# Permian Basin Seismic Data Reprocessing – A Case Study

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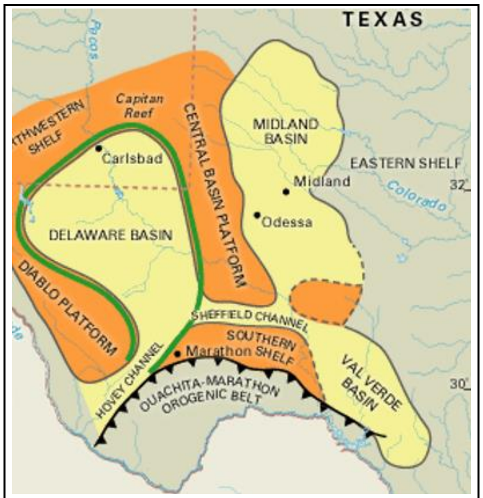


Figure 1: Location map of the study area

Source: http://www.vyey.com/assets/permian-basin

**SUMMARY**

This paper presents a case study of reprocessing seismic data in the Permian Basin. The legacy data was previously processed in 1997. Due to noise, including multiples associated with evaporites and salt near the surface, the legacy results were difficult to interpret.

Reprocessing was completed recently using an integrated approach. With high-resolution turning-ray tomography, adaptive noise removal, 5D interpolation and post-stack structure-oriented filtering algorithms, we improved the seismic images, resulting in better signal-to-noise ratio (SNR), fewer inter-bed multiples, and less surface related noise. This is significant for interpretation and horizontal drilling in the Permian Basin.

**INTRODUCTION**

The study area is located in the Delaware Basin (Figure 1), which is a part of the Permian Basin in the USA. The previously processed data, or legacy data, has a low SNR and the images were challenging to interpret at the target zone. This is because of the near-surface complexities, such as evaporites and a velocity reversal, resulting in inter-bed multiples, surface waves, and scattering noise. The purpose of the reprocessing was to improve the seismic image quality for better interpretation, fault definition, and sweet spot identification at the target zone interval.

**NEAR-SURFACE MODEL AND DE-MULTIPLES**

An extensive effort was made in de-multiple which involved incorporating the near-surface velocity depth model derived from turning-ray tomography. In this study, the multiples do not appear as lower velocity events on gathers and the traditional techniques (FK, radon, stack, etc) that rely on velocity discrimination to remove multiples are ineffective. Predictive deconvolution has proven to be a useful tool for the suppression of inter-bed multiples. The key parameters are the prediction distance and operator length. The prediction distance is generally set equal to the multiple periods, while the operator length is often set approximately equal to the wavelet length (Yilmaz, 1987).

A high-resolution near-surface velocity model was derived from a proprietary turning-ray tomography algorithm (Zhu, 1992), which was used to identify the generators of inter-bed multiples and guide us in determining the multiple periods. The turning-ray tomography uses first-break traveltimes and locations of sources and receivers to estimate the near surface velocity models.

In Figure 2, the distance between two high-velocity layers in the shallow section, being the generator of inter-bed multiples, was 220ft. The velocity between the two layers was 14500ft/s. This resulted in approximately a 30 ms two-way traveltime as the multiple period.

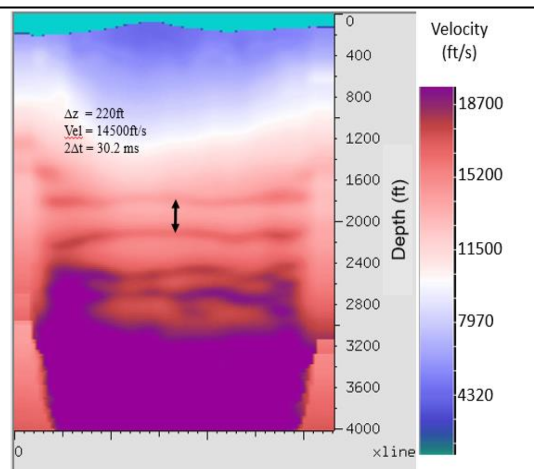


Figure 2. Near-surface velocity model by turning-ray tomography

The multiples' period (gap) can also be designed by examining the autocorrelations of traces prior to deconvolution. Figure 3 (left) shows the autocorrelation of a shot with multiples, which also shows the predictive distance of an average of 30 ms. It matched well with the gap derived from the near-surface velocity model by turning-ray tomography. Figure 3 (right) shows the autocorrelation of the same shot after applying predictive deconvolution with a gap of 30ms. Comparing these two autocorrelations (Figure 3) and stack sections (Figure 4), we can see that most interbed multiples were attenuated.

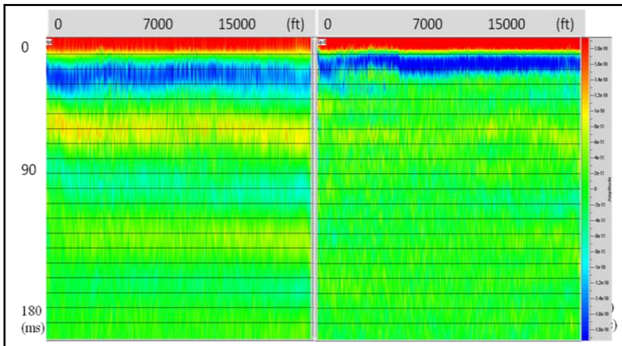


Figure 3. Autocorrelation before (left) and after de-multiple (right)

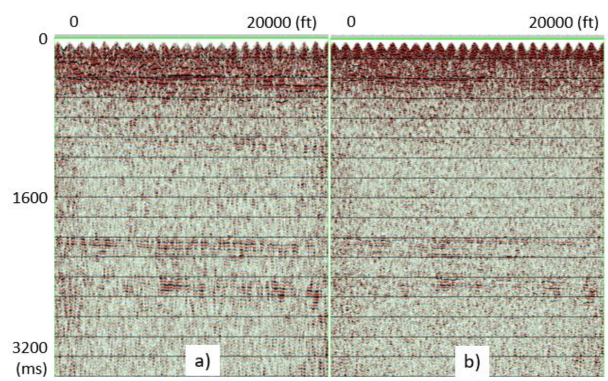


Figure 4. Stack section after tomo-refraction statics (a) followed by gap decon (b). Interbed multiples are significantly reduced in (b).

## ADAPTIVE NOISE REMOVAL

De-noising of the data is a challenging problem since the seismic data are heavily contaminated by different noise types including aliasing, surface waves, multiples, and reverberations from shallow high-velocity layers.

A two-pass approach was used for de-noising in the study area. Firstly, an eigenvector filter was used to estimate the high-energy surface wave within a window of traces using the eigenimage and then the reconstructed noise was subtracted (Carry and Zhang, 2009). Secondly, after eigenvector filtering, we input two versions of processed seismic data into signal/noise adaptive processing (SNAP): one version lightly processed and the other version heavily processed. Then we selectively replaced noisy portions in lightly processed data with the more heavily processed data - this process was implemented by comparing their trace difference with a chosen time-variant threshold. The assumption for this algorithm is that noise has higher amplitude than signals so that we keep the signal portions undamaged. This flow removed noise without introducing undesirable artifacts in places where the noise does not exist.

The shot gathers before (left) and after (right) de-noising are shown in Figure 5. The difference is shown in Figure 6. Reflections (around 2000 ms) start to show up in the shot gathers after de-noise in Figure 5 (right).

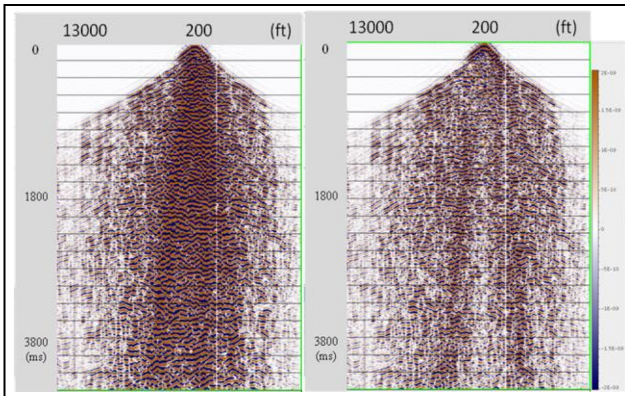


Figure 5. The shot before (left) and after de-noising (right)

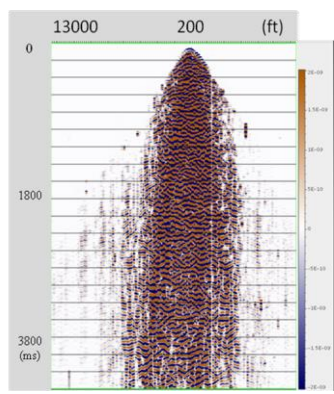


Figure 6. The difference before and after de-noising

## 5D INTERPOLATION

The 5D interpolation method is based on Fourier reconstruction by Minimum Weighted Norm Interpolation (MWNI). It operates on 5 dimensions of the seismic data (Inline, Xline, Offset, Azimuth and Temporal). In this study, it increased the cdp fold (Figure 7), reduced noise and proved to be a useful tool to precondition data before the subsequent velocity analysis (Figure 8 and 9).

Figure 7 (left) shows the original cdp fold map with maximum fold of 51, and Figure 7 (right) shows that cdp fold is about 4 times higher with maximum fold of 189 after 5D interpolation.

Figure 8 shows a cdp gather with NMO before (left) and after (right) interpolation. It clearly can be seen that the gather after interpolation provided much more information for the velocity analysis. Note that 5D interpolation has been proved to be useful only after noise removal.

Figure 9 shows the stack section before (left) and after (right) interpolation. The interpolated section has better SNR and continuity.

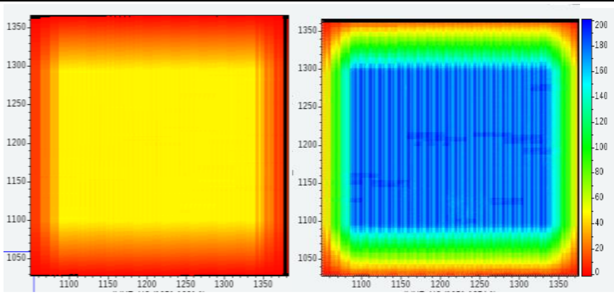

Figure 7. CDP fold map before (left) and after (right) interpolation

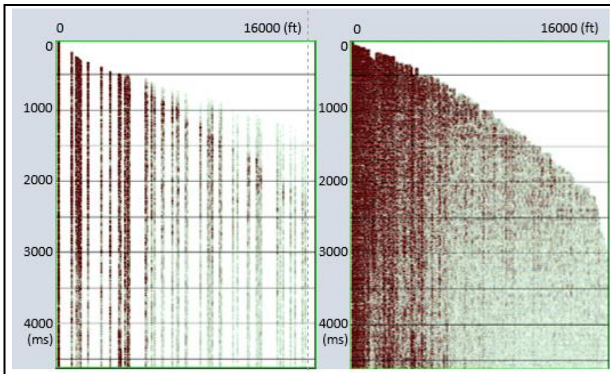

Figure 8. CDP gather before (left) and after (right) interpolation

## POST-STACK ENHANCEMENT

Structure-oriented filtering was applied to this data to further clean-up and enhance the image to improve subsurface understanding – without remigration. Structure tensors (Hale, 2009) were calculated following the orientation of the structure, linear or point like features, then an edge-preserving filter was used.

Figure 10 shows the PSTM stack sections before (left) and after (right) structure-oriented filter.

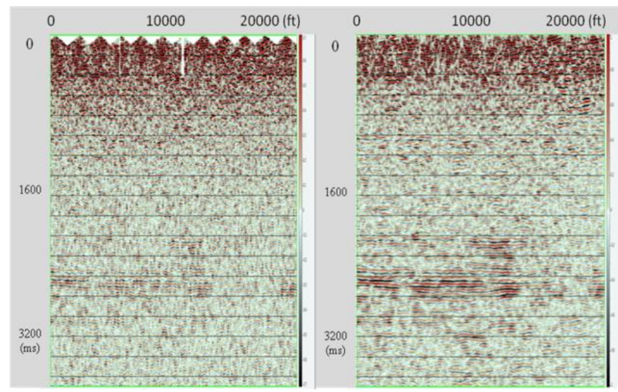

Figure 9. Stack before (left) and after (right) interpolation.

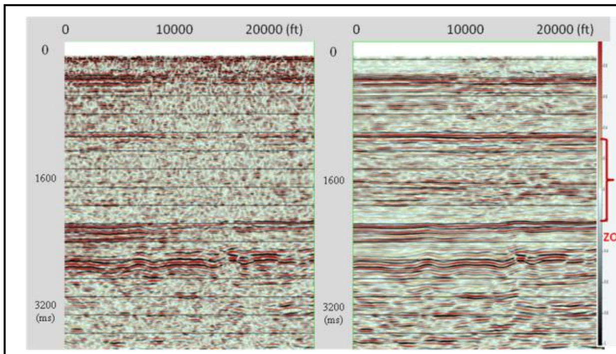

Figure 10. PSTM before (left) and after (right) structure-oriented filter (ZOI stands for Zone of Interest).

## PSTM COMPARISONS

The legacy data, the PSTM stacks previously processed by the third party in 1997, are shown in Figure 11 (left) and 12 (left), and the recently re-processed final PSTM results are shown in Figure 11 (right) and 12 (right). The re-processed results exhibit an improved SNR and better imaging of the target interval and deep faults with less noise and fewer multiples.

Figure 13 shows a time slice of PSTM stack at 2000ms. The legacy data is shown on the left and current processing result is shown on the right. Clearly the re-processed result shows a cleaner image with better focusing.

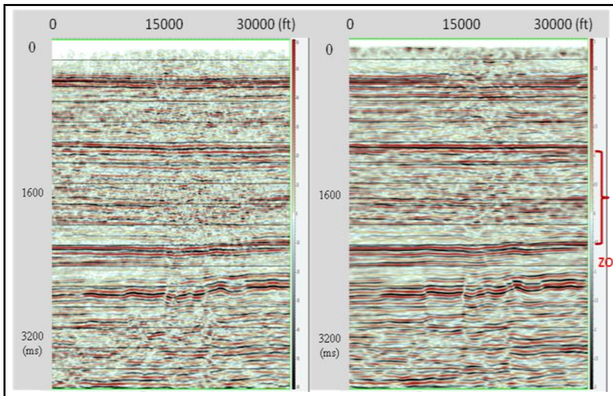


Figure 11. Inline PSTM Stack – Legacy (left) & Current (right)

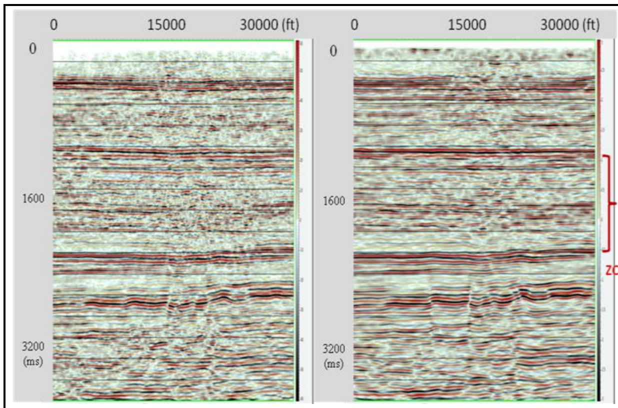


Figure 12. Xline PSTM Stack – Legacy (left) & Current (right)

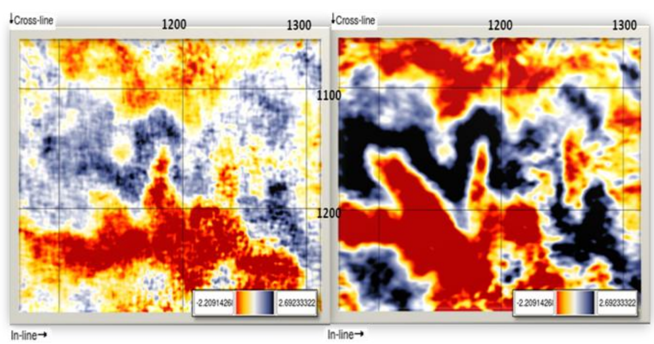


Figure 13. Depth slice of PSTM Stack – Legacy (left) & Current (right)

## CONCLUSIONS

The recently re-processed results show improved images, which indicate the effectiveness of applying the latest processing techniques. The near-surface velocity depth model derived from turning-ray tomography is the key for an accurate identification of multiple source and multiple period to remove interbed multiple successfully. The de-noise with adaptive noise removal algorithm improved event continuity and fault definition. More accurate velocity analysis benefited from 5D interpolation that overcame the acquisition constraints to yield higher folds and cleaner data. Post-stack structure-oriented filtering was also implemented to improve the SNR.

The reprocessing has improved seismic images for interpretation and subsequent horizontal drilling, indicating that legacy data can be utilized to add values to unconventional resource play areas such as the Permian Basin.

## ACKNOWLEDGMENTS

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