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LOOKING AT VOLUMETRIC SEISMIC ATTRIBUTES IN DEPTH DOMAIN

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Summary

The campaign to calculate seismic attributes and inversion on depth migrated data without first stretching back to time started about five years ago. One obvious disadvantage of stretching time data to depth or depth data to time before processing qc, analysis or interpretation is the potential loss of resolution and misplacement of horizons and faults as well as other structures in addition to a general mis-match when trying to tie seismic to well data.

We show in this work with the aid of a raw 3D seismic data from South Texas processed to pre-stack time migration (PSTM) and pre-stack depth migration (PSDM), that seismic attributes like similarity/coherency and spectral decomposition calculated on PSDM data in depth domain show sharper and more authentic images than attributes calculated on PSTM data stretched to depth.

Introduction

Since the domain of drilling is depth, it then brings up the question why for so many years in the seismic industry our primary domain for data analysis and interpretation is in time. One obvious answer to this question is that seismic data is shot in time and not depth and also most of our software and algorithms for processing and interpretation are based in time.

Chopra (2016) has also examined the reason why it took so long for us to come to the realization of analyzing data in depth:

- There is now a significant advancement in depth migration algorithms when compared to 20 years ago and there are also more demands for depth migration products where time migration has proved insufficient especially in complex geological settings with rapid lateral and vertical velocity variations. We also see more demands for depth migration products in unconventional plays even though the geology may not be that complex but for the need to accurately stay within a formation in horizontal drilling and fracking.
- The computational speed and efficiency of processing and interpretation machines have greatly increased compared to the last decade. Large volumes of 2D and 3D data can now be efficiently depth migrated with very fast tomographic velocity updates.

Rauch-Davies et al. (2017) have performed a benchmark study of post-stack and pre-stack impedance inversions on three versions of a 3D dataset over the Woodford formation in the Anadarko basin, Oklahoma, USA - namely PSTM, PSDM and PSTM stretched to depth. Their results and findings are summarized below:

- PSDM produces a more superior impedance inversion results to PSTM or PSTM converted to depth data even in areas that are not structurally complex.

- Converting PSTM data to depth introduces errors in depth registration and formation thickness estimates.
- When stretching PSTM data to depth, limitations introduced by time processing on interpretation are carried over to the depth conversion. PSDM on the other hand produces a more accurate depth image hence the superiority of its depth inversion results.

Lin et al. (2013) have computed spectral decomposition (using a matching pursuit algorithm) on a 3D depth migrated data from an oilfield in East China. Lin et al. (2014) also computed reflector dip azimuth, coherence and curvature on a depth migrated 3D data from East China.

Method/Workflow

The following highlights the major processing and analysis steps employed in the study of our 3D seismic data from South Texas:

- Pre-processing.
- 5D interpolation.
- Kirchhoff pre-stack time migration.
- Remove rms/stacking velocities from unmigrated 5D CDP gathers and correct data to floating datum or depth migration surface.
- Convert final pre-stack time migration velocities to depth interval velocities.
- Smooth depth interval velocities.
- Perform depth impulse response tests to ascertain migration angle, aperture and anti-aliasing filter.
- First pass travel time computation and Kirchhoff pre-stack depth migration to gathers.
- Tomographic velocity update.
- Second pass travel time computation and Kirchhoff pre-stack depth migration to gathers.
- Tomographic velocity update.
- Final pass travel time computation and Kirchhoff pre-stack depth migration to gathers.
- Mute
- Stack.
- Filter/Scale.
- Compute volumetric seismic attributes namely similarity/coherency and spectral decomposition on PSDM stack and display results along selected horizons.
- Compare results with volumetric seismic attributes computed on PSTM data stretched to depth and stacked.

Since the sole purpose of this work is to show the superiority of computing seismic attributes on depth migrated data over time migrated data stretched to depth, we have not included anisotropy in building the depth velocity model. We certainly expect even better results with anisotropic tomographic velocity updates.

Example

The 3D land Vibroseis data from South Texas was acquired with the following parameters:

Survey size: 8.75 square miles, **Shot line distance:** 880ft, **Number of shot lines:** 16, **Number of receiver lines:** 16, **Receiver line distance:** 1320ft, **Number of shots:** 1038, **Number of receivers:** 1680, **Shot distance:** 220ft, **Receiver distance:** 110ft, **Sweep frequency:** 8-120Hz, **Sweep length:** 14s, **Record length:** 6s and **Sample rate:** 2ms.

Figure 1 is the 3D survey map.

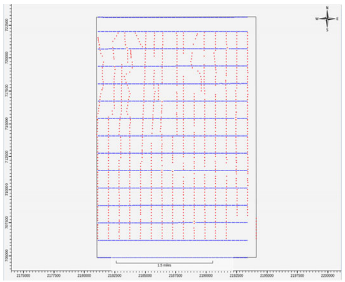

Figure 1: 3D survey map. Receivers are blue and shots are red. Inlines are east-west. Crosslines are north-south.

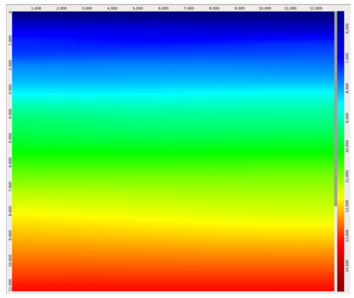

Figure 2: PSDM velocity profile for an inline. The bar on the right shows the actual velocity values.

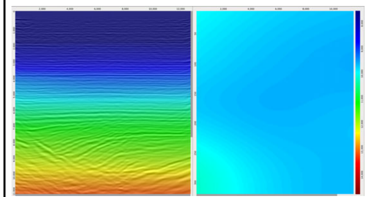

Figure 3: Left: PSDM velocity overlaid on seismic for an inline. Right: Velocity slice at 5010 ft. The bar on the right shows the actual velocity values.

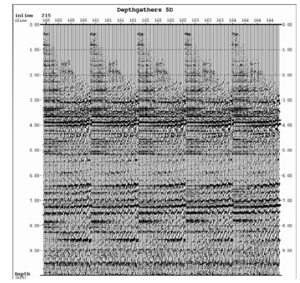

Figure 4: PSDM gathers for an inline. The gathers look reasonably flat without incorporating HTI and VTI anisotropy.

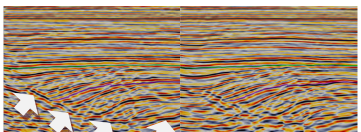

Figure 5: Left: PSDM stack. Right: PSTM stack stretched to depth. The green and purple horizons were picked for seismic attribute analysis display. The PSDM image is superior to PSTM image stretched to depth as shown by the white arrows.

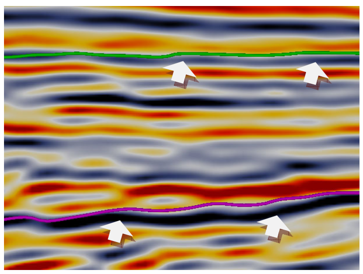

Figure 6: Zoomed PSTM stack stretched to depth overlaid with horizons picked on peak amplitude of PSDM stack. Black color is peak.

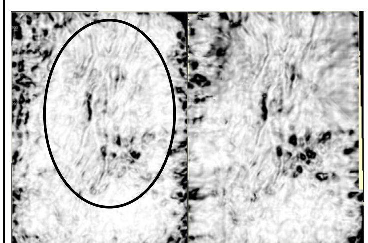

Figure 7: Similarity display of green horizon in depth domain. Left: PSDM. Right: PSTM stretched to depth. Image on the left is clearer, sharper and more coherent. Areas of better clarity are shown by the black circle.

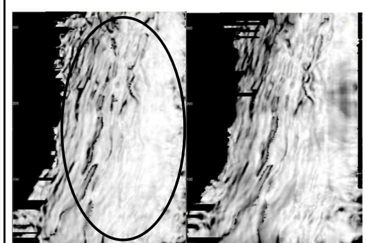

Figure 8: Similarity display of purple horizon in depth domain. Left: PSDM. Right: PSTM stretched to depth. Image on the left is clearer, sharper and more coherent. Areas of better clarity are shown by the black circle.

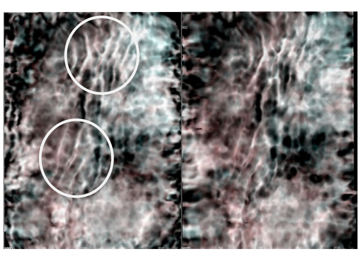

Figure 9: Spectral decomposition along green horizon in depth domain. Left: PSDM. Right: PSTM stretched to depth. Image on the left is sharper, as shown by the circles.

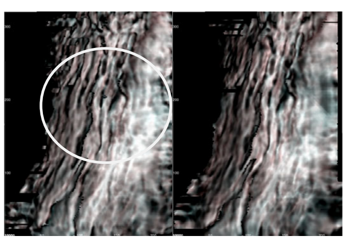

Figure 10: Spectral decomposition along purple horizon in depth domain. Left: PSDM. Right: PSTM stretched to depth. Image on the left is sharper, as shown by the circle.

The data was taken through two different seismic data processing flows and analysis. The first flow was a PSTM processing flow with the data stretched to depth for volumetric seismic analysis. The second flow was a PSDM flow with the volumetric seismic analysis also done in depth. The results of these two flows were then compared. Figures 2 and 3 are the PSDM velocity structure for an inline and a velocity slice at 5010 ft. Figure 4 shows some PSDM gathers. The depth gathers look reasonably flat considering the fact that HTI and VTI anisotropy were not factored in.

Figure 5 is the comparison of PSDM stack (left) and PSTM data stretched to depth (right). We see a superior structural imaging of the boundary fault as shown by the white arrows with PSDM. Figure 6 shows a zoomed image of PSTM stack stretched to depth with the horizons picked on peak amplitude of PSDM stack overlaid. We see the peak amplitude events (black color on the section and indicated by the white arrows) of the PSTM stack not matching the horizons even when the events are not structurally complex. This will definitely be an issue in horizontal drilling as it would mean going in and out of an intended formation. Stretching the PSTM data into depth introduces structural distortions and misplacement of horizons to the data that are not real even when the geology is very flat. Rauch-Davies et al. (2017) also made this observation in their study of the 3D dataset over the Woodford formation in Anadarko basin, Oklahoma.

Figures 7 and 8 are the similarity displays along the green and purple horizons respectively. PSDM data in both figures show clearer, sharper and more coherent images than PSTM images stretched to depth (as indicated by the black circles).

Figures 9 and 10 are the spectral decomposition displays along the green and purple horizons respectively. In calculating spectral decomposition in depth, one thing that must be noted is that the frequency axis changes to wavenumber. Instead of cycles per second, we now have cycles per unit distance. In this case example, the wavenumber unit was cycles per kilofeet since the offset was in feet and a range of 0 to 30 cycles per kilofeet was observed. Like the similarity displays for both horizons, we also see sharper spectral decomposition images with PSDM data as indicated by the white circles. The PSTM data tend to be blurry and incoherent in places due to distortions/artifacts introduced by stretching to depth.

Conclusions

Based on the results of our processing and analysis of this 3D data from South Texas, we make the following conclusions:

- The structural image obtained from PSDM is superior to that obtained from depth converting PSTM data.
- Seismic attribute analysis is not limited to time domain but can also be done in depth domain.
- Calculating seismic attributes in depth domain makes depth migration processing qc, analysis and interpretation easier and faster as the need to first stretch the data to time will no longer be necessary.
- PSTM data stretched to depth experiences structural distortions and misplacement of horizons even in flat geological settings.
- Seismic attribute analysis on PSDM data show clearer, sharper and more coherent images when compared to PSTM data converted to depth.

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