Anisotropic PSDM at Campos Basin, Brazil offshore. Imaging complex post- and pre-salt carbonates.

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Abstract

In this paper we review the anisotropic depth imaging workflow we have used in the imaging of the sedimentary sequence in the BC-10 and BC-60 offshore blocks at the Campos Basin, offshore Brazil. The large vertical and lateral variability in lithology types result in heterogeneities in the velocity field that, if not properly handled, may result in ambiguous structures. These significantly increase the exploration risk in deeper prospects. Close interaction between processing and interpretation teams is thus required to address the geological plausibility of such structures and select, among many possible geophysical solutions, the most appropriate subsurface image.

Introduction

Deep-water oil exploration in Brazil has gained worldwide attention in view of the significant pre-salt oil discoveries announced by Petrobras in the recent years. The Santos basin (Figure 1) hosts the largest of these discoveries such as the Lula and Cernambi fields with estimates reported in the range of several billions BOE recoverable. Towards the north in the Campos Basin (Figure 1), major discoveries have been announced as well. Particularly in the Petrobras-operated blocks in a region referred to as Whale Park, significant recoverable volumes have been reported.

Such large exploration potential has shifted the focus of oil companies exploring in offshore Brazil from post-salt targets (mainly clastics but also carbonates deposited above the salt layer) to pre-salt carbonate deposits. Subsurface challenges exist in both settings but are markedly distinct.

While post-salt exploration relies heavily on the characterization of DHI's (such as AVO analysis and seismic inversion-derived attributes), pre-salt exploration demands accurate structural imaging -- a difficult objective given the large variation in lithology that seismic wavefronts have to encounter before getting to deeper exploration targets. As depicted in Figure 2, this variation includes (1) irregular thickness of the salt layer, (2) post-salt rafted Albian carbonates and (3) anisotropy in post-salt clastics as well as in carbonates. The work by Huang et al. (2009) and Gerrard et al. (2009) provide insight on the impact of such complexities on seismic imaging.

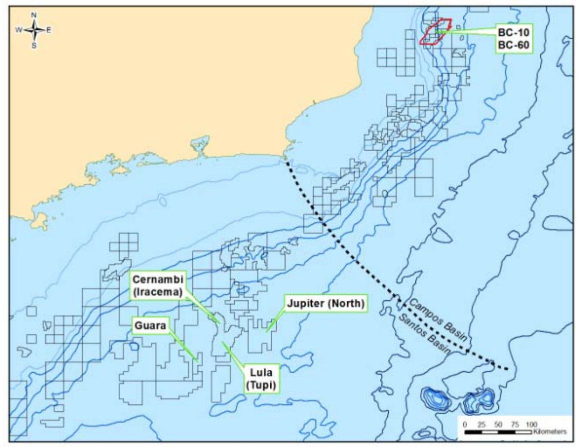

Figure 1: Location of the Santos and Campos basins in offshore Brazil and some relevant pre-salt discoveries. The red polygon to the north defines the area of interest for the seismic imaging project described in this paper, and includes the Shell-operated BC-10 and Petrobras-operated BC-60 blocks.

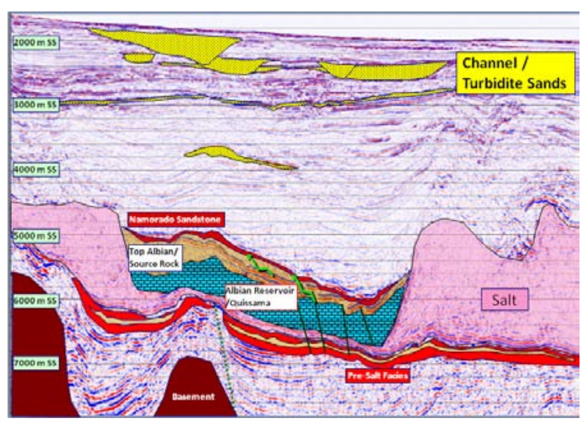

Figure 2: Cartoon illustrating some of the geological complexities faced in the pre-salt imaging in deep water Brazil. .

Here we describe the anisotropic Kirchhoff PSDM workflow we used in the imaging of the post- and pre-salt sedimentary sequence in the area outlined in Figure 1. This area includes the Shell-operated BC-10 (Shell Park) and Petrobras operated BC-60 blocks (Whale Park). A stratigraphic-layered approach, in which specific stratigraphic sequences were imaged and subsequently "frozen" has been adopted. The processing was done internally in the Shell offices in Houston and Rijswijk, and used as input data a conventional narrow-azimuth dataset acquired in the Campos basin during the years of 1999 and 2000.

Imaging Workflow

Figure 3 shows a representative seismic cross section through three key BC-60 wells. This section, a depth-converted time-migration output, is displayed in time and is meant to illustrate the geological variability present in the area of interest. The red-surface defines the top of the Albian carbonate layer and the magenta surface defines the base of salt (BOS). The imaging workflow, which benefited from a quite extensive pre-migration processing not described in this abstract, can be outlined as follows:

1. Post-Albian isotropic sequence:
   a. PSDM imaging with an initial velocity field. A very smooth velocity field, constrained by well data, was used in this first step.
   b. Residual move-out picking followed by a tomographic velocity update and re-migration.
   c. One additional tomographic update and re-migration.
2. Post-Albian anisotropic (VTI) sequence:
   a. Selection of well data for seismic-to-well ties used in the derivation of a □ profile.
   b. Estimation of the □ field via higher -order move-out analysis.
3. Freeze post-Albian sequence.
4. Albian isotropic sequence:
   a. Residual move-out picking followed by a tomographic velocity update and re-migration.
5. Albian anisotropic sequence:
   a. Analogous to 2.a: a carbonate □ function built from well ties.
   b. An elliptical anisotropic model was assumed within this sequence.
6. Freeze Albian sequence.
7. Selective salt flooding, considered necessary in regions of thick salts.
8. Freeze entire post-salt sequence.
9. Isotropic pre-salt sequence:
   a. Residual move-out picking followed by a tomographic velocity update and re-migration.
10. Post-migration processing.

The imaging results of post-salt sediments and the reduction of seismic-to-well misties has been considerably improved by this depth imaging workflow. However, the largest challenge faced in the processing was to resolve the structural relief of the pre-salt carbonates in the presence of the significant lateral velocity variation induced by the Albian carbonates. Figure 4 zooms in on a particular structural artifact, which suggests a correlation between the absence of the Albian carbonates (Albian gap) and a BOS pull-up. Finally, it is worth mentioning that the isotropic imaging opted in the pre-salt sequence was a consequence of the lack of sufficient well control to establish the level of seismic-to-well misties for this interval.

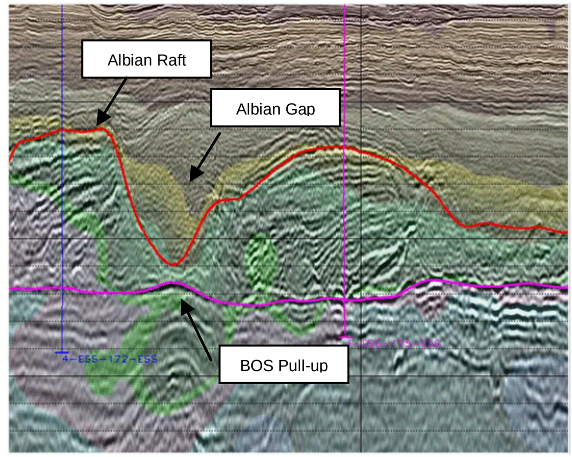

Figure 4: Potential artifact at BOS surface, which could be induced by a gap in the Albian carbonate layer above. The cross-section is displayed in depth.

Imaging Results

Figures 5.a and 5.b illustrate the evolution of the seismic image throughout two of the steps of the processing workflow. The colors in the background represent the velocity field at a particular iteration. The top Albian and BOS surfaces are the same in both figures and they have been mapped using the final processing seismic volume.

Figure 5.a shows the results after all tomographic updates in the post-salt section, including clastics and Albian carbonates. Note the good image definition in the clastic post-Albian sedimentary sequence, when compared to the time-image in Figure 3. Well misties have been considerably reduced after the anisotropic update. The □ field estimated at this step (not shown) is small and has a maximum value of approximately 4% at the top Albian interface.

Imaging of Albian carbonates is also enhanced by the Albian tomographic updates as a comparison between Figures 3 and 5.a demonstrates. Figure 5.b shows the seismic image obtained after the isotropic pre-salt update. In addition to the improved image, the spectral bandwidth has been enhanced via shaping filters as can be seen by the higher frequency content of the aPSDM result.

Finally, Figure 6 displays a set of typical gathers resulting from the processing. The pre-salt events are indicated by the red outline. The location of these gathers are shown in the inset of the figure, and was selected where there is a pull-up at the BOS surface, mentioned as an artifact in the previous section. As one can see in the figure, the alignment of the gathers is quite satisfactory even at a location that may be questionable in terms of geological plausibility. This observation emphasizes the non-uniqueness of the velocity models in such complex geological setting: even though an acceptable geophysical solution has been obtained (flat gathers), the resulting depth image may be imperfect, and needs to be interpreted with a geological concept in mind.

Final Remarks

Accurate imaging is key to the success of oil exploration worldwide. Exploration efforts in offshore Brazil pre-salt carbonates, however, pose significant and unique challenges to imaging workflows. Two of the most relevant include constraining anisotropic models and associated symmetries from limited well data, and an array of lithologies that induce significant vertical and lateral velocity variations. These can result in false deep structures that increase the exploration risk in a setting where drilling costs are high.

Here we presented an imaging workflow that was designed to deal with such complex geology in a systematic way. Careful execution of this workflow with proper QC of results and extensive parameter testing resulted in a far superior image than a conventional time-migration is able to provide. The solution, however, may still contain questionable structures that need careful interpretation.

Further work is focused on alternative anisotropic models that can resolve some of the uncertainties highlighted in this paper.

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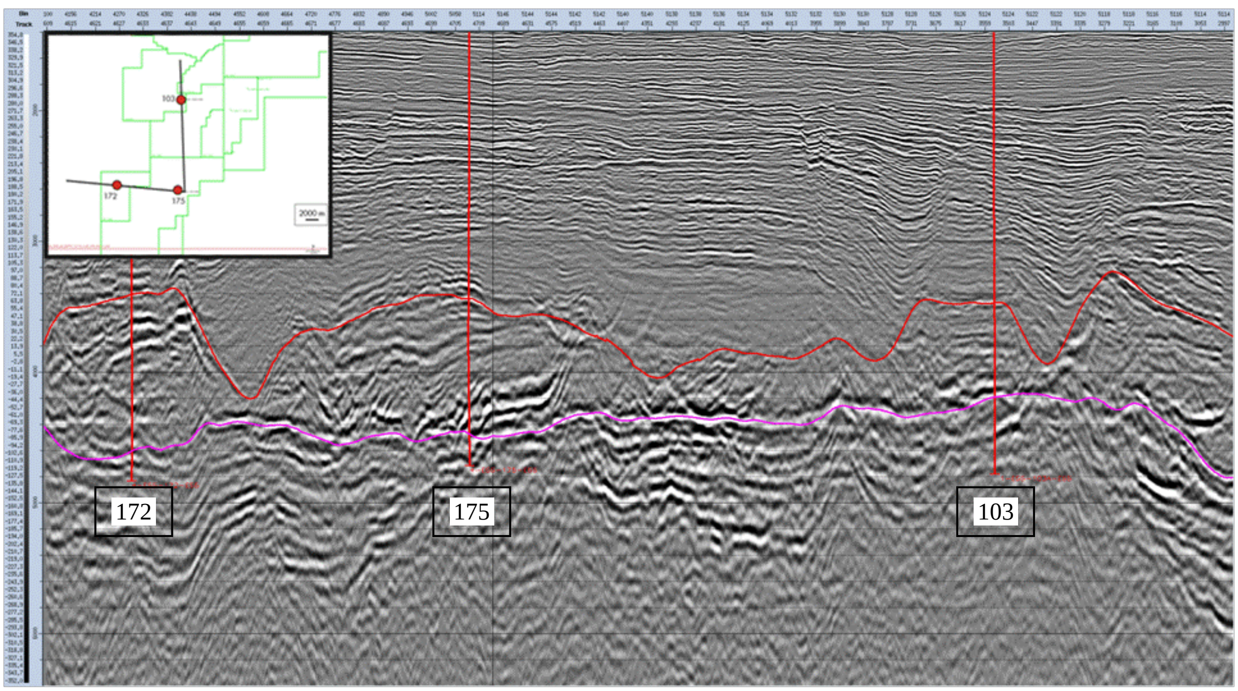

Figure 3: Time migration seismic section through key BC-60 wells, displayed in depth. The red and magenta surfaces are the top of Albian and BOS, respectively. The inset indicates the direction of the traverse.

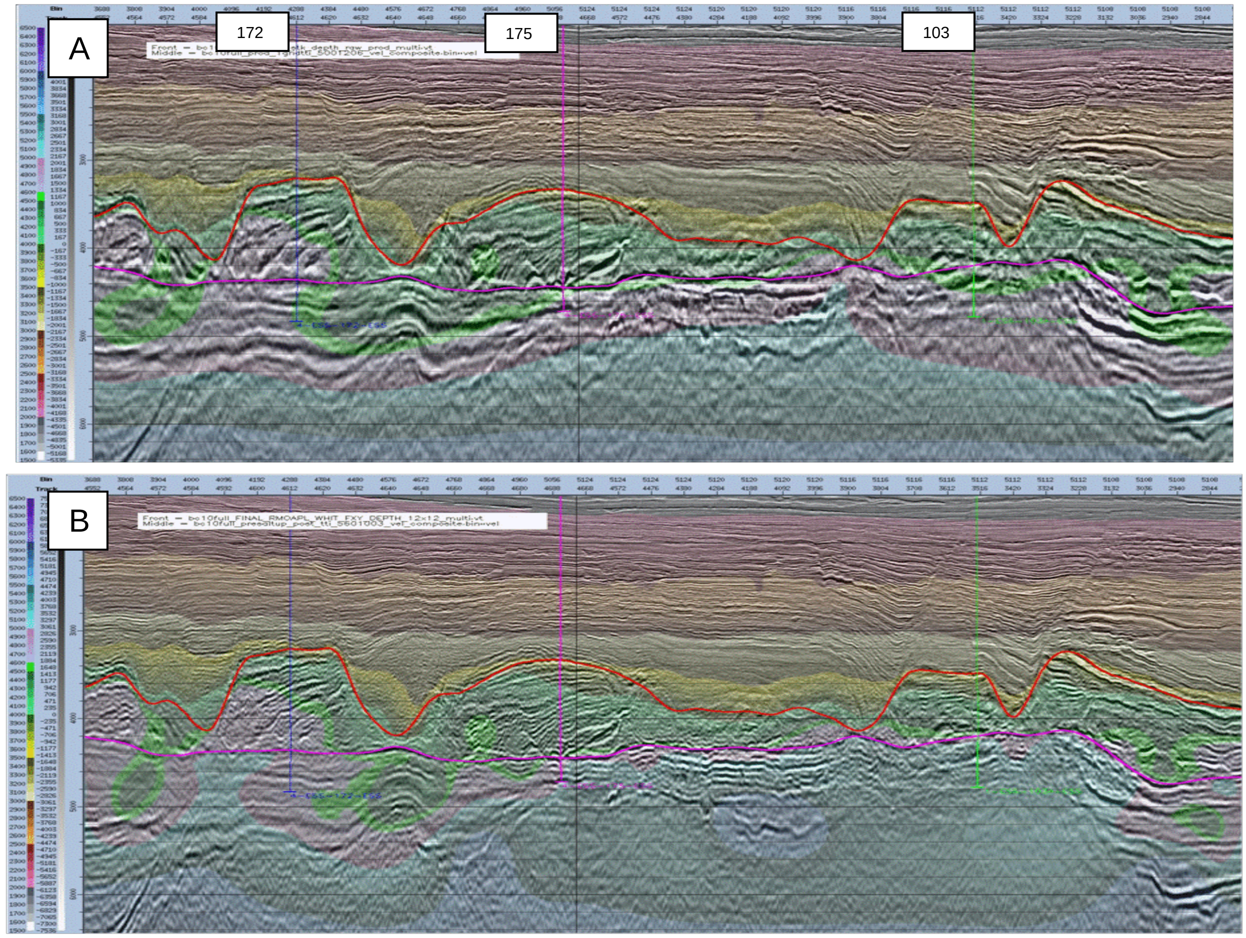

Figure 5: Seismic images and associated velocity models. (A) After sediment and Albian tomographic updates. (B) After pre-salt isotropic update. The direction of the traverse is the same as in Figure 3, but the spatial scale is slightlty different.

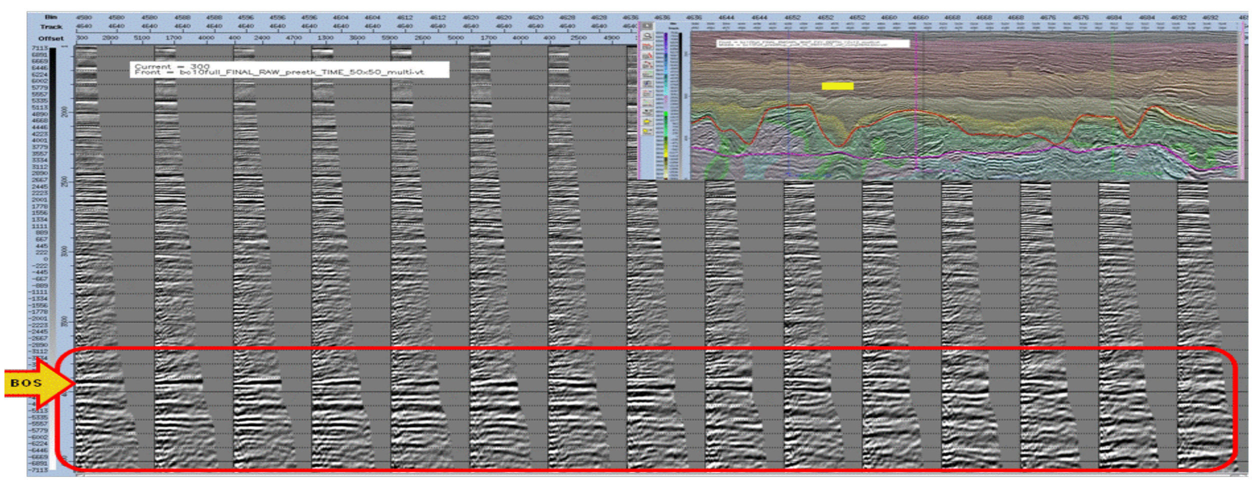

Figure 6: Common image gathers after processing sequence. The yellow bar in the inset indicates the location of the gathers, which was selected to illustrate the moveout of pre-salt events at a potential structural artifact at the BOS level.