# Fracture Detection in the Migrated Domain: Practical Aspects of Prestack Time Migration of Azimuthally-limited 3D Land Data Volumes

Mike Perz*, Juefu Wang and Ye Zheng
Divestco Inc., Calgary, AB
mike.perz@divestco.com

## Summary

In theory P-wave fracture analysis should be performed in the migrated domain. However in practice, the spatial sampling of the individual azimuth-limited data subvolumes which are input to the migration may be quite sparse and/or irregular, and if appropriate regularization measures are not employed, the resulting migration artifacts may seriously compromise downstream fracture analysis. Fortunately, various data regularization techniques exist which are capable, to varying degrees, of reducing this noise. This paper provides a comparison of three different approaches to data regularization for azimuth-limited Kirchhoff prestack migration: (i) azimuth sectoring; (ii) common offset vector gathering; and (iii) prestack interpolation.

## Introduction

As the focus continues to shift towards unconventional reservoir exploitation, the need for accurate fracture characterization tools becomes increasingly important. P-wave vertical fracture detection methods attempt to measure in-situ HTI anisotropy by exploiting azimuthal variations in stacking velocity (“VVAZ”) and/or in amplitude-versus-offset (“AVAZ”). In theory both AVAZ and VVAZ analyses should be performed in the migrated domain for several reasons: first, fracture attributes generated from migrated data naturally exhibit improved lateral resolution relative to their counterparts derived from unmigrated data because migration collapses the Fresnel zone; second, migration ensures that the fracture attributes are mapped to their true subsurface locations; third, migration removes the influence of dip from the VVAZ analysis, thereby preventing the misidentification of structure-related azimuthal velocity variation with anisotropy.

Unfortunately, 3D prestack time migration (PSTM) of wide-azimuth land data is known to be sensitive to the effects of irregular and/or sparse spatial sampling. This problem was recently explored by Hunt et al., (2008), who sought to minimize migration noise on unstacked image gathers generated by industry-standard offset-limited migration in order to improve the quality of post-migration AVO inversion. Post-migration fracture detection analysis is also performed on unstacked migrated data--although in this case the analysis requires running separate migrations on data subvolumes whose traces share similar offsets *and* similar azimuths (i.e., offset-and-azimuth-limited migration), so we expect the migrated images to exhibit high sensitivity to the effects of irregular sampling. We are aware of three approaches for data regularization prior to running offset-and-azimuth-limited migration: (i) azimuth sectoring; (ii) common offset vector gathering; (iii) prestack interpolation. Recently Calvert et al. (2008) showed a real data comparison of the first two of these approaches in a data flow for post-migration VVAZ fracture detection. In this paper, we compare all three techniques for both AVAZ and VVAZ.

## Theory

Offset-and-azimuth-limited migration enjoys a solid theoretical underpinning because it attempts to mimic common-offset-and-azimuth (COA) migration (i.e., migration for which all input traces have identical offsets and azimuths), and that latter process, if implemented with suitable migration weights, gives an estimate of angle-and-azimuth-dependent reflectivity consistent with the acoustic wave equation under certain simplifying assumptions (e.g., Bleistein, 2001). Unfortunately, irregular and/or sparse sampling precludes the formation of perfectly sampled input COA volumes, and in an effort to *approximately* replicate the ideal COA experiment, we must either perform some binning of the input data or we must use these input data to synthesize traces at the desired azimuth and offset. Of the three regularization schemes discussed below, both azimuth sectoring and common offset vector gathering assume the former tack, while interpolation assumes the latter.

### *(i) Azimuth sectoring*

This approach entails first sorting the data into azimuth-restricted sectors, then performing separate industry-standard offset-limited migrations (i.e., so-called “common offset” migrations) on each sector (Lynn et al., 1996). It’s worth noting that common offset migration has been fortified over the years by various industry-strength tricks which can help mitigate sampling-related artifacts (e.g.., appropriate normalization of input traces to compensate for fold variations; use of variable-width offset slots; gap-filling via borrowing of traces from neighbouring offset slots, etc.), and the presence or absence of such tricks may have a significant influence on output image quality.

### *(ii) Common offset vector (“COV”) gathering*

In this approach, the data are first sorted into COV ensembles, then separate prestack migrations are performed on each ensemble. COV gathering, which was developed independently by Cary (1999) and Vermeer (2002), and which is also known as “offset vector tile gathering”, provides an *implicit* localization in azimuth and offset because the gathering process *explicitly* collects traces which have similar inline and crossline offsets. One advantage of this approach relative to azimuth sectoring is that COV ensembles naturally exhibit single-fold CMP coverage for regularly sampled orthogonal shooting, whereas corresponding azimuth-sectored offset-limited ensembles show spatial fluctuations in CMP fold. Note that many of the same industry-strength tricks in use for common offset migration can be carried over to COV migration. One potential disadvantage of the COV approach, though admittedly unexplored, is that the azimuth localization is poor for COV ensembles associated with small values of polar (i.e., scalar) offset.

### *(iii) Prestack interpolation*

Prestack interpolation may be used to regularize the input data prior to migration. In the idealized scenario of a perfect interpolation algorithm and infinite computational resources, there would be no downside to this approach, since the interpolated traces would provide a perfect replication of the ideal COA experiment at no cost. The practical reality is that no interpolation algorithm gives perfect results, each one being based on its own set of assumptions, and runtime may be considerable. The present algorithm, which is a Fourier reconstruction technique based on the work of Liu and Sacchi (2004), assumes a smooth energy distribution in the frequency-wavenumber domain based on a priori model information. Because our implementation synthesizes data on a regular CMP grid with regularly sampled offsets and azimuths, the interpolated traces may be directly input to the migration without data binning (thus the offset-and-azimuth-limited migration “reduces” to a true COA migration).

## Examples

A full suite of data results will be shown in the oral presentation; for brevity we include only a few representative examples in the abstract. The data set under study features a well-delineated fracture regime whose presence has been inferred by various field observations, and has been confirmed by several wells (Wang et al., 2007). Figure 1a shows an azimuth-limited stack along an inline after a naïve azimuth sectoring approach in which the input data volume was sectored into eight azimuth-limited subvolumes at 22.5° degree increments from 0° to 180°, and separate common offset migrations were run on each subvolume with each migration comprising sixty offset bins of uniform width (50 m). Figure 1b shows the result of a more sophisticated "optimized" azimuth-sectored migration in which the same eight azimuth-limited subvolumes were first formed (as in Fig. 1a), but this time all the aforementioned industry-strength trickery was invoked in the individual common offset migrations in order to minimize sampling artifacts. Note that the migration noise is significantly suppressed relative to Figure 1a, most markedly in the shallow events (green box) but also in the deeper structure. Figure 1c shows the corresponding result after prestack interpolation followed by COA migration. The image quality in Figures 1b and 1c is comparable and both images are clearly superior to the one produced by the naïve azimuth sectoring approach; we conclude that the migrated data generated by the naïve azimuth sectoring approach would be too noisy to qualify as suitable input to AVAZ/VVAZ fracture analysis.

Figures 2a and 2b show the fracture intensity attribute maps at the zone-of-interest (indicated by red arrows in Fig. 1a) derived from AVAZ and VVAZ analyses, respectively, using the migrated data generated by the optimized azimuth-sectored migration shown in Figure 1b. Figures 2c and 2d show the corresponding results obtained using the migrated data generated by the interpolation-plus-migration flow shown in Figure 1c. For reference, we have provided AVAZ and VVAZ fracture intensity attributes generated from the unmigrated data in Figures 2e and 2f, respectively.  The four figures associated with the migrated data (i.e., Figs. 2a, b, c, d) reveal intriguing similarities and also puzzling differences. In spite of these differences, we can make the following general comments: (i) all six fracture intensity maps show strong fracturing along a NE to SW trend (black box, Fig 2a) which is consistent with the well control and with field observations; (ii) the migration process seems to have improved the lateral resolution of the attributes (although in the unmigrated example, it is difficult to isolate the smoothing induced by the industry-standard process of CMP super-binning (7 x 7 smash size) from the smoothing associated with intrinsic Fresnel zone blurring); (iii)  the results suggest that both data regularization schemes are producing reasonable results (though not shown here, the COV results were also reasonable); (iv) the results after interpolation plus PSTM are very encouraging, and we note that they are somewhat cleaner than those associated with the optimized azimuth sectoring approach. Finally, it is worth noting that even in the absence of migration noise, result interpretation is complicated by the fact that several factors can conspire to destroy similarity between AVAZ and VVAZ attributes, even though both of these fracture detection techniques are ostensibly aimed at the same objective (Wang et al., 2007; Zheng et al., 2008.).

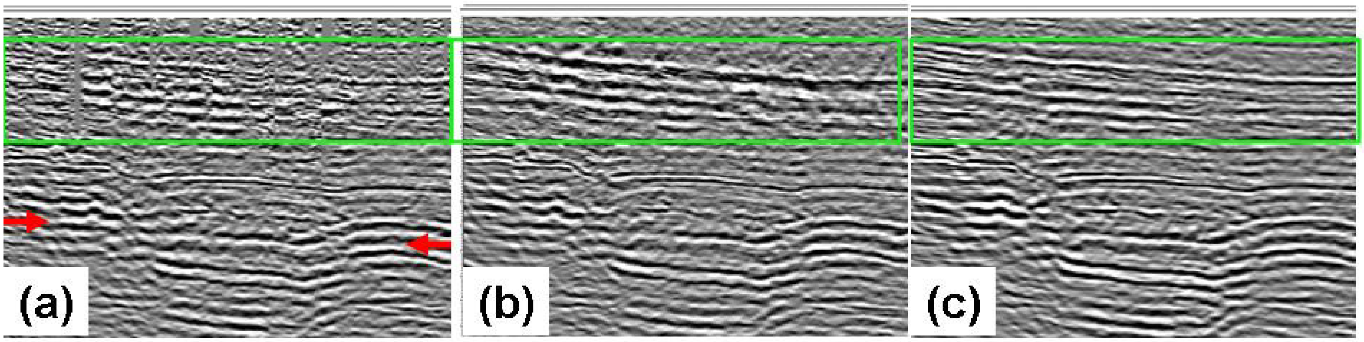

Figure 1: Images obtained by stacking all common offset migrations associated with a single source-receiver azimuth (22.5 degrees E of N). (a) result after "naïve" azimuth-sectored  offset-limited migration; (b) result after optimized azimuth-sectored offset-limited migration; (c) result after prestack interpolation plus common azimuth/offset migration.

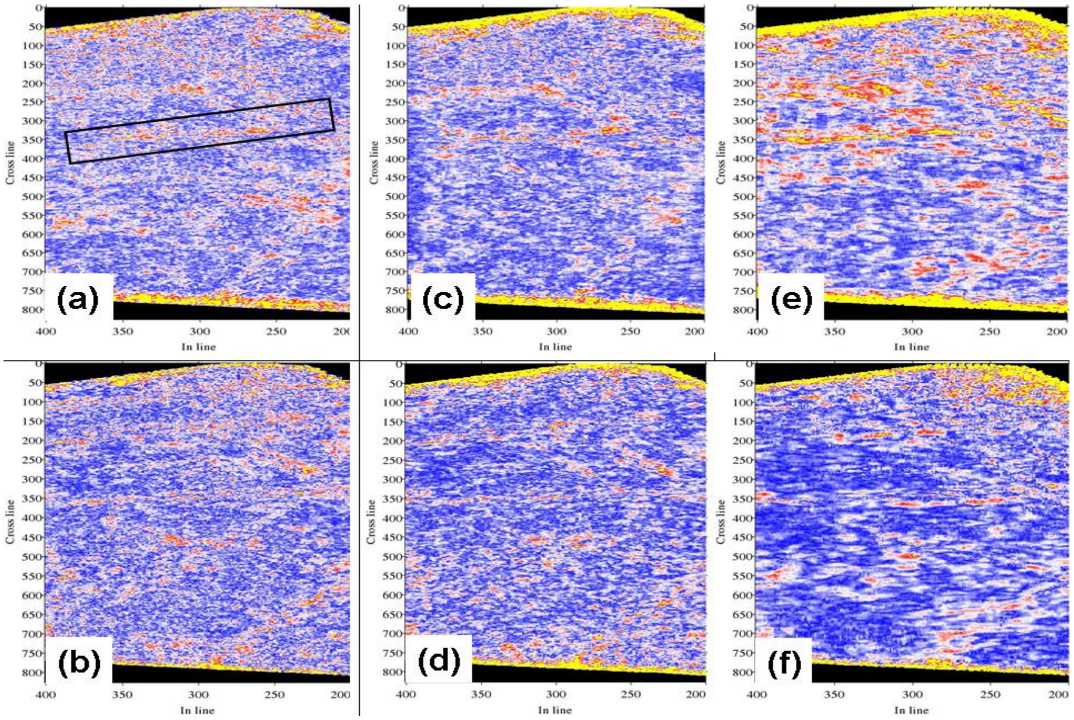

Figure 2: Fracture intensity maps. (a) AVAZ fracture intensity after azimuth-sectored PSTM; (b) VVAZ fracture intensity after azimuth-sectored PSTM; (c) AVAZ fracture intensity after interpolation plus PSTM; (d) VVAZ fracture intensity after interpolation plus PSTM; (e) AVAZ fracture intensity from unmigrated data; (f) VVAZ fracture intensity from unmigrated data.

## Conclusions

We have reviewed and compared three strategies for minimizing sampling-related artifacts in offset-and-azimuth-limited PSTM with a view towards downstream migrated-domain fracture detection analysis. While we are reluctant to draw definitive conclusions about which approach is best, we can say with certitude that it is much better to adopt one of the three than to do “nothing” (as in Fig. 1a). Future work will focus on additional validation based on real data decimation experiments and synthetic data testing.

## Acknowledgements

We thank Divestco Inc. for allowing us to present our findings.

### References

Bleistein, N., Cohen, J.K., and Stockwell, J.W., 2001, Mathematics of multidimensional seismic imaging, migration and inversion: Springer Press.560 pp.

Calvert, A., Jenner, E., Jefferson, R., Bloor, R., Adams, N., Ramkhelawan, R., and St. Clair, C., Wide azimuth imaging and azimuthal velocity analysis using offset vector tile prestack migration: First Break (September) ,**26**, 103-107.

Cary, P.W., 1999, Common-offset-vector gathers: an alternative to cross-spreads for wide-azimuth 3-D surveys: 69th Ann. Int. Mtg., SEG, Exp. Abs., 1496-1499

Hunt, L., Hadley, S., Hadley, M., Downton, J., and Durrani, B., 2008, Interpolation, PSTM, AVO, and a thin gas charged Viking shoreface in West Central Alberta: CSEG National Convention, 177-182.

Liu, B. and Sacchi, M.D., 2004, Minimum weighted norm interpolation of seismic records, Geophysics, **69**, 1560-1568.

Lynn, H.B., Simon, K.M., Bates, C.R.., and Van Dok, R., 1996, Azimuthal anisotropy in P-wave 3-D (multiazimuth) data: The Leading Edge, **15**, 923-928.

Vermeer, G.J.O., 2002, 3-D seismic survey design. SEG, USA.

Wang, J., Zheng, Y., and Perz, M., 2007, VVAZ vs AVAZ, Practical implementation and comparison of two fracture detection methods: 77th Annual International Meeting SEG, Expanded Abstracts, 189-192.

Zheng, Y., Wang, J., and Perz, M., 2008, Pitfalls and tips for seismic fracture analysis: 78th Annual International Meeting SEG, Expanded Abstracts, 1531-1534.