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2D TTI Imaging in the Santos Basin: A Case History

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Abstract

The pre-salt section of the Santos Basin has been the focus of much recent interest following the discovery of significant reserves in the region. An evaluation project on two 2D lines from a large regional survey shows that a redesigned processing flow incorporating Tilted Transverse Isotropy (TTI) and Reverse Time Migration (RTM) delivers improved images of the salt and pre-salt structures.

Introduction

Following the recent discovery of a number of giant fields in the pre-salt section of the Santos Basin offshore Brazil, this area has generated significant exploration interest. This has, in turn, created a need for higher quality seismic imaging of the pre-salt section. The complexity of the overburden means that the latest processing and imaging techniques are needed to accurately image the geological structures at these depths (Huang et al., 2010).

In this paper we present a case history of an evaluation project to assess the impact of Pre-stack Depth Migration (PSDM) incorporating TTI and using Kirchhoff and RTM algorithms on existing 2D data from the region.

Geological setting

The petroleum system in the Santos Basin (Figure 1) is sourced by the Aptian and Barremian fluvial and lacustrine rift section. The accommodation and progradation of Albian carbonates and overlying Tertiary sediments was facilitated by the basinward withdrawal of Aptian evaporites. This placed Cretaceous and earlier reservoir rocks in direct contact with Albian source rocks.

The discovery of the giant Tupi field in 2006 focused attention on the reservoir potential of the pre-salt section. Tupi reached a depth of 5314 m, drilling subsalt into the lower Aptian and Barremian rift section, discovering reserves of six to eight billions of barrels of oil equivalent. This discovery, as well as subsequent discoveries including Jupiter and Carioca-Sugar Loaf, have focused exploration interest on the pre-salt sediments of the Santos Basin.

Geophysical challenges

The principal geophysical challenge of the region is to image beneath the evaporite layer. The salt geometry is extremely complex and is composed of massive salt as well as layered evaporite sequences. In addition, fast carbonate layers are sometimes present above the salt.

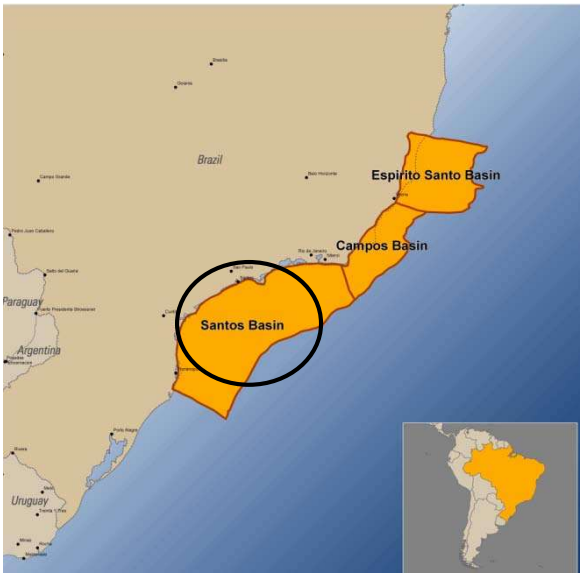

Figure 1. Location of the project

The data set selected for the evaluation project consisted of two lines (referred to as Line A and Line B) from the WesternGeco/TGS Brazil 2D Alliance survey. This data set was first processed in 1999/2000 and subsequently reprocessed in order to take full advantage of the latest developments in depth imaging.

The initial processing in 1999/2000 used a Pre-stack Time Migration (PSTM) flow that utilized dip-moveout correction (DMO) and FK-PSTM, followed by a final post-stack time migration. Although advanced for its time the PSTM flow was sub-optimal when it came to imaging the complex salt structures and steeply dipping sediments, highlighting the need for a depth imaging solution.

Starting in 2007 the data set was reprocessed through isotropic PSDM using Kirchhoff and one-way Wave-Equation Migration (WEM) algorithms. The introduction of depth imaging facilitated improved resolution of the salt geometry and sub-salt sedimentary basins.

The goal of the test processing was to evaluate the benefit of applying the most recent advances in imaging technology to a subset of the 2D data set. TTI was employed to improve the lateral positioning, placement in depth and focusing of events. RTM was used alongside Kirchhoff migration in the model building steps as well as the final migration.

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The anisotropic parameters delta and epsilon were calculated using the focusing analysis (FAN) methodology developed by Cai et al. (2009) (see also He et al., 2009).

Earlier depth imaging efforts used a layer-based carbonate tomography to define the fast velocity layers above the salt. However, subsequent work has shown that at least some of these layers are considered to be layered anhydrite sequences. Consequently, in the current study many of these areas have been interpreted as salt.

The preprocessing was fully revised to include zero-phasing and de-bubble, rigorous multi-domain noise attenuation and a full multiple attenuation sequence including 2D Surface-related Multiple Attenuation (SRME) and high-resolution Radon transform multiple attenuation.

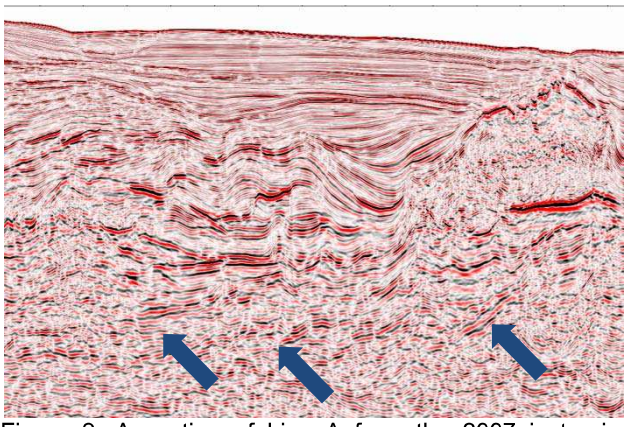

Figure 2. A section of Line A from the 2007 isotropic Kirchhoff PSDM.

Results

Figures 2 and 3 show a comparison of the Kirchhoff PSDM results for Line A. Figure 2 shows the isotropic Kirchhoff and Figure 3 the TTI Kirchhoff. The anisotropic Kirchhoff shows considerable improvement throughout the section; in particular, there is a notable improvement in the subsalt rift and post-rift section as indicated by the blue arrows. Comparable improvement in the pre-salt section was also achieved on the second line, Line B. This is illustrated by figures 4 and 5, which show a comparison between the isotropic and TTI Kirchhoff results.

Figures 6 and 7 also illustrate the results achieved on Line B. In this case, they demonstrate the improvement to salt geometry resulting from an updated top of salt pick and an improved base of salt (BOS) interpretation. The BOS interpretation was facilitated by the introduction of TTI and by the use of RTM and Kirchhoff migration for the salt flood iterations. The differences in the final velocity model for these two lines can be seen by comparing Figures 9 and 10.

Accounting for TTI anisotropy significantly improved the imaging of the salt bodies and steeply dipping sediments. Delta values of around 7% and epsilon values of around 15% were estimated. Epsilon and delta were limited to the post-salt section.

Figure 8 shows the improvement in imaging of the pre-salt section that results from the introduction of RTM. The improved BOS and basement reflections are indicated by white arrows.

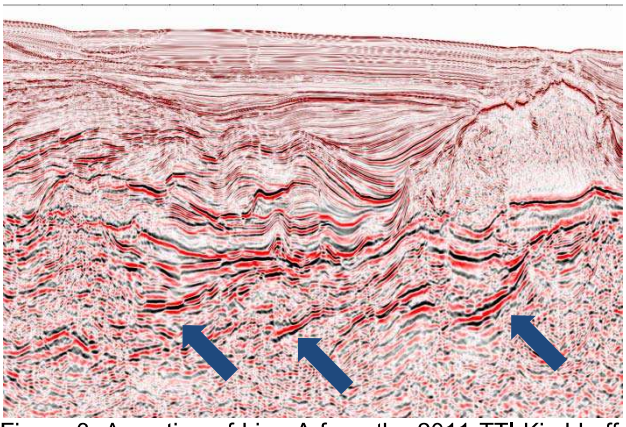

Figure 3. A section of Line A from the 2011 TTI Kirchhoff PSDM. Compared with Figure 2 the updated workflow has delivered significant improvement throughout the section, in particular the salt and pre-salt structures.

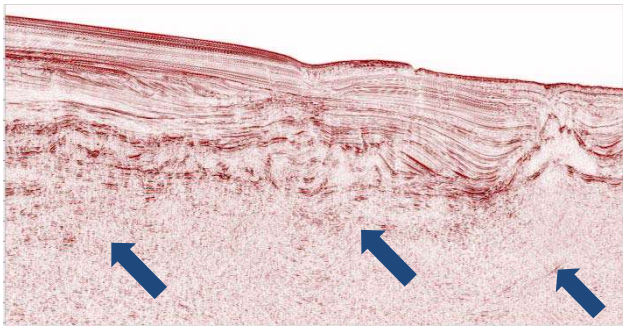

Figure 4. A section of Line B from the 2007 isotropic Kirchhoff PSDM.

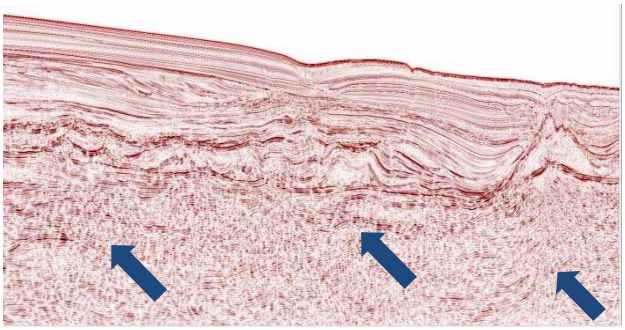

Figure 5. A section of Line B from the 2011 TTI Kirchhoff PSDM. Compared with Figure 4 the updated workflow has again delivered significant improvement throughout the section, in particular the salt and pre-salt structures.

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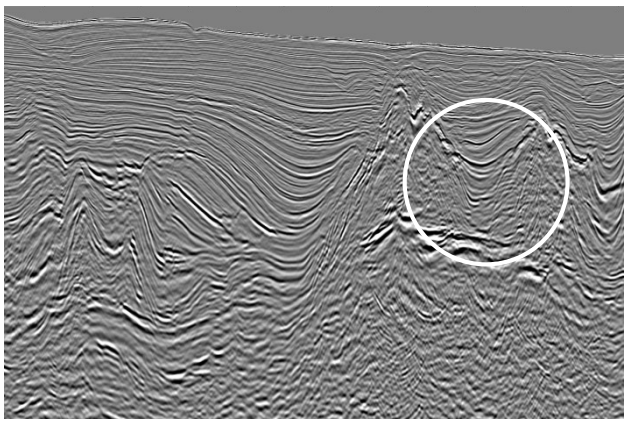

Figure 6. A section of Line B from the 2007 isotropic Kirchhoff PSDM.

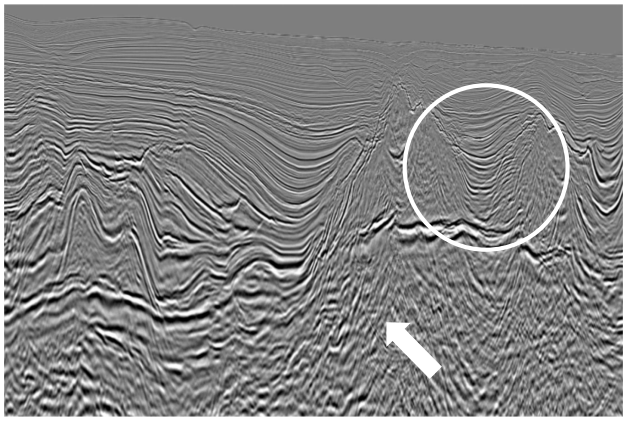

Figure 7. A section of Line B from the 2011 Kirchhoff PSDM. Compared with Figure 6 the imaging above and in between the salt bodies on the right-hand side of the section has been considerably improved (white circles).

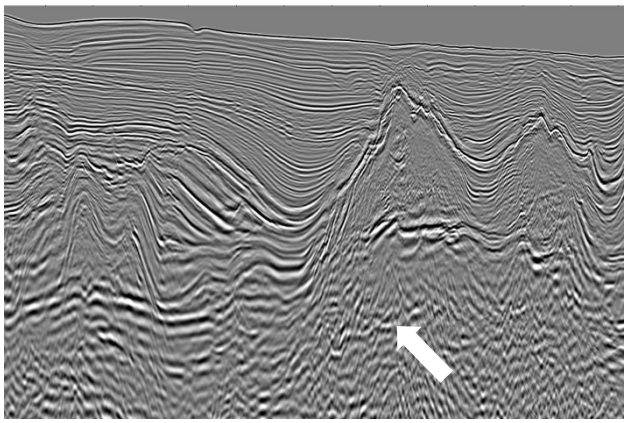

Figure 8. A section of Line B from the 2011 RTM migration. Compared with Figure 7 the imaging of the deeper sediments and basement reflector is better on the RTM image (white arrows).

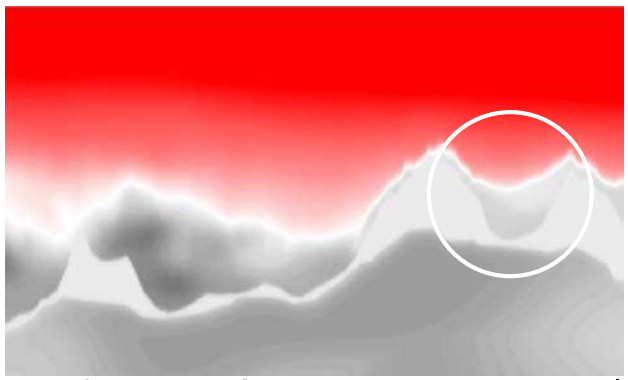

Figure 9. A section of Line B showing the depth model derived for the 2007 depth imaging.

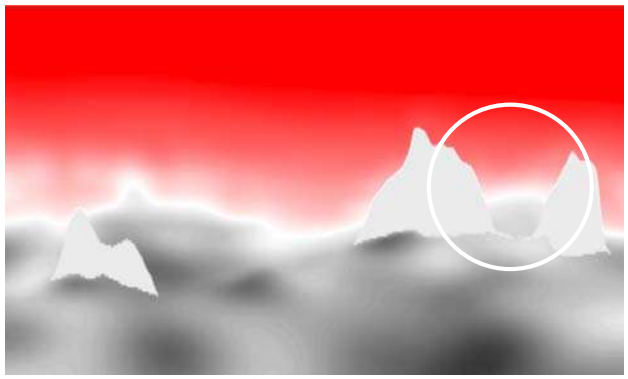

Figure 10. A section of Line B showing the depth model derived for the 2011 reprocessing. Compare with Figure 9 and with Figures 6 and 7: the salt-body definition and supra-salt velocity was significantly revised for the new model (white circles).

Conclusions

The evaluation project was considered a success. It demonstrated that good quality images of the pre-salt section can be achieved through the application to 2D data of careful designed pre-processing and velocity model building flows. These results are significantly enhanced through the inclusion of TTI imaging and RTM.

Acknowledgments

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