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# Unfolding Marine Multiazimuth Data from the Gulf of Mexico

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## Summary

The first evolution of WAZ seismic data acquired over 10 years ago provided a sizable uplift over previous NAZ data sets. The addition of orthogonal surveys, advances in data processing, and improved geological understanding have recently introduced another step change in the data quality. These improvements are now leading to a greater improvement in data analysis and interpretation than just structural imaging uplift.

We can see 4 distinct behaviors in 6 azimuth M-WAZ marine data. When data is acquired over “simple” geology, we get common signal in all azimuths. We also notice that close to salt, there are major differences between the 6 azimuths over large depth ranges due to illumination. These two observations have been known and published for the last decade. Our findings show that there are untapped potential and knowledge in marine M-WAZ data if acquired and proccessed correctly. We believe that we can map azimuthal-amplitude variations, and therefore, map stress and fracture fields to facilitate the production of hydrocarbons. If the data is acquired with a significant time lapse between acquisition, there is also an opportunitiy to perform 4D studies.

## Introduction

Since the beginning of this millennium, the advancement of wide-azimuth seismic acquisition techniques, combined with an increase in computer power to enable the use of RTM, has transformed imaging in the Gulf of Mexico. These are proven methods for near-salt exploration and production. However, a consequence of the common multidirectional surveys is that data from basins distant to salt have been acquired many times and the value of this has not been explored to its fullest extent. We show four main observations: Areas that are considered azimuthally quiet and have the same seismic response in all directions. Major obstructions to the ray paths, e.g. a salt diapir and considerable loss of signal in some azimuth sectors, are observed. Amplitude variations, on single reflectors, with azimuth and offset can be mapped and give further insights to stress and fracture patterns in the subsurface. Finally, amplitude responses, as a function of acquisition time, can be utilized for 4D light to enhance the understanding of production history.

The methodology for obtaining these results starts from Multi-WAZ acquisition, continues with amplitude-preserving broadband processing, orthorhombic model building to correct for kinematics and Kirchhoff migration, then concludes with detailed amplitude work.

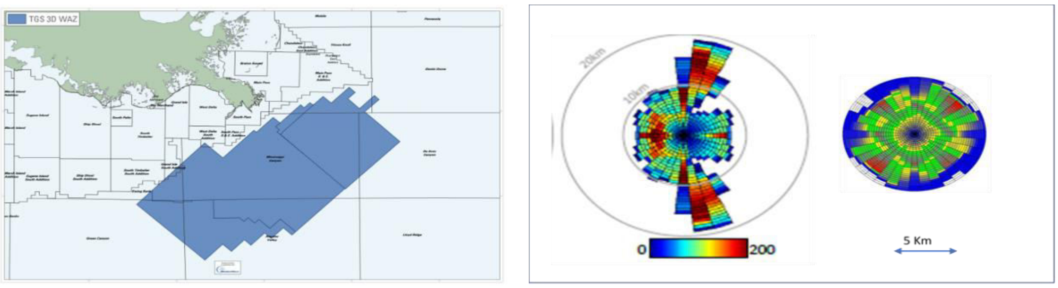

***Figure 1a*** *Location of M-WAZ area in Missippi Canyon, US Gulf of Mexico figure;* ***1b*** *rose diagrams of the two surveys with 6 azimuth-sectored Kirchhoff PSDM gathers.*

## Geological/historical background

The greater Mississippi Canyon area (Figure 1a) encompasses a wide variety of play types and has been a highly prospective area for many years. Many layers of seismic data have helped drive exploration efforts in this area and increasing levels of technology have helped to improve the imaging. Exploration targets exist from the Pliocene to Jurassic with the main challenge of seismic imaging coming from the complex salt structures in the area. While the area is characterized by the lack of extensive, thick allochthonous salt canopy found further west in the Gulf of Mexico, the salt can still be kilometres thick. This requires modern WAZ and Multi-WAZ imaging technology to start to unlock the subsalt and near-salt plays.

## Acquisition History

The original acquisition for this study was a 2010 traditional dual orthogonal 2x4 WAZ acquisition with maximum of 8 km offset (Baldock et al., 2011), Figure 1b. This methodology extended further to the Northeast, where a traditional 2x4 WAZ survey was overshot by an orthogonal staggered WAZ acquisition in 2015 with a maximum of 16 km offset (Guo et al., 2017) Figure 1b. The processing of this M-WAZ survey utilized all offsets up to 16 km for better deep velocity control. However, for this study, we limited offsets to 8 km and assumed reciprocity to obtain 6 azimuthal sectors of 30 degrees from zero to 180 degrees from North. The main azimuths of acquisition are 45 and 135 degrees.

## Key Processing Technologies

The processing job-flow must be designed to maintain the azimuthal amplitude variations, but should also be designed to handle the kinematic challenges that come with multiazimuth sectored data. Creating a broadband seismic wavelet is key for reservoir work, and a high-fidelity 3D algorithm that can handle the broadside ghost from the large cross spreads of a WAZ survey is needed (Zhang et al.,2017). 3D SRME benefits from having both surveys to build a better multiple table with more source and receiver bounce points recorded to better predict and eliminate multiples. Denoise transforms should be carefully coded to avoid any smearing of the azimuthal signal and a 5D Antileakage Fourier transform is an integral part of obtaining an equal distribution of traces to migrate in the final Kirchhoff migration.

## Orthorhombic Model Building Technologies

The kinematics are handled by an orthorhombic model-building workflow (Tsvankin, 1997; Hilburn et al., 2017), and the resulting parameters can be interpreted to provide a macroscopic view of velocity-field variation with azimuth. The imaging uplift due to orthorhombic model building is noticeable but typically modest in areas of high-azimuthal anisotropy, with the key motivation for gather improvement being to encourage confidence in the model. As can be seen in Figure 3a, high-resolution TTI azimuthal velocity-model building is insufficient to resolve the moveout differences between azimuthal sectors. Only after appropriate consideration of orthorhombic anisotropy are the gathers properly flattened (Figure 3b).

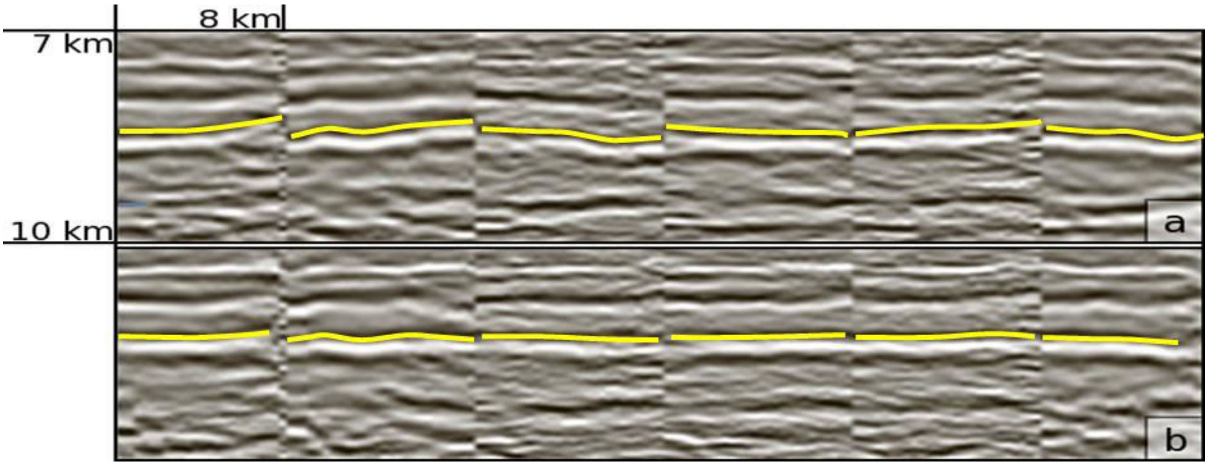

**Figure 3a** *High-resolution TTI azimuthal velocity-model building is insufficient to resolve the moveout differences between 6 azimuthal sectors.* ***3b*** *Orthorhombic, model building leads to properly flattened gathers.*

## Observations

If data is adequately acquired and processed, we observe that the six azimuths have the same kinematic and amplitude behavior on all 6 azimuths when there are little or no obstructions of the ray paths, as seen in Figure 3b.

Close to salt bodies, where we expect significant impact from acquisition direction, we see there is very little common signal in the sectors. The data can be described in some sectors with good signal from near to far offsets. In the other sectors, there is a loss of signal from near to far offsets, but the signal is also lost over a significant depth range of approximately 3 km, as shown in Figure 4.

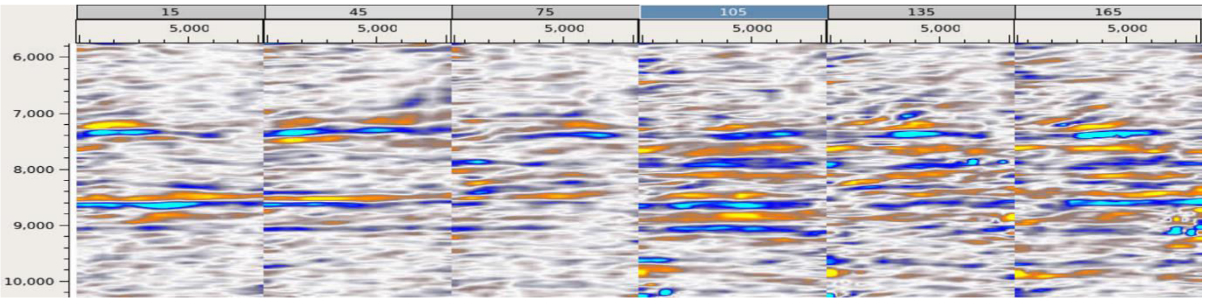

***Figure 4*** *Six azimuths showing responses varying in all sectors and along all offsets over 3000 m of depth.*

We note that the event around 3750 m is flat in Figure 5c; however, the amplitude changes with azimuth (AVAZ). These changes have been mapped for AVAZ (Rueger, 1995, Roende et al.,2008). The results are seemingly geologically meaningful after calculating the AVAZ attributes conforming to either stress or fracture patterns (Figure 5b).

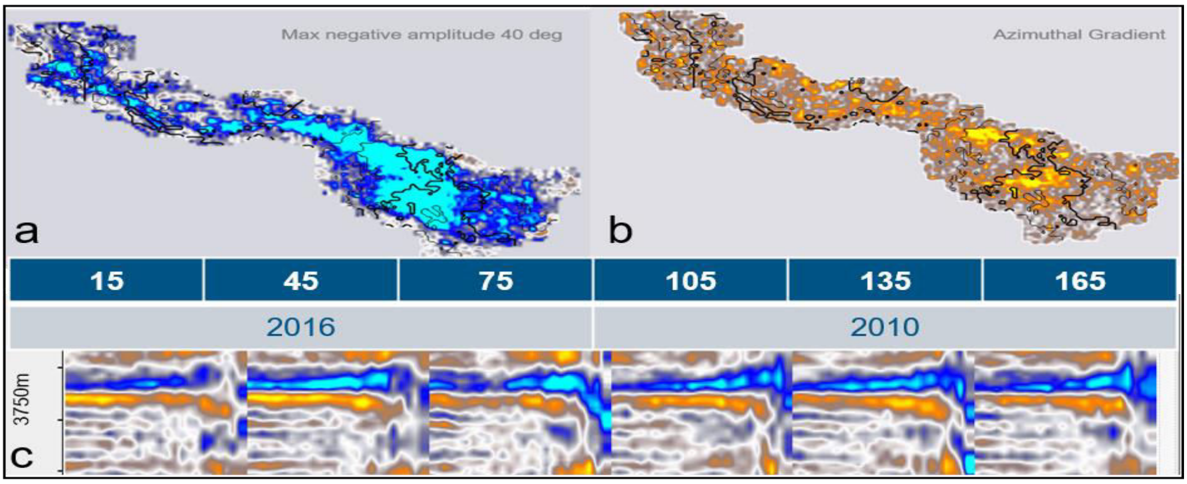

***Figure 5*** *The amplitude extracted on a single event in* ***5c*** *over 6 azimuths.* ***5a*** *shows extraction of max negative amplitude at 40 degrees incidence angle for the summed sectors.* ***5b*** *shows the maximum azimuthal gradient extracted at the horizon and we observe areas of higher azimuthal anisotropy conforming to geological features.*

We notice on Figure 6 that around a producing reservoir we observe a different pattern. The overall signal across the 6 azimuths looks identical. However, the producing reservoir levels (2650 m) show that individual reflections have a behavior correlated to the times of acquisition, 2010 and 2016, not the azimuth sectors. This is interpreted as a 4D signal. With equal processing of the 6 azimuths, this can be considered a 4D light experiment (Roende et al., 2009).

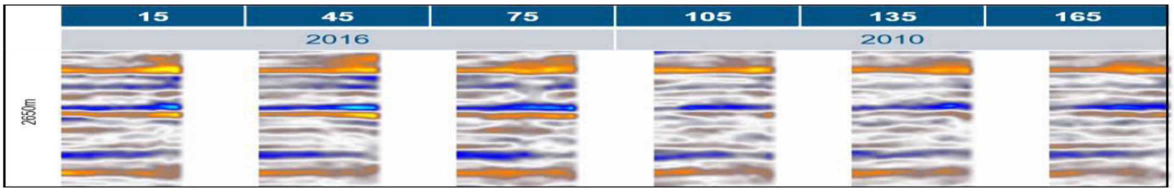

***Figure 6*** *Example of production-induced change in signal on azimuth.Overall, the gathers are identical in the 6 azimuths except the event at 2650 m, where there is a correlation between the acquisition year. The first three azimuths are from 2016, the second three azimuths are from 2010.*

## Discussion

We can see 4 distinct behaviors in 6 azimuth M-WAZ marine data. When data is acquired over "simple" geology, we get common signal in all azimuths. We also notice that close to salt, there are major differences between the 6 azimuths over large depth ranges due to illumination. These two observations have been known and published for the last decade. Our findings show that there are untapped potential and knowledge in marine M-WAZ data if acquired and proccessed correctly. We believe that we can map azimuthal-amplitude variations, and therefore, map stress and fracture fields to facilitate the production of hydrocarbons. If the data is acquired with a significant time lapse between acquisition, there is also an opportunitiy to perform 4D studies.

## Conclusion

We have shown that with careful considerations of marine multiazimuth data, we can extract more information than with the industry standard RTM stacked migrations. We have demonstrated that four distinct patterns for wide-azimuth data can be observed: Quiet azimuthally-anisotropic zones; illumination-related patterns with large washout zones in both offset and depth; and AVAZ behaviours with sinusoidal changes in amplitudes on specific events. Finally, we can observe production-related changes on single events which can be tied to the timing of the surveys.

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## References

Baldock, S., Reta-Tang, C., Beck B., Gao W., Doue, E. and Hightower, S. [2011] Orthogonal Wide Azimuth Surveys: Acquisition and Imaging. 81st Annual International Meeting, SEG, Expanded Abstracts, 147.

Guo, Z., He, Y., Hilburn, G., and Rodriguez, G. [2017] Dual WAZ Processing and Orthorhombic Imaging - A Case Study in Mississippi Canyon, Gulf of Mexico. 79th EAGE Conference and Exhibition, Extended Abstracts, Tu B3 01.

Hilburn, G., He, Y., and Wang, B. [2017] Uncertainty in orthorhombic model building: Analysis, mitigation, and validation. The Leading Edge, **36**(2), 133–139.

Roende, H., Meeder, C., Allen, J., Peterson, S., Eubanks, D., and Ribeiro, C. [2008] Estimating subsurface stress direction and intensity from surface full azimuth land data. 78th Annual International Meeting ,SEG, Expanded Abstracts, 217-221.

Roende, H., Uden, R., Meeder, C., Opich, J., Murat, M., Bird, B., Yu, M., Vasick, P., Wilkerson D., and Wier, B. [2009] Co-processing and repeatability issues of speculative seismic data from Ewing Bank, Gulf of Mexico, for a 4D time lapse study. 79th Annual International Meeting, SEG, Expanded Abstracts, 3564-3568.

Rueger, A. [1995] P-wave reflection coefficients for transversely isotropic media with vertical and horizontal axis of symmetry. 65th Annual International Meeting, SEG, Expanded Abstracts, 278-281.

Tsvankin, I. [1997] Anisotropic parameters and P-wave velocity for orthorhombic media. *Geophysics*, **62**(4), 1292-1309.

Zhang, Z., Masoomzadeh, H. and Wang, B., [2017] Evolution of deghosting process for single sensor streamer data from 2D to 3D. Geophysical Prospecting, https://doi.org/10.1111/1365-2478.12614.