Benefits of broadband reprocessing in the Southern Santos Basin, Brazil

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Abstract

Reprocessing of conventional streamer data using increased data sampling and techniques that were not available at the time of the initial processing achieved clear improvements in the PreSTM imaging of a post-salt play in the Santos Basin. Previous processing of the dataset by the same contractor provides an opportunity to see the benefits of relatively new methods such as broadband de-ghosting; 3DSRME; and dip-steered median filtering. Image quality improvement judged from a seismic interpreter's perspective uses a comprehensive set of qualitative and quantitative measures.

Introduction

This case study looks at some of the challenges overcome whilst reprocessing conventional streamer data using more advanced techniques, including broadband processing for a post-salt play in the shallow water regions of the southern Santos Basin. Previous PreSTM processing in the area from 2008 has provided a rare opportunity to see the benefits of these advances.

The study is located 112 km offshore of the Santa Catarina region in Brazil, in an area containing numerous shallow salt domes within a thick post-salt Tertiary to Late Cretaceous sedimentary basin. The key challenges were to obtain improved resolution of thin sedimentary beds against the salt flanks as well as improving the imaging of the salt domes and related complex fault systems. Rojo, et al. (2016) faced similar challenges although their study focused on the use of advanced seismic attributes rather than reprocessing from field tapes.

We identify several parts of the reprocessing workflow during which clear improvements were noted before taking a closer look at qualitative and quantitative indications of improved data quality in the final products. Improvements in noise suppression; imaging; bandwidth; and amplitude integrity have led to higher confidence in structural mapping and amplitude interpretation, with immediate impact upon the planning of upcoming appraisal wells. We also review a number of remaining data quality issues to be addressed during planned PreSDM processing.

Pre-processing challenges

Pre-processing commenced with great care in an attempt to obtain high resolution imaging. Firstly, 2 ms sampling was maintained to retain possible higher frequency information and a low cut filter of only 2.5 Hz was used to maintain possible low frequency signal while removing a high concentration of swell energy. The standard pre-processing flow of de-noise, direct arrival attenuation, seismic interference removal and de-multiple was applied with the goal of not harming diffraction information.

Direct arrival and swell noise attenuation processes were applied in a manner to preserve salt diffractions visible on the shots. These noise types were often similar in character to the diffractions in terms of dips and frequency content. The tau-p domain was used to isolate these noise types to generate a model, followed by filtering of this model to remove any possible diffraction information.

For the de-multiple sequence a dual subtraction using models from Shallow Water De-multiple (SWD) and 3D Surface Related Multiple Attenuation (3DSRME) was conducted to optimally suppress a strong first water-bottom multiple and a variety of other water-bottom related multiples, generated in the moderate water depths present in the area (160 to 700 m). During the 2008 processing, only 2DSRME was used. A trade-off was sought between removing as much multiple energy as possible around the salt flanks without harming the resolution of the flatter horizons.

In a standard flow, pre-migration Radon might be implemented to help remove this residual multiple using the hyperbolic information once the velocities were picked. However the results of even the mildest Radon filtering showed that the (so far) preserved diffraction energy was also removed. This is visible on post-migration stacks shown in Figure 1, where the flank of the salt was damaged showing the importance of preserving diffractions.

Advantages gained from broadband processing

It is becoming common practice to exploit the advantages of broadband processing techniques to improve upon older, conventionally acquired surveys. A key process is the tau-p bootstrap de-ghosting method known as Ghost Wave Elimination (GWE) by Wang et al. (2013), which removes the interference generated by the source and receiver ghost information on the wavelet. Figures 2 and 3 show that after the de-ghosting flow consisting of de-bubbling, receiver and source de-ghosting and de-signature to zero phase, the data is left with a clear and precise wavelet. Figure 3 also demonstrates broadening of the frequency range on the spectrum.

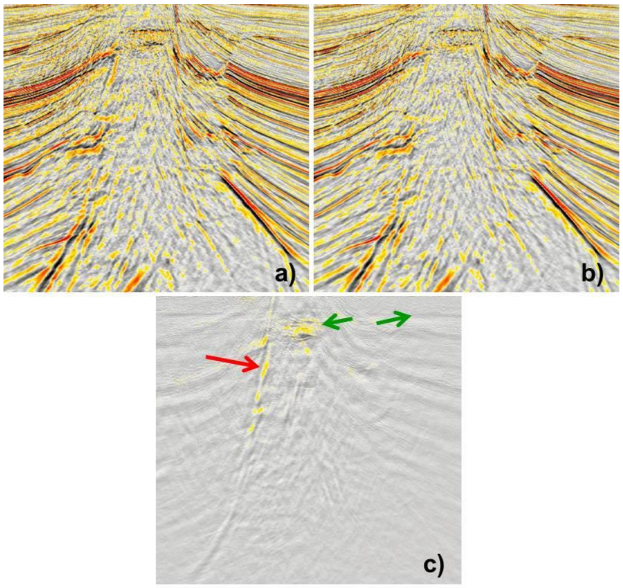

Figure 1: PreSTM 3D Stack a) without and b) with pre-migration Radon and c) difference showing residual multiple but also salt flank information being removed.

The advantages of broadening the frequency content is demonstrated nicely on the post migration stacks in Figure 4, where prior to GWE the definition of the steep salt flanks is only partially visible in places. With the implementation of GWE we can see that the lower frequencies cause the salt flank information to burst out allowing clearer interpretation of termination points against the salt. There is also improved definition within the sedimentary packages again allowing easier interpretation of events.

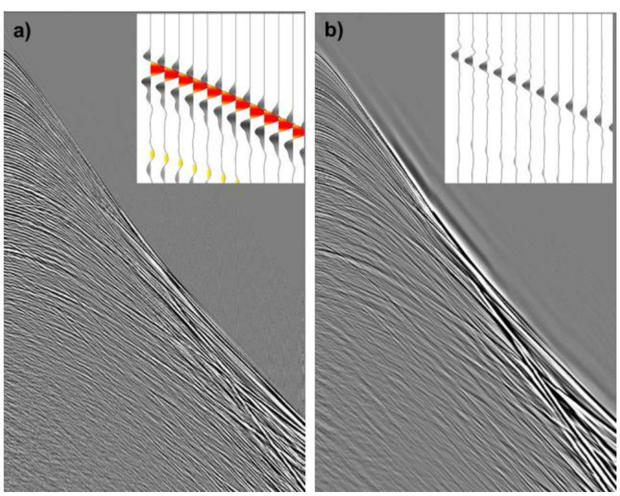

Figure 2: Shot point before a) and after b) de-ghosting with zooms of the first 11 channels in wiggle display.

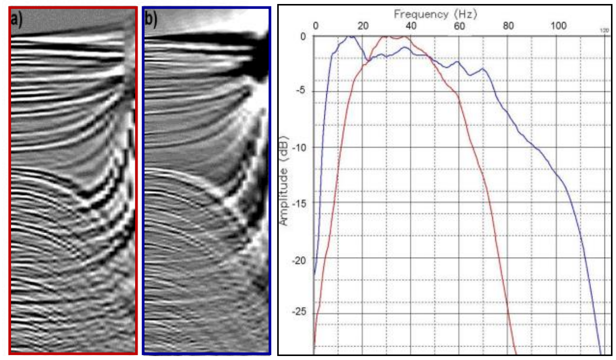

Figure 3: 2DCMP before a) and after b) de-ghosting and c) the spectra of the data before (red) and after (blue).

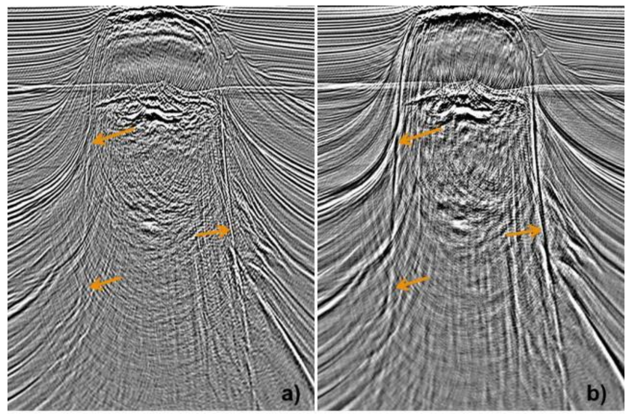

Figure 4: 2D PreSTM before a) and after b) de-ghosting using broadband techniques.

Migration and post-processing

Kirchhoff prestack time migration was applied during the 2008 processing using a bin spacing of 12.5 x 18.75 m and a time sampling of 4 ms. For the 2014 reprocessing, the sampling has increased substantially to a bin spacing of 12.5 x 12.5 m and a time sampling rate of 2 ms.

Following the migration additional care was taken to preserve amplitudes during the final processing steps. Each step was tested and parameterized using gathers near a well with known class II AvO (polarity reversal) in the main target interval. The standard RMO routine (used during the 2008 processing) was replaced with an "amplitude-friendly" alternative, with amplitudes monitored on key events. Post-migration Radon and Trim Statics were removed from the 2014 processing sequence after it became clear that they were not preserving amplitudes.

Dip-steered median filtering was applied to reduce any remaining artefacts (diffraction "smiles") resulting from the Kirchhoff migration. The steering volume was computed from the full-offset stack and required some heavy filtering to clean up errant dip/azimuth estimates. The "cleaned" steering volume was used to structurally guide the application of a small-footprint median filter to the full-offset and angle stacks.

Qualitative data comparison

When comparing the final PreSTM full-offset stacks between 2008 and 2014, as shown in figures 5 and 6, we note the improved resolution of thin beds within sedimentary packages as well as the appearance of the salt flanks allowing much clearer interpretation of sediment terminations against the salt domes. Deeper down, it is also possible to see the benefits of the 3DSRME removing more water-bottom multiples which had previously confounded interpretation in some places.

More general criteria for assessing data quality have also been considered and these may be qualitative or, to some extent, quantitative in nature (depending on how they are assessed). For example, on figure 6 there is an obvious improvement in event continuity, which could perhaps be quantified in terms of the greater ease in auto-tracking events.

Lateral resolution (of faults mainly) also improved considerably (Figure 6), although the best indications of improved fault imaging appear in the shallow section and on time-sliced attributes such as dip-steered similarity. Such attributes show enhanced imaging of the radial faulting surrounding and arching between the salt domes, as well as pockmarks that are possibly caused by hydrocarbon migration through the area.

Quantitative data comparison

A number of more quantitative criteria were also considered in assessing the uplift in data quality. For example, bandwidth improvement was assessed using filter tests to reveal meaningful geological information over both higher and lower frequency ranges than in the 2008 dataset.

Illumination was also considered by measuring amplitudes over a background window, expected to be laterally invariant (or at least slowly varying). The 2014 reprocessing appears to have reduced the imprint of striping (mostly caused by streamer feathering) but without the addition of additional offset or azimuthal data, the illumination near the salt walls has not changed.

Event-based amplitude maps at known fields were reviewed using both full stack and AvO attributes. The amplitude maps from the 2014 reprocessing have less artefacts and tend to show better structural conformity for areas where we have high confidence that pay sands exist.

Similarly, the 2014 reprocessing shows clearer flatspots at known fields (Figure 6). In some cases, these flatspots have been verified using Gassmann fluid substitution combined with synthetic modelling. Also, for some fields it has been possible to use pressure data to constrain a most-likely depth of the oil-water contact and these depths match those of the flatspots (after time-depth conversion).

Seismic-well ties offer perhaps the most compelling quantitative evidence for improved data quality although this assessment is limited to small areas around well control within the 3D. It is now possible to tie all 10 wells within the 3D area using a consistent approach, with statistically significant correlation coefficients recorded over long time windows. The correlation coefficients often show statistically significant improvements relative to those recorded from well ties made using the 2008 data.

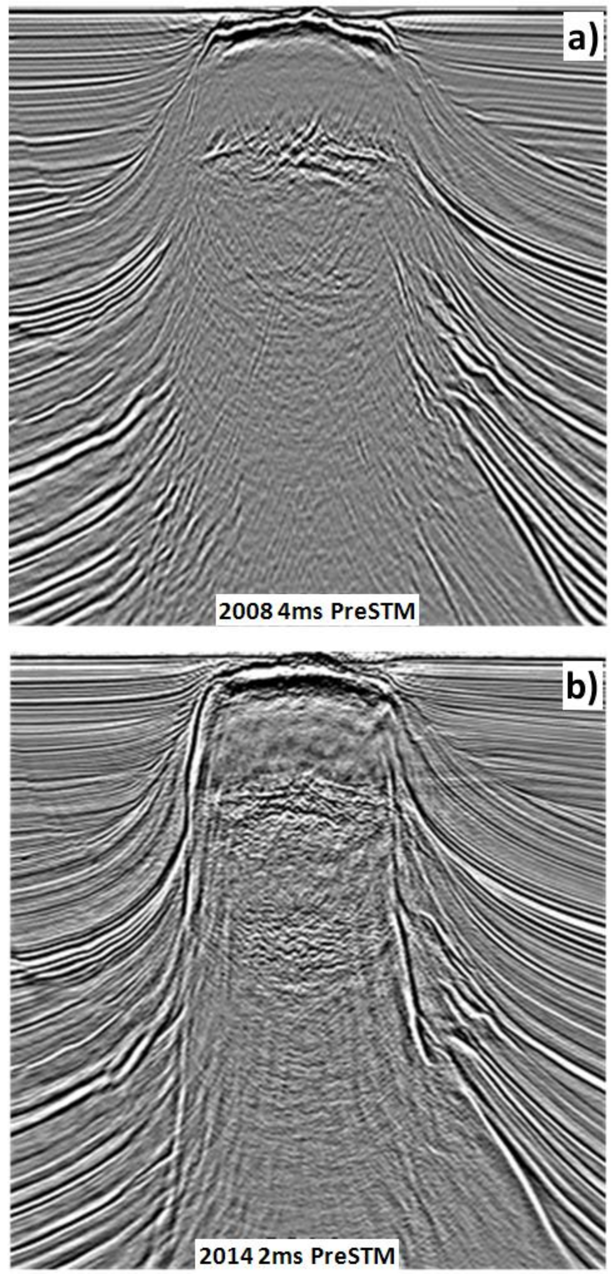

Figure 5: Final stack of the 2008 4ms PreSTM a) compared to final stack of the 2014 2ms PreSTM b) showing a clear improvement in salt flank imaging.

Wavelets estimated (with phase) during the well-tie process show a high degree of consistency (at least when using the full-offset stack). These wavelets also suggest a maximum reliable frequency of 60 Hz at the target level. The well-tie process also includes a QC of well (and seismic) positioning and these displays now show much clearer patterns confirming the accurate positioning of both seismic and well datasets.

Remaining data quality issues

Despite the noted improvements, PreSDM processing has been initiated from an appropriate archive point to address the focusing and positioning issues expected in a salt province. The velocity model from the PreSDM processing is also expected improve time-depth conversion, because the PreSTM velocities (unavoidably) show leakage of salt velocities across the salt-sediment interface and therefore are not suitable for time-depth conversion near the salt walls.

Despite best efforts, the 2014 PreSTM reprocessing still contains some residual multiples, most noticeably in the shallow part of Figure 5b. Also, some parts of the dataset suffer from strong artefacts (diffraction smiles) associated with the use of the Kirchhoff migration method. Dip-steered median filtering struggles to suppress these where they are stronger than the reflection signal as they bias the dip/azimuth estimate. This problem is exacerbated further on the lower-fold angle stacks, thus destabilizing AvO attributes near the salt-walls.

Conclusions

In the six years between the initial processing and reprocessing, computationally intensive processes such as 3DSRME have become standard in the preprocessing flow. Improved de-ghosting, maintaining higher sampling rates through the processing and removing unnecessary processing steps such as Radon also contributed to the improved imaging within our PreSTM workflow.

A series of qualitative and quantitative criteria help to confirm a clear data quality improvement that is most noticeable to a seismic interpreter in the clearer images of steep salt flanks; the detection of extra layering within sedimentary packages; and in the higher confidence amplitude and flatspot mapping at known fields.

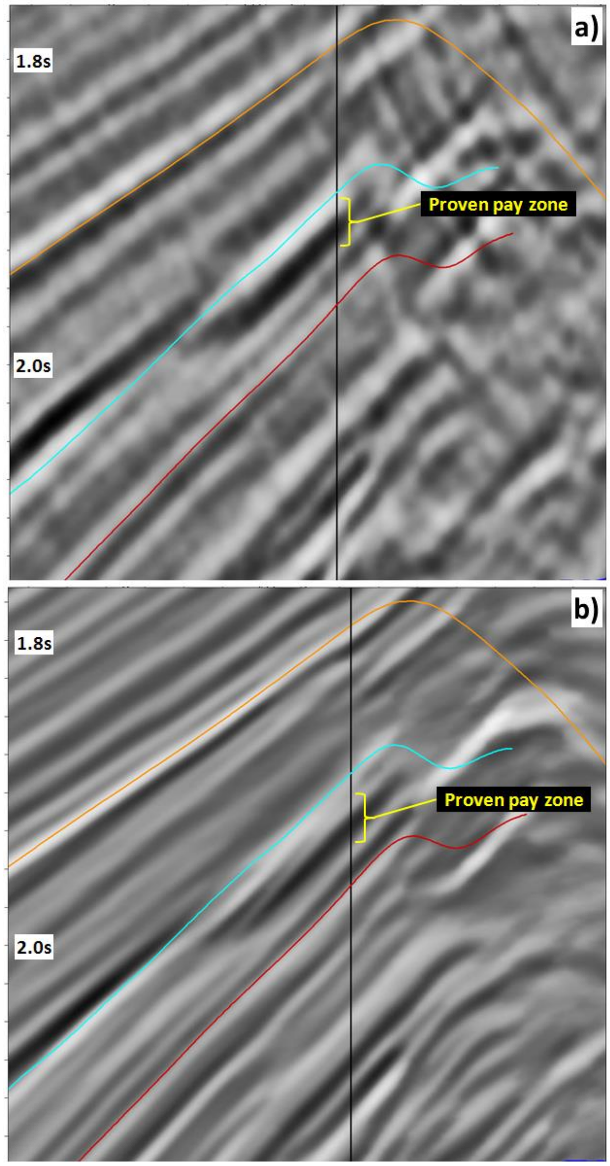

Figure 6: Zoomed up section through an oil discovery comparing the final full-offset stack of the 2008 4ms PreSTM a) to the final stack of the 2014 2ms PreSTM b).The reprocessing shows strong improvements in continuity; vertical; and lateral resolution, as well as a clearer image of the amplitude brightening associated with oil pay sands and a flatspot believed to represent an oil-water contact (just above 2.0s between the cyan and red horizons).

Acknowledgments

The authors would like to acknowledge the efforts of colleagues in the CGG Rio Centre (Mathieu Reinier and Jaqueline Krueger) for their work on the reprocessing project at various stages. We also thank Karoon for permission to publish.

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