Enhanced Structure and Subsalt Imaging of the Perdido Fold Belt Offshore Mexico

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Summary

We present a case study on 2D Prestack Depth Migration (PSDM) project, acquired in a complex geologic setting in offshore Mexico. The complexity is related to fold systems, irregular salt structure with the occurrence of sediment carapace on top of salt, and a low-velocity shale diapir.

To overcome the imaging challenges and achieve a correct image of the subsurface the methodology we use includes a high-resolution image-guided tomography (IGT), improved salt interpretation by examining the 2D lines in 3D visualization and based on focusing and continuity of subsalt reflections, interpretation driven modeling (IDM) to remove structural distortions, and subsalt tomography followed by directional image stack (DIS) to improve the subsalt image.

The use of TTI anisotropic Kirchhoff PSDM combined with TTI Reverse Time Migration in the model building provided accurate velocity model and high quality image especially in the presence of complex geology.

Introduction

The Perdido Fold Belt is located offshore Mexico, in the Western part of the Gulf of Mexico (Figure 1) and consists of fold systems, faults and salt bodies of complex structures. The fold systems are NE-SW trending, cored by autochthonous middle Jurassic Louann salt and bounded by steep reverse faults. The Perdido Fold Belt contain folded Cretaceous to Eocene sedimentary rocks and overlies rifted transitional crust. Recent major discoveries of hydrocarbons resulted in several exploration activities in the Perdido Fold Belt. The anticlinal structures are the potential hydrocarbon traps and the potential reservoir rocks include Cretaceous fractured carbonates and Tertiary turbidite sandstones (Fiduk et al., 1999; Trudgill et al., 1999).

The project is part of Gigante 2D, a 186,000 km regional 2D seismic survey acquired in 2016 by TGS. The objectives of the TTI imaging in the area are to obtain high resolution velocity model and high quality seismic image with properly imaged suprasalt, salt bodies and subsalt reflectors.

The main challenges in the imaging include:

- complex structures (folds and faults) resulting in strong lateral and vertical velocity variations,
- irregular salt geometry hindering the illumination of deeper reflectors due to ray path divergence at salt boundaries, and
- deep seated shale layers producing low-velocity regions that are difficult to define with the standard model-building tools such as reflection tomography.

In addition to these, the presence of minibasins, a sediment carapace and out-of-plane reflections increase the complication in imaging by creating rapid changes of the velocity, high-velocity contrast and artifacts.

In order to overcome the imaging challenges and to obtain a high resolution velocity model and high quality image of the subsurface, we incorporated high resolution image guided tomography (IGT), improved salt interpretation methodology and interpretation driven modeling (IDM).

In this paper we present a workflow detailing the TTI anisotropic velocity model building steps and the prestack depth migration results. The TTI imaging process starts from initial model building, then imaging suprasalt region, and progressing to iterative salt model building and finally subsalt imaging.

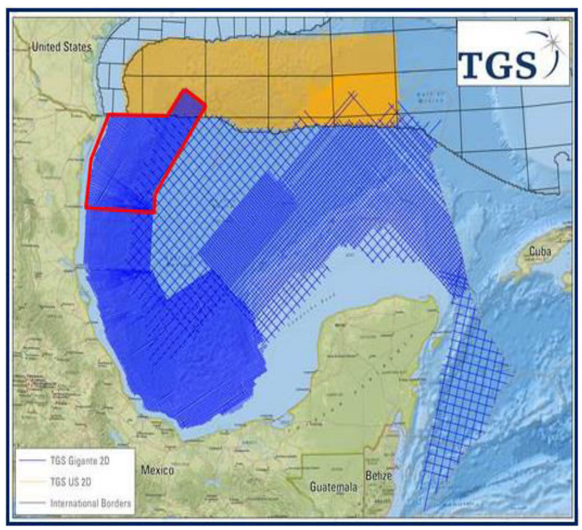

Figure 1. Location map of the project area.

Preprocessing of input data

The 2D seismic data in the Perdido Prestack Depth Migration encompasses 29,000 km with 5 km by 5 km grid spacing, 12 km source-to-receiver offset and 160 fold. The time preprocessing applied on the data mainly include shot and CDP domain noise attenuation, deghosting, 2D SRME, high resolution radon and apex-shifted demultiple.

Initial model building

The initial velocity model is derived from RMS velocity which is smoothed in 3D-consistent way and converted to depth-interval velocity domain. The 3D smoothing results in a velocity model which is consistent from line to line with a minimum mis-tie of velocity and reflectors after migration. After conversion, we attach a depth and spatially varying water velocity above the water bottom, and the model is calibrated with check shots. Isotropic Kirchhoff migration follows, using the calibrated model. We estimate the anisotropic parameters delta and epsilon at check shot locations by a focusing analysis (FAN) using the common image gathers from the isotropic PSDM. The FAN methodology (Cai et al., 2009; He et al., 2009) involves demigration to get the correct focusing operator, calculating focusing operators for different delta and epsilon values, and searching for the correct delta and epsilon values by minimizing the difference between the calculated and true focusing operators. The resulting delta and epsilon values are interpolated along key regional horizons. Then we compute the velocity V_0 from V_z using the estimated anisotropic parameters delta and epsilon.

Imaging Suprasalt region

In updating the suprasalt sediment velocity model the common image gathers from the Kirchhoff PSDM are produced on 100 m by 100 m grid and residual moveout curvatures are picked. Together with the dip estimate, three iterations of high-resolution image-guided tomography (IGT) are conducted. We apply image-guided tomography (Hale, 2009, Hilburn et al., 2014) in order to obtain a geologically plausible velocity model update which follows the complex structure (Figure 2). Image-guided inversion is a structure-oriented inversion preconditioning and involves defining an array of zones, calculating tensors which describe directionality and continuity of structures, and calculating structure-related propagation time (Hilburn et al., 2014).

For each iteration of the tomography, we use gather flatness, focusing and continuity of events, and checkshot ties for the validation of the velocity model. Figure 3 shows the resulting velocity model and migration.

Salt modeling

After the development of a reliable model for the complex overburden we build the salt model with an iterative application of TTI Kirchhoff and TTI RTM application. The interpretation of the top and base of salt in the area is challenging due to the irregular geometry of the salt, the presence of carbonate-dominated sediments or “carapace” sitting on top of the salt, and the out-of-plane reflections resulting in unwanted migration swings. Figure 4 shows three out-of-plane base of salt (BOS) reflections

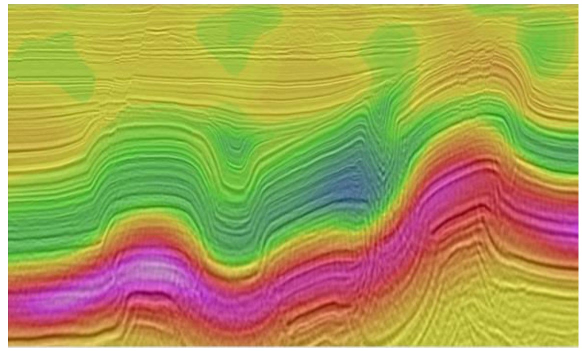

Figure 2. Migrated stack with IGT update overlay. The update follows the geologic structure.

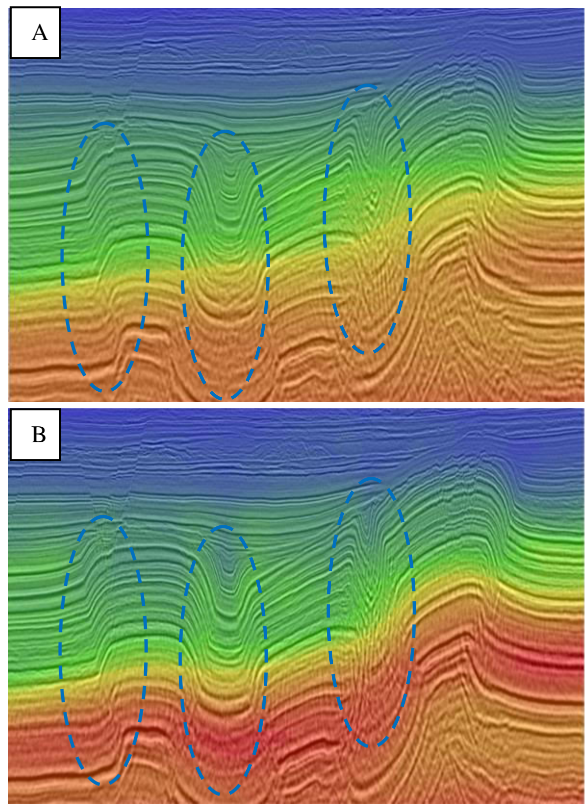

Figure 3. Velocity model overlay on corresponding TTI Kirchhoff PSDM stacks A) Initial velocity model B) velocity model updated with IGT.

appearing in a shallower part of the salt and the true BOS only appears in the intersecting line. If the base of salt is picked on one of the out of plane BOS reflections, the image will result in a “pull-up” of the image and not show the correct position of the base of salt and, therefore, not tie the intersecting Base of Salt which is clearly at a deeper level. True events will not position under this shallower base of salt.

In areas where the carapace occurs, the top of salt is ambiguous because of velocity similarity, and in this case the base of the carapace was picked as top of salt.

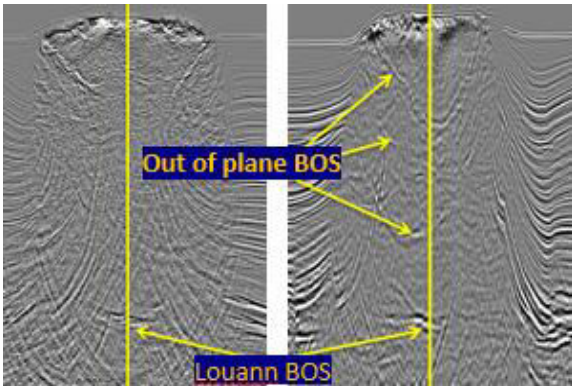

Figure 4. Salt flood migration showing true Louann salt base in both but out of plane BOS on one of the intersecting lines.

In order to obtain a correct salt model we incorporate a 3D-consistent modeling approach to the 2D interpretation with a two salt-body model. This helps obtain a geologically reliable salt-body model with a better tie and a thickness consistent with our expectation for the geologic area. Furthermore, in areas where the base of salt is not clear due to the position of the top of salt, out-of-plane reflections, and migration swings, a migration test is performed with thin vs thick salt modeling to see which interpretation results in a better subsalt image. The result shows that generally the subsalt image improves with a thicker salt by minimizing migration swings and enhancing subsalt reflectors (Figure 5). Figure 5 also demonstrates that picking the correct position of the base of salt is important to improve the quality of the subsalt image.

Interpretation Driven Modeling

The complex salt geometry and presence of a shale diapir in the Perdido Fold Belt produce areas of poor illumination and low velocity that are difficult to image using the standard model-building tools such as reflection tomography, which is based on ray tracing. To better image these areas a technique of interpretation driven modeling (IDM) is employed. In this case, the horizons below the anomalous zones are thought to be simple and continuous. Four horizon interpretations are performed: top and base of the anomalous zone, a detailed picking of the structure beneath the anomalous zone as imaged or “actual” and an interpretation of the model or “desired” horizon. We use the depth differences in the desired and actual horizons to derive a velocity update that changes the actual horizon to the desired horizon.

The result from the IDM produces a better image with minimized structural distortion and improved continuity and focusing of reflectors. The common image gathers from migration using the IDM updated velocity model show improved flatness (Figure 6).

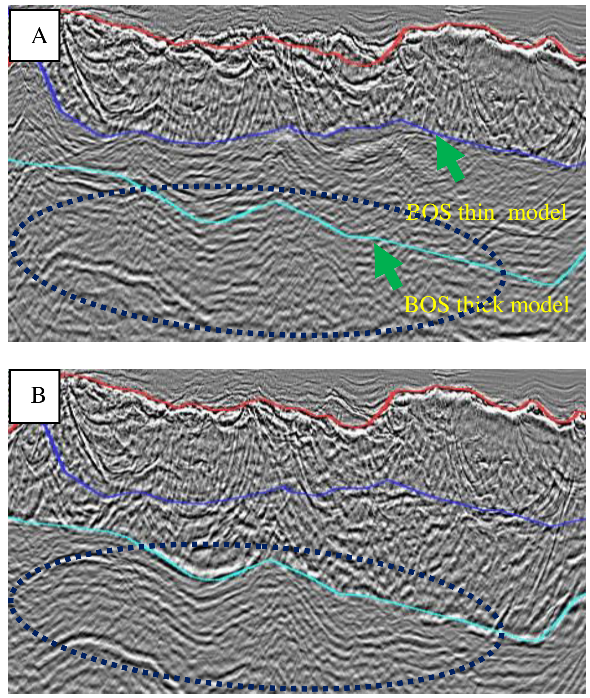

Figure 5. Kirchhoff migration with A) thin salt model and B) thick salt model.

Subsalt Imaging

Subsalt imaging of the area is very challenging due to poor illumination and noise related to the irregular salt body structure and occurrence of multiples. After the salt model definition and IDM, a grid based tomography is conducted to update the velocity in the subsalt region and the result shows an improved subsalt image (Figure 7).

To further enhance the subsalt image we apply a directional image stack (DIS). The main steps for DIS (Whiteside et al., 2012) include creation of RTM shot images; binning the shot images, according to their shot to an image-point offset vector; summing the partial images in each bin; and stacking the images based on unequal weights as a function of position. Figure 7B shows the improvement in signal-to-noise ratio and image quality of the subsalt due to the DIS.

Enhanced Structure and Subsalt imaging

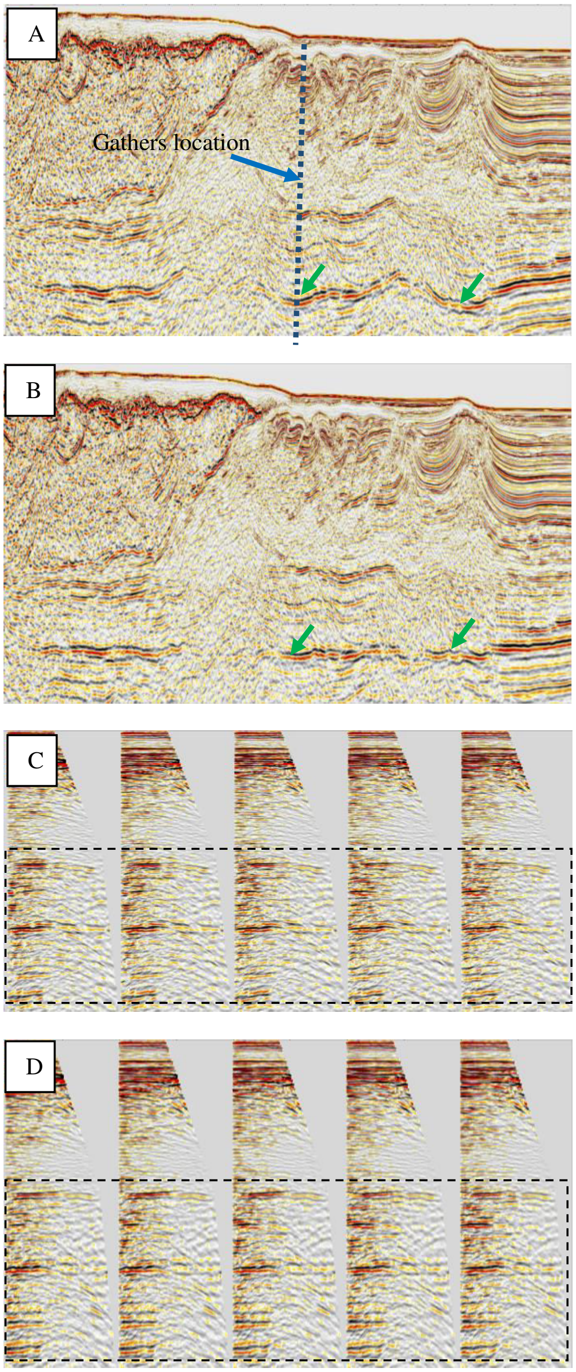

Figure 6. Kirchhoff migration: A and C before and B and D after IDM.

Conclusions

The application of high-resolution image-guided tomography and TTI migration combined with improved salt-body interpretation methods and interpretation driven modeling results in a high-resolution velocity model, a high-quality image of the overburden, an improved salt geometry and an improved image of the subsalt. The results from the PSDM project that we present show that in a geologically complex region using a combination of methodologies in addition to ray-based tomography is important for TTI imaging.

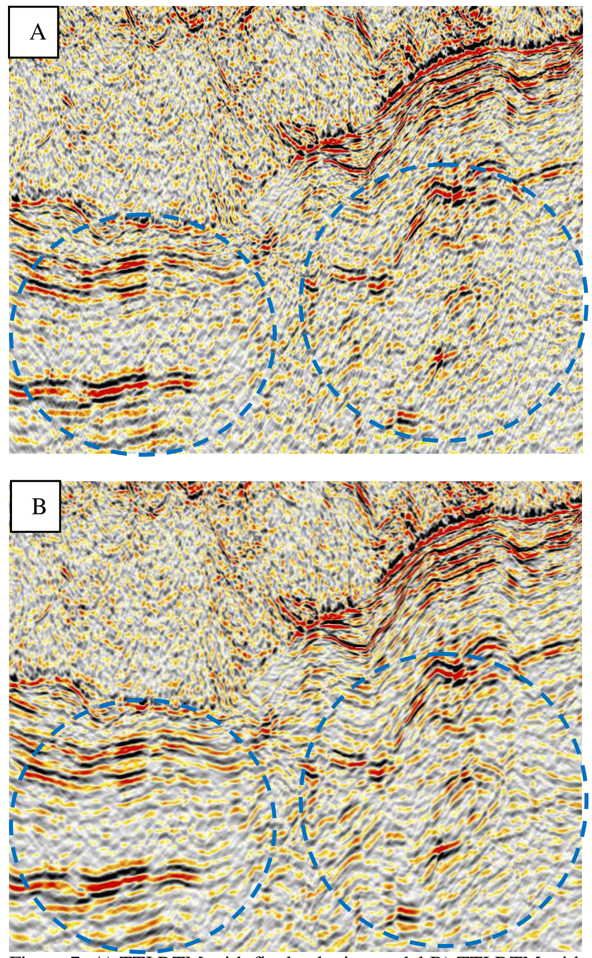

Figure 7. A) TTI RTM with final velocity model B) TTI RTM with final velocity model and after DIS.

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EDITED REFERENCES

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