Unlocking the Potential of WAZ data at the Tonga Discovery with TTI Reverse Time Migration
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Summary

Over the past decade, deep water Tertiary subsalt structural plays in the Gulf of Mexico have attracted a lot of attention from exploration companies. However, accurately imaging these reservoirs has been very challenging since they are very deep and obscured by thick salt. Fortunately, the availability of wide-azimuth data and the development of reverse time migration (RTM) have significantly increased our ability to image subsalt. Still, there is room for improvement. One area currently under development is the incorporation of anisotropy in subsalt imaging, especially tilted transverse isotropy (TTI). Wide-azimuth data contains more abundant azimuthal information than either narrow-azimuth or multiple narrow-azimuth datasets. This additional azimuthal information can be used to further constrain the estimation of TTI parameters.

The Tonga discovery is located in Green Canyon, Gulf of Mexico, and is about 10 miles from the Tahiti field. Analyzing a depth slice at 8000 meters shows a good quality Miocene reservoir from Tahiti to the Heidelberg discovery. The reservoir resides in a complex geologic setting, under a salt canopy and beside a salt withdrawal mini-basin. The steeply dipping, anisotropic overburden is more accurately imaged using TTI RTM, as the axis of symmetry is now taken into account.

Introduction

TTI depth imaging technology is routinely applied to image structures that lie beneath dipping, anisotropic overburden in the Canadian Foothills (Vestrum and Vermeulen, 2004), North Sea (Hawkins et al, 2002), and Offshore West Africa (Ball, 1995). Until now, ray-based migration algorithms served as the only choice for TTI imaging because upgrading them to handle TTI was straightforward and incurred minor additional computational cost. Unlike ray-based algorithms, TTI wave-base algorithms are difficult to formulate and their implementation is often unstable and computationally intensive. Unfortunately, ray-based algorithms perform poorly in comparison to wave-based algorithms with regard to imaging structures beneath complex overburden, such as the subsalt in the Gulf of Mexico. This impeded the use of TTI technology for subsalt imaging in the Gulf of Mexico.

There has been a surge of wide-azimuth (WAZ) data acquisition in the deep water Gulf of Mexico in the last three years, starting with BP’s initial experiment at Mad Dog and Atlantis (Michell et al, 2006; Clark et al, 2006). Due to the added azimuthal sampling on the surface, WAZ data provides better illumination of the subsalt regions than narrow-azimuth (NAZ) data. In addition, the abundant azimuthal sampling produces better noise cancellation and reveals TTI effects that are not apparent in NAZ data. Potentially, we can derive reliable TTI parameters from WAZ data. Motivated by this theory, Zhang and Zhang (2008) developed a stable TTI RTM for imaging complex structures. Combining TTI with RTM, we have processed several WAZ datasets in the Deepwater Gulf of Mexico.

In this abstract, we exam the imaging objective at the Tonga Discovery and the resultant issues associated with WAZ VTI imaging. Then we use simple 2D TTI synthetic data to demonstrate the pitfalls of ignoring the TTI effects for subsalt imaging. Finally, we demonstrate the benefit of TTI RTM on subsalt images using WAZ data at the Tonga discovery.

Tonga Imaging Challenge

The Tonga discovery is located in Green Canyon, Gulf of Mexico (Figure 1), along a trend of major hydrocarbon discoveries. It is under a salt canopy and located next to a salt withdrawn mini-basin (Figure 2). Wide-azimuth data were acquired in 2007 and the resultant isotropic migration provides a significant improvement of imaging quality over the NAZ data (Figure 3). The regional Miocene reservoir is clearly delineated in the WAZ isotropic volume at an 8000 meter depth slice. However, there are many areas that can be targeted for improvement, most notably in the area closest to the minibasin (highlighted in the green circle, Figure 3). The challenge is to provide a clearer image of the Miocene sand reservoir, especially where it truncates against the salt.
TTI RTM at the Tonga Discovery

VTI imaging at the Tonga Discovery

The first step in the VTI imaging was to calibrate the isotropic velocity with a checkshot to obtain the vertical velocity. In addition, the inverted delta and epsilon values were simultaneously derived at the well locations (Huang and Xu, 2007). Delta varied from 4 to 6 percent, while epsilon varied from 8 to 12 percent. Delta and epsilon measurements were interpolated along horizons to generate delta and epsilon models. Next, several iterations of VTI tomography were applied in order to flatten the gathers. Figure 4 shows a few of the vector offset gathers from the VTI migration in the mini-basin. There is inconsistent residual moveout among different offset tiles. The negative offset tile (offset_y = -2 km) exhibits over-corrected residual moveout, requiring a faster velocity to flatten them. The positive offset tile (offset_y = 2 km) exhibits under-corrected residual moveout, necessitating a slower velocity. The solution to this problem cannot be found using an isotropic migration or a VTI migration. Next, the solution of using TTI to improve the flatness of the gathers within vector offset tiles will be shown with the aid of a 2D synthetic.

Figure 2: a) Depth slice of isotropic WEM at Tonga Discovery. The purple dotted line denotes an outline of the Miocene reservoir; b) Top of Salt. The reservoir is under a salt canopy.

Figure 3: Significant imaging improvement from WAZ WEM (bottom), compared with NAZ WEM (top). The green circle highlights the area for further improvement.

Figure 4: VTI WAZ vector offset gathers in the minibasin. The map view location of the gathers is shown in Figure 2b (red star). The panel displays vector offset gathers from four different tiles (offset_y = -2 km on the left, and offset_y = +2 km on the right). Blue and green lines show the depth of two key subsalt events. Note the inconsistent residual moveout among the different offset tiles.
TTI RTM at the Tonga Discovery

A 2-D TTI synthetic study: TTI effect of a salt-withdrawal minibasin

This synthetic study aims to simulate the TTI effects of a salt-withdrawal minibasin. The 2D TTI model consists of four major units: water, suprasalt, salt, and subsalt. Water and salt are isotropic and have constant velocities. Suprasalt and sub-salt layers are TTI media with tilt axes normal to the sedimentary bedding planes. Their Thomson’s parameters ε and δ are 0.09 and 0.04, respectively. For simplicity, the suprasalt and subsalt layers also have constant velocities. Figure 5 shows the migrated image with velocity overlay on the left and a common-image-gather (CIG) selected from the center of the basin and its semblance on the right. The migrated image is perfect, because we used the correct TTI models (i.e. velocity, ε, δ, and the dip field or tilted symmetry axes). Neither the CIG nor semblance shows any residual curvature or depth errors.

Next, we produced a VTI image by setting the tilted symmetry axes to vertical. Figure 6 shows the corresponding VTI image, CIG and semblance. By setting the tilted symmetry axes to vertical, CIG is now over-corrected, and the semblance indicates up to 6% in depth error near the bottom of the basin. To reduce the depth error, VTI tomography was used to update the velocity field within the suprasalt layer. In this case, ε and δ were not updated.

Figure 7 shows the VTI image, CIG, and semblance using the velocity field derived from VTI tomography. Again, correct ε and δ were used in the migration. By ignoring the tilted symmetry axes, the tomography sped up the velocity to 6% within the minibasin. The updated velocity field resulted in flat CIGs in the suprasalt layer, but distorted the subsalt structure underneath the minibasin in Figure 3.

From this synthetic experiment, it was learned that flat CIGs can be obtained using either TTI imaging with a correct model or VTI imaging with velocity after tomography (in Figure 5 and 7). However, only TTI imaging yields correct subsalt structures. In practice, the correct structure is not known, and the CIG curvatures are mostly relied upon as a barometer to guide the workflow. Therefore, it is difficult to judge the validity of TTI versus VTI imaging. In the next section, it will be shown that using additional azimuthal information from wide azimuth acquisition can reduce this ambiguity.

TTI RTM imaging at the Tonga Discovery

Starting with the same delta and epsilon parameters, VTI and TTI tomography were applied, resulting in separate VTI and TTI sediment models. The respective salt geometries were derived and inserted, creating the final velocity models. The data were then migrated with VTI RTM and TTI RTM algorithms. Figure 8 shows comparison of vector offset CIGs with VTI imaging and TTI imaging. TTI imaging flattens gathers, and overcomes inconsistency moveout patterns among different vector
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offset tiles versus the VTI imaging. Geologically, the main salt body dips to the right and a well imaged TTI subsalt section shows up-dip truncation to the salt weld. Overall, TTI RTM produced better images than VTI RTM, particularly along the steeply dipping salt flanks and the subsalt region underneath the minibasin (Figure 9). The results of TTI RTM on WAZ data are consistent with those from the 2-D synthetic data and dual-azimuth results (Huang et al, 2008).

Conclusions

Until now, the majority of RTM applications were performed on NAZ data for isotropic and VTI media. The development and applications of TTI RTM face two hurdles: first, the difficulty in numerical formulation and high computing cost, and second, the lack of azimuthal information of NAZ data to support the derivation of velocity and corresponding TTI parameters. Both of the hurdles are gradually disappearing. Zhang and Zhang (2008) showed that a stable 3D TTI RTM implementation is achievable for imaging complex structures such as subsalt in Gulf of Mexico. WAZ data with abundant azimuthal information are becoming the standard dataset for subsalt imaging.

At the Tonga discovery, TTI RTM unlocks the potential of Wide Azimuth data, and delivers imaging improvements that are fundamental to future development.

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Figure 8: Comparison of vector offset CIGs between VTI (left) and TTI (right) at the location in minibasin (Figure 2 – red star). TTI migration overcomes inconsistent moveout pattern among different offset tiles when compared to the VTI migration.

Figure 9: Comparison of RTM WAZ data in Tonga discovery with VTI imaging (left) and TTI imaging (right). TTI RTM yields better truncation of subsalt events against salt weld.