Rejuvenation of regional 2D data in the Campos Basin, offshore Brazil through broadband processing and TTI imaging: A case study

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Summary

The Campos Basin, offshore Brazil has generated significant exploration interest after several discoveries, most recently the Pão de Açúcar well in 2012. The basin is covered with more than 55,000 km of 2D data which can aid in understanding the structural style and continuity of the petroleum system throughout the presalt trend.

In this paper we present new processing methodologies applied to 2D data acquired in 1999-2001. The key methodologies that have contributed to the rejuvenated dataset are:

1) Broadband processing: fully deghosted solution in tau-*p* domain (source and receiver deghosting).
2) De-multiple: SRME (surface-related multiple elimination) and HMT (High-resolution Move-out Transform) for multiple removal
3) Tilted-Transverse Isotropic (TTI) model building and imaging

Finally, we compare a test line with broadband processing and TTI PSDM imaging to a previously processed isotropic PSDM with conventional pre-processing. The application of the new methodologies contributes to a significant uplift of the 2D images and increases confidence in identifying presalt leads.

Introduction

The Brazilian presalt trend spans the Santos, Campos, and Espiritu Santo sedimentary basins. These basins are centered along the continental shelf of the Brazilian Atlantic margin and formed as a result of rifting during the early Cretaceous that ultimately opened the South Atlantic. The basins accumulated considerable volumes of primarily lacustrine sediments, which developed into prolific source rocks and reservoirs of the Lagoa Feia petroleum system. These pre-salt source rocks are believed responsible for most of the oil discovered to date in Brazil.

The Pão de Açúcar well in the Campos Basin (Figure 1) found a pre-salt hydrocarbon column of 500 m, one of the thickest to date in Brazil. The Pão de Açúcar well is the third discovery in BM-C-33 block after Seat and Gavea. Numerous presalt discoveries dating from 2008 and including the Pão de Açúcar attest the significant potential of the Campos Basin presalt, which is emerging as a prolific hydrocarbon fairway similar to the Santos Basin.

Imaging of the pre-salt events is a key element in determining the continuity of the Lagoa Feia petroleum system. Improved velocity models can provide more accuracy at the base of salt and better definition of the presalt section to assess and rank leads. Resolution is important for estimating reservoir thickness, due to the potential for depositional thinning of the presalt section over basement highs.

In this paper we discuss the reprocessing of a dataset that is part of a 2D survey acquired in 1999-2001 in the Campos Basin, offshore Brazil. Processing efforts began more than a decade ago using PSTM imaging algorithms and Isotropic PSDM in 2009. The 2D survey overlaps the recently acquired Olho de Boi 3D survey.

In an effort to achieve better imaging and resolution, a processing-based broadband solution and advanced TTI model building and imaging was applied to the data. Another important factor in improving the overall image and in particular presalt structures is the application of multiple attenuation techniques. The demultiple techniques include SRME and HMT.

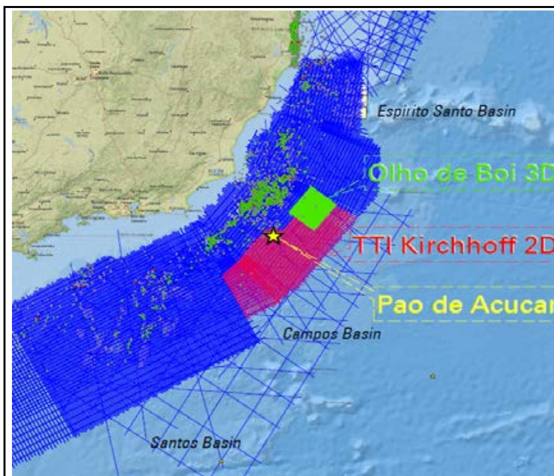

Figure 1: Campos Basin, offshore Brazil

Broadband processing

The data were acquired with conventional streamer configuration (gun depth ~ 6m; streamer depth ~ 7m and 8000-8100 m streamer length).

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Conventional marine data frequency content and temporal resolution are affected by the interference from ghosts in both the source and receiver side.

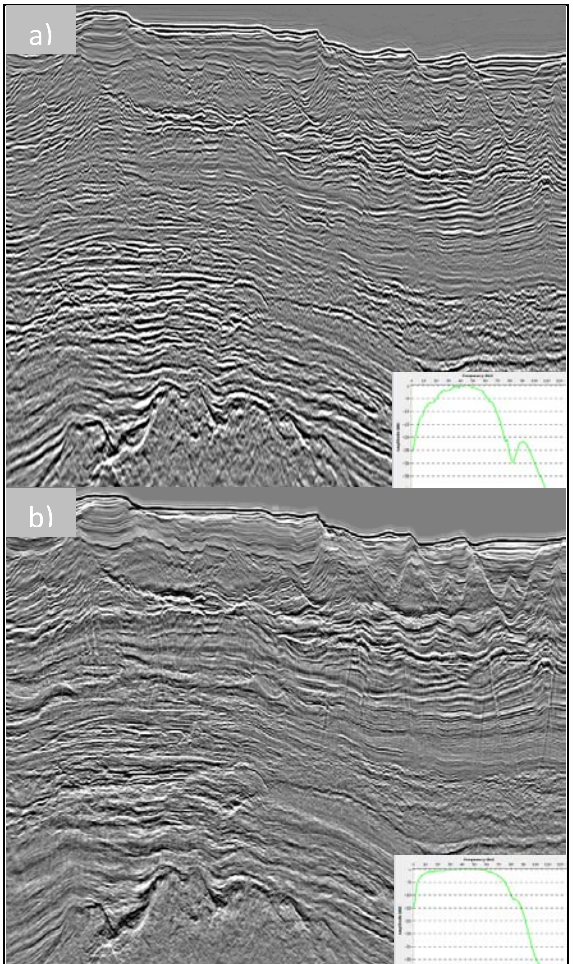

Figure 2: A 2D profile from the Campos basin a) with and b) without de-ghosting in tau-*p* domain and deconvolution common-*p*. Note the improvement in resolution and also the enhacement achived by the contribution from the recovered frequencies.

The natural diversity provided by propagation directions, depth variations and imperfect reflections of the sea surface means the notches are not as deep as they often appear after stack. For a flat streamer, the apparent time delay between the main signal and its ghost is dependent on the angle of the propagation.

For this dataset, we apply a processing-based solution as described by Masoomzadeh, et al., 2013. We first debubble the data with an emphasis on all offsets to remove the undesirable low frequency of the bubble energy. We perform a stochastic search for the best deghosting operator. Then, a search is performed for frequency dependent free surface reflection coefficients, typically for low, mid and high reflection coefficients. After this, the deghosting operator is applied in the plane-wave domain complemented by a statistical stage which includes a carefully designed deconvolution operation, averaging over a large number of common-slowness traces in order to address the remaining residual ghost.

Figure 2 shows a 2D profile from the Campos basin with conventional processing (Figure 2a) and broadband processing (Figure 2b). The removal of the ghost leads to recovering the low frequency content of the signal, consequently suppressing the side lobe and sharpening the images, which are beneficial for interpretation.

De-multiple

In areas of rugose water bottom, a main challenge in 2D processing is to attenuate multiples that are both in and out of the plane. The multiples are attacked using a combination of techniques: conventional SRME and our proprietary HMT (Masoomzadeh, et al., 2012) followed by multi-domain denoise.

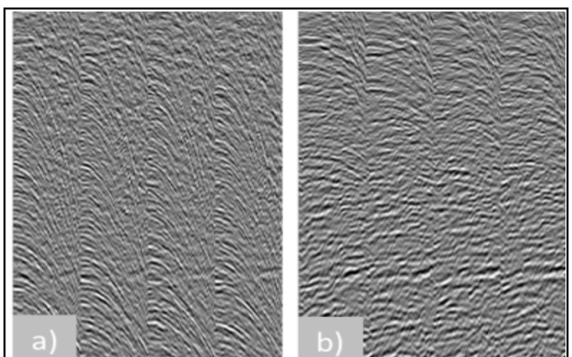

Figure 3: PSDM gathers a) with SRME and b) SRME plus HMT

HMT is a time domain approach to transform a gather of prestack seismic data into an ensemble of highly resolved traces in the transformed domain. As a time domain forward approach, this transform is fundamentally different from Radon methods. HMT is not affected by inversion and frequency domain artifacts. Nonhyperbolic moveout, apex shift and amplitude decay with offset can also be accommodated. The technique is minimally sensitive to missing offsets and presents a robust expansion in the offset domain, providing superior demultiple power especially in the near offsets.

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After applying a combination of techniques, the complex multiples below the salt are considerably reduced and the presalt events are cleaner and more continuous.

TTI model building and imaging

Improving the overall image, and in particular the subsalt structures, is key for exploration success. The complex overburden, thick salt, and salt layer heterogeneity are an additional challenge in the Campos basin. Due to the presence of minibasins with steeply dipping events and other complexities, the PSDM velocity model is designed TTI instead of isotropic like the 2009 PSDM project. With an enhanced pre-processing workflow, the mid and far-offsets of the input data are more reliable for anisotropy estimation.

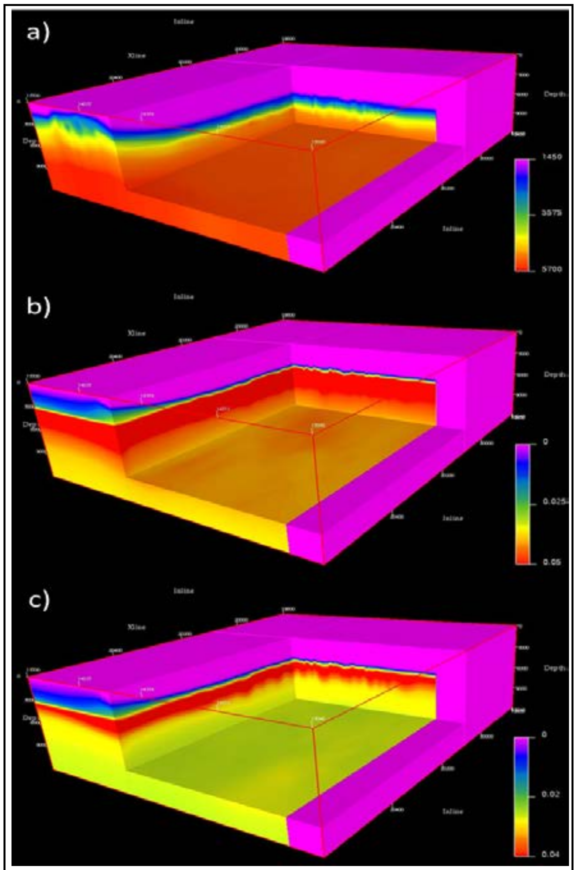

Figure 4: a) initial velocity, b) epsilon and c) delta. Starting models for the 2D TTI project were extracted from geologically consistent 3D cubes.

The TTI model building process started with previous 2D isotropic sediment models from PSDM. The 2D velocity models were converted to a 3D cube. Discrepancies at intercepting lines were edited and reconciled. The model was calibrated using available check-shots in the area by deriving scalar functions between seismic velocities at check-shot locations and check-shot velocities. The scalar functions were spatially propagated along geologic horizons creating a 3D scalar cube that was applied to the initial 3D velocity cube. Dips were scanned from the isotropic depth migrated images to determine the axes of symmetry which are assumed to be perpendicular to the bedding. Anisotropic parameters, delta and epsilon, were calculated using Focusing Analysis (FAN) methodology (Cai, et al., 2009 and He et al., 2009). Epsilon and delta were estimated at well locations, mainly in shallow water areas, and at representative minibasins locations. The functions were propagated along geologic horizons to the deep-water areas where there were poor well control.

Though the survey is 2D, the initial velocity, and the anisotropy parameters epsilon and delta were created as 3D cubes (Figure 4) ensuring spatially consistent models at intersecting lines and throughout the entire survey. This methodology has the advantage of providing an initial understanding of the regional velocities and anisotropy models. From the 3D cubes, 2D models were extracted and then each line was processed independently. The velocity model was refined with 3 passes of structure conformed tomography above the top of salt or top of the Albian when present. The Albian layers only extends in the southern part of the Campos Basin, but when present, the model was updated with an additional pass of tomography constrained between the top of the Albian layer and the top of the salt.

Due to the imaging challenges generated by out of the plane energy typical in 2D data processing, the selection of the most likely salt geometry and thickness of the salt was based on evaluation of the continuity of the base of salt and structures below with the aid of multiple salt scenarios. The velocity model was completed after tomographic velocity update below the base of salt.

Examples

A comparison of the previous isotropic migration and broadband TTI PSDM is illustrated in Figure 5. There are clear improvements in the definition of top and base of salt. Broadband processing improves resolution of the shallow section in particular faulted areas.

Figure 6 shows better continuity of the presalt structures. TTI imaging has improved steeply dipping salt flanks and sediments in the minibasins. The presalt events are more continuous and geologically plausible allowing better definition of leads and risk assessment.

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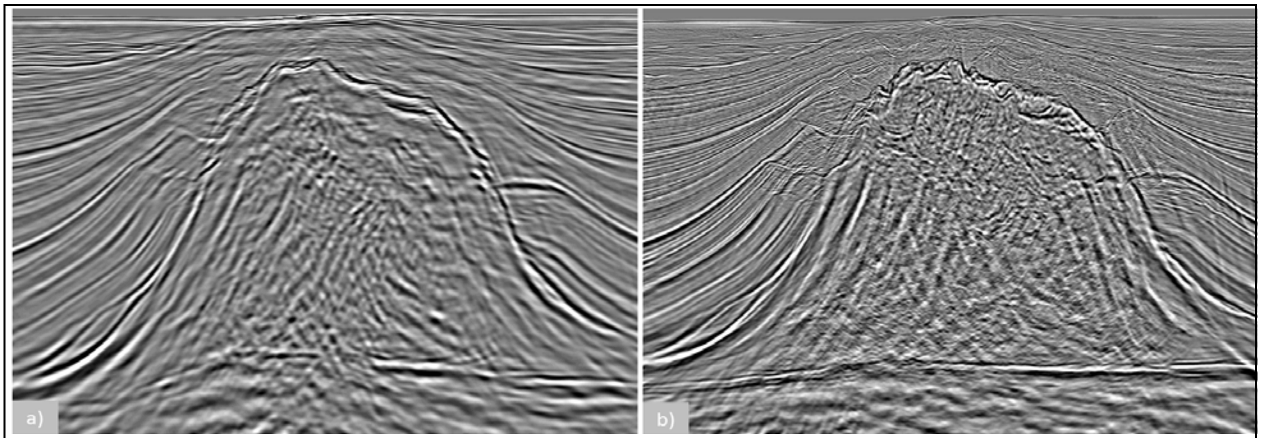

Figure 5: a) Isotropic and b) TTI PSDM with enhanced pre-processing. Note the clear fault definition above the top of salt and the top of salt resolution.

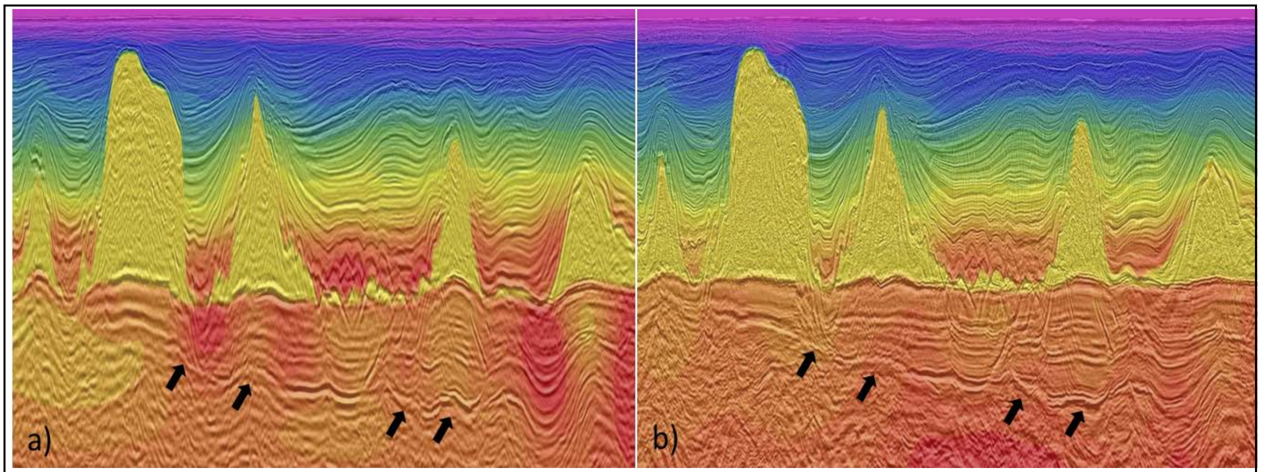

Figure 6: a) Isotropic and b) TTI PSDM. TTI PSDM pre-salt events exhibit better continuity.

Conclusions

Application of broadband processing, improved multiple attenuation and TTI imaging can considerably improve the quality of 2D images and increase the confidence in identifying presalt leads with characteristics similar to the Pão de Açúcar structure. Initial TTI models built as 3D cubes contributed to geologic consistency throughout the project area. In this study, good quality 2D data proved to be valuable for improving confidence in the continuity of the petroleum system in the pre-salt trend throughout the Campos basin. However, imaging with 2D data, in particular below salt, is not optimal due to scattering of the wavefield. Accurate imaging of the presalt events remains a risk factor that will be better addressed by 3D data.

The methodologies applied in this study and increased knowledge can be easily transferred to 3D data like the recently acquired Olho de Boi 3D survey located in the Campos Basin.

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EDITED REFERENCES

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