Pre-salt Depth Imaging of Santos Basin, Brasil

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Abstract

Recent large pre-salt discoveries in deep water Santos Basin, Brasil, such as Tupi and Sugarloaf, prompt significant interest in better pre-salt imaging. In this paper, we present a pre-stack depth migration (PSDM) velocity model building flow that would produce a better velocity field. This allows us to obtain better pre-salt images through high-end imaging algorithms such as Controlled Beam Migration (CBM) and Reverse Time Migration (RTM). We also explore the benefits of tilted transverse isotropy (TTI) imaging in this area.

Introduction

Offshore Brasil has become one of the hottest areas for the oil & gas industry. Since Petrobras announced 5-8 billion BOE of recoverable oil in Tupi field in 2007, more discoveries, such as Sugarloaf and Jupiter, were announced in Santos Basin, Brasil. Most recently, ExxonMobil has announced the Azulão discovery in BM-S-22 in January 2009.

Most of the recent discoveries in Santos Basin are in pre-salt regions. Although the sedimentary velocity variation is relatively smooth, depth migration is required for imaging complex salt and pre-salt layers. The presence of both mobile salt and layered evaporates makes the velocity model building flow more challenging than the flow in the Gulf of Mexico (GOM). The main difference is that we introduce an additional step of salt layer velocity update. Together with advanced imaging algorithms such as CBM & RTM, this new flow can significantly improve the image of pre-salt structure.

To further improve the pre-salt images, we may have to include anisotropy in the model building flow. Without a lot of publicly available well information in Santos Basin, it is difficult to determine the anisotropy level, but seismic data indicates that anisotropy does exist in this area. Ignoring the anisotropic effects can incorrectly position salt flanks and distort the base of salt (BOS) and pre-salt structures. Furthermore, the dip angles of some deep basins can reach more than 50 degrees. With such highly-dipping bedding, even vertical transverse isotropy (VTI) may be significantly inaccurate. A TTI PSDM test was conducted and gives promising results.

In the next two sections, we will discuss the PSDM velocity model building flow and the benefits of TTI imaging in deep water Santos Basin.

Velocity model building flow in Santos Basin

Table 1 compares the PSDM velocity model building flow in deep water Santos Basin to the regular GOM flow (Siddiqui 2003; Woodward 2008). The first step in the flow was to determine the water bottom surface. The water depth in this area is approximately 1600 to 2600 meters. A range of water velocities were tested through water flood migrations and 1495 m/s was chosen based on the flatness of the water bottom events in the common image gathers (CIGs). The water bottom was then interpreted on the water flood migration volume and had less than 3 meter mis-ties with well measurements.

Tomographic inversion was then used to derive the velocity in the sediment region between the water bottom and the top of salt. A relatively smooth sedimentary velocity field was obtained after the tomographic updates.

The next step was to interpret the TOS surface. Unlike the top of salt in the GOM, most of the TOS events in this area were buried in a sequence of reflectors on seismic sections, and were difficult to pick. From the velocity model building point of view, the TOS is where the salt velocity kicks in underneath the sedimentary layers, so migrated gathers are very helpful in TOS interpretation. Our study demonstrates that the images of the BOS and pre-salt events are very sensitive to the position of the TOS. Figure 1 shows a salt flood section with two slightly different TOS interpretations. The BOS and pre-salt events in figure 1a have some undulation that mirrors the TOS shape. In figure 1b, where the TOS interpretation is slightly shallower in two mini-basins, the BOS and pre-salt events are straighter, and the migration gathers are flatter.

GOM	Santos Basin
Water bottom determination	Water bottom determination
Sediment tomography	Sediment tomography
TOS interpretation	TOS interpretation
Salt Flood	Salt flood
	Salt layer Tomography
BOS interpretation	BOS interpretation
Subsalt velocity update	Subsalt velocity update

Table 1. Comparison of GOM and Santos Basin velocity model building flows.

In most PSDM velocity model building flows, a constant salt velocity is used for the salt flood migration. This is because of the difficulty in determining the extent of salt velocity variation due to the lack of reflectors. In this area, the layered evaporates provide an opportunity for updating the velocity inside the salt. By carefully picking the residual curvature of those events, a better velocity field inside the salt (evaporates) layer was obtained through tomographic inversion.

Compared to the TOS, the BOS was relatively easy to interpret. It is believed that the BOS structure should not be geologically complex. This is one of the criteria used to evaluate the velocity field above the BOS. Below the BOS, we observed a faster velocity trend, which was updated through tomographic inversion.

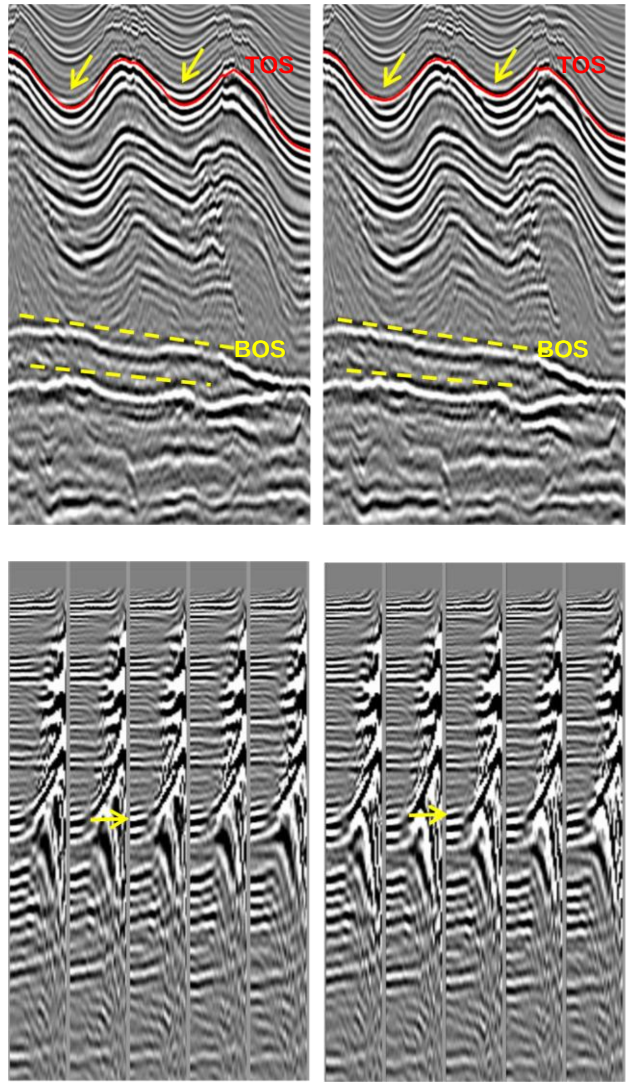
This PSDM velocity model building flow produces a better velocity field, and allows us to obtain better pre-salt images through high-end imaging algorithms such as CBM and RTM. Figure 2 shows a migration comparison. In this seismic section, the BOS is shallow on the left side and deep on the right side, with a rapid transition in between. Figure 2a is a previous Kirchhoff migration, using an old salt flood model with a constant salt velocity. Figure 2b is a Kichhoff migration using the velocity model derived through the current flow. The new image shows uplift in the BOS image and the pre-salt structures. The deep BOS on the right side, for example, is much better imaged in the new result. Also, on the left side of figure 2a, the BOS shows a syncline structure below the mobile salt indicating over-burden velocity errors. With the improved velocity model, the structure of the BOS and pre-salt are simpler and flatter in figure 2b.

The data were also migrated with the new velocity model using CBM and RTM. These high-end imaging algorithms give further uplift on the images. CBM (figure 2c) reduces the noise significantly. RTM (figure 2d) improves the BOS and pre-salt images, particularly in the areas where the BOS and pre-salt are poorly imaged or not imaged at all by the other migrations.

Benefits of TTI imaging

Huang (2008) proposed a TTI velocity model building flow which resulted in improvements on salt flank images in the GOM. We conducted a similar TTI PSDM test, which shows some promising results in the BOS images.

In this test, constant values for ε and δ ($\varepsilon = 5.1\%$ and $\delta = 3\%$) were used in the sedimentary area. The symmetry axis was assumed to be perpendicular to the sedimentary bedding, so it is spatially variant. V_0 was updated with multiple iterations of 3D TTI tomographic inversion. After the TTI sedimentary velocity update, the TOS was interpreted. Below the TOS, the velocity volume was flooded with a constant salt velocity. Migrations with the isotropic and TTI models are compared in Figure 3. For comparison purposes, an isotropic salt flood model was used. The BOS from the isotropic migration (Figure 3a) has a push-down below the center of the basin where the salt body is thin. The TTI migration, shown in Figure 3b, makes the BOS flatter and more continuous. With this encouraging result, further TTI tests will be carried out in the near future.



1a **1b**

Figure 1. Salt flood migration with different TOS interpretations. TOS interpretation (red line) is overlaid on stack sections (upper half). The arrows indicate the locations of different TOS interpretations in the two mini-basins. TOS in figure 1b is slightly shallower. The BOS and pre-salt events in figure 1a have some undulation that mirrors the TOS shape. In figure 1b, the BOS and pre-salt events are flatter. Arrows in the gather sections (lower half) point to the position of the TOS. Gathers are flatter in figure 1b.

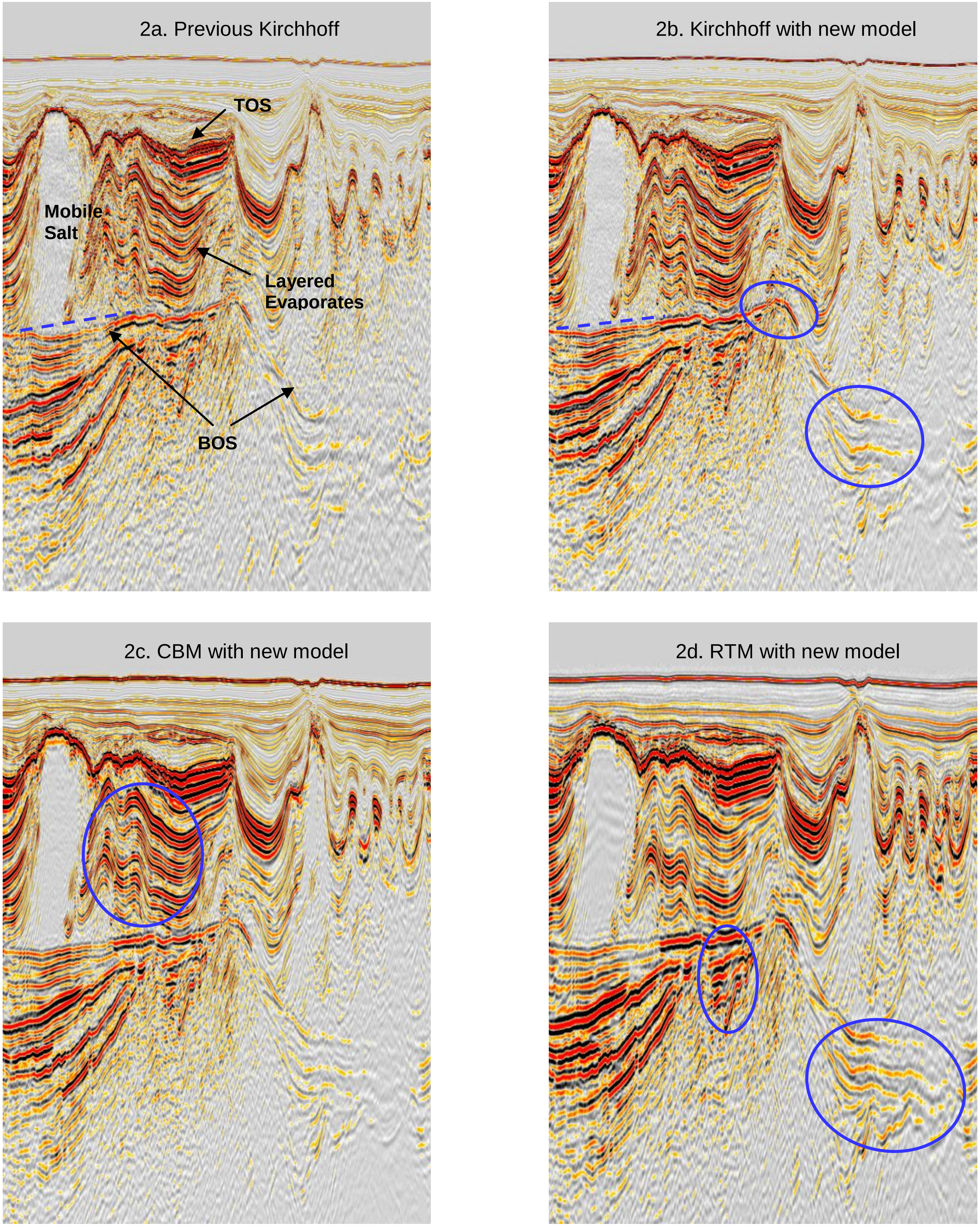


Figure 2. Migration Comparison. Compared to previous Kirchhoff (2a), the new migrations (2b Kirchhoff, 2c CBM, and 2d RTM) show better BOS and pre-salt imaging. CBM reduces the noise significantly. RTM shows a significant uplift in BOS and pre-salt imaging.

Conclusions

In this paper, we presented a PSDM velocity model building flow in deep water Santos Basin. This flow produced a more accurate velocity model, and allowed us to obtain better pre-salt images through high-end imaging algorithms such as CBM and RTM. The initial TTI PSDM test showed that anisotropic imaging may be important in this area.

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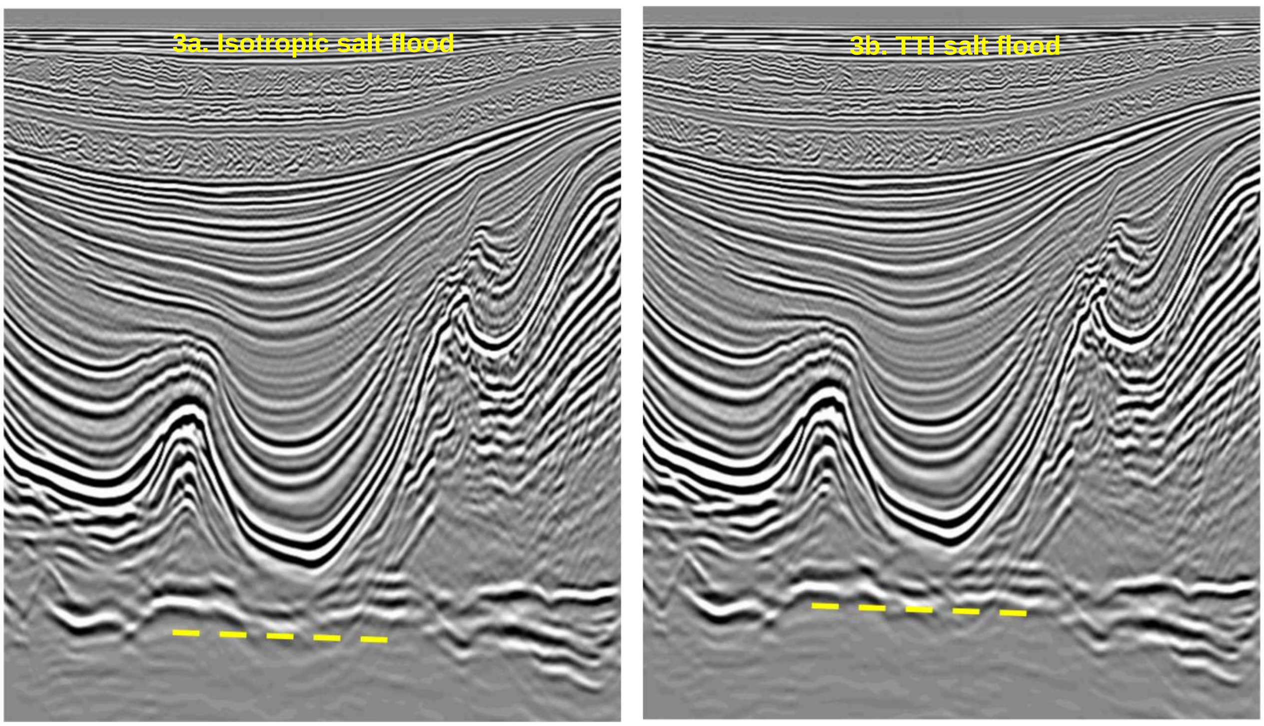

Figure 3. Isotropic salt flood migration (3a) and TTI salt flood migration (3b) comparison. The BOS in the isotropic migration has a push-down below the center of the basin. In the TTI migration, the BOS is flatter and more continuous. Yellow dashed lines are drawn to illustrate the difference.