The benefit of tilted orthorhombic imaging on a FAZ dataset in the central Gulf of Mexico

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Summary

In the central Gulf of Mexico, tilted transverse isotropic (TTI) imaging is widely used to resolve anisotropic effects of steeply dipping events. However, in complex geological settings, where thin layers with aligned fractures are present, inconsistent residual moveouts in azithumal gathers are observed on TTI common image gathers (CIGs). These kind of residual moveouts cannot be easily resolved by TTI models and are mainly caused by azimuth-dependent velocity variations. In this study, we have integrated tilted orthorhombic (TORT) imaging and 5D regularized dual-coil shooting full-azimuth (FAZ) data in the model building to derive more detailed and accurate TORT models for depth imaging. After several passes of TORT tomographic updates, most CIGs of prestack depth Kirchhoff migration (KPSDM) are flattened arcoss different azimuths. In the subsalt area, we further update the velocity using common offset (COR) reverse time migration (RTM) tomography. Compared with legacy TTI images, the TORT RTM produces more focused shallow sediments and sharper faults images. In the deep area, the subsalt events are more continuous and interpretable.

Introduction

In the central Gulf of Mexico, tilted transverse isotropy (TTI) imaging is widely used to resolve the anisotropic effects of steeply dipping events and to improve subsalt images by combining narrow azimuth (NAZ) and wide-azimuth (WAZ) data. However, in the complex salt-withdrawl minibasins where the thin layers with aligned fractures and directional stress are present, inconsistent residual moveouts have been observed in the azimuthal common image gathers (CIGs). This azimuthually dependent velocity variation cannot be easily resolved by TTI imaging. The reason for this inconsistency among different azimuths has been studied quite a lot in the past few years (Li et al., 2012; He el al., 2013; Tiwari et al., 2015; Guo et al., 2017).

As seismic acquision improves and the recordings of long-offset and full-azimuth (FAZ) seismic data becomes available, it also becomes clear that this directional velocity variation is due to differential sendiment loading and/or aligned fractures in the shallow sediments. The fast velocity is polarized in the direction that is parallel to the principle stress; and the slow velocity is polarized in the weak direction (Lynn and Michelena 2011). To descibe more accurate velocity models and produce better images, a more complex anisotropic model – tilted orthrohmobic (TORT) is applied in the project to represent this azimuthal effect. Three orthorhombic symmetrical planes and nine parameters are required (Tsvankin 1997).

In this study, we use a subset data of dual-coil shooting acquisition in the Green Canyon area in the Central GOM. The dataset is over 360° full azimuth (Figure 1). 5D regularization is applied in the processing to fill the large gaps in offsets, to reduce migration artifacts and to improve the S/N and the residual curvature analysis in the model building where conventional seismic data is difficult to resolve. This FAZ dataset with 5D regularization provides us abundant azimuthal information to build and update a TORT velocity model.

We present a case study from TTI to TORT model building and the benefit of integrating TORT imaging and 5D regularized FAZ data to better delineate the shallow sediment events and to improve subsalt images.

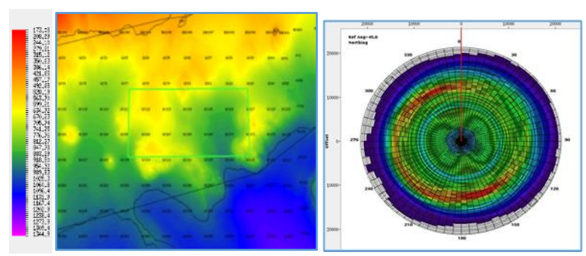

Figure 1 (left) Map view of the study area in the central US GOM overlaid with bathymetry; the green line shows the outline of the project. (right) Rose diagram of dual-coil shooting data over 360° azimuth coverage used in this study. North is defined as zero.

5D Regularization

5D regularization interpolates every output trace from all the input trace(s) within a CDP offset bin to a single trace at the bin center; and regularization is performed in: time, line, CDP, azimuth and offset dimensions. A computationally efficient 5D antileakage inversion is applied in time processing. For seismic data reconstruction, all output traces are regularized in each offset bin from an irregularly sampled grid to a regular grid that overcomes the spectral leakage difficulties (Whiteside et al., 2014).

In this project, 5D regularization output six azimuth datasets over 360° with an increment of 30°. The gathers from Kirchhoff prestack depth migration (KPSDM) for six individual azimuthal datasets are less noisy, more coherent and in turn better for residual curvature picking compared to those gathers using the conventional input data. It is observed that migration artifacts are obviously mitigated in the stacks.

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Tilted Orthorhombic (TORT) Velocity Model Building Workflow

During velocity model building, the FAZ data has been split split into six azimuths and regularized.

Figure 2 illustrates the TORT workflow. First, we perform multiazimuth TTI tomography iteratively. The goal is to reduce residual curvature on CIGs and then generate an initial model for TORT. Each of the six azimuth sectors are migrated and updated independently by residual moveout analysis and ray tracing. After two passes of TTI tomographic updates, most CIGs are overall flattened.

The key to building an orthorhombic model is to generate a set of delta and epsilon models corresponding to the local fast velocity orientation α, which is used to solve the inconsistency of the moveout of CIGs between different azimuths.Here, we applied six sets of individual updated TTI anisotropy models (δ and ε) to fit an approximate ellipse, and then derived a set of initial orthorhombic parameters (V0, δ1, δ2, δ3, ε1, ε2, α) (Li et al. 2012). Dip and azimuth models (θ and φ) are directly from TTI models. α is the fast velocity direction which is parallel to the strike of fractures or faults. Compared to five parameters for TTI models, a total of nine parameters are required in TORT models. In this project, three passes of TORT tomography are run to reduce velocity variations among six azimuths.

Both TORT KPSDM and RTM are used in the model building process.

Figure 3 compares the CIGs of six individual azimuths and the common-offset, common-azimuth (COCA) gathers from TTI KPSDM and TORT KPSDM. On the TTI CIGs, the inconsistency of residual moveout across the six azimuths is observed. The CIGs from 150° azimuth need a faster velocity, which indicates this is the azimuthal bin close to the expected fast-velocity direction in this study area. This fast-velocity direction is consistent to the strike direction of faults in the local supra-salt sediments. Comparing before (a) and after (b) TORT tomographic updates, the CIGs are flat overall across different azimuths; and the undulations are greatly reduced in the TORT COCA gathers.

In shallow sediments, four sonic logs are analysed and compared with the updated velocity to assure a seismic-well tie at the well locations. Also, TORT models are calibrated by populating the scalar locally to match the one check shot measurement

In the deeper subsalt area, common offset RTM (COR) tomography is applied to further update the velocity (Rodriguez et al. 2016). 5D data provides us better S/N and more coherent gathers for reliable picking at far offsets

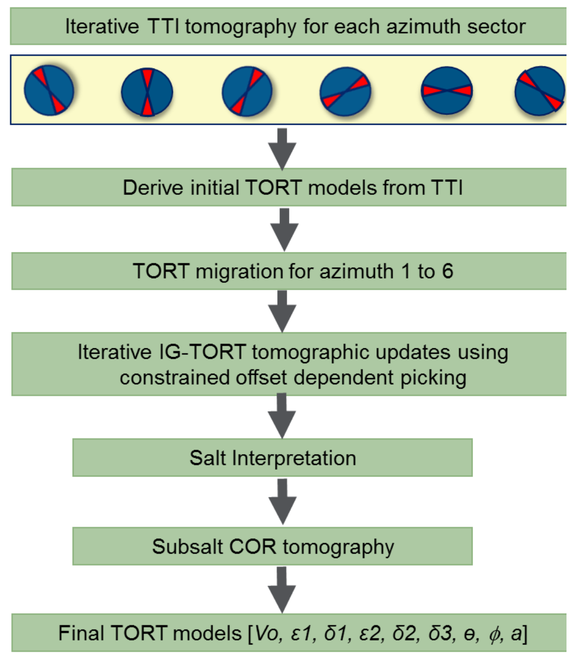

Figure 2 Tilted orthorhombic (TORT) model building workflow implemented in the project

which is often lacking in conventional data. After the subsalt velocity is updated, the migrated images show the deep subsalt events are more coherent and geologically conformable.

Results and Examples

Figure 4 compares depth slices at a depth 2500 m of the TTI image using conventional data and a TORT image using 5D regularized data after three passes of TORT tomography. The corresponding velocity models are overlaid with migrated images. First, the S/N of the TORT KPSDM image is highly improved. Second, shallow sedimentary events above the salt are more focused and the subtle faults become much sharper. Third, the more accurate.TORT models are carefully derived to correct for the tilted orthorhombic anisotropic effect for depth imaging.

Figure 5 shows TORT KPSDM stack compared with TTI sediment flood KPSDM image. In the salt-withdrawal mini-basin, aligned subtle faults become clearly visible on the TORT KPSDM image as the small arrows point out. The S/N is improved, and the migrated subtle faults become sharper, and thus easier for fault interpretation.

Figure 6 compares a final TORT RTM image before and after subsalt COR tomographic update in the subsalt area. Image uplifts are observed – the base of salt is better defined; the subsalt events are more focused and continuous; and the subsalt dipping sediments clearly truncated against the base of salt. Both salt and sediment models are different in this comparison.

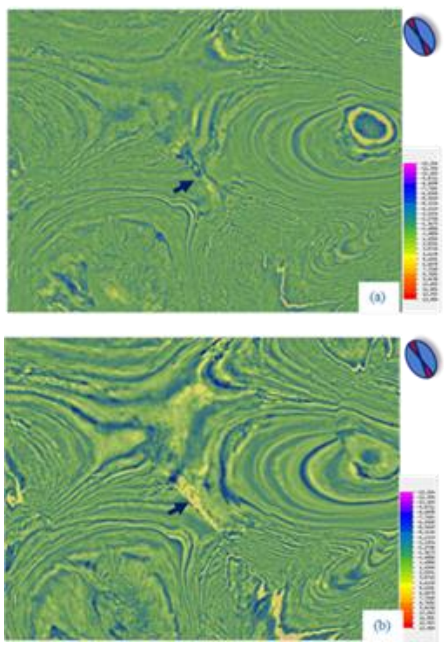

Figure 4 (a) TTI depth slice using conventional 3D binned data overlaid with TTI velocity model; (b) final TORT depth slice of this project using 5D regularization data overlaid with final TORT velocity model. Sediments are more coherent, and faults become sharper. The strike direction of faults is close to 150° from North in this area.

Conclusions

To improve model accuracy, integrating TORT depth imaging and 5D regularized dual-coil full-azimuth seismic data is an optimal way. By using regularized data, KPSDM gathers are less noisy, more coherent and better for residual curvature picking compared to those gathers using the conventional input data.

To correct anisotropic effects associated with the aligned faults in this study area, three passes of multiparameter TORT tomography have been carefully performed to improve gather coherency and flatness across different azimuths in the supra-salt area; and the undulations in the

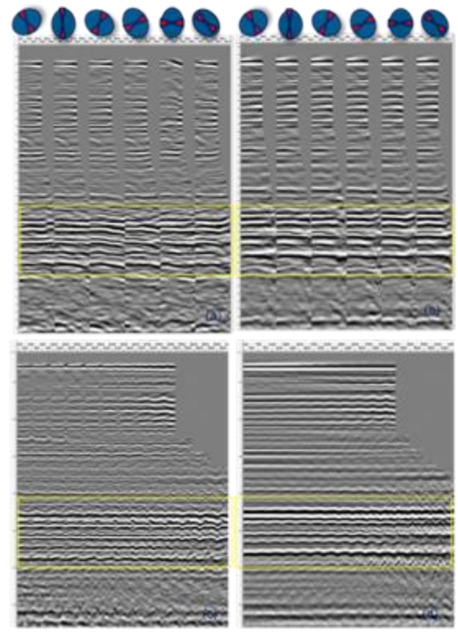

Figure 3 (a) TTI azimuth-offset CIGs show inconsistent curvatures across azimuths using conventional 3D binned data; (b) TORT CIGs are flat overall across six azimuths and missing offset is compensated by 5D regularization; (c) TTI COCA gathers; (d) TORT COCA gathers.

TORT COCA gathers are reduced. Comparing with legacy TTI imaging, TORT sediment models are more accurate in the shallow and further updated by COR tomography in the deep subsalt area. TORT RTM migrated images provide better-defined salt geometry, sharper faults and more continous subsalt events, which lead to easier seismic interpretation.

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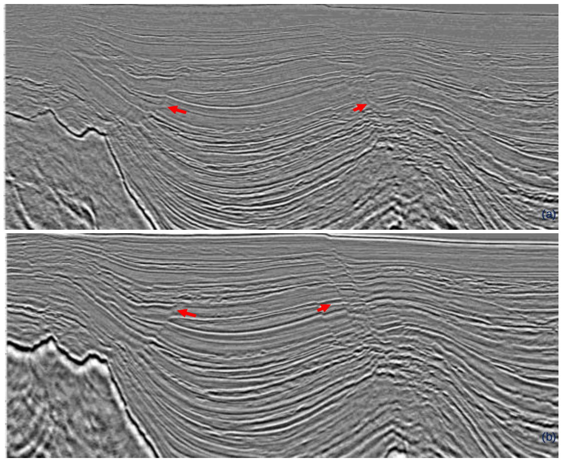

Figure 5 (a) TTI sediment flood KPSDM image using conventional 3D binned data; (b) TORT KPSDM image using 5D regularization data. The small red arrows show the sharper faults on TORT migrated image.

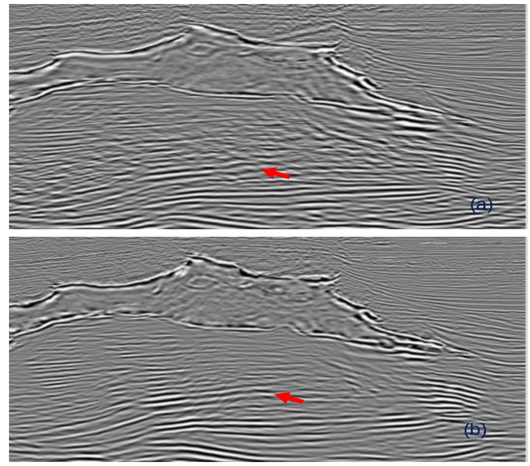

Figure 6 (a) TORT RTM subsalt image before subsalt COR tomohtaphy; (b) Subsalt image after COR tomography. The red arrows show the more coherent subsalt events with clear sediment truncation against the base of salt.

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