Julie Willmore, Brad Torry, Henrik Roende, Chris Egger and Adriana Thames, TGS, USA, examine a data driven solution designed to improve imaging of current and future reserves in the Mississippi Canyon.

ILLUMINATING RESERVES

With considerable seismic coverage in the Gulf of Mexico progressing from narrow azimuth (NAZ) to wide azimuth (WAZ) to multi wide azimuth (MWAZ)/full azimuth (FAZ); what comes next? In the world of low commodity prices and the desire of E&P companies to improve return on investment (ROI), how can companies get more from their seismic data? The simple answer is acquiring the right data to meet the objectives. Historically new marine seismic has been acquired in accordance with the current technology available (a.k.a. technology driven solutions). In today's information era with access to hardware and software for modelling, the value of 'data driven solutions' has become reality. Utilising salt models driven by existing seismic data optimisation of acquisition parameters is conducted through the application of full waveform modelling. An illumination study was conducted using 3D ray based modelling (NORSAR™) with unrestricted offsets and azimuths and 2D finite difference modelling of various cable lengths to optimise new acquisition.

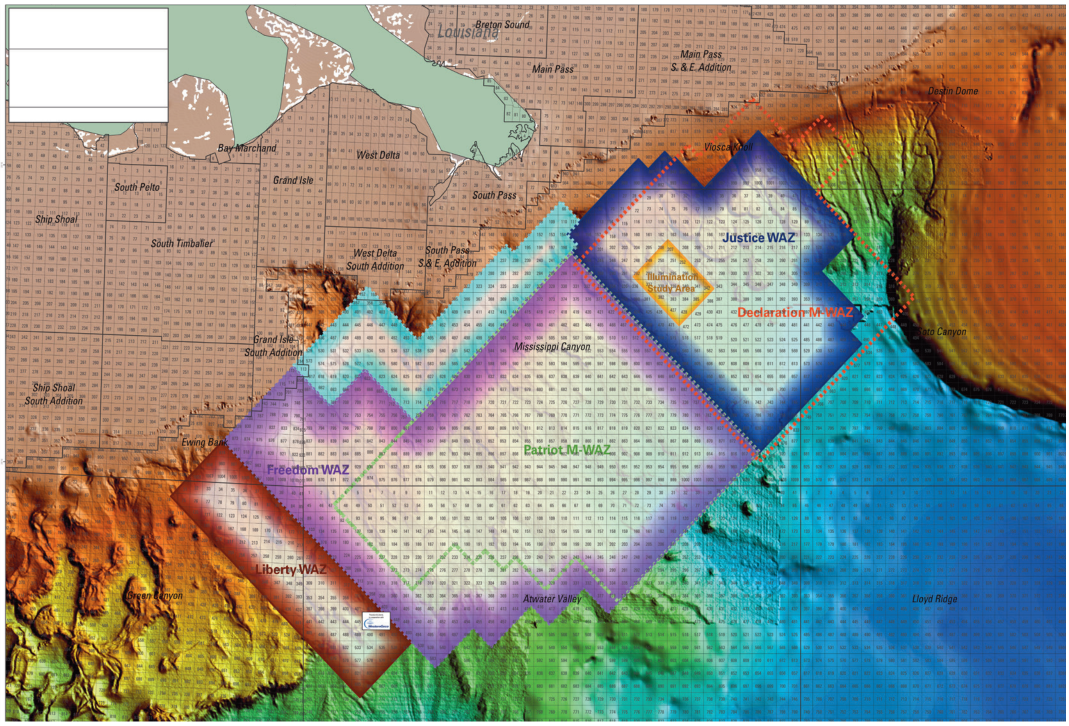

Figure 1. *Study area shown in orange.*

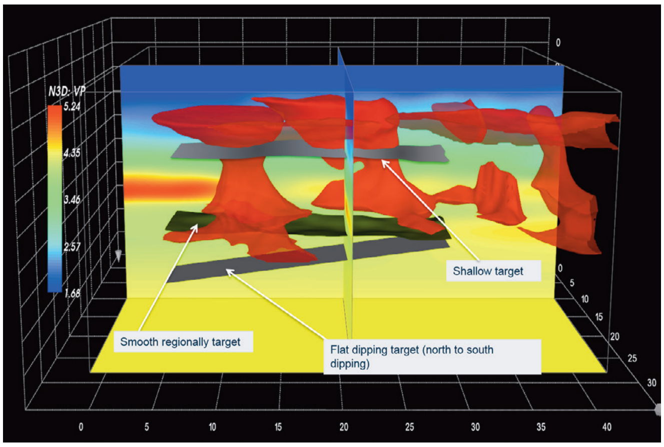

Figure 2. *Inputs to the illumination study; velocity model, salt bodies and target horizons.*

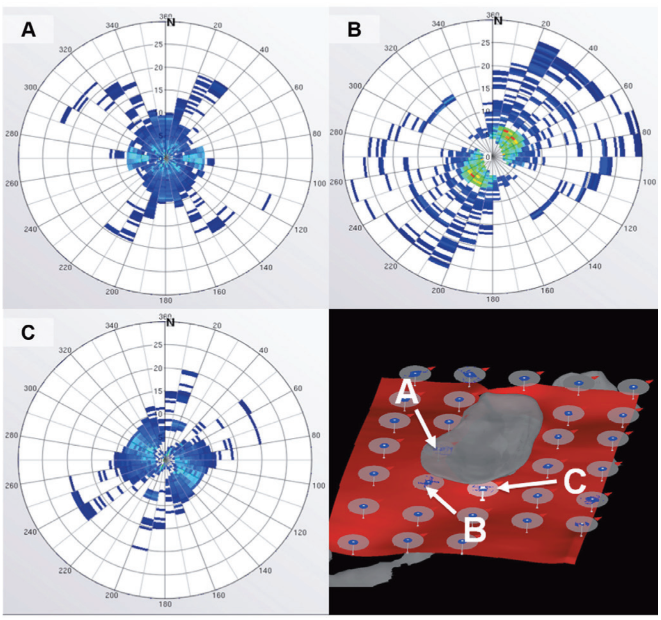

Figure 3. *Rose diagrams from salt flank section of salt horizon.*

With increased focus on sub salt prospectivity, the need to provide greater certainty to field/reservoir size and requirements for derisking long term investment, the request of geoscience teams is to advance these understandings. Due to complex ray paths associated with salt provinces the advantages of multi azimuth recording have been well documented. So why then is it impossible to image certain salt flanks and subsalt regions? The answer: the necessary data has not been acquired.

The basis for this study was the complex Kepler salt and prolific hydrocarbon resources of the Mississippi Canyon region (Figure 1) where the overall salt interpretation is regarded as very good. The Mississippi Canyon is an area with existing NAZ, WAZ and MWAZ seismic data which produced a reliable velocity model. This model (Figure 2) provided the data driven input to this study.

The existing data represents a traditional orthogonal WAZ survey in a 7 km offset configuration. Using this as the starting velocity model the study focused on illuminating a flat and regionally dipping surface below the salt. Justification for the two planar sub salt surfaces was to show the differences and implications that sub salt structure will have on the ability to image these surfaces.

Analysis of the hit target counts, rose diagrams, illumination surface maps, finite difference amplitude and other observations from the modelling leads to increased understanding of modern day requirements for seismic acquisition.

On the basis of the illumination study new vessel configurations were evaluated to acquire data with offsets to 16 km. Initial results from the acquisition are providing validity to the modelling observations and points to the importance of data driven solutions to meet the expectations of today's geoscientists.

The study area

To validate observations a 20 block area surrounding the Kepler salt complex in Mississippi Canyon was the basis for this study. This area was chosen as the current orthogonal WAZ projects, Justice and Kepler, provide a solid baseline salt model from which modelling is built. Figure 1 shows the general study area outline and Figure 2 the starting velocity model for analysis.

With primary objectives for the study to illuminate salt flanks, under salt canopy and subsalt the initiative was focused on understanding ray paths to critical target horizons. Without strong confidence in the illumination targets, derisking exploration targets is at risk. With this assessment it was determined to establish two primary targets for analysis. To capture salt flanks/canopy of complex salt structures the first target horizon was established at 4500 m depth (Figure 2). For the second target, the deeper turbidite sands beneath the Louann salt was interpreted at 10 000 m depth. Given the lack of strong coherent sub salt reflectivity the subsalt horizon was modelled as both a flat reflector and a dipping reflector (Figure 2). Analysis of both resultant products would determine any sensitivity on the sub salt reflectors.

Illumination methodology

To understand the complexity of limited ray paths impacted by the salt-sediment boundaries the model was run with unlimited offsets and azimuths – a data driven solution. The only limit was to restrict the maximum take-off angle to 60˚, thus all post critical angles (refractions) were not included. With numerous options to visualise and understand the results, the primary tool presented here is looking at the subsurface coverage on the target horizon using rose diagrams. The rose diagrams are created by simulating all source-receiver combinations from ray paths landed on the surface (essentially providing the number of times the particular sub-surface point is sampled and from which directions and offsets the rays have travelled). Rose diagrams are then computed for each sub surface point (based on the defined subsurface sample interval (25 m). The results show the 'illumination distribution' as a function of shot-receiver azimuth (0 - 360˚) and shot-receiver offset (km).

Observations – sediment/salt surface

Figure 3 shows a sampling of the rose diagrams along the salt-sediment boundary. In reviewing the rose diagrams it becomes clear that there exists a bias towards certain azimuths based on the location of the measurement relative to salt configuration. This bias will exist in all areas but will be variable depending on the shape and distribution of the salt. Primary observations are the importance of capturing data from all azimuths (hence the value of MWAZ data). When reviewing offsets however the story becomes a little different. Under the salt overhangs and on the steeply dipping flanks, limited ray paths out to 20 km are observed (the majority exist below 8 km) contributing to the illumination.

Moving away from the salt flanks and into the sediment (Figure 4), the azimuthal bias plays a very limited role in

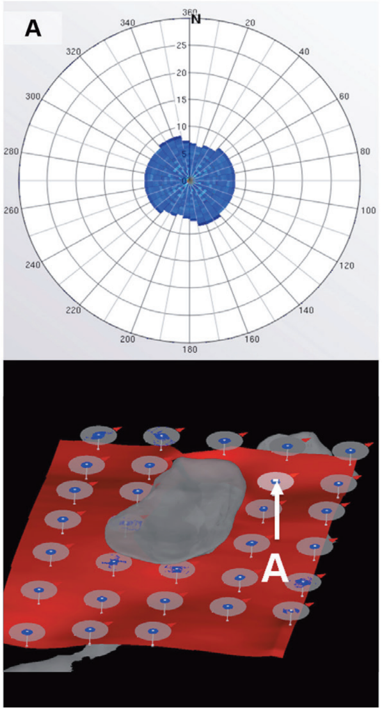

Figure 4. *Rose diagram from within sediment section of salt horizon.*

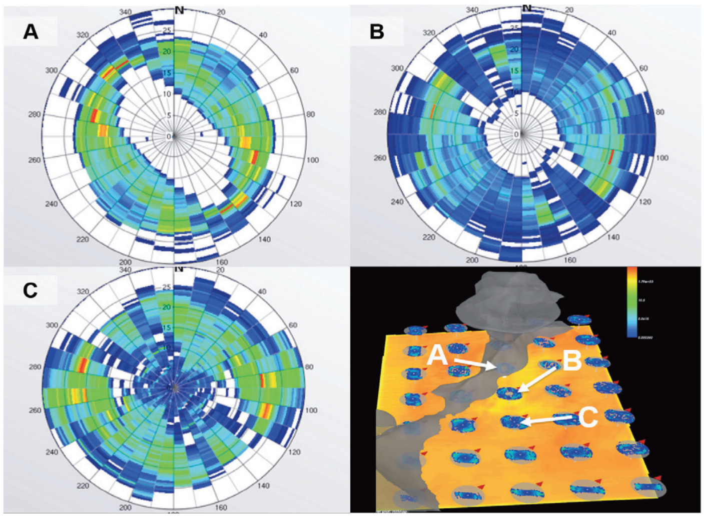

Figure 5. *Rose diagrams from dipping presalt horizon.*

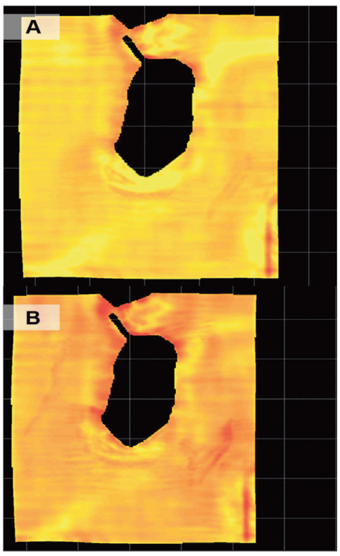

Figure 6. *(A) Illumination maps for the sed/salt horizon: (A) 4 x 9 km (B) 4 x 16 km.*

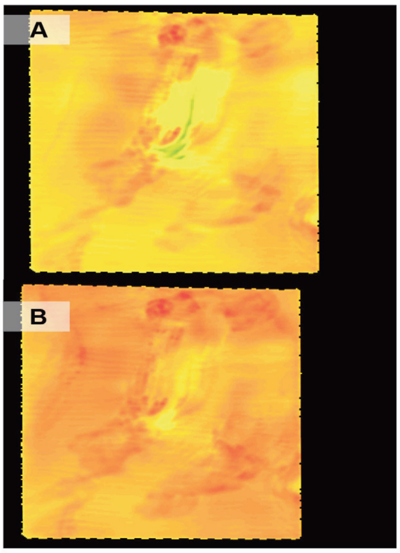

Figure 7. *Illumination maps for the smooth pre-salt horizon: (A) 4 x 9 km (B) 4 x 16 km.*

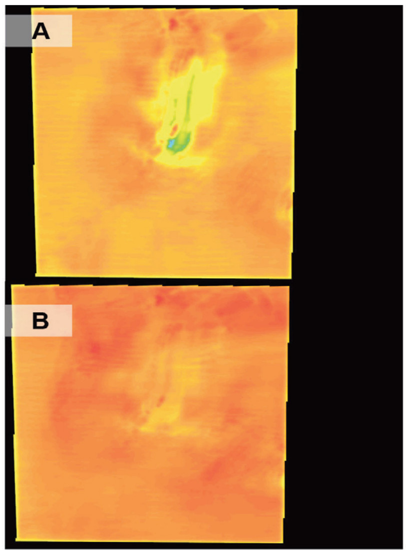

Figure 8. *Illumination maps for the dipping pre-salt horizon: (A) 4 x 9 km (B) 4 x 16 km .*

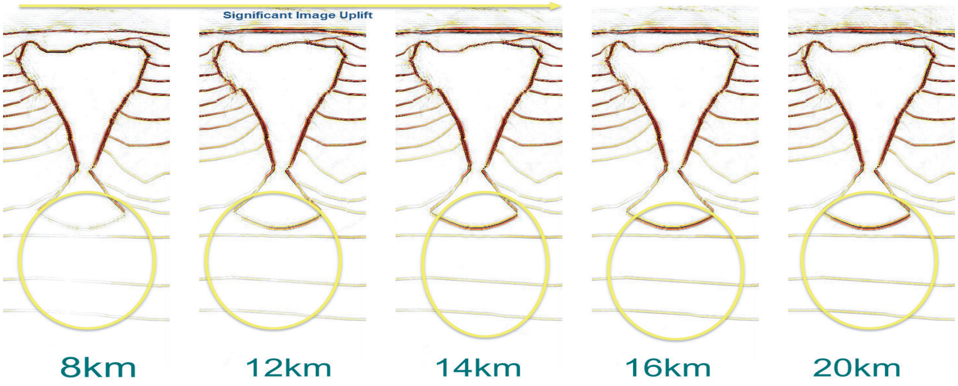

Figure 9. *2D finite modelling.*

nor the salt flanks (although the overall number of hits increased). This will vary with the salt configuration but a reasonable conclusion is that offset is more critical in areas of salt diapirism.

A different story is clear when we look at the subsalt illumination. Figures 7 and 8 show the illumination hit counts for the 4 x 9 and 4 x 16 km geometries for both the smooth and dipping deep horizon. The 4 x 9 km geometries for both horizons show poor illumination under the salt body. Now look to the dipping surface and it becomes clear that a material step change occurs between the 9 km and 16 km configuration. Considering that in reality it is known that this surface will not be completely smooth, the importance of long-offset data becomes critical to illuminating subsalt plays.

2D finite modelling

As validation for the above observations, additional finite difference modelling was conducted to assess the potential uplift from longer offsets. Using the existing PSDM volume and the associated velocity model (a data driven solution) a reflectivity model was created. Using this model, shot gathers were forward modelled with offsets to 20 km. These shot gathers were migrated using maximum offsets of 8 km, 12 km, 16 km and 20 km respectively and stacked with the same velocity model. The results (Figure 9), confirm the waveform modelling. Increasing the offset makes a limited difference in the sediment and salt flanks but makes a material difference in the subsalt illumination. The presalt horizon under the salt flank is visible with 8 km image but the material gain with offset to 12 or 16 km is confirmed. In this specific case, the difference in the images between 16 km and 20 km is not material and would probably not justify the additional acquisition expense.

Conclusions

Historical NAZ, WAZ and MWAZ data in the Gulf of Mexico has served its purpose well in illuminating sediment sections and salt flanks in areas of diapirism. As the industry moves to new deeper exploration and more complex salt overhangs, data driven solutions reveal that azimuth alone doe not provide the optimal solution. In the Kepler area it has been demonstrated for subsalt exploration the true value exists in acquiring long-offset data. It is critical in each scenario to assess the length of offsets required (hence the importance of data-driven solutions). In this study it can be concluded that the largest material uplift is in offsets from 8 - 16 km.

As a result of this case study new data has been acquired to validate these findings. Early results show validation of the modelling and should lead to materially improved subsalt imaging and greater understanding of subsalt paleo topography and the controls on exploration targets.

improving the illumination (why NAZ data was historically successful in the early days of exploration in the GoM). Additionally the conclusion from analysis of the results suggests for target horizons along the top of salt and in the sediment section can be successfully achieved with maximum offsets to 8 km.

Observations - presalt surfaces

Rose diagrams for the presalt surfaces tell a different story. Figure 5 shows a series of rose diagrams and illumination of the presalt surface (scenario 2 dipping horizon). This shows that although azimuth is still important, offset becomes the key factor in illuminating the subsalt surfaces. In this modelling the subsalt events were interpreted as a planar and a dipping surface to assess the difference in observations and represent what is known will be a rugose subsalt surface. The results of the comparison are key to subsalt imaging. As expected, the dipping horizon showed a preference for a NE-SW acquisition (based on the dip of the surface). The more staggering observation clearly illustrated by the rose diagrams is the amount of data contributing to the illumination beyond 12 km offsets.

3D wavefield reconstruction

To validate these observations, specific acquisition geometries were tested. The geometries were chosen based on historical WAZ acquisition parameters for the GoM with additional offsets (as identified above) to demonstrate their value.

The specific geometries tests were:

- 4 x 8 km shooting direction of 135˚ – subsalt horizons only.
- 4 x 9 km shooting direction of 45˚.
- 6 x 9 km shooting direction of 45˚.
- 4 x 12 km shooting direction of 45˚.
- 4 x 16 km shooting direction of 45˚.

The results of this step are shown via illumination hit maps (Figures 6 - 8). As the benefits of MWAZ acquisition are well documented the primary purpose of this step was to show the uplift of long offsets. Figure 6 shows a comparison between 4 x 9 km (A) and 4 x 16 km (B) acquisition. The results confirmed the previous observation that the offset beyond 8 km does not make a significant contribution in imaging the sediment section