Monument Butte 3D – Reprocessing case study in Uinta Basin

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Summary

A 3D land seismic survey was processed using amplitude and azimuth-friendly workflow. The sequence includes multiple iterations of surface consistent amplitude balancing and surface consistent deconvolution, along with the attenuation of various types of noise in several domains at different processing stages. The resulting final PSTM gathers and stack volumes provide uplift compared to previous processing results. These improvements include broader bandwidths in the low and high end of the spectrum, enhanced structural feature imaging, and improved S/N. Furthermore, using 5D interpolation, data was regularized in offset and azimuth domains allowing surface-related multiple reflections to be identified and successfully removed. The azimuth-separated PSTM gathers preserve the azimuthal variations in the data. The azimuthal velocity variation analysis (VVAz) on the PSTM gathers successfully captured stress anisotropy caused by local and regional features. The anisotropy results corroborate drilling-induced tensile fractures and borehole breakouts on image logs.

Introduction

Modern subsurface imaging supports oil and gas development and motivated the Monument Butte 3D reprocessing effort. Efficient drilling programs can utilize 3D seismic data to improve project economics by reducing subsurface risks (such as drilling near faults), high-grading reservoir targets, and drilling at an optimal angle to SHmax. These holistic benefits are vital in today's market and align with Ovintiv's processing goals. Ovintiv undertook an extensive reprocessing effort with TGS Imaging Services to achieve modern subsurface imaging.

Legacy Monument Butte Phase I and II 3D data were acquired in eastern Utah, Uinta Basin. The approximately 250 square mile 3D survey was acquired in 2011 by two different acquisition companies in the Uinta Basin. The acquisition consisted of a mix of both vibroseis and dynamite sources. The legacy processing served its purpose, but a much-needed refresh with modern processing techniques was desired. The primary objectives of reprocessing include PP amplitude recovery, 5D interpolation, and multiple attenuation.

The Monument Butte processing sequence uplift includes standard signal processing, proprietary algorithms, and a novel demultiple approach. TGS' amplitude-friendly processing strategy successfully produced an improved product. The processing sequence had multiple surface consistent deconvolutions, surface consistent amplitude corrections, and noise attenuation in different data domains.

Extra caution is needed to analyze azimuthal properties in seismic data, such as azimuthal velocity variation (VVAz) and azimuthal amplitude variation (AVAz). The pre-processing sequences in the flow, including data interpolation and regularization, need to ensure that azimuthal variations in the data are preserved. The traces from different azimuths and offsets need to be migrated separately. This study observes Azimuthal velocity variations in seismic reflection data. Reliable estimation of such variations can provide helpful insights into faulting, fractures swarms, and other structures. Additional details regarding azimuthal anisotropy analysis can be found in Peng et al. (2017). This abstract shows successful examples of the azimuthal anisotropy estimated through VVAz analysis.

Theory and Method

Due to the variations of near-surface conditions, land seismic data processing demands robust handling of surface-related complexities in data. These complexities include the rapid spatial changes of wave travel times, frequency contents and amplitudes, and various types of noise. Vital elements of seismic signal, such as the source wavelet and its amplitude, are estimated using the statistics of the acquired traces. These traces are usually contaminated with unwanted signals (such as ground roll) and different types of environmental noise. To obtain a good quality subsurface image with reliable amplitudes and broad frequency bands, one needs to consider using an iterative approach with multiple runs of surface consistent deconvolution, surface consistent scaling, and noise attenuation in various data domains.

Analysis of prominent reflectors showing bright events at twice the travel time of known primaries led to suspicions of a substantial surface-related multiple in the data. This conclusion is reinforced by comparing modeled surface multiples to a zero-offset VSP located within the 3D survey. Surface Related Multiple Estimation (SRME) was used to predict and subtract the multiples successfully. SRME was tested using unregularized and 5D regularized data as the input. The continuity of constant azimuth sections made possible by 5D regularization provided the best results, both in prediction and subtraction. The subtraction was performed on constant P sections produced with a Tau-P transform.

Monument Butte reprocessing experiences

The preservation of azimuthal and offset variations through 5D trace interpolation and azimuth-offset separated prestack migration capture possible azimuthal anisotropy in the data. Historically, for two decades VVAz analysis using migrated gathers consistently extracts potential azimuthal anisotropy. In TGS's VVAz analysis procedure, time-shifts at each prestack migrated trace's formation horizons are estimated using crosscorrelations with pilot traces. These time shifts and their corresponding azimuth and offset values are input to an elliptical curve fitting process, where a set of RMS azimuthal parameters are estimated. These RMS type estimates are converted to a group of interval azimuthal parameters through the Generalized Dix Inversion (Cheng et al., 2017). The typical attributes include the layered fast and slow velocities and their orientations. The normalized relative difference between the fast and slow velocities can be defined as anisotropy intensity, a valuable indicator of the strength of estimated anisotropy.

Examples

Comparisons with legacy volume have shown that the new processing broadens the data's bandwidth. In the Figure 1 comparison, a PSTM stack from the TGS and legacy processing are shown. The stacks are different in many aspects. One difference is that the new processing has noticeably lower frequency content than the legacy stack. This low-frequency uplift can be seen clearly in Figure 2, where the amplitude spectra of the stacks are displayed. The newly processed data has a broadband spectrum; frequencies below 15 Hz and beyond 60 Hz are improved, having a similar amplitude level as the dominant frequency range.

The surface-related multiples were identified on this dataset due to the dipping structure of the multiple generator. In Figure 3, three gathers are shown before and after the application of SRME, along with the multiples removed from the gathers. The moveout of the multiples is small, and it is impossible to differentiate the primary and the multiples at these locations. Figure 4 shows a stack section before and after SRME and their difference. The multiple energy removal and subsequent data improvement are distinct on the before and after SRME time slice, shown in Figure 5. A meandering trend of multiple energy is apparent across the survey from east to west.

The azimuthal velocity anisotropy (VVAz) analysis matches image logs and reduces the faulting structure uncertainty in the area. Figure 6 shows the impact of the VVAz analysis on one of the layers in the subsurface. In Figure 6, the color map and the lengths of the needles are proportional to the strength of the estimated azimuthal velocity anisotropy. The orientation of the needles represents the orientation of the fast velocity. The anisotropy intensity is defined as the ratio between the difference of the fast velocity over the slow velocity and the fast velocity in percentage.

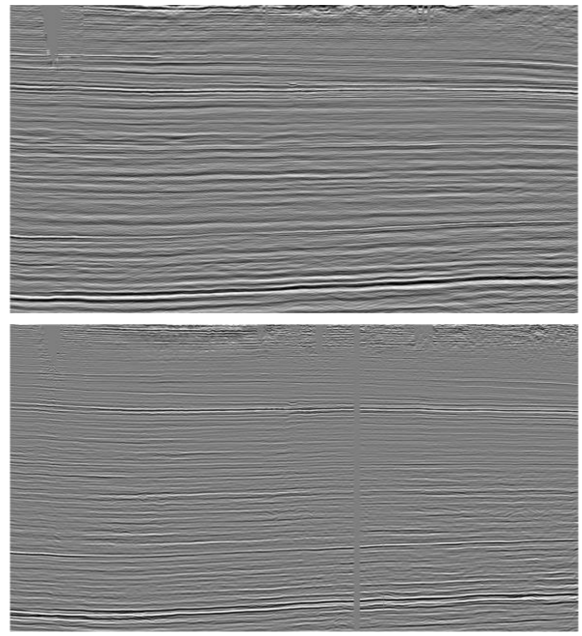

Figure 1: TGS' broadband final migrated stack (upper), compared with the legacy product (lower). The spectrum comparison is shown in Figure 2.

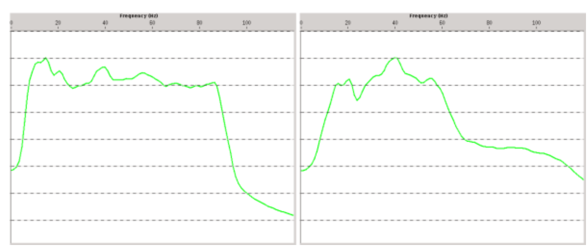

Figure 2: Frequency spectrum of TGS' broad bandwidth final migrated stack (left), compared with the spectrum of the legacy product (right). Note that the spectra are computed from a large middle time gate across the stack sections shown in Figure 1.

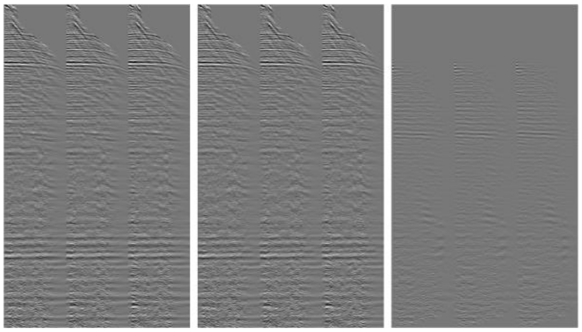

Figure 3: Three consecutive 5D interpolated CMP gathers, before (left), after (middle) SRME, and the multiple energy removed by SRME (right). Note that the offset range of the gathers is from 0 to 15,000 ft; the yellow star in Figure 5a indicates their locations.

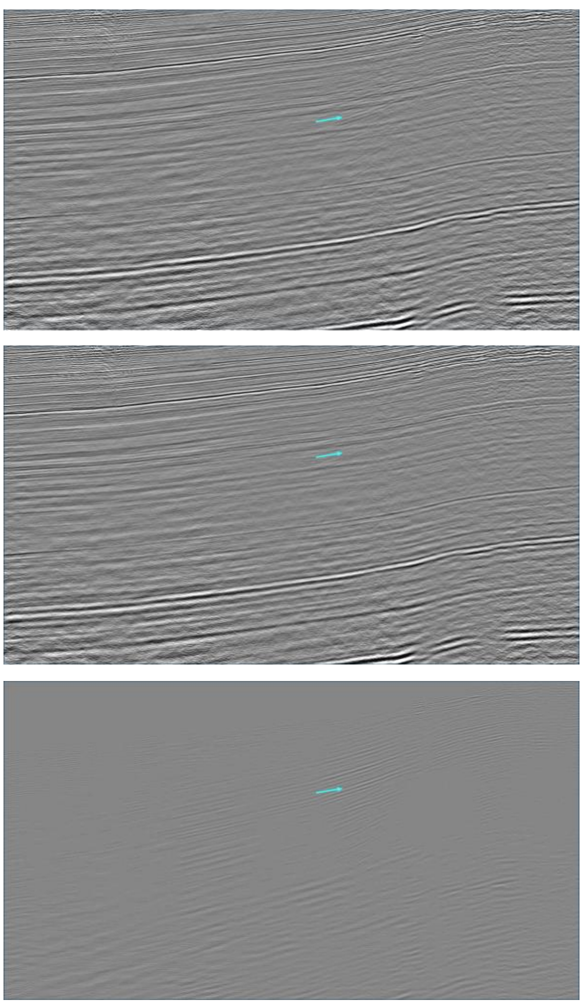

Figure 4: A north-south line stack section before (top), after (middle) SRME, and the multiples removed from the data (bottom). This line is marked in red on Figure 5.

Figure 5: Time slices before (top) and after (middle) the application SRME, along with the difference (bottom). All slices shown are approximately 100 square miles in area.

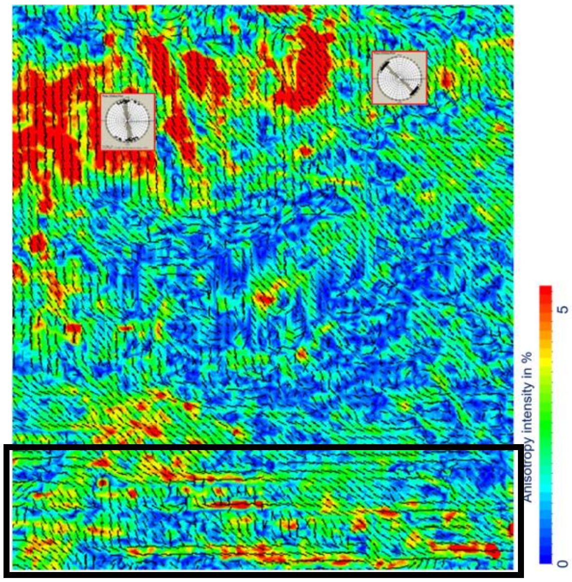

Figure 6: VVAZ velocity anisotropy intensity color map overlaid with black needles representing the orientation of fast velocity orientation. Both the color map and the lengths of the needles represent the intensity of the velocity anisotropy. Two Rose diagrams from image logs are shown. The stress indicators from the image logs corroborate the VVAZ method. The black box at the bottom of the image marks the Duchesne Fault Zone – a series of normal faults with an average strike of N89°W.

Conclusions

We have demonstrated reprocessing results for the Monument Butte 3D, with focused examples on three specific topics: bandwidth of the final PSTM product, successful application of SRME on 5D interpolated and regularized data, and successful horizontal anisotropy detection on multiple-azimuth PSTM gathers.

The iterative approach in land seismic data processing with multiple iterations of surface consistent decon and surface consistent scaling proved to successfully generate high-quality broadband final images. The amplitude-friendly processing designed to preserve the azimuthal variations in the data provided reliable azimuthal anisotropy information in the area. The 5D interpolation that regularizes the data in azimuth-offset dimensions proved helpful for the successful application of SRME on this data.

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