Advanced Seismic Processing: A Case Study on Imaging in the Delaware Basin

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Summary

With the emergence of new seismic techniques to increase reservoir knowledge from unconventional resources, seismic imaging of land data has sought out new methods and workflows to provide more accurate subsurface images. One area with unconventional resources is the Delaware Basin (Texas, USA), a sub-basin of the Permian that is fault-bounded by the Diablo and Central basin platforms. In the near surface are: clay beds that obscure the reflections below; a west to east dipping high velocity anhydrite layer that creates a velocity inversion; and inter-bed salt, with large velocity and density contrasts, that generates complex multiples in the data. Near-surface complexities give rise to varying ground roll characteristics across the survey. When it is not spatially sampled adequately, the ground roll is aliased, a problem which needs to be addressed effectively to obtain a high-quality image. In addition to near-surface complexities, azimuthal-dependent velocity variation is observed throughout the subsurface.
This abstract presents a case study that explores the challenges faced and overcome in processing a survey from this area through an AVO compliant orthorhombic PSTM workflow. The ongoing reservoir study of the processed data suggests that the presented workflow overcame complicated imaging problems and decreased uncertainty in imaging the reservoir.

Introduction

In the broken foreland of the Marathon-Ouachite orogenic belt, under the relatively flat and featureless plains of west Texas lays the complex basement structure of the Permian Basin. It is composed of the Delaware, Midland and Val Verde sub-basins. The Delaware sub-basin, the region of interest in this case study is fault-bounded by the Diablo and Central Basin platforms. Since the 1920's, drilling in this region has produced both oil and gas from various depths. Recently, as drilling has moved deeper to new production zones, and with the shift to unconventional driven plays, seismic imaging of the region has continued to be needed to further enhance production in the region.
The case study focuses on the complications and processing steps for a 730 sq. km survey in the central region of the Delaware basin. In this abstract, we present an AVO compliant orthorhombic PSTM workflow which addresses the challenges and difficulties observed in the processing.

Refraction statics

Near-surface statics are always a significant concern, primarily due to existing surface conditions that influence the accuracy of the resulting imaged time structure. For this survey region, complex near surface conditions such as variable depth clay beds necessitated a unique and labor intensive consideration for the first arrivals. Picking first breaks by applying a guide function to the shot gathers resulted in an inadequate refraction tomography (TOMO) solution, as the guide function was not able to appropriately model the first arrivals. Instead, a guide function was produced by picking the first arrival time as a horizon on Linear Move Out (LMO) stacks of increasing offset range and velocity. The resulting first breaks were used to generate an accurate TOMO solution.

Ground roll attenuation

One of the challenges in processing seismic data is to effectively attenuate ground roll. Near-surface complexities in the Delaware Basin give rise to varying ground roll characteristics across the survey. In such cases, techniques that rely solely on fixed parameterization and regular grids become ineffective. Furthermore, when seismic data are not spatially sampled adequately, the ground roll is aliased, which increases the complexity of the ground roll attenuation.

A data-driven approach performing accurate ground roll attenuation by three-dimensionally adapting to the ground roll and guided-wave characteristics was applied. Ground roll is modelled and adaptively subtracted from the data, providing robust and effective ground roll attenuation while ensuring excellent preservation of reflections (Le Meur et al, 2014). It is effective even in challenging conditions such as an irregular offset distribution or where ground roll is aliased or dispersive.

Figure 1 shows an example of a stack before and after ground roll attenuation. While the ground roll has been attenuated effectively, there is no sign of signal leakage in the difference volume.

Random noise attenuation

There are various techniques proposed to attenuate random noise while improving the signal to noise ratio, such as f-x predictive filtering (Canales, 1984), Empirical Mode Decomposition (EMD) techniques to prepare stable input for the Hilbert Transform (Huang et al.,1998), projection filtering (Soubaras, 1995), and rank reduction filtering. Cadzow rank reduction noise attenuation is a multi-dimensional random noise attenuation technique which uses a noise-suppression strategy called "matrix rank reduction" (Cadzow, 1988; Trickett, 2002, 2003, 2008). It processes the data in spatial and temporal blocks that can have several spatial dimensions (for example, subline, crossline, offset, and azimuth) in order to separate linear signals from random noise. Linear signals are coherent in the defined spatial direction whereas random noise is spread randomly in space. In seismic data the rank represents the number of distinct dips to preserve.

One of the best domains to apply Cadzow is the Common Offset Vector (COV) domain, which provides a single-fold data volume where each bin contains one trace whose X and Y offsets are close to a nominal value. The coherence of reflectors was enhanced by improving the signal to noise ratio significantly after applying Cadzow-type approach without causing any damage to the primaries (Figure 2).

Multiple attenuation

In this region, a near surface high velocity anhydrite layer with an irregular top creates a large velocity inversion, and is a major generator of complex surface related multiples. Further complexity is due to inter-bed salt layers throughout the anhydrate. These layers have a large density contrast relative to the anhydrite, and are responsible for multiples too.

With such a large velocity inversion near the surface, the multiples show themselves to be almost flat on normal moveout (NMO) gathers, and are present throughout the formations of interest. It is extremely difficult to distinguish multiple from primary because of the lack of contrast in move-out. Consequently, move-out based techniques (fk-filtering, Radon, etc.) are prone to targeting primaries along with multiples, and are therefore ineffective. In this survey, we used Surface Related Multiple Elimination (SRME). The multiples for one source/receiver pair can be calculated by summing contributions related to all possible relaying paths, and each contribution is equal to the convolution of two traces corresponding to two ray paths. In production, SRME takes a horizon based approach to model the surface related multiples in the CDP domain. It then uses a two-step adaptive subtraction to match the modeled multiples to the data in both time and amplitude prior to their removal (Wang and Wang, 2013).

Trace interpolation

Before COV pre-stack migration, trace interpolation was performed to minimize any artifacts that would have been created by the migration of incompletely populated COV volumes. Hybrid 5D (inline, crossline, offset, azimuth and frequency) interpolation was applied to the data to regularize shots and receivers. The result was a survey with a uniform CDP fold of 385 where each COV volume is full with single fold. The method is able to handle data with large residual moveout due to strong anisotropy and dipping reflectors (Wang and Wang, 2014)

Figure 3 shows a snail gather (COV azimuth sorted gather) before and after interpolation. The output gather has an increase in signal to noise and more continuous distribution by azimuth and offset; therefore, it exhibits the azimuthal anisotropy much more visibly. As the COV's move through 360 degrees of azimuth, a sinusoidal trend can be seen in the events (red picks on the seismic), caused by the difference in moving through the quadrants of V_{fast} and V_{slow} or slightly dipping reflectors. This residual moveout, if it's due to orthorhombic anisotropy, will be corrected later with an orthorhombic velocity analysis.

Orthorhombic pre-stack time migration

In the Delaware Basin, the reservoir can be characterized by the combined effects of vertically aligned fractures (Horizontal Transverse Isotropy or HTI) and horizontal layering (Vertical Transverse Isotropy or VTI). In order to properly image this type of reservoir, we need to consider simultaneous effects of VTI and HTI in the form of orthorhombic anisotropy. Grechka and Tsvankin (1999) showed that the azimuth of one of the vertical symmetry planes (β, the azimuth of V_{fast}), the NMO velocities (V_{fast} and V_{slow}) in the symmetry-plane directions, and three anisotropic "anellipticity" coefficients (η1, η2, η3) are responsible for all time processing steps for orthorhombic anisotropy, including NMO correction, dip moveout (DMO) and pre-stack time migration. The estimation of the velocity parameters for orthorhombic medium is the key for azimuthal processing using an orthorhombic velocity model.

The orthorhombic velocity parameters are estimated simultaneously on COV volumes with a curved-ray PSTM velocity field. The estimation of orthorhombic parameters is stabilized by proper data preparation and parameter constraints consistent with the moveout characteristics associated with seismic data (Wang and Wilkinson, 2012).

Figure **4** displays the stack results after curved-ray isotropic PSTM and orthorhombic PSTM. The orthorhombic PSTM shows more structure details and improved consistency of the events (arrows in Figure 4).

Conclusion

We showed that near surface complexities and imaging challenges due to azimuthal velocity variations in the subsurface can be overcome with an orthorhombic PSTM workflow. A specialized approach for defining the guide function for first arrival picking led to a good refraction tomography model for weathering statics. A data-driven approach targeted the aliased ground roll, a Cadzow-type approach attenuated the bulk of the random noise, land SRME removed complex multiples while preserving primaries, and 5D interpolation solved the sampling issues in preparation for imaging. In the imaging portion of the workflow, the orthorhombic PSTM successfully removed most of the azimuthal velocity variation, yielding an accurate time image for reservoir analysis. The ongoing reservoir study of the processed data suggests that the presented workflow overcame complicated imaging problems and decreased uncertainty in imaging the reservoir. The presented orthorhombic PSTM workflow is effective for the challenging Delaware Basin.

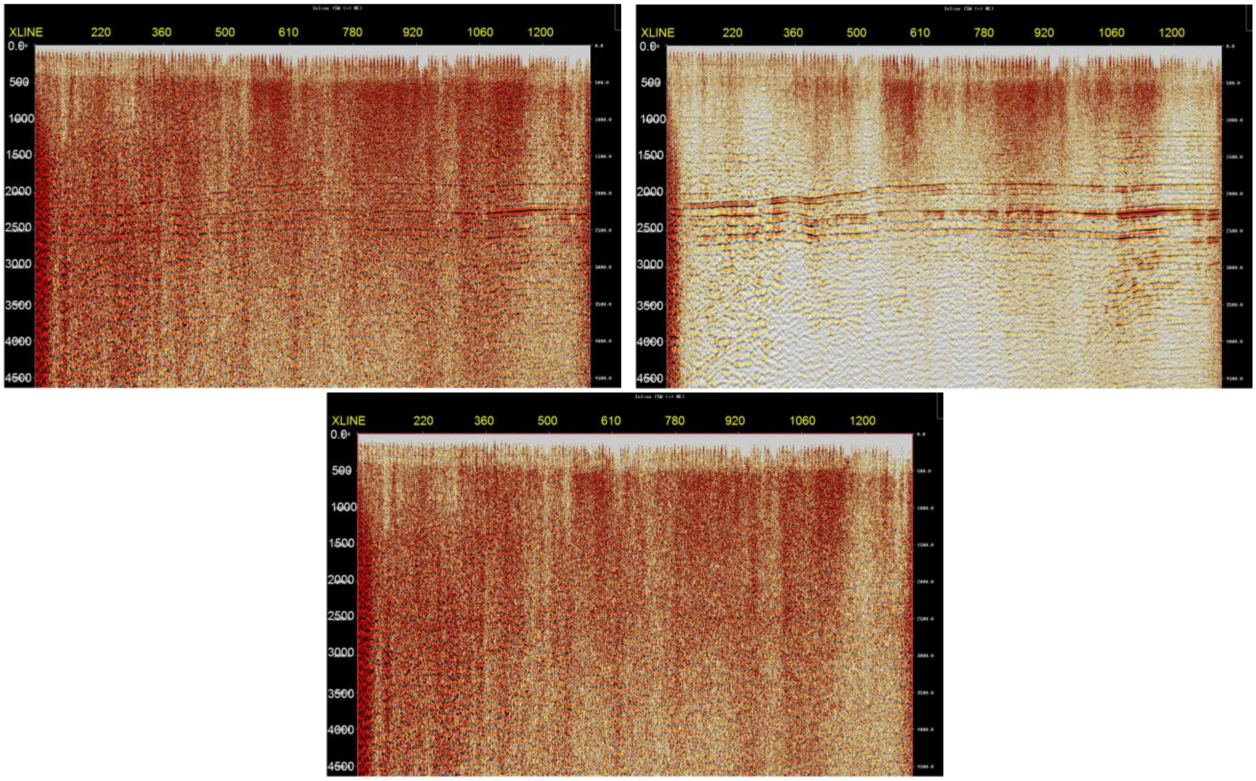

Figure 1**:** Example of stack line before (top-left) and after ground roll attenuation (top-right). No sign of signal leakage can be observed in the difference volume (bottom).

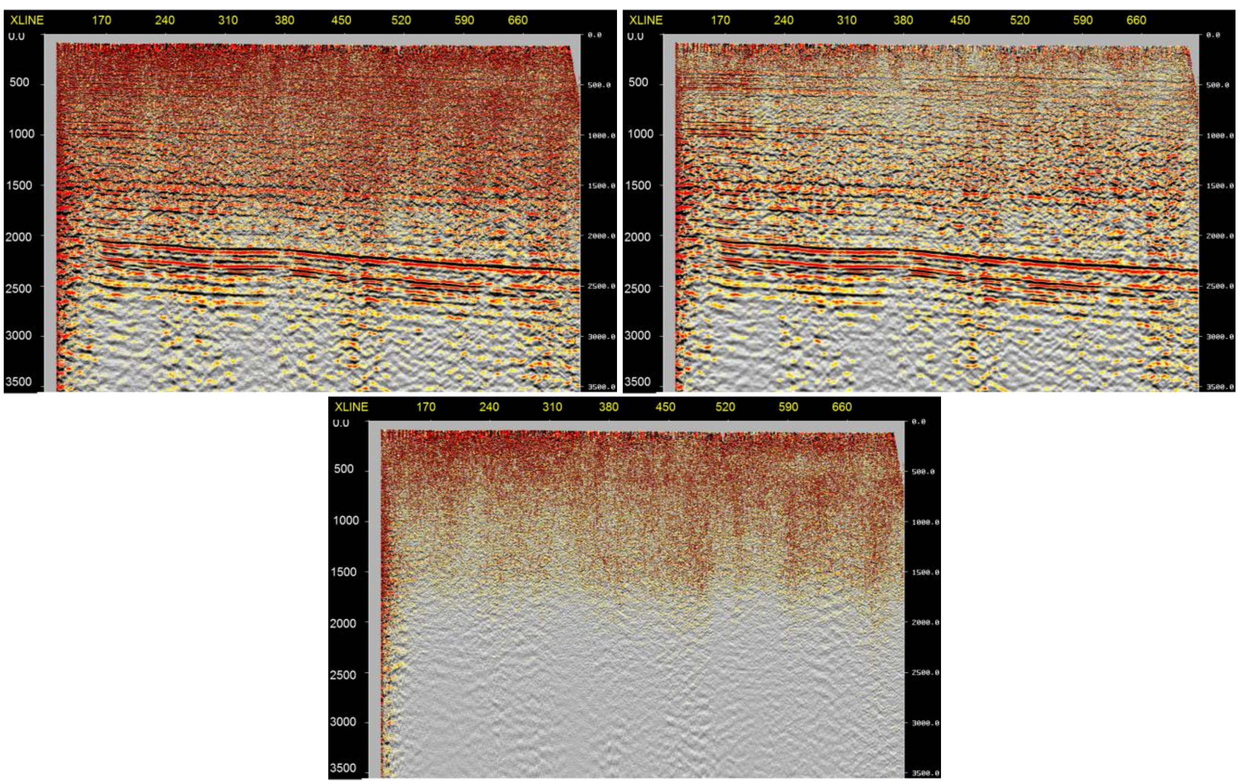

Figure 2: Example of stack line before (top-left) and after Cadzow random noise attenuation (top-right). The difference volume (bottom) shows that only random noise has been attenuated, with no coherent primary signal apparent.

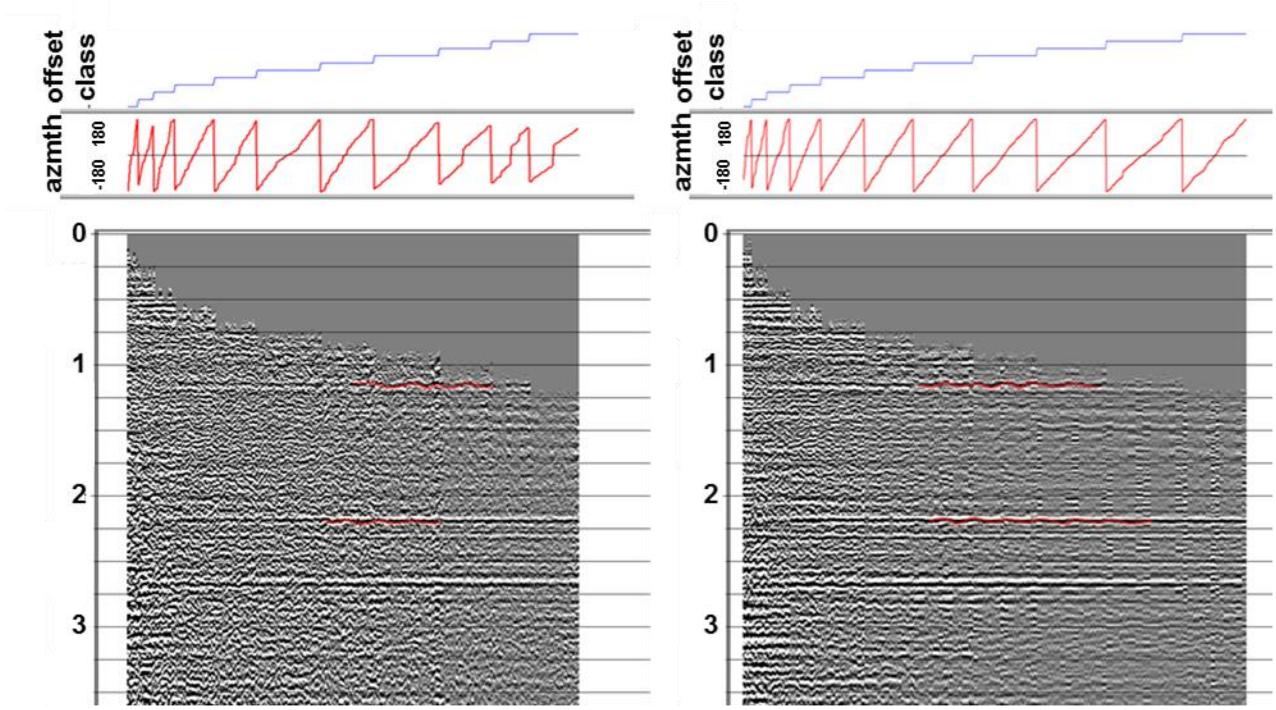

Figure 3: Snail gather before (left) and after (right) 5D interpolation. Above the graph, the blue line represents a group of COV with similar offset and the red line represents order of the group by azimuth from -180 to 180 degrees.

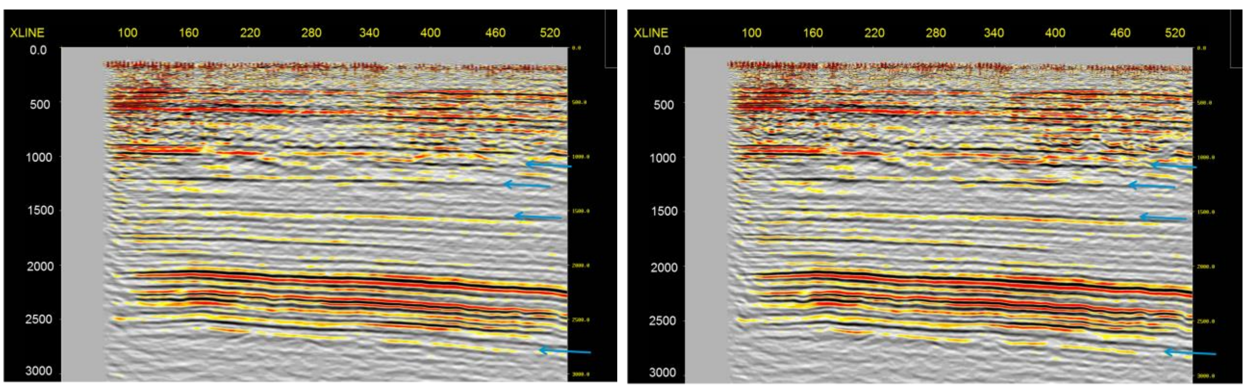

Figure 4: Example of a stack line with isotropic PSTM (left) and orthorhombic PSTM (right). The events after orthorhombic migration look more continuous, sharper and more focused.

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