Improved subsalt imaging using TTI anisotropy and reverse time migration scans

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Summary

We present an advanced velocity model building and imaging methodology that resulted in significant enhancements in defining the salt flanks with overhangs and subsalt structures. The key technologies used were (a) True Azimuth Multiple Elimination (TAME), (b) Tilted Transverse Isotropy (TTI) model building (FAN), (c) TTI Reverse Time Migration (RTM), (d) RTM Delayed Imaging Time (DIT) scans and (e) post-migration multiple attenuation.

Approximately 39 OCS blocks of the Lena narrow-azimuth survey located in the Mississippi Canyon area of the Gulf of Mexico were imaged. The area was previously imaged with the Vertical Transverse Isotropy (VTI) Kirchhoff migration. Significant improvements have been achieved by reprocessing the same data with the new imaging methodology.

Introduction

It is well known that anisotropy must be taken into account for successful imaging of Gulf of Mexico seismic data. Whiteside et al. (2008) noted that typical depthing errors using the isotropically derived model in this region ranged from 5% to 12% at a depth of 6 km.

Traditional VTI imaging assumes the velocity changes are symmetric along the vertical axis. However, the VTI assumption often breaks down for dipping layers in mini-basins and steep dip truncations against base of salt. TTI honors the trend of the depositional systems and incorporates geological information, thus providing a better velocity model and seismic image.

The current study area, the Lena project, is located in the Mississippi Canyon area of the Gulf of Mexico. The PSDM area comprised 39 OCS input blocks (909 sq km). The input data to the 3D pre-stack depth migration was preprocessed to improve the signal to noise ratio. This flow included swell noise interference removal and 3D surface-related multiple attenuation. Debubble and water column static correction steps were also applied.

The TTI model building workflow used for this data set is given in Figure 1. There are five aspects of this project described below that make it unique: (1) TAME, a modified version of SRME, where the prediction of multiples is performed using the true azimuth, (2) FAN to define TTI anisotropic parameters, (3) TTI RTM as a model building tool as early as possible in the work flow to clearly define the salt geometries, (4) RTM DIT scans to update the subsalt velocities and (5) post-migration attribute based residual multiple attenuation.

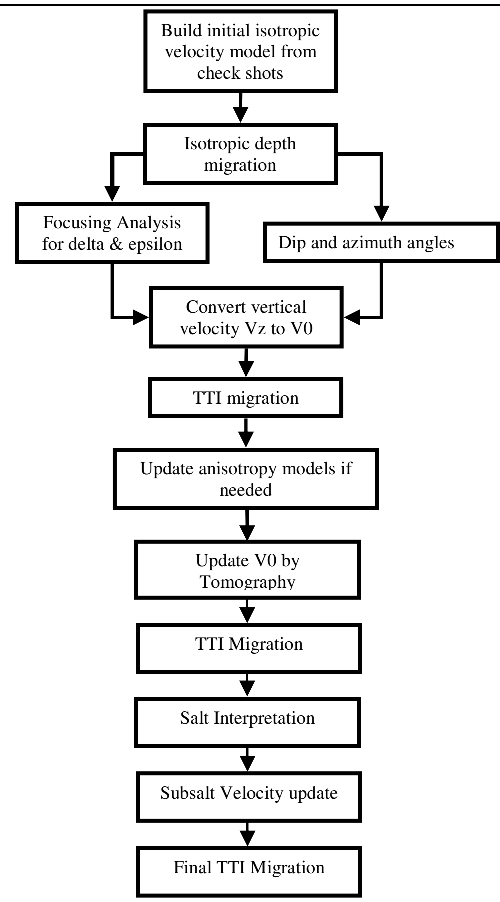


Figure 1: TTI model building work flow.

Multiple attenuation

We used TAME and high-resolution residual multiple Radon filter for multiple attenuation. TAME is a data driven, convolution based surface related multiple prediction and attenuation technology. The details of the technique are described in Cai et al. (2010). It includes three major components: (1) data interpolation/ regularization, (2) multiple prediction and (3) subtraction. Figures 2a and 2b show the input and output from the TAME processing.

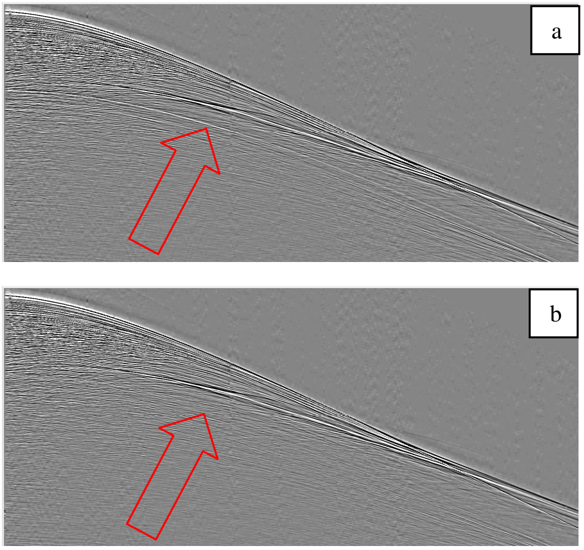


Figure 2: Shot record (a) input (b) after TAME adaptive subtraction.

TTI Focusing Analysis (FAN)

Thirty-one check shots were analyzed in the survey area. The seismic velocity model from a prior isotropic Kirchhoff migration was heavily smoothed and calibrated to generate the initial isotropic velocity model (Vz). The resulting vertical velocity model was used to generate isotropic PSDM image gathers (using Kirchhoff migration) and to estimate the TTI anisotropy parameters epsilon (ε) and delta (δ). These fields were derived using an automated FAN methodology. The details of the FAN approach are described in Cai et al. (2009) and He et al. (2009), therefore; only a brief summary is given here. The specific steps for the FAN analysis are as follows:

(1) Take a zero-offset migration image point in a Common Image Gather (CIG) as a focal point and perform ray based offset dependent demigration to get the correct focusing operator in the time domain.
(2) Construct the calculated focusing operators for the current anisotropy model from the focal point for different ε and δ values. The search for the correct ε and δ is done automatically using L1 optimization criteria (to minimize the difference between the calculated and the true focusing operators). The validity of ε and δ is evaluated by the flatness of the image gathers.
(3) Construct a volume of epsilon and delta through interpolation along key horizons.

We interpreted seven key horizons to define the axes of symmetry and built anisotropic model volumes (δ, ε) by interpolating and smoothing along the horizons. The estimated δ and ε models were used for all subsequent iterations of anisotropic migration. The anisotropy had a maximum of 6% for δ and 9% for ε.

Using a velocity perpendicular to the bedding (V0, computed from Vz), ε, δ, dip and azimuth, a first pass of TTI Kirchhoff migration was performed to check the gather flatness, focusing and well ties. Figures 3a and 3b show the gathers from isotropic and anisotropic migrations.

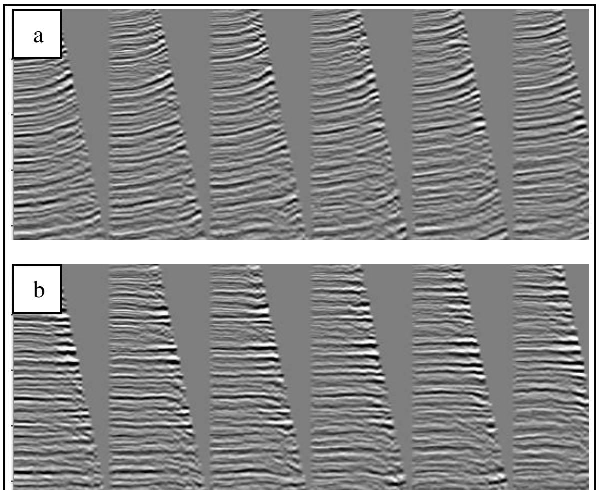


Figure 3: CIGs near a well location before (a) and after (b) anisotropic Kirchhoff migration.

Velocity Model Building and Salt Geometry Definition

Three iterations of volume based high-resolution grid tomography were performed to update the supra-salt sediment velocity model. For each of the tomography iterations, 3D TTI anisotropic pre-stack Kirchhoff depth migration was run. Automatic residual curvature analysis on the resulting image gathers and dip estimation on the PSDM stack volume were performed for use in the tomography. Care was taken to mask out rays passing through salt during the ray tracing stage. V0 was updated from the inversion results. Using a multi-scale iterative approach, long wavelength features of velocity anomalies were derived first. The short wavelength anomalies were gradually added in the subsequent iterations. Gather flatness, event focusing and well ties were checked after each iteration, and it was noted that further compensation for ε and δ was not needed.

The final sediment velocity model was validated against check shot velocities and salt top picks. The salt top picks from wells match with the PSDM seismic with less than 0.1% error indicating the accuracy of the velocity model.

TTI RTM and TTI Kirchhoff migration were run to define the salt geometry (top, base and overhangs). After the salt model definition, a grid based subsalt tomography was run to enhance the subsalt events followed by RTM DIT scans.

Subsalt Velocity Model Update (RTM DIT Scan)

DIT scan is a set of RTM images, typically 21 images created during the regular RTM run by applying the regular zero-time imaging condition and a time-shifted imaging condition. The details of this technique are given in Wang et al. (2009). The main steps for RTM DIT scans subsalt velocity updating are as follows:

1) Run RTM to create 21 DIT scan images, perform gather conditioning and form semblance panels.
2) Use a non-linear search to find the best DIT values, which maximize the semblances.
3) Compute the residual velocity using the picked DITs.
4) Update the subsalt velocity by applying smoothed residual velocities.
5) Compute the composite image using the back-computed DIT values to check the result.

Composite images are formed by selecting the DIT panels which produce the best focused, coherent images for quality control purposes. Figures 4a and 4b show the enhancements due to the DIT scans model update. The base of the turtle structure is improved after running RTM on the DIT updated velocity model.

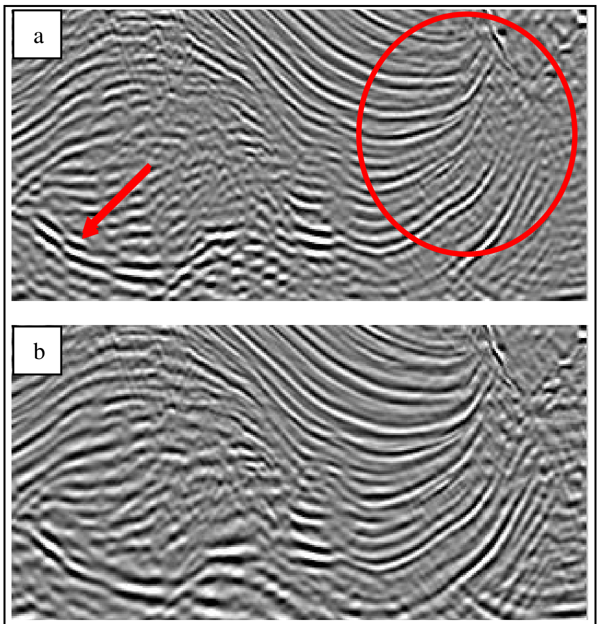


Figure 4: Image enhancement due to DIT scan velocity update before (a) and after (b).

Post-Migration Demultiple

A post-migration demultiple technique was performed which is based on a multiple prediction and adaptive subtraction method (Guo et al., 2008; Wang et al., 2010). The multiple of the base of salt (BOS) surface is predicted by ray tracing. Adaptive subtraction is used to attenuate the residual multiples according to the predicted multiple surface. Figures 5a and 5b show the effectiveness of the post-migration demultiple technique.

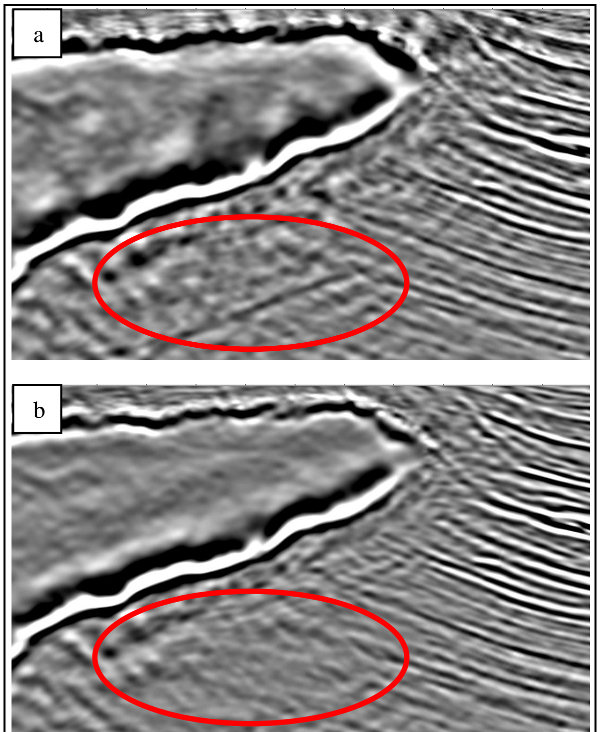


Figure 5: TTI Kirchhoff PSDM stack before (a) and after (b) post-migration demultiple processing.

Image Improvements

We built geologically constrained anisotropic models using a focusing analysis based TTI parameter estimation methodology and volume based grid tomography that tie the well information. The fault imaging improved through detailed anisotropic model building. We built salt models with iterative application of TTI Kirchhoff and TTI RTM. This helped us delineate the correct salt geometry whereas the previous imaged Kirchhoff VTI volumes failed to do so.

Figures 6a, 6b and 6c are the inline comparisons of VTI Kirchhoff PSDM (previously depth processed), current TTI

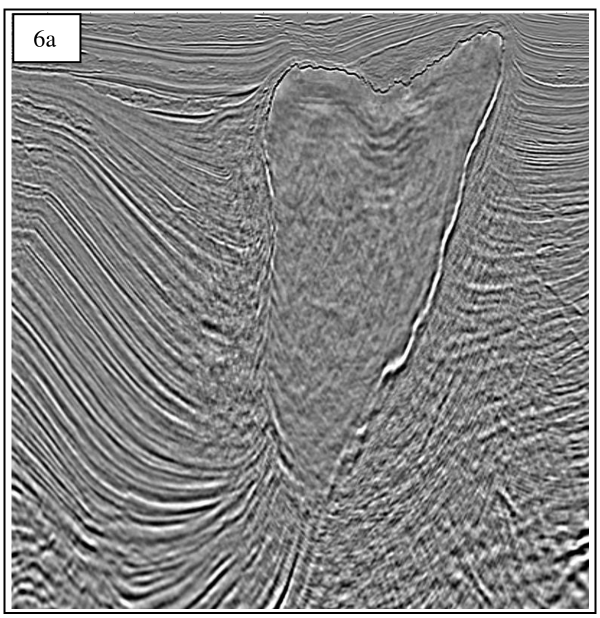
Kirchhoff PSDM and TTI RTM PSDM over a complex salt body. Note the clarity of the sediment truncation against the steeply dipping salt flank and the subsalt reflections in the TTI RTM image.

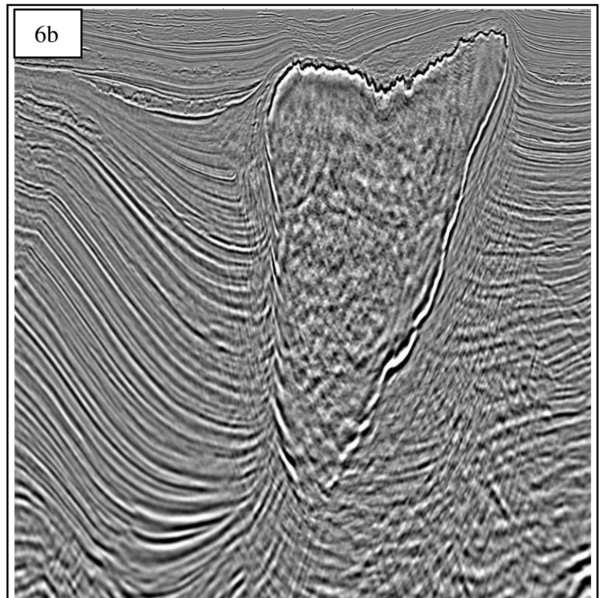
Conclusions

The improvements to the imaging were accomplished by (a) removing as much noise as possible from the input data without affecting the quality of the signal, and (b) utilizing new technologies such as true azimuth multiple elimination, TTI focusing analysis for anisotropic parameter estimation, TTI Kirchhoff, TTI RTM, RTM DIT scans for velocity update and post-migration demultiple. A combination of enhanced model building and migration methodology is the key to the success of the Lena project.

Acknowledgments

The authors would like to thank their colleagues Itze Chang, ZhongYang Dong, Sampath Gajawada, Manhong Guo, Yang He, Jean Ji, Zhiming Li, Xinyi Sun, Xuening Ma, Gary Rodriguez, Boedi Soelistijo, Bin Wang and Kwangjin Yoon for their valuable contribution during various phases of velocity model building, interpretation and depth migration processing. We also thank Laurie Geiger and Wilfred Whiteside for reviewing the manuscript and Simon Baldock and Randy Hebert for their support on this project. The authors wish to thank TGS management for support and release of the material for publication.





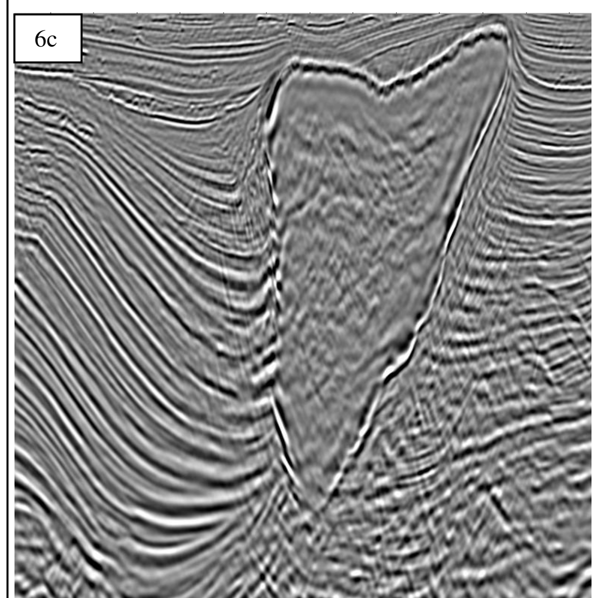


Figure 6: Inline comparisons of (a) VTI Kirchhoff, (b) TTI Kirchhoff and (c) TTI RTM PSDMs over a complex salt body. Note the improvements in salt body geometry, overhangs and the subsalt reflections in TTI RTM section.

EDITED REFERENCES

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