Improved Pre-Salt Imaging from Post-Salt High-Resolution Velocity Updates

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Abstract

The exploration interest in the Santos basin offshore Brazil has increased with the large deep water pre-Salt discoveries, such as Tupi and Iara. Given the complexity of the overburden, reliable seismic image in depth domain of this interval is critical to exploration success in the region. An accurate anisotropic velocity is crucial for this purpose. This paper describes the significant effect of velocities in the post-Salt portion of the model on the pre-Salt imaging quality. An initial previous attempt of using a sub-optimal velocity model, in order to gain time for the subsequent model building steps, negatively impacted the pre-Salt image quality. It is well known how demanding it is to obtain reliable velocities at the post-Salt interval to further improve the interpretability of pre-Salt targets. Here, we illustrate this point specifically for the Libra field.

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. In late 2007 Petrobras discovered what was estimated to be a mammoth-size new basin of high-quality oil on the Brazilian Continental Shelf offshore in the Santos basin. Since then, Petrobras has drilled dozens of oil wells at a high success rate. The estimated hydrocarbon reserves in the pre-Salt reservoirs may turn the country into a major oil and gas producer in the near future.
The Libra field located in water depths of approximately 2,000 m, about 200 km south of Rio de Janeiro (Figure 1), is potentially another example of a large, world-class pre-Salt reservoir The carbonatic reservoir is overlain by a sequence of evaporites, marls, igneous, and clastics, perhaps displaying a more complex geometry than other pre-Salt reservoirs, which makes its accurate imaging a challenge.
A reprocessing effort of the Spec data acquired under the name Santos 6A which include the Libra discovery, is currently going on. The acquisition was a NAZ towed-streamer data with a standard cable length (8 km).
The main goal for the reprocessing is to improve the imaging of the pre-salt sequence for exploration/appraisal purposes by doing a full pre-processing, model building and migration sequence, using the latest technologies.

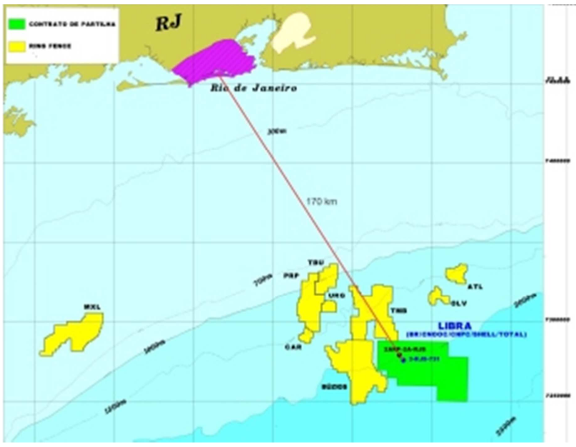


Figure 1: Libra field location map

CGG is building, under the consortium supervision, a detailed tilted transversely isotropic (TTI) model over an area of 2.900 km^2, with limited well control.
The objective of this paper is to compare the results obtained from the high resolution tomography at the sediment layers, which incorporates geological interpretations, with results derived from the SPEC processing, both using Kirchhoff migration algorithms and velocity model derived from tomography updates.

Method

The geology of the processing area is very complex, mainly in the igneous and salt areas. It was thought that by avoiding tomography in the sediments it would allow ourselves to spend more time on these other more complex areas. Decision was taken then to start with a general update of the sediment layer SPEC velocities rather than a full tomographic approach.
Figure 2 shows a schematic of this initial workflow. The SPEC sediment velocity model is the velocity model built by CGG during the processing of the SPEC data in the sediment interval.
Initially an anisotropic scaling was performed to match the available well information (resulting in a mode we refer to as “INI”). After the well calibration check, a 1x1km grid migration was run on the whole survey using the “INI” model in order to check the flatness of the gathers.

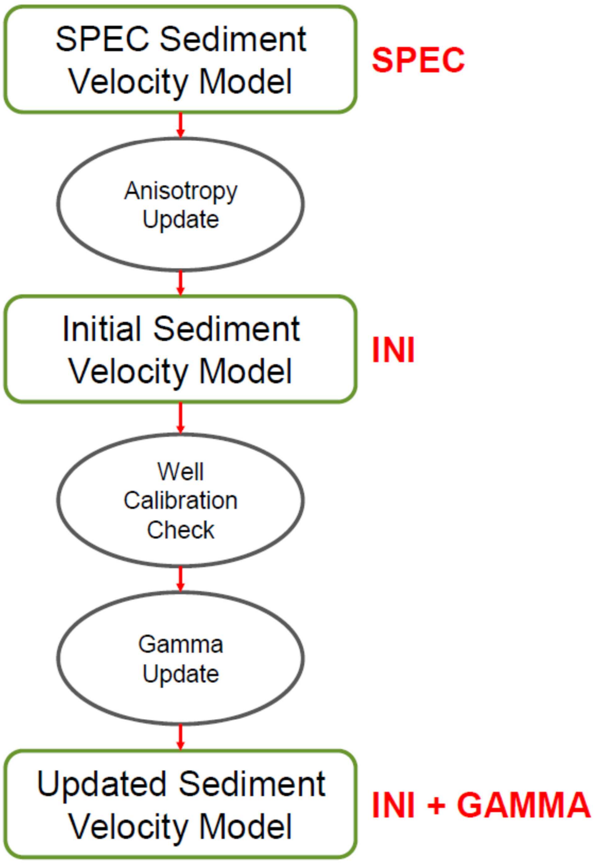
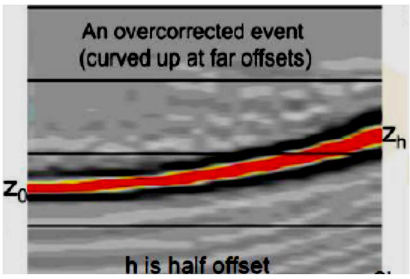


Figure 2: Workflow to update the SPEC velocity model

It was noted that high RMO still remained for deep sediments. With the observation that the problem was for deep sediments only, and just in a few regions of the survey, it was decided to perform a 1D correction using a gamma factor computed from RMO (gamma definition in Figure 3). Only the vertical velocity changed compared to the "INI" model. The results of the "gamma update" were deemed satisfactory and the resulting velocity field was used in the subsequent work.



$$gamma\ (\gamma)definition$$

$$z_h - z_0 = \frac{(\gamma^2 - 1)h^2}{2z_0}$$

Figure 3: Gamma correction

During the tests carried out on some key lines, migrated with the updated sediment velocity model (INI+GAMMA), it became clear that there were non-geological lateral variations in the model, given the sediment velocity does not follow dips and seems to be influenced by the top of salt geometry. Velocity behavior like that can cause severe ray-path distortion. It was noted that this non geological details were already present in the SPEC velocity. These tests hence showed that the tomography performed during the SPEC processing was not optimal. We therefore decided to assess if a smoothing in the sediment could significantly influence the imaging of the pre-Salt structure. Each model (before and after smoothing) was also flooded in the salt and pre-Salt with the SPEC final model so the pre-Salt image quality could be assessed for both models. Results (Figure 4) brought good improvement in the pre-Salt, showing better alignment for the smoothed model.

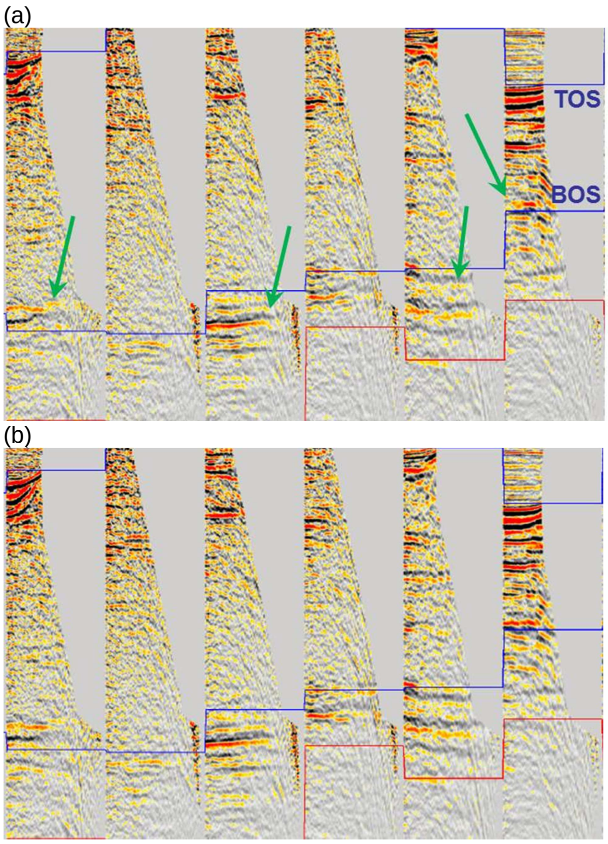


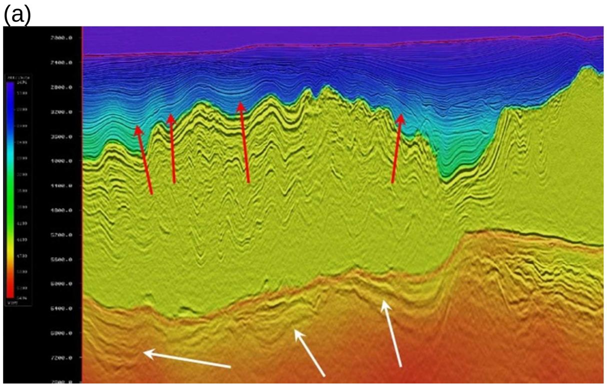
Figure 4: - Kirchhoff migrated gathers showing improvements (green arrows) at the base of salt and pre-Salt, from (a) Spec velocity +GAMMA model to (b) its smoothed version.

The RMO sensitivity of the pre-Salt events with respect to the post-Salt velocity model led the team to pursue a full post-Salt tomographic update of this interval.
The initial tomography velocity model was then based on the SPEC sediment model which went through a gamma update (INI+GAMMA) with a smoothing of 2000x2000m. The anisotropic symmetry was TTI and had its parameters derived as constant and calibrated from well control.

Results

A comparison of the SPEC velocity against the new sediment update (both with a salt flood and pre-Salt velocity of the SPEC model) is shown in Figure 5. Great improvement can be observed in the salt and pre-Salt areas. High definition tomography clearly allowed recovering better details in the velocity field and the impact can be noticeable on migrated gathers (not shown). Results showed better focusing for the Tomographic based model. The structures are more continuous and with more details. Even the sediment layer and top of salt are better imaged, especially in the mini-basins.
This encouraging result is likely to lead to a potentially better pre-Salt imaging than what was obtained in the SPEC processing.

(a)



(b)

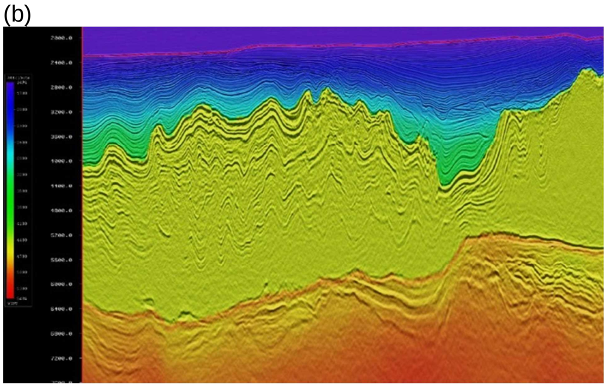


Figure 5: – Kirchhoff Migrated images with corresponding V_{P0} overlaid on the seismic data: (a) Spec velocity model and (b) Tomo update at the post-Salt – note the unrealistic lateral variation of post-Salt (red arrows) leading to a poor image at the base of salt and pre-Salt (white arrows)

Ongoing work

Additional work is being carried out and is focused on different strategies: (1) Explicit geological constraints, defined by the top Albian interpretation are being used in the last iterations of tomography, and (2) Full waveform inversion is being applied in more complex post-Salt sequences where volcanics rocks are present. Results of both approaches will be shown during the oral presentation.

Conclusions

In this paper, we demonstrated the sensitivity of the pre-Salt imaging with respect to the post-Salt velocity field. The post-Salt velocity update resulting from a high-resolution tomography is geologically plausible and leads to a better image of the pre-Salt targets than what was obtained from a previous SPEC processing effort.

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References

Farmer, H., Gouveia, W., Isom, E., Roden, T., and Strawn, B., 2011, Anisotropic PSDM at Campos Basin, Brazil offshore: Imaging complex post- and pre-Salt carbonates: 81st Annual International Meeting, SEG, Expanded Abstracts, 3263–3268, http://dx.doi.org/10.1190/1.3627874.

Hu L. and Zhou J., 2011, Velocity Update Using High Resolution Tomography in Santos Basin, Brazil, SBGF, Expanded Abstracts