Orthogonal Wide Azimuth Surveys: Acquisition and Imaging

Simon Baldock, Cristina Reta-Tang, Brad Beck, Wei Gao, Elayne Doue and Steve Hightower*

Summary

We present results from a case study being performed in the Gulf of Mexico (GoM) that utilizes two orthogonal Wide Azimuth (WAZ) surveys to create an improved image of the subsurface. The role of WAZ data in subsalt exploration and production in the GoM is now firmly established. The next challenge is to further improve subsalt images in areas with existing WAZ coverage. Orthogonal WAZ acquisition – acquiring a second WAZ dataset over existing WAZ data – provides an efficient way to obtain near Full Azimuth (FAZ) coverage while utilizing existing WAZ data. A case study from the GoM demonstrates that orthogonal WAZ data provides significant imaging uplift and brings added benefit to the tomography and model building steps.

Introduction

Wide azimuth (WAZ) acquisition is firmly established as an indispensible seismic acquisition and processing methodology for exploration and development objectives, especially for the Gulf of Mexico and other parts of the world where conventional Narrow Azimuth (NAZ) data fails to provide sufficient subsurface illumination. WAZ has been so successful that in only a short time there is now almost blanket coverage in the GoM.

The task that now faces the industry is to improve imaging results in areas with existing WAZ data. Advances in processing technology and algorithms continue apace. These include the implementation of true-azimuth surface-related multiple elimination algorithms and the development of new imaging algorithms and workflows, including Tilted Transverse Isotropy (TTI), multi-azimuth tomography, subsalt velocity scanning, Reverse Time Migration (RTM) including 3D RTM angle gathers and full waveform inversion.

However, even though these new techniques have delivered impressive results they do not address the underlying limitations that may exist in the data itself. For example, even though wide azimuth data delivers increased azimuth distribution for offsets up to 4 km to 4.5 km, most streamer wide azimuth data fall short of so-called full azimuth (FAZ) coverage (a full 360° of azimuth coverage at all offsets). The limited azimuth coverage, especially at offsets beyond 4 km, causes insufficient illumination of complex subsurface structures in the conventional WAZ surveys.

A range of methodologies for full azimuth acquisition have been implemented. These include node acquisition (Ross and Beaudoin, 2006) and, more recently, coil shooting (Moldoveanu and Kapoor, 2009). Howard (2007) proposed “Rich Azimuth” or RAZ acquisition in which three wide azimuth surveys with 60 degree separation are combined together.

In this paper we present the results of acquiring and processing wide azimuth data in two orthogonal directions, an approach that comes close to providing full azimuth data. Furthermore, by acquiring over the top of an existing survey, it has the advantage of utilizing existing wide azimuth data by combining it with new data into one unified processing sequence. The additional azimuth and offset information from the orthogonal acquisition provides valuable new independent information that helps to improve the accuracy of the velocity model and salt geometry updates.

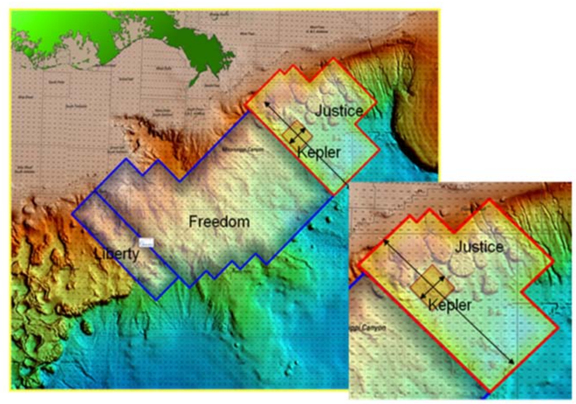

Figure 1. The Kepler and Justice wide-azimuth surveys, located in the Mississippi Canyon area of the Gulf of Mexico.

Method

In 2010 TGS acquired the Kepler wide azimuth survey covering approximately 420 km^2 in the Mississippi Canyon area of the Gulf of Mexico. The data overlays TGS’s Justice wide azimuth survey acquired in the same year. Each survey was acquired using four source vessels; the outer two vessels towed ten cables each (Figure 2). The source boats are 1200 m apart with 1200 m between acquisition swaths. Alternate acquisition swaths are acquired in opposing directions to give a final shot spacing of 150 m in the inline direction and 600 m in the crossline direction. The Kepler survey was acquired in a NE-SW direction and the Justice survey in a NW-SE direction. When the two surveys are combined 1-way supershots are spaced at 150 m intervals on a 600 m x 600 m grid of lines and 2-way supershots are formed at the intersection of the 600 m x 600 m grid (Figure 3).

© 2011 SEG

Downloaded 03 Oct 2011 to 192.160.56.249. Redistribution subject to SEG license or copyright; see Terms of Use at http://segdl.org/

Figure 4 shows the rose diagram for a CMP from each survey (Figures 4a and 4b) and for the combined surveys (Figure 4c). It shows that the combined survey provides a full range of azimuths at all offsets. The addition of the orthogonal shooting direction creates the possibility of better penetration of the subsurface through the introduction of additional source and, more importantly, receiver illumination in the presence of complex salt bodies.

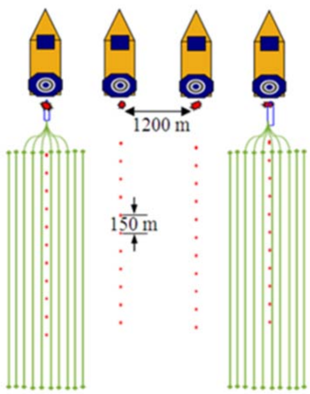

Figure 2. Acquisition set up for the Kepler and Justice surveys.

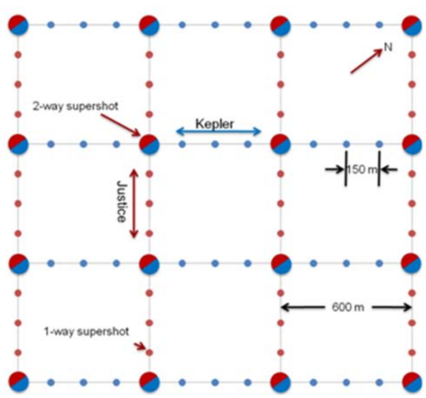

Figure 3. Supershot distribution for the Justice and Kepler surveys.

Once each survey has been processed through a pre-processing sequence, including 3D SRME, the acquisition of two surveys creates the potential for three distinct depth imaging workflows. The Kepler and Justice surveys can be processed as two independent data sets and they may be processed together, utilizing both surveys for the tomography and salt model building steps. TGS elected to pursue all three workflows in this pilot project. Initial work focused on creating a fast track migration using a velocity model produced independently of either survey, attention then shifted to full pre-processing and depth imaging using the three different workflows. We will use the fast track results to highlight the illumination uplift that results from the introduction of orthogonally acquired data, we will then review the methodology for the joint tomography and model building steps.

Illumination

Figure 5 shows an inline from the fast track migration volume. The model includes VTI anisotropy and the images were produced using reverse-time migration. In this example the data is oriented along the inline direction of the Justice survey (NW-SE). Figure 5a shows the results from the Justice survey and Figure 5b the results from the Kepler survey. The acquisition direction is shown in the inset box in the bottom left hand corner of the image.

The two images show contrasting areas of poor and good imaging. In Figure 5a the Justice survey images well the sediments dipping up against the salt flank that are indicated by the green arrows. Deeper events and the area between the two salt bodies are poorly imaged; these

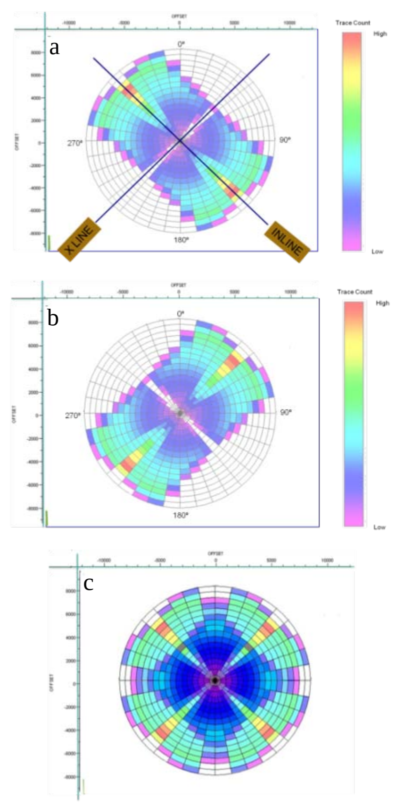

Figure 4. A series of Rose diagrams showing the azimuth and offset distribution for a) the Justice survey; b) the Kepler survey; c) the Justice and Kepler surveys combined.

are highlighted by the red markers. The areas that are poor in the Justice image are much better imaged on the Kepler

© 2011 SEG

Downloaded 03 Oct 2011 to 192.160.56.249. Redistribution subject to SEG license or copyright; see Terms of Use at http://segdl.org/

image (Figure 5c, shown by the green highlights). This image represents a crossline from the Kepler volume. Because the same velocity model was used to migrate each volume, it is reasonable to conclude that the imaging differences come from differences in illumination by the two orthogonal acquisition directions.

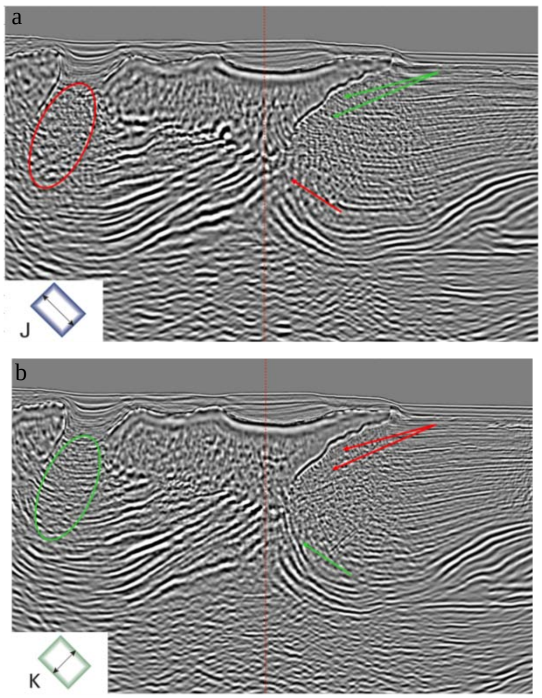

Figure 5. Inline direction: VTI RTM of a) the Justice survey and b) the Kepler survey. Green and red markers indicate areas of good and poor imaging, respectively.

Figure 6 shows a comparison in the crossline direction of the Justice survey, which is the inline direction of the Kepler survey. A strong amplitude anomaly against the flank of the salt in Figure 6b (the Kepler survey, indicated by the green arrow) is absent from the Justice image (Figure 6a, indicated by the red arrow). This comparison again shows how additional independent data is able to better illuminate the areas beneath and against salt.

Tomography and model building

Current practice for wide azimuth processing is to use the additional azimuth coverage generated by wide azimuth acquisition to resolve lateral heterogeneity in the velocity structure more easily during tomography. For a standard WAZ acquisition the CMP binned data is typically partitioned into three azimuth sectors. These azimuth sectors are of unequal size to maintain consistent fold between sectors. Curvature picking and ray-tracing are performed for each azimuth sector separately. The individual ray-trace volumes (ray-paths) are then combined to create a single ray-path volume which is input to a single inversion. With the introduction of orthogonal WAZ data the number of azimuth sectors is increased from three to six enabling valuable far-offset data in the crossline direction of the underlying data to be used; in addition, the fold of coverage is also doubled.

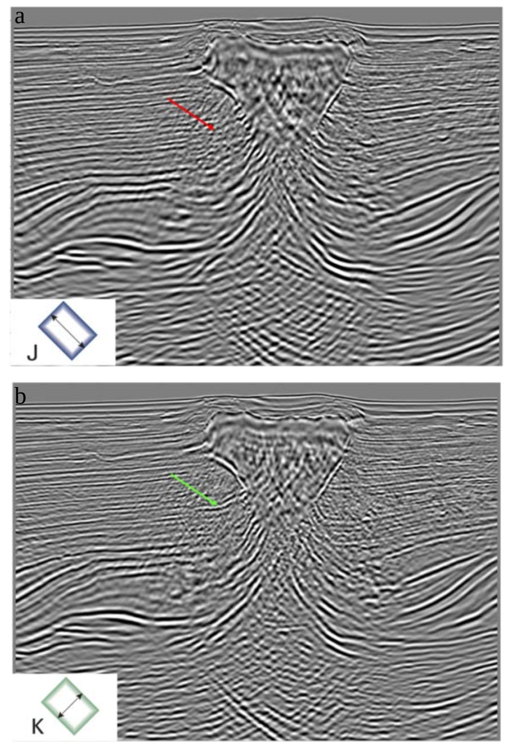

Figure 6. Crossline direction: VTI RTM of a) the Justice survey and b) the Kepler survey. Green and red markers indicate areas of good and poor imaging, respectively.

Image gathers for the three azimuth sectors from the Kepler survey were used to compute the residual moveout semblances shown in Figure 7a. After one iteration of three azimuth tomography the semblances at the same locations show convergence to zero (or smaller) moveout (center of the panels) in all three azimuths (Figure 7b). Figure 8a shows the six azimuth semblance panels from both Kepler and Justice surveys and the velocity depth slices after one iteration of tomography from Kepler only (Figure 8b) and Kepler plus Justice (Figure 8c). It clearly shows the improvement of velocity model by using the orthogonal WAZ.

In the salt model building phase both volumes are utilized. As was shown in Figure 5, some salt flank and base of salt events are better imaged in one direction than the other due to the complex nature of the wave propagation in and

© 2011 SEG

Downloaded 03 Oct 2011 to 192.160.56.249. Redistribution subject to SEG license or copyright; see Terms of Use at http://segdl.org/

around the salt. Model building is optimized by incorporating information from both volumes into a single unified model.

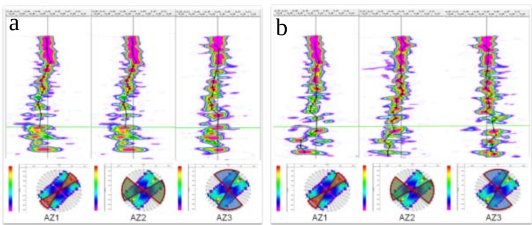

Figure 7. Semblance displays from Kepler three azimuth-sector tomography a) prior to tomography, and b) after one pass of azimuth-sector tomography.

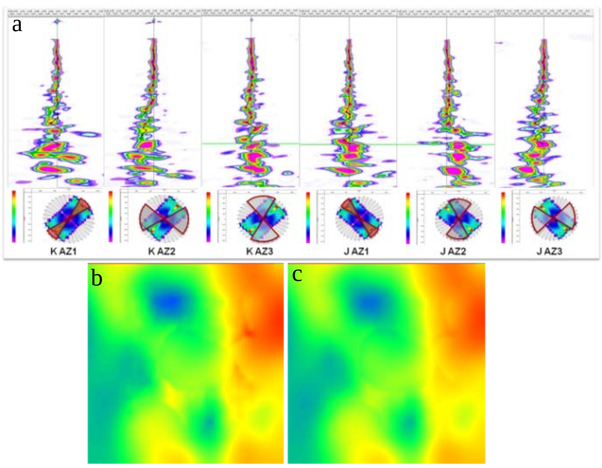

Figure 8. Kepler plus Justice three azimuth tomography: a) semblance display after tomography, same location as Figure 7, b) 3600 m velocity depth slice after tomography using the Kepler survey only, c) 3600 m depth slice after tomography using Kepler plus Justice.

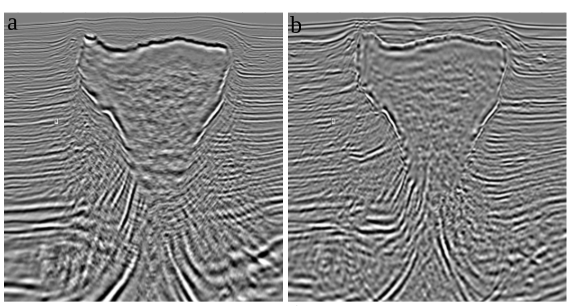

Figure 9. Final migration results from the Kepler only processing, showing a) VTI Kirchhoff PSDM and b) VTI RTM.

We have completed the Kepler final migration while work continues on the model building using both Kepler and Justice. Figure 9 shows a comparison of final Kepler Kirchhoff migration and RTM migration. Significant subsalt imaging improvement has been achieved using the RTM migration. Figure 10 shows a comparison of the Kepler (Figure 10a) and the Justice (Figure 10b) RTM result from the combined flow after the interpretation of the first salt body. In these examples, although the velocity model was build using information from each survey, the final migrations were performed separately. Cai et al. (2011) describe an innovative approach to combining orthogonal WAZ datasets prior to reverse-time migration.

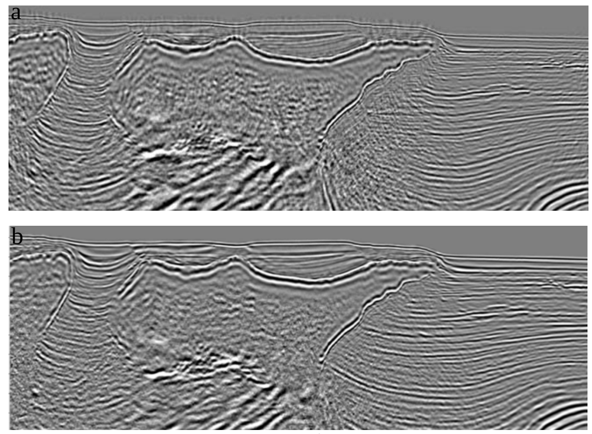

Figure 10. Final VTI RTM results from the combined Kepler and Justice processing, showing a) Kepler, and b) Justice.

Conclusions

The Kepler and Justice orthogonal wide azimuth surveys demonstrate that considerable uplift in the imaging of complex salt structures and the surrounding sediments can be achieved through the utilization of orthogonal wide-azimuth data sets. The initial fast track results indicated that, even for wide azimuth data, survey orientation is a key factor in the quality of the final migration image. These indications have been confirmed in the full depth imaging flow, in which tomographic inversion and salt body interpretation have also benefited from the additional azimuth and offset information provided by the orthogonal survey.

Acknowledgements

The authors would like to thank their colleagues at TGS, in particular Gary Rodriguez, George Cloudy, Zhiming Li, Xuening Ma and Laurie Geiger, and also TGS management for permission to publish the work.

© 2011 SEG

Downloaded 03 Oct 2011 to 192.160.56.249. Redistribution subject to SEG license or copyright; see Terms of Use at http://segdl.org/

EDITED REFERENCES

Note: This reference list is a copy-edited version of the reference list submitted by the author. Reference lists for the 2011 SEG Technical Program Expanded Abstracts have been copy edited so that references provided with the online metadata for each paper will achieve a high degree of linking to cited sources that appear on the Web.

REFERENCES

Cai, J., M. Guo, and S. Dong, 2011, Merging multiple surveys before imaging: Presented at the 81st Annual International Meeting, SEG.

Howard, M., 2007, Marine seismic surveys with enhanced azimuth coverage: Lessons in survey design and acquisition: The Leading Edge, **26**, 480–493, doi:10.1190/1.2723212.

Ross, A., and G. Beaudoin, 2006, Field design and operation of a deep water, wide azimuth node seismic survey: 76th Annual International Meeting, SEG, Expanded Abstracts, 25, 2920.

Moldoveanu, N., and J. Kapoor, 2009, What is the next step after WAZ for exploration in the Gulf of Mexico?: 79th Annual International Meeting, SEG, Expanded Abstracts, 28, 41.

© 2011 SEG

Downloaded 03 Oct 2011 to 192.160.56.249. Redistribution subject to SEG license or copyright; see Terms of Use at http://segdl.org/