Anisotropic Depth Migration and High-Resolution Tomography in Gulf of Mexico: A Case History

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Summary

We present a case study of an anisotropic prestack depth migration (APSDM) project which used high-resolution, shallow tomography and anisotropic model building for a large depth migration project in the Gulf of Mexico. The enhanced work flow resulted in high quality images and more accurate placement of events, compared to previous processing in the area.

The goals of this project were to produce a more accurate velocity model which would enhance event placement and improve the imaging of steep dips, salt boundaries, and subsalt events. To this end high resolution tomographic velocity inversion was employed to produce a more accurate velocity field. Additionally anisotropic prestack depth migration was used to better tie the seismic events with well information.

Introduction

We present a case study of an anisotropic prestack depth migration (APSDM) for Gulf of Mexico projects which used high-resolution, shallow tomography and anisotropic model building. Both VTI and TTI imaging algorithms were employed. The enhanced work flow resulted in high quality images and more accurate placement of events, compared to previous processing in the area. The results demonstrate the need for incorporation of TTI anisotropy for optimal imaging of complex structures.

The goals of this project were to produce a more accurate velocity model which would enhance event placement and improve the imaging of steep dips, salt boundaries, and subsalt events. To this end, high resolution tomographic velocity inversions were preformed. One particular area which had a shallow low velocity zone (previously addressed via refraction statics) was modeled using high resolution tomographic velocity inversion. Anisotropic prestack depth migration algorithms were employed to better tie the seismic events to the well markers.

All data was located in a mature area of the central Gulf of Mexico with many complex surface structures and geologic challenges. One benefit of working in such mature areas is that there is an abundance of wells. Hundreds of checkshot surveys were used in deriving the initial vertical velocity model. This checkshot information was also used for subsequent calibration of the velocity model yielding a better tie of the seismic data to the well information.

Method

Initial Anisotropic Model Buiding

Hundreds of checkshots were used as a starting point for building the initial velocity model. The checkshot velocity functions we reviewed and spurious trends were edited out. These edited checkshot velocities were gridded, interpolated and smoothed to generate the initial vertical velocity model V_z.
An isotropic Kirchhoff migration was run using the V_z model. The resultant depth image gathers were used in a two-parameter semblance scan. The semblance cube that was generated had three axes, which consisted of: depth, epsilon, and delta (two of Thomsen's weak anisotropic parameters, Thomsen, 2002). The maximum semblance on each of these depth slices would occur at the epsilon and delta values that would best flatten the gather at that depth. A semblance cube was generated for each of the key well locations. The semblance cubes were automatically scanned to estimate the optimal epsilon and delta trends. These epsilon and delta curves were then smoothed, interpolated and gridded to populate the 3D model. To verify the integrity of the epsilon and delta fields, these fields were used to remigrate the data, this time using anisotropic Kirchhoff prestack depth migration. Gather flatness, event focusing, and well ties were checked. Another iteration of parameter estimation was run, after which the initial anisotropic sediment model was complete.

High Resolution Tomography

The resultant V_z, epsilon and delta fields were then used as a starting point for tomographic velocity updating (Woodward,et.al, 1999). A full volume high resolution anisotropic prestack depth migration was output.

One particular area had a slow velocity anomaly related to a large trench extending off the Mississippi River delta. In order to correctly derive residual curvature estimates for the shallow data, a finer offset and depth sampling were deemed necessary.

The APSDM gathers were scanned for residual curvature. These values along with derived dip fields were input into the first tomographic inversion. In evaluating the residual curvature picks it was noted that there was a strong correlation between areas of positive residual curvature (indicating the need for a negative velocity update) and the previously derived refraction statics solution. A shallow slow velocity region is exactly what one would expect in the unconsolidated sediments of the trench area.

Shown in Figure 1 is the seismic image obtained before high resolution, shallow tomography.

Figure 2 shows the seismic image after migrating with the velocity field derived from high resolution shallow tomography.

The blue circles in Figures 1 and 2 indicate the slow velocity zone. Before tomography there is a pronounced event "sag" that is induced by the slow velocity anomaly. After tomographic velocity updates the "sag" is reduced. The events below this slow velocity zone are much improved. Previous processing schemes attacked this problem with refraction statics, which introduced distorted raypaths and resulted in inferior image quality.

Velocity Model Updating

The anisotropic sediment model was further updated with two passes of grid based tomography. For each of the tomography iterations, 3D anisotropic prestack Kirchhoff depth migration was run and residual curvature analysis was performed on the resulting image gathers. Automatic dip estimation was performed on the stack volume for use in the tomography ray tracing steps. A new dip field was created for each of the iterations that were run. V_z was updated from the inversion results, and well ties were rechecked and recalibrated. After recalibration of the velocity field, the epsilon and delta fields were then adjusted in order to preserve both flatness of the resultant gathers and the tie to the checkshots.

Accounting for the shallow velocity variations in the area allowed for better imaging and placement of events. Because the imaging was more accurate, sub-trench structures, including salt, were more correctly shaped and positioned. This in turn allowed for a more accurate dip field and, therefore, better tomographic velocity updates below the slow velocity zone. Having this shallow slow velocity region in the model had a positive influence in the region allowing for more accurate velocities and images all around.

The salt geometry was quite complex. In order to correctly define salt overhangs, the salt geometry was defined using four passes of APSDM. Initially, top of salt was picked on the image produced by migration with the final supra-salt sediment velocity field. At this stage salt boundaries interpreted from the seismic images were checked against top salt events picked from well data. V_z, epsilon, and delta were then adjusted accordingly in order for salt tops to image at the proper depths, while simultaneously preserving the image gather flatness.

After the salt geometries had been interpreted, a final tomography pass was performed for the sub-salt areas. In this iteration, sedimentary regions of the model, both under salt and away from the salt were updated.
Figure 3 shows a section from the previous processing effort. The red line on the section is the resistivity log from the well whose track is shown by the black line in the section. The yellow line is the gamma ray log from the same well. The characteristic kicks at the top and base salt show that salt is mis-positioned in this image. Salt is imaged deeper than the well would indicate.

Contrasted with the isotropic migration in Figure 3 is the anisotropic depth image shown in Figure 4. Note that the APSDM result has a much better tie to the gamma ray and resistivity logs at both salt-sediment interfaces. Additionally the steeply dipping salt structures are imaged significantly better than the previous results. Furthermore, the improved definition of the top salt geometry has resulted in a better focused base salt image as well as better subsalt images

Finally, in some areas it was felt that the image quality could be further improved using a TTI migration rather that VTI. Figures 5 and 6 show the result of including the an axis of symmetry to account for the dipping nature of the anisotropy. Event continuity in the dipping beds truncating at the base of salt is much enhanced.

Examples

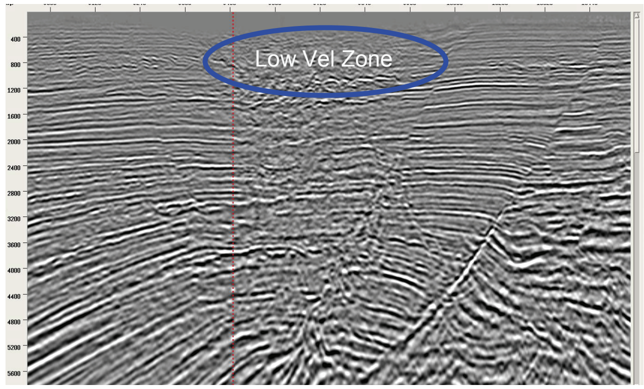

Figure 1 *Seismic section before high resolution tomography*

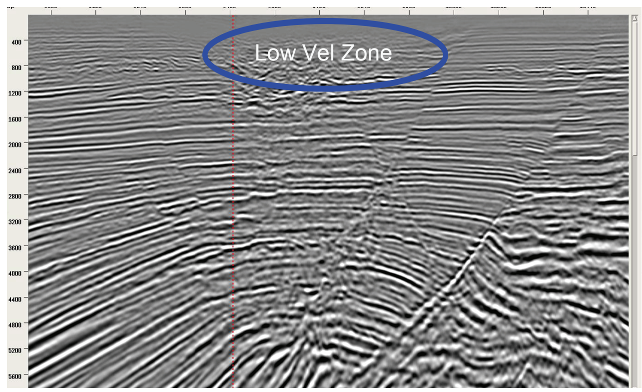

Figure 2 *Seismic section after high resolution tomography*

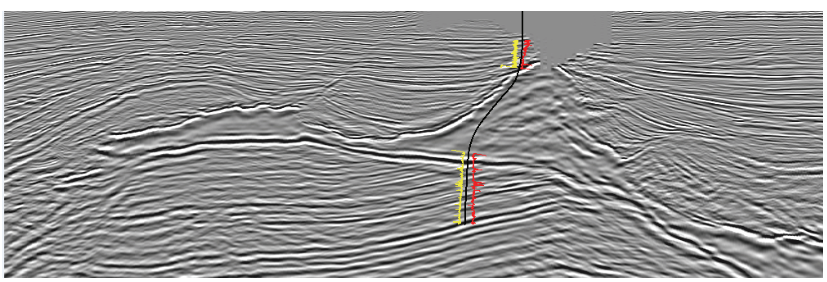

Figure 3 *Seismic section : Isotropic*

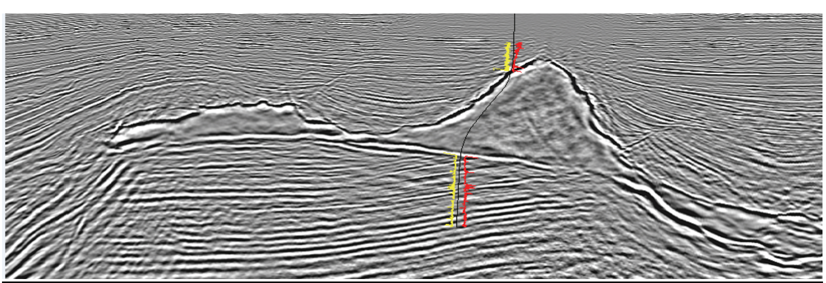

Figure 4 *Seismic section : VTI Kirchhoff PSDM*

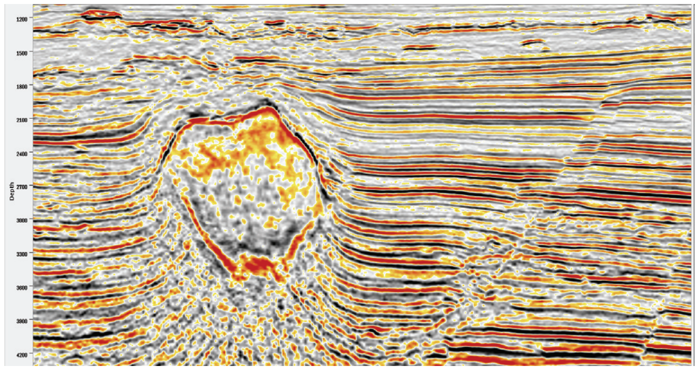

Figure 5 *Seismic section : VTI Kirchhoff PSDM*

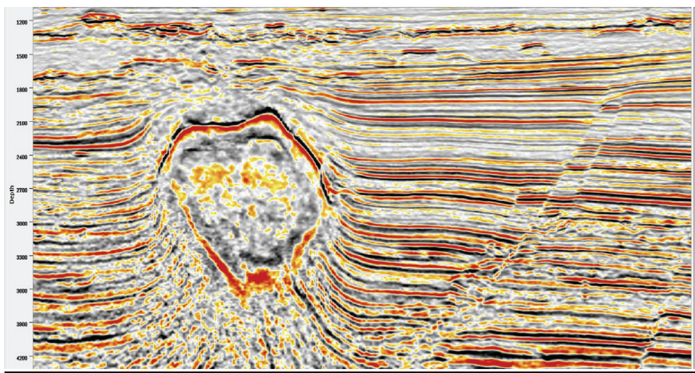

Figure 6 *Seismic section : TTI Kirchhoff PSDM*

Conclusions

The enhanced workflow for this project included using a well-tied anisotropic sediment model, anisotropic prestack Kirchhoff depth migration, modeling of salt bodies with overhangs, and iterations of both supra-salt and subsalt tomography, including two shallow, high-resolution iterations. This methodology resulted in a high quality image with more accurate event placement and geologic structures. Salt boundaries and steep or overturned events were imaged much better than in previous processing. Deep structures and subsalt events were more geologically sensible and had increased continuity. Addressing the slow velocity zone via tomography rather than using a refraction statics solutions resulted in better focused shallow faults and more realistic structures in the Timbalier trench.

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