5D Interpolation adds value at the drill bit for a Texas 3D

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Summary

Often there are cases where acquiring newer seismic data is either difficult or not cost effective. The geophysicist then looks to reprocessing with newer technology to improve the subsurface image of seismic data to reduce the risk prior to drilling. Such is the following case study in a North Central Texas Basin where reprocessing reduced the risk by improving well planning and completions in the drilling of additional wells that added an estimated ultimate recoverable of 12.4 Bcf to the lease.

Introduction

The objective of the project was to improve the current seismic data via reprocessing using modern algorithms in order to optimize input for seismic attribute calculations. The attribute of interest for this case study is a geometrical attribute maximum curvature which aids in readily identifying carbonate karsting, minor fracturing and major faulting.

Field Description

The seismic data were acquired in 2006 in a small 2.4 square mile 3D survey in Parker County, Texas. One challenge in acquiring good quality data was the use of an accelerated weight drop source. Although AWD is cost effective, lightweight, portable, and an environmentally friendly source to use in populated areas, the source typically generates a narrow bandwidth signal with poor depth of penetration. As such, AWD source surveys may be best suited for imaging shallow targets.

<u>Original Processing workflow</u>

1. Geometry
2. Trace scaling
3. Surface consistent deconvolution
4. Statics
5. Dip moveout
6. Velocity analysis
7. Stack
8. Trace interpolation from 110'x 220' to 110'x110'
9. Fxy decon
10. Migration

The original processed data exhibited remnant noise in the data that is manifest as irregular amplitude distribution, poor illumination at the deep basement level and coherent lineation artifacts. The remnant noise is readily viewed in timeslice as irregular amplitude boundaries and vertical lineations shown in Figure 1.

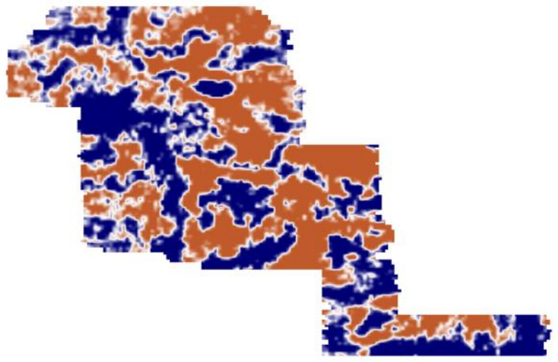

Figure 1: Noise is represented in timeslice as irregular amplitude boundaries (peak is blue, red is trough) and vertical lineations.

When the initial interpretation was conducted after acquiring the lease in 2012, the structural interpretation was fairly straightforward, entailing the integration of time horizons with field well control to create a depth map. The concern arose when the seismic attribute maximum curvature was calculated. The resulting horizon extraction indicated abundant karsting and faults on the lease at the base of the reservoir. These subsurface features were not a surprise to the team as the estimated ultimate recoveries of the existing wells were low in relationship to the established production to the east and south of the lease. (Figure 2)

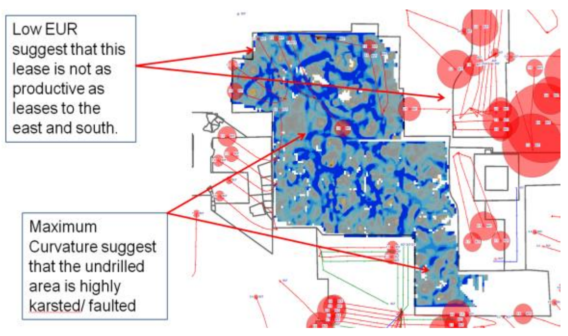

Figure 2: Seismic attribute maximum curvature indicated abundant karsts and faulting which was supported by low EUR calculations of existing wells within the seismic boundaries.

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As a comparison, the original nine wells drilled on the lease prior to EnerVest, Ltd ownership have a calculated average estimated ultimate recovery of .7 Bcf whereas the field average is 1.5 Bcf or higher for surrounding production.

Close inspection of the individual drilled wells using the seismic data illustrated that the wells' poor performance is explained by the wellbores encountering and completing over karst and through faults. The 201H well is an example of one well that drew water from the underlying Ellenburger formation through faulting encountered early in the wellbore when reviewed on depth converted seismic data (Figure 3). Moreover, a few of the other wells examined in the lease showed that they did not change their target line to follow structure and thereby penetrated directly into the water bearing Ellenburger. (Figure 4)

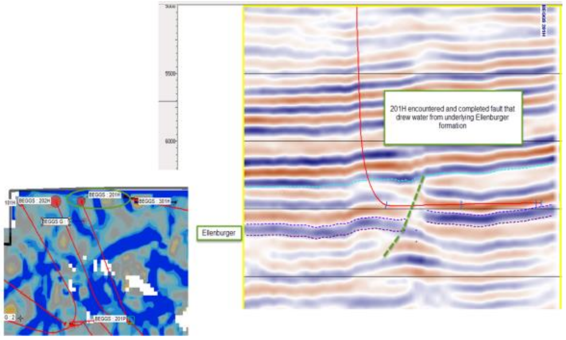

Figure 3: A vertical seismic line in depth illustrates the 201H wellbore encountered and completed through a fault that drew water from the underling Ellenburger formation.

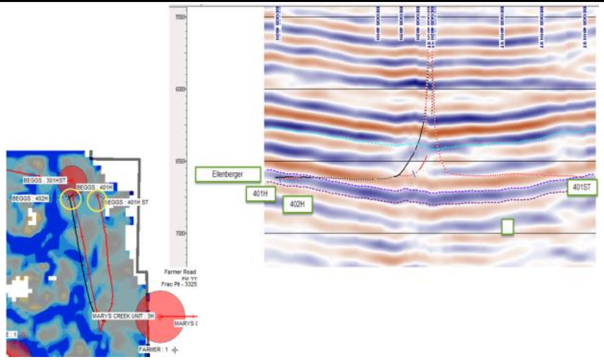

Figure 4: A vertical seismic line in depth illustrates the 401H, 401H ST, and the 402H wellbores did not account for structure and finished the well into the water bearing Ellenburger formation.

Our analysis showed that these historical poor wells did not reflect poor reservoir quality, but rather errors in planning and completions for this area in the early days of the basin's development cycle. Once the post mortem was conducted on the existing wells, a future plan to improve the quality of data to aid in better planning and completion was executed.

Reprocessing

A reprocessing effort was undertaken whose key elements included coherent noise attenuation, pre-stack interpolation, and pre-stack time migration as shown below:

Reprocessing workflow

1. Geometry
2. Pre-decon noise attenuation
3. Surface consistent decon
4. Spectral balance
5. Refraction statics
6. 1 mile x 1mile velocity analysis
7. 1st pass residual statics
8. ½ mile x ½ mile velocity analysis
9. 2nd pass residual statics, NMO and Trim statics
10. Prestack interpolation
11. ¼ mile x ¼ mile PSTM velocity analysis
12. PSTM

Because the data were submitted to an entirely different processing flow using different software (i.e., relative to the original processing), it is impossible to measure the uplift in image quality provided by any one element of the new flow; nonetheless intermediate QC analysis (not shown here) suggests that the pre-stack interpolation in particular seems to have accounted for a large amount of the image improvement.

The pre-stack interpolation was accomplished via the cascading of two algorithms: first a time-domain dip-scan interpolation followed by 5D interpolation. The dip-scan interpolation algorithm identifies dominant dip directions via trial scanning across adjacent traces and then interpolates by performing a local slant stack along the dominant directions (e.g., Bardan, 1987; Hedefa, et al., 2010). This algorithm is ideally suited to regular upsampling across the CMP coordinates, and accordingly it was employed to reduce the CMP bin size from the original 110'x220' to 110'x110'. Although the algorithm typically produces very good results, one drawback is that it cannot synthesize traces in areas exhibiting even small gaps in acquisition coverage, a consequence of the fact that the dip-scan algorithm is a local technique using only a very small number of neighboring traces. In order to fill in remaining gaps, and also to ensure optimal sampling for minimizing

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migration noise, these interpolated data were next submitted to a pass of 5D interpolation (e.g., Trad, 2009). The 5D interpolation algorithm under study employs the 5D minimum-weighted-norm approach of Liu and Sacchi (2004) and it produces a set of CMP gathers which are regularly sampled across the offset and azimuth coordinates. A comparison of stacked data before and after 5D interpolation is shown in Figs. 5a and 5b, respectively. From these figures, we observe improvement to signal-to-noise (S/N) after 5D interpolation, an observation which we will address in the following section by analyzing the '5D leakage' stack in Fig. 5c.

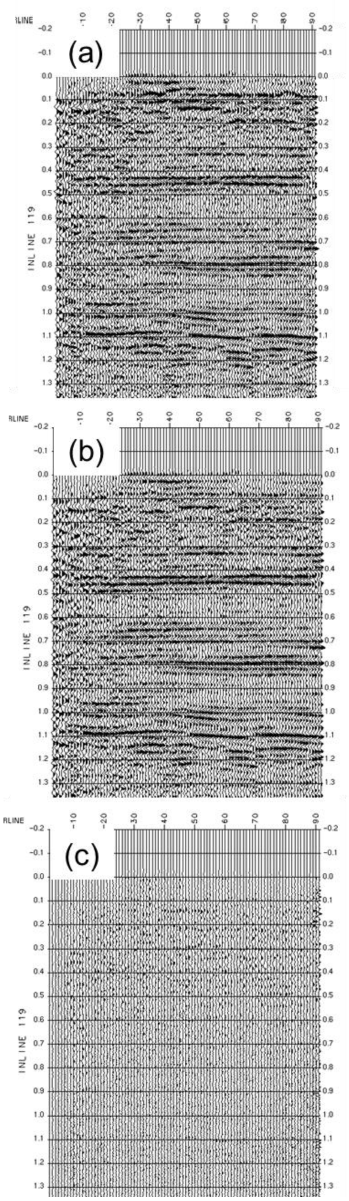

Figure 5: Stacked sections for inline 119. (a) input to 5D; (b) output after 5D; (c) 5D leakage stack.

Result Discussion/Conclusions

Figure 6 shows a section view of both original and reprocessed final migrated stacks in the vicinity of the target interval. It is obvious that the reprocessed data show better definition of fault displacement relative to the original data, and also appear to show higher lateral resolution as evidenced by the crisper imaging of the reflector terminations across the faults. Though not shown here, improved imaging was also observed as deep as basement, and also in the shallow section.

The above observation of apparent improvement in lateral resolution after reprocessing seems to be at odds with the well-known fact that any data interpolation scheme is fundamentally incapable of improving *true* signal resolution by synthesizing brand new information out of sparse field soundings, a recognition which in turn leads us to question precisely what aspect of the interpolation might be accounting for our observation of *apparent* resolution increase? Of the two interpolation algorithms used in the reprocessing, the 5D interpolation's ability to increase apparent resolution might seem particularly puzzling because it is a global, rather than local, technique involving simultaneous analysis of many thousands of traces and therefore we might expect a smearing of information which ought to degrade, rather than enhance, resolution. Some insight is gained by examining the so-called "5D leakage" stack in Figure 5c. Computation of the 5D leakage stack provides a practical and inexpensive means of estimating the reconstruction error after 5D interpolation without resorting to the prohibitively expensive procedure of acquiring a very densely-sampled control data set in the field (Cary and Perz, 2013). From the 5D leakage stack we can make two important observations: first, the overall energy level in the leakage plot is quite weak, suggesting that the reconstruction error for this data set is small and therefore that the 5D interpolation algorithm is generally working well; second, most of the energy seems to be incoherent (with the exception of the shallowest part of the section), suggesting that the algorithm is failing to model the complicated aspects of the noise and is therefore acting as a noise attenuator. Although one could easily argue on philosophical grounds that the ideal interpolator should be capable of interpolating both signal and noise, the practical reality is that the in-situ noise attenuation associated with imperfect interpolation seems to be having a beneficial effect on this data set (recall also the improved S/N after 5D shown on the stack in Fig. 5b).

The above analysis shows that the S/N improvement after 5D arises from the algorithm's inability to perfectly

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reconstruct the noise and helps dispel the common misconception that the algorithm improves S/N by creating a very large number of output traces and thereby increasing the CMP fold. This misconception is further quelled in the present discussion by the recognition that the interpolation's failure to perfectly reconstruct noise implies that the fold increase brought on by interpolation is not equivalent to performing additional independent measurements of repeatable signal and non-repeatable noise (i.e., as would be the case when we attempt to increase fold in the usual way through increased acquisition effort in the field). Accordingly, it follows that the S/N will not increase with increasing fold of interpolated traces in the same way that it does with increasing fold brought on by better field sampling.

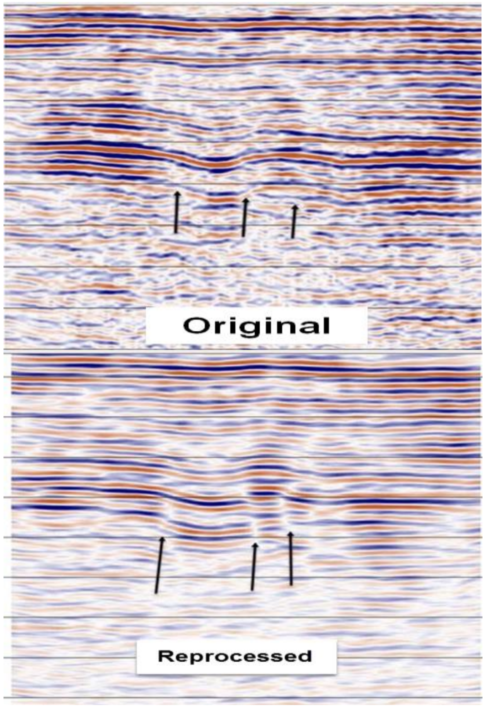

Figure 6: Vertical view of original seismic data at the target interval (top) and the reprocessed data (bottom) containing higher resolution and better definition of faulting at the target interval.

Returning now to our question of why 5D interpolation has helped improve apparent resolution in the final image, we assert that the algorithm's in-situ S/N enhancement has combined with its ability to minimize migration noise to account for the observed uplift. A corollary to our assertion is that we believe that diffraction events (whose presence is critically important for proper fault delineation) have been satisfactorily preserved through the 5D data interpolation process, a belief which is reinforced by the absence of coherent diffraction energy in the leakage plot (Fig. 5c) in the zone of interest between 1.0 and 1.3 s. Finally, we reiterate that it is impossible to pinpoint the precise amount of image uplift associated with the 5D interpolation process alone, and it's likely that other reprocessing steps such as careful velocity analysis have had a material effect on image improvement.

After final processing, the resulting PSTM stacked volume was put through a second iteration of interpretation and calculation of maximum curvature. The new interpretation revealed areas that did not contain faulting or karst features. The dramatic increase in data quality after reprocessing enabled the team to plan four new wells to be drilled on the lease. The data were also used daily by the geosteering team throughout the drilling of the wells to stay within target and to avoid drilling into the Ellenburger formation at the bottom of the target interval. After the wells were drilled, the reprocessed seismic data was used to guide a completions program to logically stimulate the wells. These four wells are expected to produce more than double the field average and have a combined EUR of 12.4 Bcf. (Figure 7)

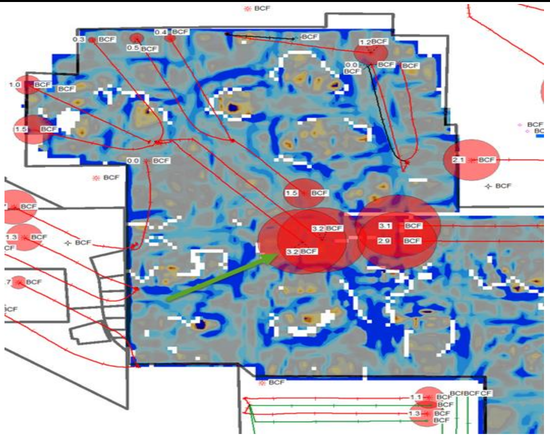

Figure 7: Four additional wells were drilled (indicated by green arrow) and completed with the integration of the reprocessed seismic adding 12.4 Bcf to the lease.

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EDITED REFERENCES

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