



## Fracture Prospecting with 3D Azimuthal Imaging

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### Summary

*Seismic characterization of fractured reservoirs using standard land acquisition techniques has been a stretch goal of the processing industry for more than 20 years. Proper placement of wells either in a fractured ‘sweet-spot’ or away from a potential frac ‘thief-zone’ is critical for effective field development. Advances in pre-migration azimuthal velocity analysis have given us a glimpse of what’s available from 3D seismic surveys but have lacked the spatial resolution to reduce drilling risk. Azimuthal Imaging is the next step in the progression of technology for the seismic prediction of stress and fracture distribution in a target reservoir.*

### Introduction

Stress and Fracture changes across a stratigraphic interval result in azimuthal changes in the velocity field. Azimuthal variations in the velocity field have long been recognized as critical reservoir information but generally disregarded in the imaging process for lack of a proper imaging tool. The focus of this paper is on the use of azimuthal imaging technology in various shale and complex-structure plays to identify and map stress variations and open fractures.

In shale and fracture targets we offer a technique for improving the spatial resolution of the reservoir variations for better fracture delineation. The azimuthal migration removes dip effects and improves signal to noise for greatly improved interval ellipticity mapping. In complex structural settings, azimuthal migration has the potential to properly image structures where isotropic time and depth migration fails.

### Background

Prospecting for oil and gas in tight, hard rocks is one of the consequences of higher hydrocarbon prices. Reservoir previously considered marginal can be economically tapped

when the proper engineering and geophysical techniques are applied. Critical in developing hard-rock fields is an understanding of the current stress and fracture setting. Wells provide single point measurements of the stress field. Multicomponent seismic acquisition can highlight open fractures but is expensive to shoot and difficult to process. Curvature analysis can identify potential fractures but can’t distinguish open versus closed fractures. Conventional azimuthal analysis (e.g. Corrigan, 1996; Lynn, 1999; Tod, 2007) has been hampered by poor signal to noise and dip effects from working with unmigrated super gathers.

Defining fast and slow directions is the initial goal of the azimuthal analysis. Typical land acquisition collects a range of source-receiver azimuths (e.g. Grimm, 1999). Sorting an unmigrated super gather by azimuth can highlight apparent fast and slow directions (figure 1). The event highlighted would be relatively flat in this display if not for azimuthal variations in the velocity field.

Standard pre-stack migration destroys azimuth information so identifying azimuthal velocity variations has been left to studying un-migrated gathers. An improvement on this technique is to migrate the gathers with a migration that understands azimuthal velocity variations. The basic workflow for this effort is as follows:

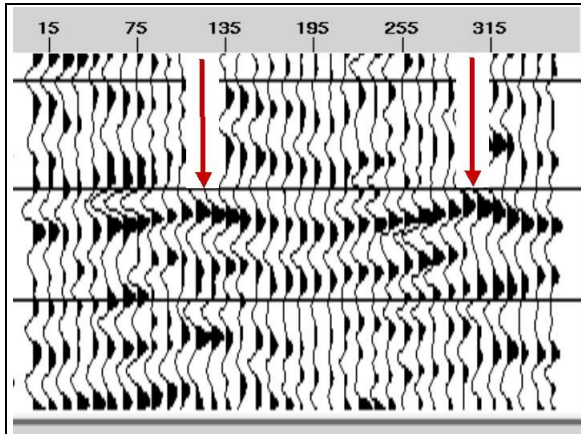


Figure 1. Super gather sorted by azimuth highlights fast (red arrows) and slow azimuths. Amplitude of the sinusoid formed by the event reflects the magnitude of azimuthal anisotropy.

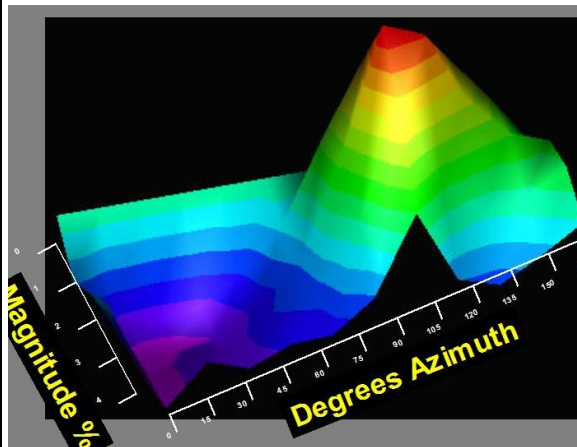


Figure 2: Optimal azimuth and magnitude for imaging a target location can be represented as a type of semblance peak described by azimuth and the percent change in the background velocity field.

1. Standard land processing flow up to PSTM

2. Standard VA's to build migration velocity field
3. Full PSTM of 3D volume
4. Post migration automatic residual VA's
5. Target horizon interpretation
6. Target horizon azimuthal VA's (on unmigrated gathers) – 60-144 migrations at every other CDP
7. to determine optimal azimuthal parameters (figure 2)
8. Update original velocity volume
9. Move down to next level and iterate

The azimuthal velocity analysis tests a set of azimuths and magnitudes to determine the optimal imaging parameters for the target horizon (figure 2). As with any velocity analysis (regular or azimuthal) the approach requires some amount of reflectivity in the zone of interest.

## Fracture Analysis

With the azimuthal velocity field defined, we now can sort the input gathers by azimuth and migrate the gathers to create the input dataset for our azimuthal AVO analysis. Elastic modeling of fractured reservoirs indicates we should see both a delayed arrival and a positive AVO response for our particular reservoir target (the Barnett Shale) (Figure 3 & 4). AVO attribute stacks for each azimuth group allow us to search for AVO changes by azimuth and thus highlight potential open fractures.

Interpretation of open fractures comes from the azimuthal interval analysis and azimuthal AVO. Figure 5 shows a map from a Barnett Shale 3D and displays the fast direction as a small vector the length of which corresponds to the magnitude of the anisotropy. Color on the map shows AVO anomalies for a specified azimuth – in this case N30E. The blue color at the northern end of the survey illustrates there are no open fractures crossed in the N30E direction.

The final figure (Figure 6) looks at the AVO response across the dominant vector direction in the northern portion of the survey. In the display we see a number of areas of positive azimuthal AVO indicating probable fracture swarms. A fault (pink) and a karsted area (black circle) are also highlighted on the display.

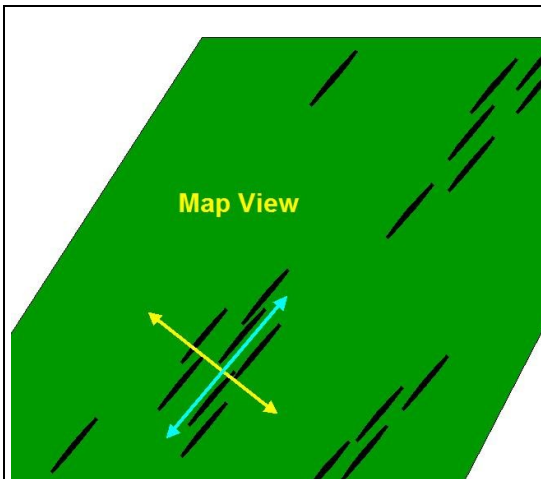


Figure 3: Azimuth sampling across open fractures shows AVO differences that can help map fracture presence and intensity.

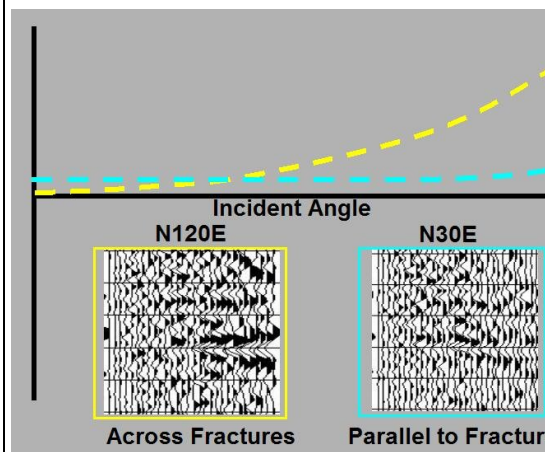


Figure 4: Example migrated gathers from a single CDP location for selected azimuth ranges show large AVO variations due to open fractures in the N120E direction.

## Conclusions

Azimuthal velocity analysis and imaging provides a new and better tool for extracting azimuthal rock property data from target reservoirs. The imaging approach improves signal to noise and addresses dip for true 3D open fracture identification and mapping.

## References

Corrigan, D., Withers, R., Darnall, J., and Skopinski, T., 1996, Fracture mapping from azimuthal velocity analysis using 3-D surface seismic data, 66th Ann. Internat. Mtg., Soc. Expl. Geophys., 1834-1837.

Grimm, R. E., Lynn, H. B., Bates, R. C., Phillips, D. R., Simon, M. K., and Beckham, W. E., 1999, Detection and analysis of naturally fractured gas reservoirs:

Multiazimuth seismic surveys in the Wind River basin, Wyoming, *Geophysics*, 64, 1277-1292.

Lynn, H. B., Campagna, D., Simon, K. M., and Beckham, W. E., 1999, Relationship of P-wave seismic attributes, azimuthal anisotropy, and commercial gas play in 3-D P-wave multiazimuth data, Rulison Field, Piceance Basin, Colorado, *Geophysics*, 64, 1293-1311.

Tod, S., Taylor, B., Johnston, R., Allen, T., 2007, Fracture prediction from wide-azimuth land seismic data in SE Algeria, *Leading Edge*, vol. 26, #9.



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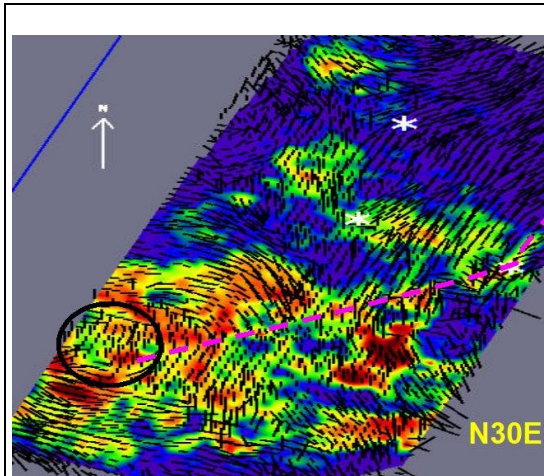


Figure 5: Azimuthal velocity vectors with color AVO anomalies for the N30E Azimuth. Solid blue in the northern portion of the survey agrees with the vectors illustrating the fast direction (parallel to potential fractures).

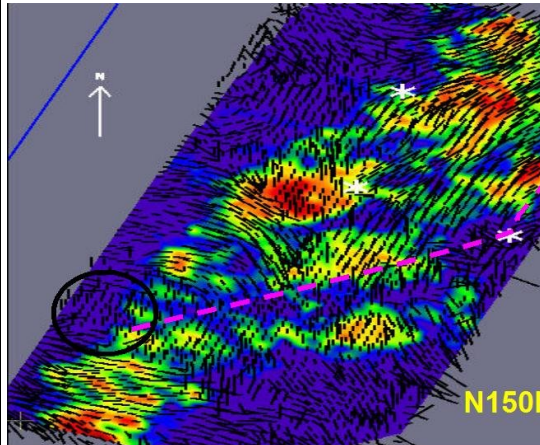


Figure 6: Azimuthal velocity vectors with color AVO anomalies for the N150E Azimuth. Hot colors in the north indicate potential open fractures were crossed by this azimuth.