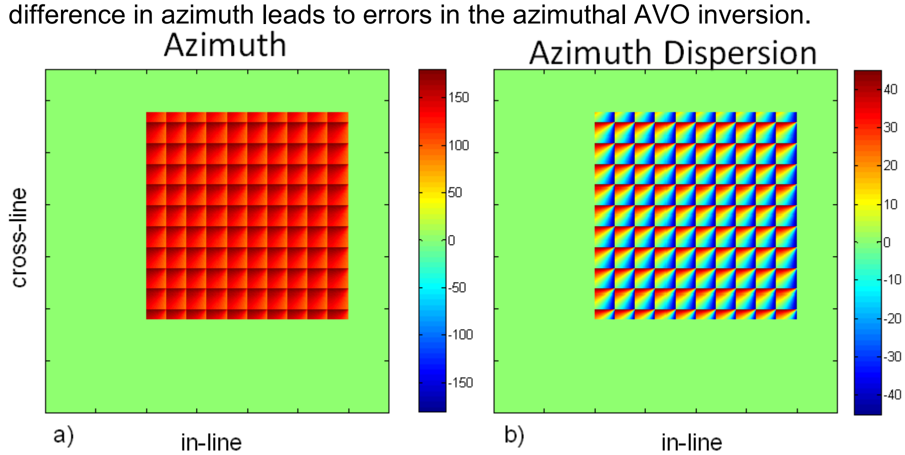

Figure 2: Azimuth a) calculated from source-receiver locations for COV cube for one of the near offsets. The difference between the bin centered azimuth and actual azimuth calculated from the source-receiver location is shown in b).

In addition, there is also scatter of the angle of incidence in each COV. Figure 3a shows the angle of incidence calculated for the reflector at 1.5 s for the same COV as shown in Figure 2. This scatter also arises due to the difference between the true coordinates and the bin centered coordinates.

The reflectivity is generated using the near offset Ruger (2002) equation,

$$R(\theta,\Phi) = A + \left[B_{iso} + B_{ani}\sin^2(\Phi - \Phi_{iso})\right]\sin^2\theta,$$

where R is the reflectivity as a function of azimuth Φ and angle of incidence θ, A is the P-wave impedance reflectivity, B_{iso} the isotropic gradient, B_{ani} the anisotropic gradient and Φ_{iso} is the isotropy axis of the HTI anisotropic media. The anisotropic gradient is related to the crack density. This along with the isotropy axis Φ_{iso} is of primary interest to the explorationist. The model was generated using constant values for A=0.1, B_{iso} =0.2, B_{ani} =0.1 and Φ_{iso} =45 degrees. Figure 3b shows the resulting reflectivity for the same COV. Note the variability of the reflectivity due to variability of the angle of incidence. If OVT bin centered values were used this would be a constant. For COV cubes based on OVT's at larger offsets the major influence is azimuth.

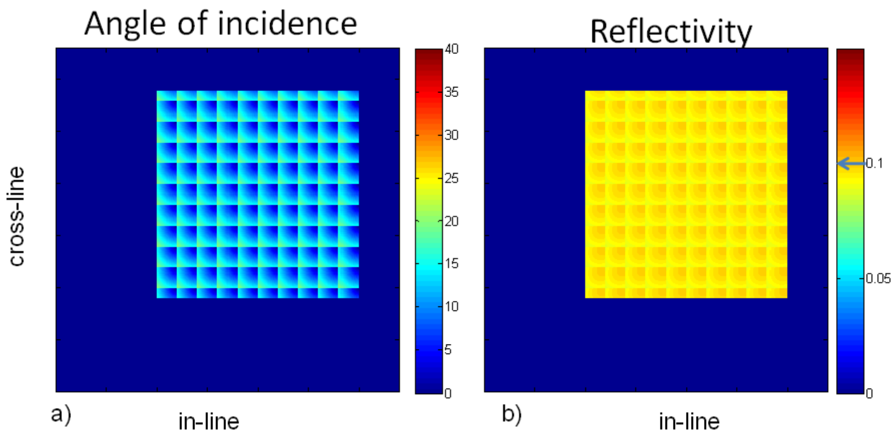

Figure 3: Angle of incidence a) for the reflector at 1.5 seconds for the same COV cube as shown in Figure 2. The calculated reflectivity is shown in b).

The reflectivity data was inverted for the above azimuthal AVO parameters. Ideally the estimates should be laterally invariant, constant quantities with the above values. Figures 4a and 4b show the estimates for the anisotropic gradient and isotropy plane azimuth. Both displays show quite a bit of variability. The anisotropic gradient shows a footprint in the full fold area (in-line 140 to 260 and cross-line 130-250). The error increases towards the edge of the survey where the data is no longer full fold. Note the error is a bias caused by theoretical error due to using the bin centered azimuth and angle of incidence values rather than the problem being ill-posed (Downton and Gray, 2006). The estimate of the isotropy plane also shows a footprint with error of the order of 30 degrees.

In Figure 4a and 4b the SLI and RLI of 600 m leads to significant error. Another model was employed to see if reducing the SLI and RLI by half to 300 m would reduce the error to a tolerable level. This increased the fold by a factor of four. Figures 4c and 4d show the estimates of the anisotropic gradient and isotropy plane azimuth for SLI=RLI=300 m. In the full fold area the footprint is much less evident suggesting that for this target depth a SLI and RLI of 300 m is sufficient to estimate the azimuthal attributes reliably.

Conclusions

The major conclusion for this particular model is that source and receiver line spacing is too coarse at 600m for estimation of azimuthal attributes for this target at 1.5 s. Reducing the line intervals to 300 m reduces the footprint and error. Ideally this should be accomplished through acquiring the data with a tighter source and receiver line interval. With the advent of higher density acquisition with simultaneous sources and increased channel counts this becomes economically feasible. Source and receiver line interpolation can be accomplished through 5D interpolation (Trad, 2009) to reduce this bias but at a slight loss of spatial resolution.

Sufficient SLI and RLI will be a function of target depth. Determining what is the optimal SLI and RLI that does not give rise to a footprint for these plays can be determined by performing a modeling study as demonstrated in this paper. The SLI and RLI used in this paper are typical of acquisition in the WCSB suggesting future seismic data acquisition should be done with tighter line intervals if the goal is to perform Azimuthal AVO.

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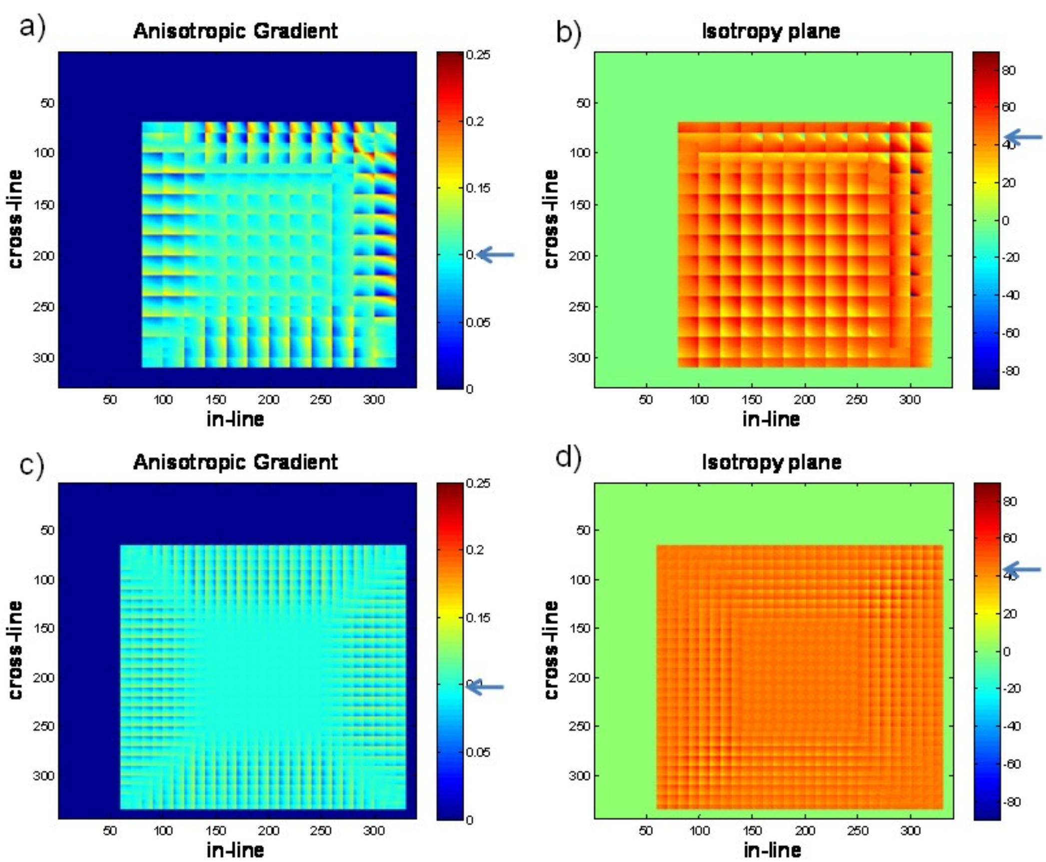

Figure 4: Estimated anisotropic gradient a) and isotropy azimuth b) for SLI=RLI=600 m. Estimated anisotropic gradient c) and isotropy azimuth d) for SLI=RLI=300 m. The arrows at the side of the color bar indicate the correct attribute value.