Imaging beneath the Florida Escarpment progressing from 2D, 3D and anisotropy : A case history

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Summary

The Florida escarpment is one of the most dramatic bathymetric features in the Eastern Gulf. In places it reaches more than 1600m above the abyssal seafloor. Dips of 40 degrees are frequent, and vertical cliffs are not uncommon¹. This feature along with geological complexities of carbonate and salt regimes present imaging challenges that are addressed through the use of:

- True azimuth 3D SRME
- Pre-stack Depth Imaging
- 3D imaging
- Anisotropic imaging
- Tomography
- Post-migration residual demultiple

The long history of imaging in this area will be reviewed. Incremental improvements in data quality and interpretability will be shown. Processing efforts started with a grid of 2D lines using PSTM imaging algorithms. Subsequent efforts included SRME for multiple elimination, PSDM and tomography. Latest results are from modern 3D acquisition utilizing 3D true azimuth multiple elimination, anisotropic pre-stack depth imaging, and post migration residual demultiple.



Figure 1: 2D grid of area

Introduction

TGS has a long history of collecting and processing data in this region of the Gulf of Mexico. The first major coverage of the area was two large 2D programs (see Figure 1). The lines were acquired in the late 1990's. Total acquisition mileage was over 23,000 miles. The data was acquired on a 2km grid shot generally strike and dip to the escarpment feature. An infill survey on a 1km grid was shot in the DeSoto Canyon and Lloyd Ridge blocks.

A portion of the initial processing of this survey included Kirchhoff pre-stack depth migration and 1D velocity updates.

Subsequent reprocessing efforts in 2007 included SRME for demultiple, tomography for velocity updates, salt and carbonate layer velocity interpretation and Wave Equation pre-stack depth migration in addition to Kirchhoff pre-stack depth migration for the final imaging.

The most current reprocessing of a portion of this survey added more detailed preprocessing as well as several more passes of tomography to high-grade the velocity model.

In 2009 a 370 block 3D survey was acquired and processed over the Desoto Canyon area. Preprocessing included 3D true azimuth demultiple (TAME)², Radon residual demultiple. Depth imaging tools included: VTI anisotropy, 3D tomography, salt body interpretation, VTI Kirchhoff pre-stack depth migration and VTI wave equation migration. Post migration interbed multiple modeling and subtraction were also done on portions of the final survey.

Imaging Strategy

One of the main goals for the 2D reprocessing of the data in 2007 was to better image structures by refining the velocity model and to better attenuate the surface related multiples. SRME was used to better remove multiples. In general this proved to be quite effective, but as there is a significant 3D component to the waterbottom structure in the area of the escarpment it was not completely successful. An additional pass of Radon demultiple was used to attenuate remnant multiple energy.

Deriving an accurate imaging velocity via tomography also provided some challenges. In the shallow water areas there was a somewhat thin layer of compacted sediments, followed by a fast velocity carbonate sequence. This fast velocity zone was followed by a faster carbonate layer in the deeper section.

Tomography has a somewhat difficult time imposing sharp velocity contrasts. Salt/sediment interfaces are an example where large velocity contrasts are best handled by interpretation of surfaces and imposing predefined velocity values. The strong velocity contrast at the

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sediment/carbonate interface is another area where this method might be attempted. The carbonate velocity in this region is not a simple constant velocity, as in areas of more pure halite.

Due to these complexities, a hybrid approach was undertaken to build the velocity model. Initial tomography runs were focused on the sediment section above the carbonate sequences. Once the sediment velocities were determined, carbonate horizons were interpreted and loop tied. Constant velocities were flooded beneath the two interpreted carbonate zones. A velocity of 4000m/s was used for the shallow layer, and 5000m/s was used for the deeper carbonate layer. Next, tomography was run in the carbonate layers to further refine the velocity and add variations within that layer. Interpretation of salt structures was also done. A constant velocity of 4500m/s was used for the velocity inside the salt.

Finally, a pass of tomography was run to update the velocities beneath the deepest salt and/or carbonate sections. Final imaging included pre-stack Kirchhoff depth migration in addition to common shot pre-stack wave equation migration.

In 2009 a portion of the 2D survey was again reprocessed. This effort focused mainly in the portion of the data close to the escarpment feature. Preprocessing focused on source signature estimation and demultiple. Imaging improvements focused on using several additional iterations of tomography to better define the velocity model. There were marked improvements resulting from the extra effort, though the 3D effects of the escarpment area still proved to be problematic.

Later in 2009, acquisition of a 3D survey over the area was completed. Time preprocessing of this data utilized 3D true azimuth multiple elimination (TAME²) for surface related multiples and high resolution Radon for residual and interbed multiples. Indeed there was quite an uplift gained in multiple reduction when compared to 2D SRME.

The initial velocity model for this survey started from the velocity work done on the 2D data. Since this processing effort would incorporate VTI anisotropy some modifications would have to be made.

The biggest hurdle in estimating the epsilon and delta fields was lack of well control within the survey. The deep water area of the survey (where the sediment section was substantially thicker) tied in with an existing anisotropically imaged 3D survey that did have the benefit of checkshot information. Additionally, one well on the shelf (DC512) tied with a 2D line that was extended from the survey. The epsilon and delta fields from the adjacent TGS deepwater survey were used to derive average functions. These average functions were extrapolated along horizons parallel to a smoothed water bottom surface. The resulting fields were used to calculate a V_z velocity field from the 2D velocity field. The resultant trend was compared to the velocity at the well location on the shelf. Additionally, the epsilon and delta fields were scaled down at the level of interpreted carbonate boundaries. Several iterations of tomography were performed in the sediment section. This was followed by iterations of tomography in the carbonate layers.

In the northern areas of the survey, salt bodies would have to be modeled. Iterations for top salt, base salt as well as two iterations to define overhang features were run.

Once the salt bodies were defined, a final deep pass of tomography was run to refine the velocities in the deep section. Final imaging was done using anisotropic Kirchhoff PSDM as well as shot domain WEM.

In reviewing the results it was noted that there were still remnant multiples present in the deep section. This multiple energy did not appear to be surface related. There were many high impedance contrast layers in the carbonate section (where velocities are already quite high). This set up the framework for a series of interbed multiples that had movout curves similar to primary events. These multiples were quite difficult to separate from primary events in either Radon domain or FK domain.

A new technique of post stack modeling of multiples using WFE³ was attempted. Modeled multiples were subtracted from the data with some quite encouraging results.

Examples

Figure 2 below shows the improvement for each process. A line is tracked from 2D processing to final 3D processing.

The top section in this figure is taken from the 2007 depth processing of a 2D line. Note the dramatic drop off in elevation and the image distortion beneath.

The next section shows the result of the 2009 reprocessing effort. The additional tomography helped with focusing of the energy, as well as improving on the structural dip in the area. Surface related multiple energy has also been reduced.

The third section of this figure shows the result of the 3D acquisition and processing. The structures at the water bottom in the area of the escarpment are much better focused. Deeper structures are more focused and events can be followed further up under the escarpment.

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Figure 2: The four images show the incremental improvements going from 2D pre-stack depth migration to a reprocessing effort (additional tomography steps and 2D SRME, to a 3D KPSDM with 3D demultiple and anisotropy, to 3D pre-stack WEM.

The bottom section of Figure 2 shows the result after 3D pre-stack wave equation migration.

Key geologic target zones at the Haynesville and Norphlet level were also improved with the 3D imaging in the shelf areas near the escarpment and the extension of these layers



Figure 3: The top image is the standard post-migration enhancements. Bottom image is after model based post migration demultiple.

in the deep water section.

Figure 3 shows the results of the poststack demultiple procedure. Note the events parallel to shallow dip that are out of character to the regional dip in the upper left hand side of the section. Similar events can be seen in the lower right hand side of the section. In the bottom section these anomalous small dip features have successfully been attenuated with the post stack demultiple procedure.

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Figure 4 is an arbitrary line extracted from the final migration volume. Note the pinnacle feature at the water bottom. There complex features are found throughout the escarpment area.

Conclusions

Incremental improvements were made with each successive processing/acquisition effort. Still there is room for improvement. Imaging directly beneath the escarpment is probably not optimal. Scattering of the wavefield still presents imaging challenges.

A few years down the road it will be interesting to see the improvements to be made with enhanced acquisition (WAZ) and imaging RTM.

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EDITED REFERENCES

Note: This reference list is a copy-edited version of the reference list submitted by the author. Reference lists for the 2010 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.

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