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An Azimuthal-AVO-Compliant 3D Land Seismic Processing Flow

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Summary

An azimuthal-AVO-compliant processing workflow for 3D land seismic data requires only minor additions and modifications to an AVO-compliant processing workflow in order to ensure that azimuthal variations in the data are maintained and properly enhanced. These modifications are examined and shown to improve the data prior to and after azimuthal AVO.

Introduction

With the increasing popularity of the use of seismic azimuthal attributes in fracture detection, the time has come to reexamine the processing sequence to ensure that it is azimuthal-AVO-compliant. Some work in this area has been done by Gomez and Angerer (2004). The conventional isotropic AVO-compliant processing flow (e.g. Lee et al., 1991) only needs a few modifications to make it azimuthal-AVO-compliant. There appear to be four key steps that need to be incorporated, which improve the azimuthal AVO result and make it easier to do. These are:

1. Azimuthal velocity corrections (e.g. Jenner et al., 2001).
2. Azimuthal spherical divergence correction (Xu and Tsvankin, 2006).
3. 5D interpolation (Trad et al., 2005).
4. Migration of Common Offset Vectors (COV's) (Cary, 1999).

Examples of these four techniques are shown to improve the seismic data before and after azimuthal AVO analysis..

Method

The recent advent of azimuthal seismic attributes warrants a review of the seismic processing workflow in order to ensure that azimuthal amplitude variations are maintained and valid throughout the sequence. This involves only some minor modifications of an AVO-compliant seismic processing workflow and the use of Common-Offset, Common-Azimuth (COCA) cubes (Gray, 2007) to validate them. The modifications are the application of azimuthal velocities (e.g. Jenner et al., 2001), azimuthal scaling (Xu and Tsvankin, 2006), 5D interpolation (Trad et al., 2005) and pre-stack time migration (PreSTM) of Common Offset Vectors (e.g. Schmidt et al., 2009).

Examples

These modifications to the processing flow all improve the output image, while maintaining azimuthal amplitude compliance. The use of azimuthal velocities greatly improves the alignment of gathers, especially at long offsets. Figure 1 shows that azimuthal variations in velocity can easily be on the order of a half-wavelength or more. Lack of awareness of these variations results in the damage of stack amplitudes and incorrect AVO behavior as all these azimuths are stacked together in conventional processing. In this example, the azimuthal residual moveouts cause peaks to align with troughs at orthogonal azimuths at long offsets, which, when stacked, will cause destructive interference of real amplitudes. After azimuthal velocities, the peaks and troughs align which maintains amplitudes and increases resolution when stacked.

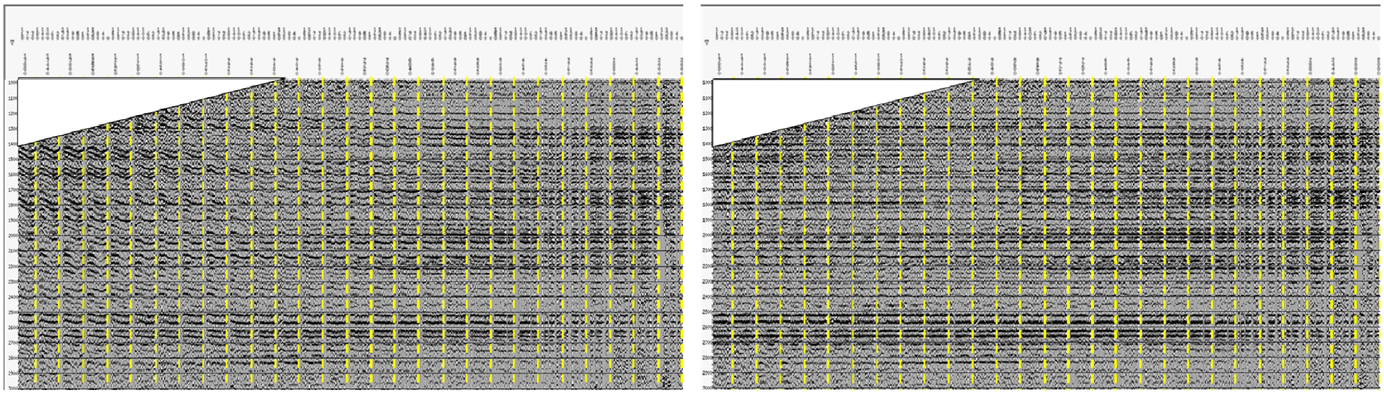

Figure 1: COCA cubes showing azimuthal velocity variations (left) and after application of azimuthal velocities (right).

Prior to AVO analysis, it is important to remove the effects of wave propagation. In an isotropic AVO processing sequence this is often done by applying a data driven geometrical divergence correction based on Ursin (1990). This has been generalized to anisotropic media by Xu and Tsvankin (2006) for symmetries up to orthorhombic. The approach is data driven, calculating the loss function from the wavefront curvature which are derived from the traveltime expressions. Orthorhombic velocities may be used to describe the velocity function so both HTI (azimuthal) and VTI (long offset) kinematic corrections can be simultaneously included. Figure 2 displays the geometrical correction as a function of offset for three separate azimuths for synthetic model data. It can be seen that azimuthal variations in wave propagation clearly changes this operator as a function of azimuth.

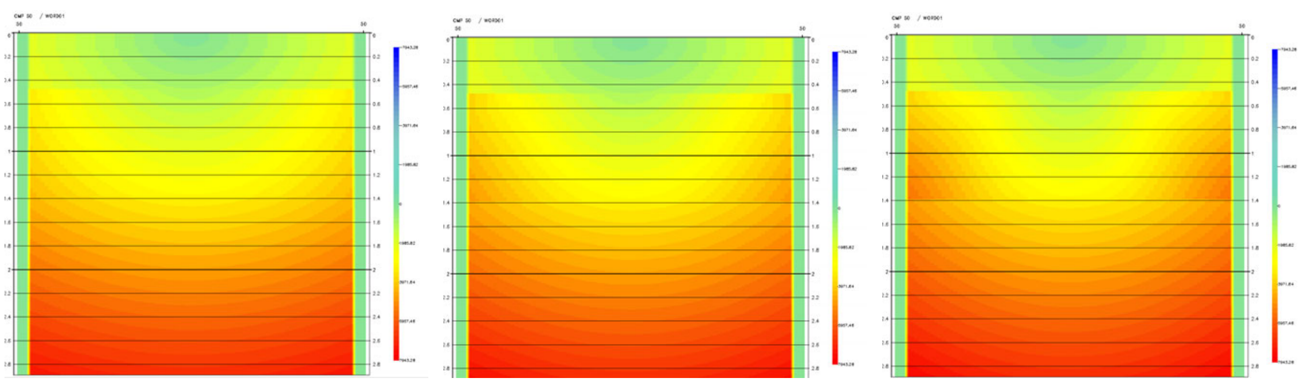

Figure 2: Azimuthal scaling showing spherical divergence correction at 0^o (N-S), 45^o, and 90^o (E-W). (After Nagarajappa, 2008)

Most land surveys are under-sampled spatially due to economic constraints. One way to get around this is pre-stack interpolation. New 5D interpolation techniques allow for variations with offset and azimuth, while better reducing shot and receiver line spacing and therefore footprint. This has a significant impact on the level of migration noise in the azimuthally-sectored PreSTM which is typically done prior to azimuthal AVO (e.g. Zheng and Wang, 2005). The improvement can be seen in Figure 3, where Gray and Wang

(2009) show that incorporating 5D interpolation into this flow significantly improves the amplitudes of the magnitude of azimuthal AVO.

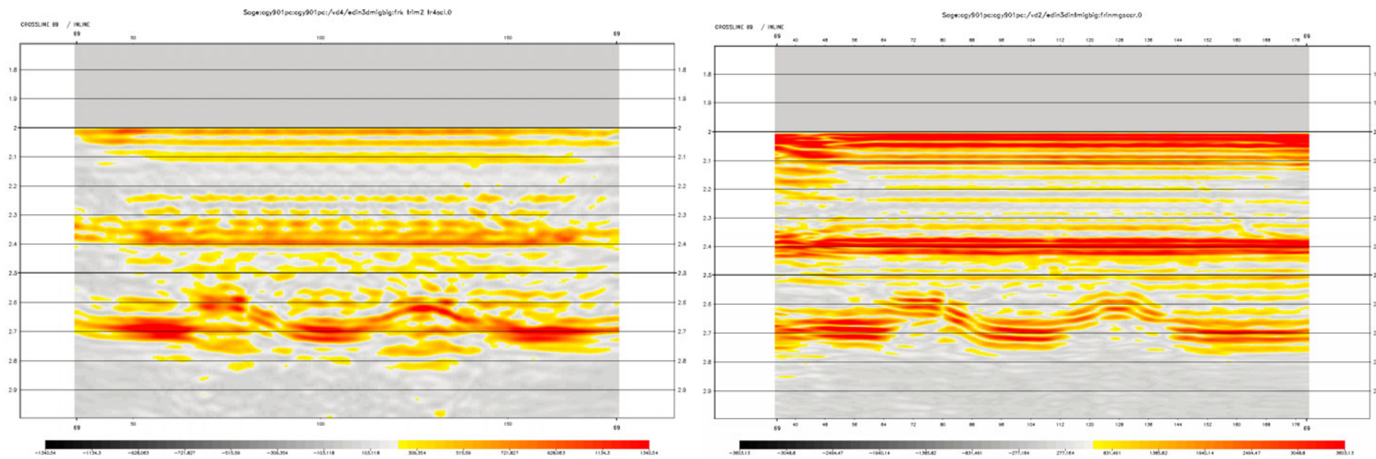

Figure 3: Azimuthal AVO results after azimuthally-sectored migration of the input data (left) and 5D interpolated data (right). (After Gray and Wang, 2009.)

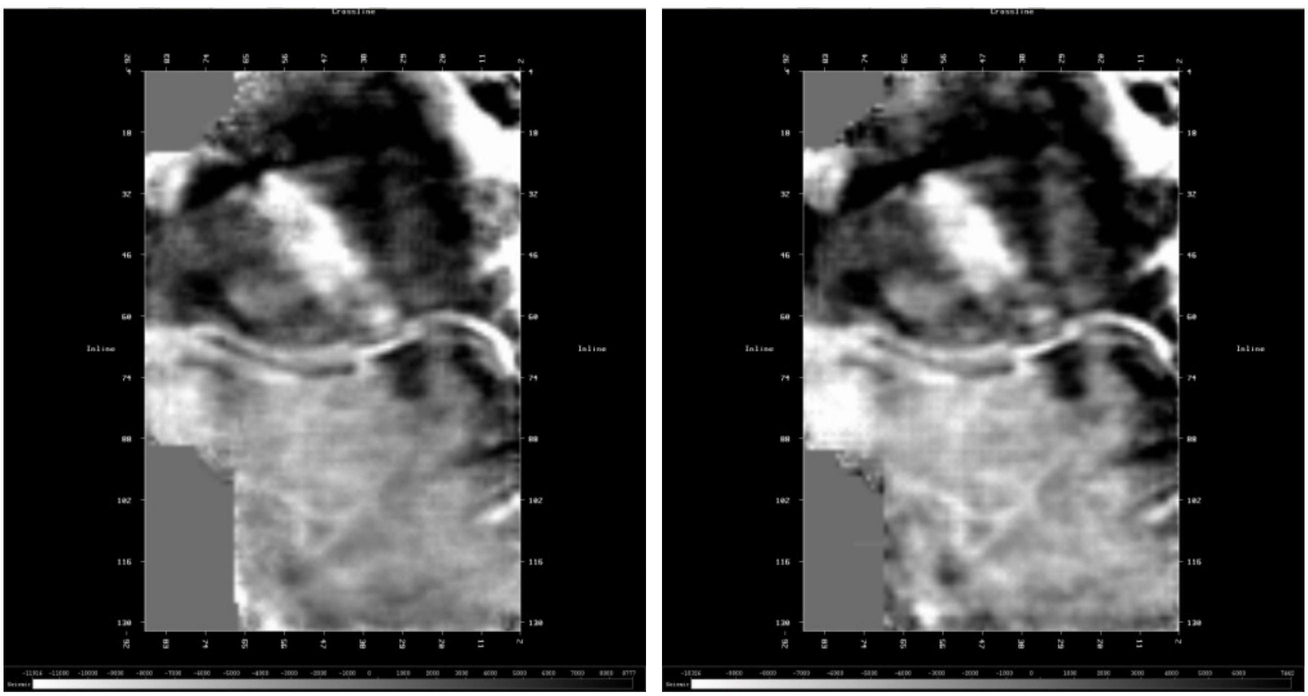

Figure 4: Timeslice showing a channel after conventional PreSTM (left) and PreSTM of COV gathers (right). (After Schmidt et al., 2009.)

Finally, COV's allow the shot-receiver azimuths and offsets to be maintained through the migration (Cary, 1999), allowing for the calculation of azimuthal attributes afterwards. Schmidt et al. (2009) show that the migration of COV gathers produces stack amplitudes that are at least as good as conventional PreSTM (Figure 4). However, COV's have not proven popular for most land 3D's because in order to be effective the COV tile size is the same size as the shot and receiver line spacing, which is on the order of hundreds of meters for most land 3D surveys. Since 5D interpolation is used to reduce the line spacing, it also makes the use of COV's more practical. If the COV tile size can be reduced to less than 200 m, then they become much more viable as a tool for AVO and azimuthal AVO analysis. Here the line spacing and therefore the

COV tile size is reduced to 70 m by the interpolation, making these data suitable for azimuthal AVO analysis after the migration of the COV gathers.

Of course, all processing steps where azimuthal modifications are made should be checked using COCA cubes (e.g. Figure 1) at key spots, such as well locations and areas where very large and very small azimuthal variations are detected.

Conclusions

It is very clear from these examples that the following processing steps are useful in the processing of seismic data to maintain azimuthal amplitude variations:

1. Azimuthal velocity corrections.
2. Azimuthal spherical divergence amplitude corrections.
3. 5D interpolation of the gathers prior to migration.
4. Migration of COV gathers.

All of these steps and any other steps that may affect variations in amplitude with azimuth should be checked using COCA cubes.

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