Multi-parametric earth model building with geological constraints in Santos Basin

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Abstract

The Santos Basin offshore Brazil is one of the pre-salt areas of complex geology. Models with multi-parameters that are geologically consistent would therefore improve imaging quality. In this paper we build such a model and use geological constraints to update the model. The results using a simple isotropic model show poorly imaged structures and velocities not consistent with geology. The improved TTI model with geological constraints closely follows the geology and the seismic gathers are flatter and seismic image improved. This workflow described in this paper would allow improved imaging of other areas offshore Brazil.

Introduction

There has been a series of significant pre-salt discoveries offshore Brazil, and thus an increase in demand for high quality interpretable images of the pre-salt targets in the deep water Santos Basin. The structure and salt present in the Santos Basin is quite complex and has several related imaging issues. In order to help resolve these challenges we require accurate and detailed models. This paper describes the use of (1) interactive and automated workflow to build an initial depth model with geological plausible detail of the anisotropic parameters from a time model and eta and (2) implicit and explicit geological constraints in tomography which would allow successful imaging of pre-salt targets and improve the quality and interpretability of the images in the Santos Basin offshore Brazil.

Method

The starting model for depth imaging is very important and should be smooth in nature and let tomography add detail. The more accurate the model the fewer iteration of tomography will be required, i.e., the initial model must be relevant to the actual geology. Additionally by introducing anisotropy we can obtain optimal structure image as surface seismic data alone cannot resolve all the parameters of an anisotropic subsurface.

Additionally to further improve image quality the use of geological constraints in the tomography were enabled by steering filters which utilizes structurally conformant 3D dip field extracted from seismic images.

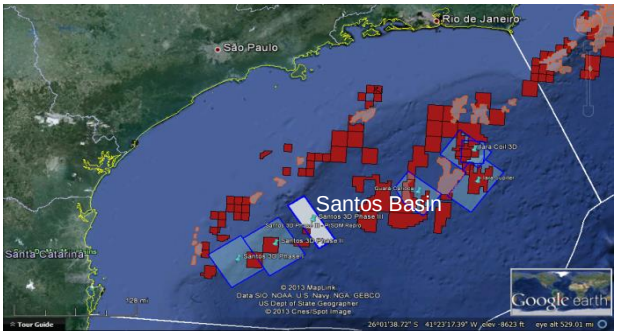

Figure 1 Santos Basin offshore Brazil

Building initial multi-parametric earth model

The methodology used for building this initial model was as follows. 1) InVA software in Omega using VIVA, Visually Interactive Velocity Analysis which is an interactive and automated time velocity analysis. This workflow allowed time domain VTI velocity model updating using the nonlinear VTI travel time inversion (Fowler et all 2008) and derivation of anellipticity eta (η) which was geologically spatially variant. 2) Derivation of Thomsen's delta (δ) at well locations in the area 3) Multi-Well Analysis toolkit in Petrel SVM that allows user to build anisotropic depth model using time model with eta and Vpn and a depth model with delta and automatically calculates Thomsen Epsilon (ε). 4) The angles describing the tilt of the anisotropy axis were derived from the initial seismic image and updated at any tomography iteration. 5) Model building with all five 3D property fields which are required to describe a TTI medium, and then validation of the model.

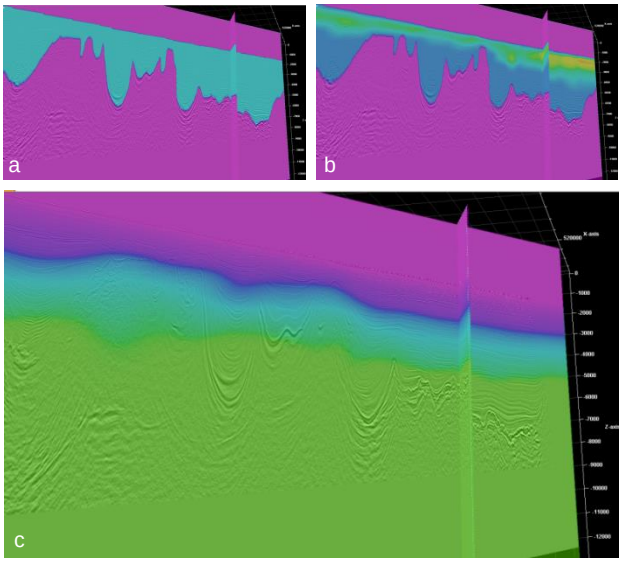

Figure 2 (a) Regional 3D δ delta field; (b) Detailed 3D epsilon field and (c) Initial 3D Vp field.

Improved TTI model with geological constraints

The model was updated using multiscale common-image-point (CIP) tomography (Woodward et al. 2008) for *Vp* refinement.
This CIP tomography is an iterative process that updates model properties from long scale length to short. CIP picks which represent the multi-parameter moveout and reflector dips from seismic image are used to generate linear equations using ray tracing. These equations are then solved and the result relates changes in the model to changes in the data measurements.
The use of geological constraints in tomography aims either to speed-up the conversion or to enable updates in areas with lower illumination and insufficient number of picks.
In this case-study, steering filters using a structurally conformant 3D dip field obtained from seismic images was used. We can observe (Figure 3) that with the use of steering filters the update closely follows the geology as expected. Additionally an explicit geological constraint based on top of salt interpretation, isolated the sediment zone for update.

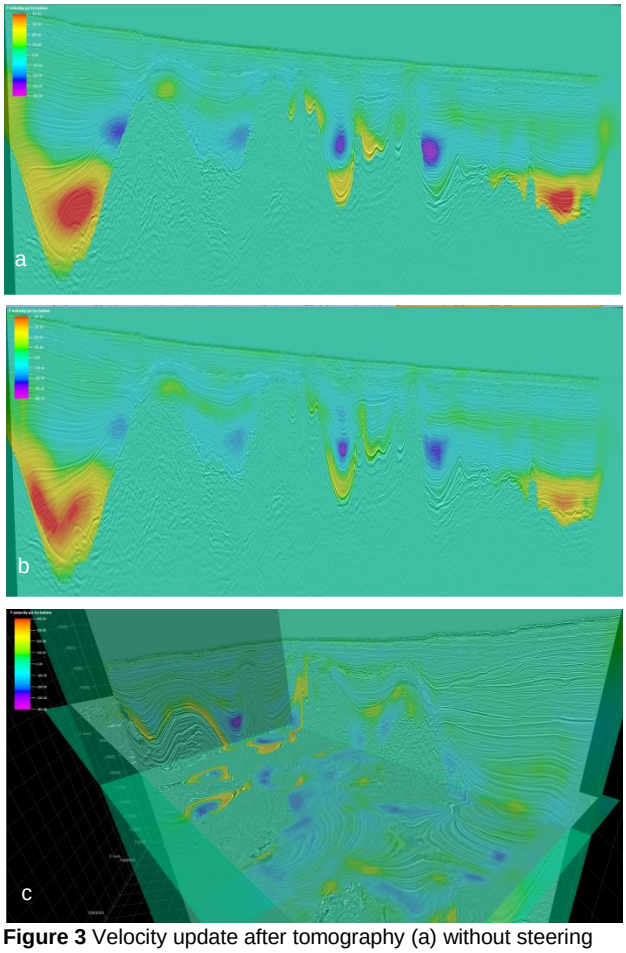

Figure 3 Velocity update after tomography (a) without steering filter; (b) with steering filters and (c) model view with steering filter.

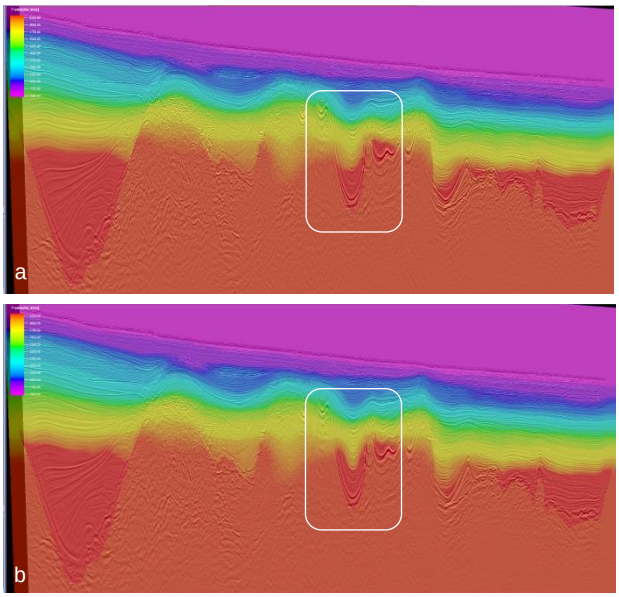

Figure 4 Velocity properties after tomography (a) without steering filter; (b) with steering filters.

Results

The 3D TTI initial model with regional constant delta, spatially variant epsilon and initial Vp was built and then validated. In the figure below we compare sediment images produced with the legacy isotropic model and the regional TTI model. The results produced with the isotropic model show poorly imaged geological structure in the deeper portions of the sedimentary basins, especially in areas with high dips. This use of a spatially variable ε and δ fields would improve the imaging of the pre-salt targets in the Santos basin area.

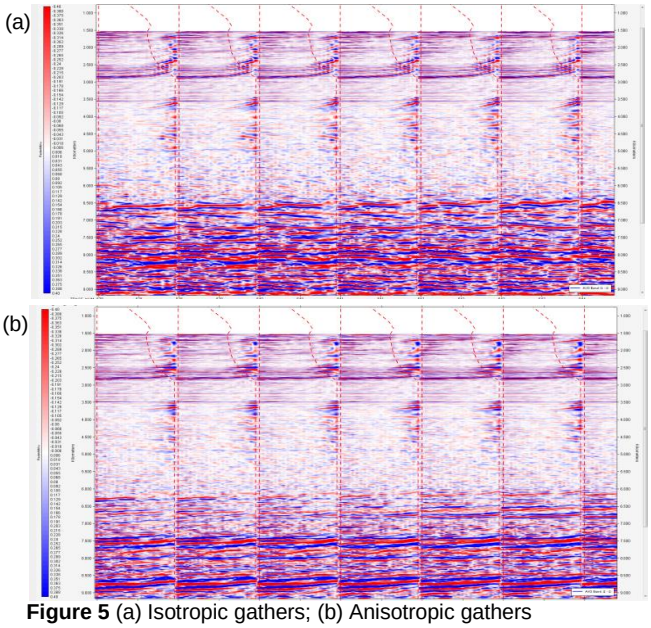

Figure 5 (a) Isotropic gathers; (b) Anisotropic gathers

The model with TTI properties produced much better images of flanks of the structure and the structure itself is broader, and simplified. The base of salt is much flatter and better focused. Also the velocities are well behaved and the residual moveout of the gathers was reduced significantly for the TTI model. Based on all these improvements, we can conclude that a TTI medium explains the seismic data much better than that of an isotropic medium.
We can observe (Figure 6b highlighted in red) a very well-focused image with reasonable geologically plausible base of salt and interpretable pre-salt events at depth.

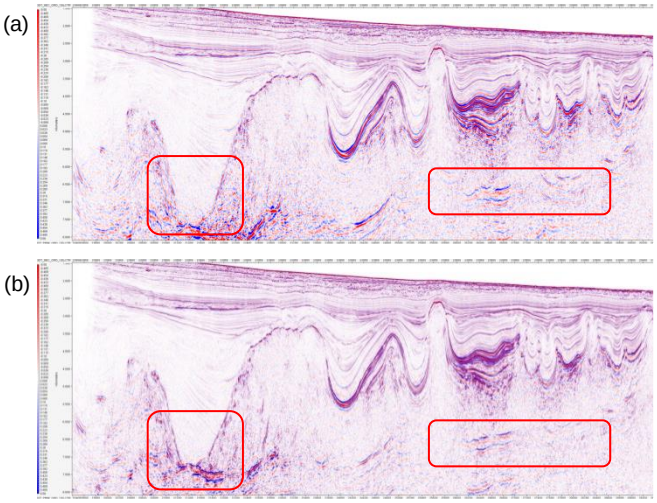

Figure 6 Velocity properties after tomography (a) without steering filter; (b) with steering filters.

The model update was done using additional iterations of TTI multiscale CIP tomography using steering filters for preconditioning instead of the conventional isotropic smoothing operator. This implicit geological constraint in tomography helps to speed-up the convergence of the model in areas that are poorly constrained by data alone. Figure7 shows a comparison between a tomography update with and without steering filters. Since the model updates closely follows the geology the seismic gathers are flatter and the seismic image improved (Figure 7c and 7d shows gathers located by the arrow)
The new TTI model, built with the help of geological constraints explains the seismic data much better than the simple anisotropic model.

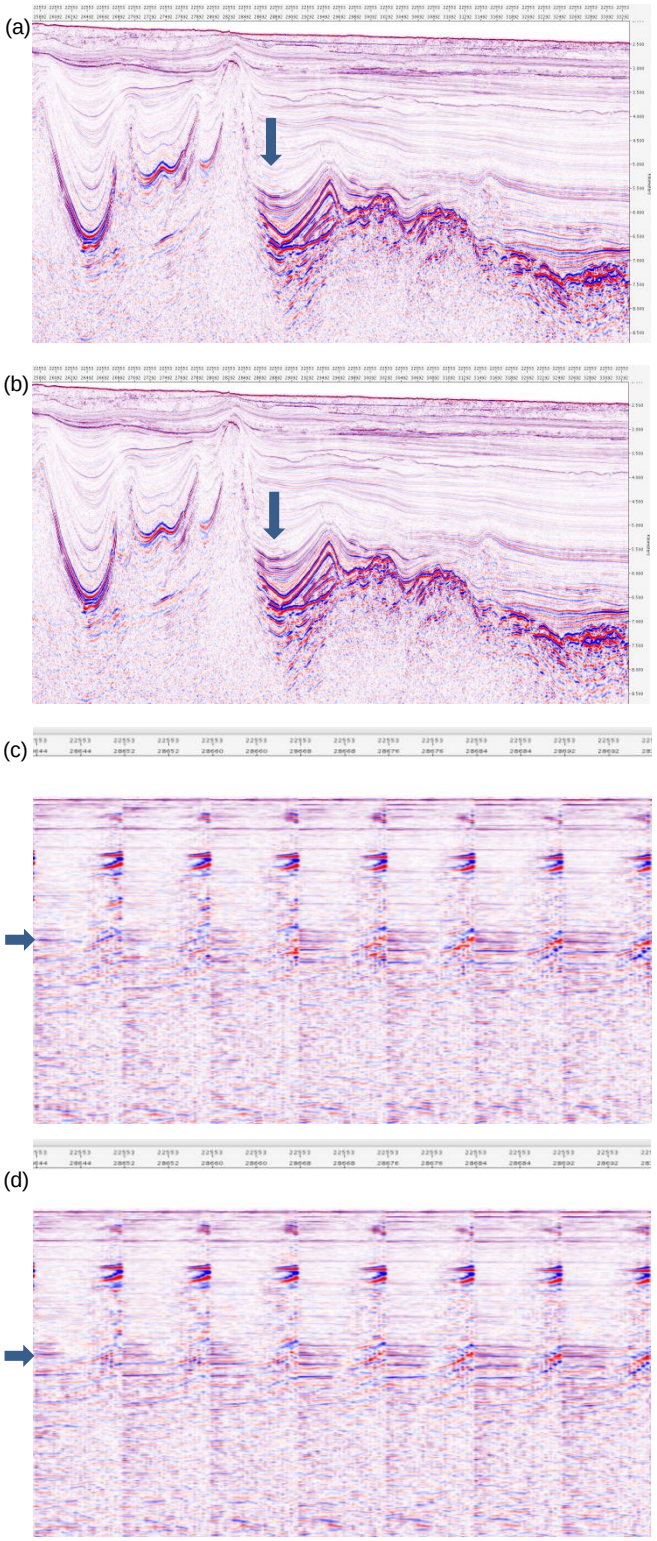

Figure 7 Migrated images and gathers after tomography (a) without steering filter; (b) with steering filters (c) without steering filters and (d) with steering filters.

Summary and conclusions

We have demonstrated a successful strategy for building detailed TTI models by using geological constraints and the importance of accounting for TTI in complex media as a prerequisite for successful imaging of pre-salt targets Also use of geologic information explicitly and implicitly during tomographic updates, produces more accurate images of the subsurface and pre salt areas. The TTI imaging workflow described in this paper would allow successful imaging of pre-salt targets and improve the quality and interpretability of other seismic surveys offshore Brazil.

Acknowledgments

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