Benefits of broadband seismic data for reservoir characterization. Santos Basin, Brasil.

*Ekaterina Kneller, Alexis Ferrer, Jeremy Langlois, CGG Brasil

This paper was prepared for presentation during the 13th International Congress of the Brazilian Geophysical Society held in Rio de Janeiro, Brazil, August 26-29, 2013.

Abstract

Quantitative interpretation teams face two challenges when using model-based inversion: to extract meaningful wavelets and to build accurate low frequency models. The lack of low frequencies in conventional seismic data means that a low frequency model must be incorporated in the inversion process in order to recover absolute impedance values. Typically, low frequency models are obtained from low-pass filtered impedance logs. If well-logs are sparse and the geology complex, the well-derived low frequency model may be inaccurate and cause biased inversion results. One option to improve the low frequency model is to use seismic velocities. However, while seismic velocities provide information at very low frequencies (0-5 Hz), they are not usually suitable to provide information for the missing frequencies in the range from 5 to 10 Hz with conventional seismic data. Seismic data acquired using variable depth streamers are ideally suited for inversion as they provide directly these missing low frequencies, hence removing the need to build low frequency initial models from well data. In order to quantify the impact of the low frequency content on seismic inversion, comparative elastic inversion tests have been conducted using 3-D seismic data from conventionally towed Constant Depth Streamer (CDS) acquisition and broadband Variable Depth Streamer (VDS) acquisition. Both datasets from offshore Brasil, Santos Basin were acquired at different time. The CDS survey was acquired and processed in 2000, the VDS was acquired in 2012 and this paper uses fast-track processing results. The VDS survey was acquired with streamer depth ranging from 10 to 50m.

Introduction

This paper presents the results of a 3D acoustic inversion over a Brazilian offshore field. The test area is around 1330 km2. The first target was the Eocene reservoir and the second target was the pre-salt carbonates. For the test-comparison 2 datasets were used: the conventional CDS survey final PSTM and broadband VDS fast-track PSDM. So we have to keep in mind that this test is not using completely equivalent materials for analysis. The objective of this project was to see clearly the difference in acoustic inversion results for conventional and broadband seismic datasets. The test was executed with effort to synchronize all parameters of both inversions and see the result caused by the differences in the input data.

Acoustic inversion

A stratigraphic model-based acoustic inversion algorithm was used. The seismic data is band-limited and there is significant noise. This approach allows us to incorporate into the seismic interpretation a “stratigraphic” horizon model, based on the known or suspected geology. This can result in better resolution and a better link between the seismic data and the actual lithology (e.g. from well data and geological mapping). Since for any seismic data, we can find more than one model whose synthetic matches that data, having such prior information can become crucial in handling the non-uniqueness problem.

We used generalized linear inversion (GLI) which attempts to modify the model until the resulting derived synthetic matches the seismic trace within some acceptable bounds. In other words, the initial geological model is perturbed until the error between the synthetic created by that perturbed model and the original seismic data is minimized. It is assumed that the wavelet in the seismic data is known and, in fact, is the current wavelet. For each trace, a synthetic seismogram is calculated using the initial guess impedance and the known wavelet. That impedance is then modified gradually, until the resulting synthetic trace matches the real trace within some tolerance level. By inversion parameters the user controls how far the algorithm may move from the initial guess in order to match the real data with the predefined constraints. The section through two datasets, - conventional and broadband, is shown Figure 1.Spectrums of the corresponding datasets for the time interval 2800-5400ms are presented in Figure 2. Here we can see the difference in the frequency content, notably the presence of low-frequencies in the broadband data. And one more significant difference can be noticed in the wavelet shape of the broadband signal – the side lobes are very small. The last fact is critically important for the inversion algorithm: the less side lobes we have, the less interference there is in the seismic signal and, as a consequence, less ambiguity in the inversion. Technically it means that there is less uncertainty in the inversion result and the minimum of the cost function for inversion can be reached in fewer iterations. This was confirmed during the execution of this test. A map of the test area and well X and Y locations is shown in Figure 3. Both wells penetrate the pay part within the Eocene reservoir but neither of them reaches the pre-salt section.

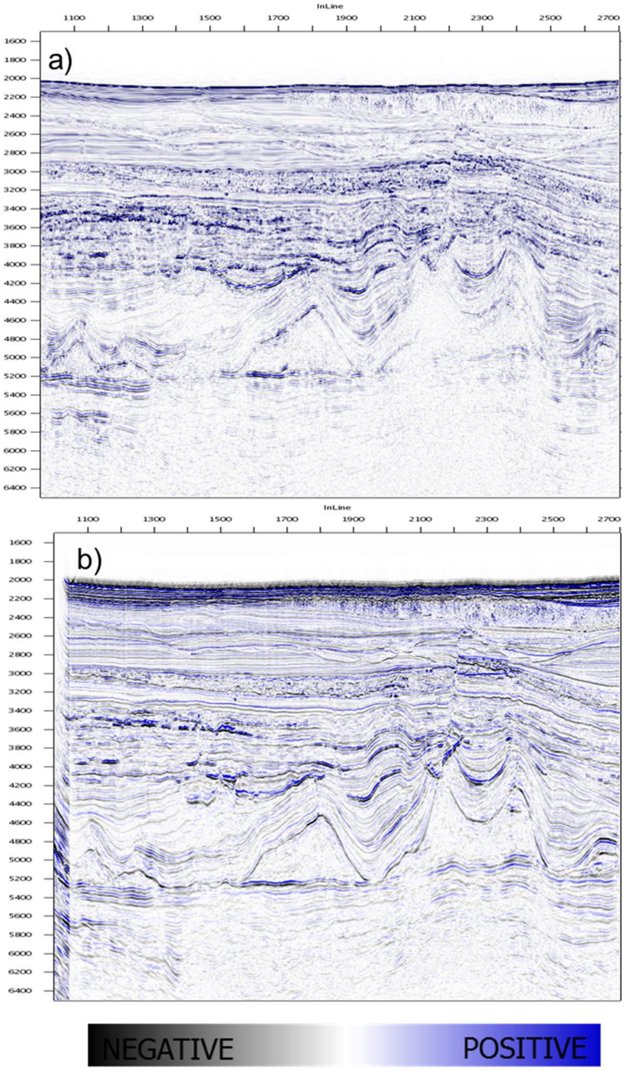

Figure 1. Section showing conventional (a) and broadband variable depth streamer acquisition (b) seismic data.

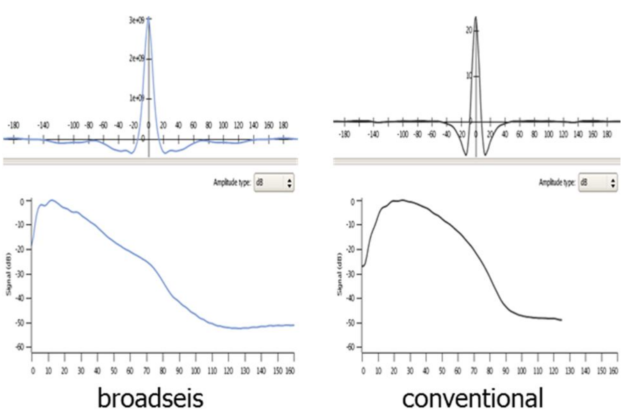

Figure 2. Spectra of broadband variable depth streamer and conventional seismic data.

The same initial model was used for two inversions. The model was created based on well X logs with Vp (P-waves velocity) and density values being interpolated along basic horizons. The model was filtered with the low-pass filter 2-5Hz. The model and all parameters of inversion are based on well X. Well Y is used as a blind test. In Figure 4 an illustration with a section through the initial model of acoustic impedance is presented (a). The interval of Eocene reservoir is shown. In the same figure the inversion results are shown for conventional (a) and broadband variable depth streamer (b) datasets. A better separation of geo-bodies is observed on the broadband inversion. The inversion parameters were designed to reach the same quality of result at well X location. Figure 5 shows a QC of well X created during the inversion parameterization. At this step the actual impedance values from the well and the inversion result at the well location are compared as well as the residuals, the difference between seismic and synthetic at the well location, are estimated. Residuals resulting from the conventional inversion are of higher frequency compared to residuals from the broadband inversion. This is caused by the frequency content of the initial data and the corresponding wavelet. But it was also noticed that two factors make a big difference in the parameterization of inversion of broadband and conventional seismic datasets: 1) focusing the parameters on the target only, we reach better results outside the target zone automatically for the broadband inversion, 2) the good solution (minimized cost function and small residuals) of the broadband inversion can be reached in fewer iterations, as mentioned before. For both inversions the same level of constraint was chosen – allowing the inversion result to move quite far away from the initial model.

False events appearing on the conventional dataset inversion are probably caused by the presence of side lobes in the corresponding wavelet and they prove the greater ambiguity of the inversion results using conventional data.

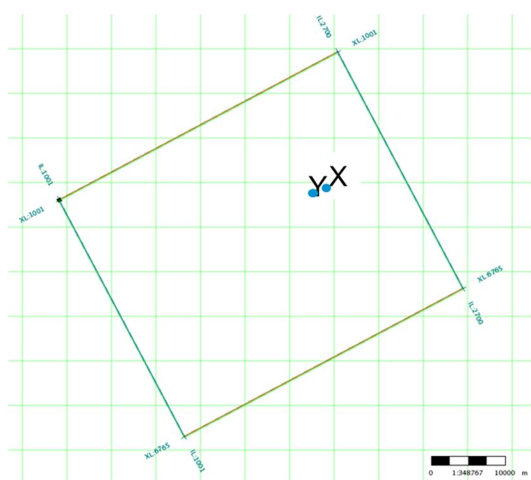

Figure 3. Test area and wells.

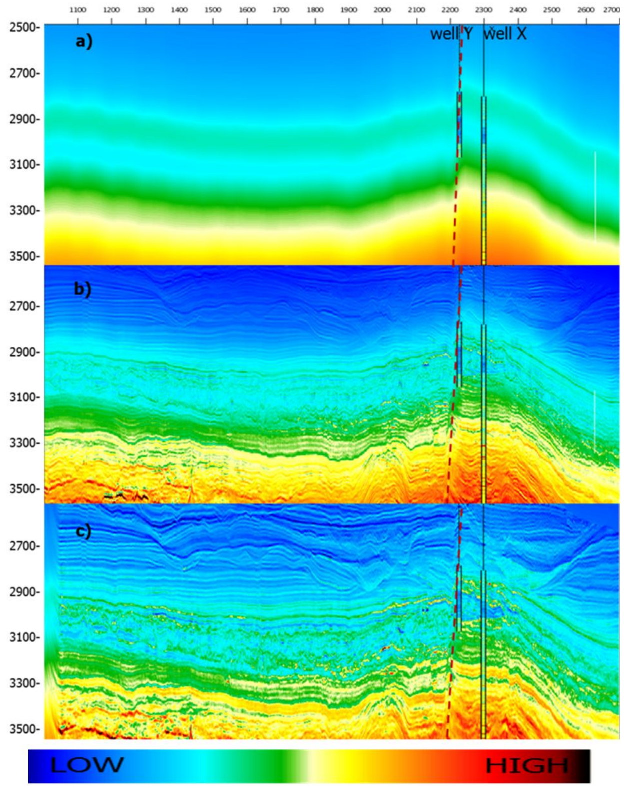

Figure 4. Section through initial model and inversion results: a) initial model, and inversion results for b) conventional and c) broadband variable depth streamer datasets

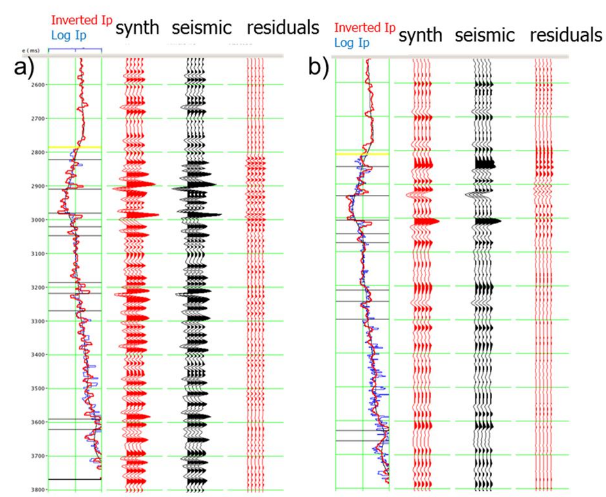

Figure 5. Well QC a) conventional, b) broadband variable depth streamer acquisition

Results

As a result of the inversion processes two acoustic impedance volumes were generated: one for broadband variable depth streamer and one for conventional streamer. Figure 6 shows horizontal slices through both of them – which correspond to the level of the oil-water contact within the Eocene reservoir. The most obvious difference between them is that the broadband result lets us see the sharper borders of the pay interval of the reservoir (indicated by blue – low impedance zones). The same effect can be seen on the vertical section shown in Figure 7. This benefit gained from the inversion of the broadband data will help to better define the geometry of the reservoir and decrease the uncertainty in calculating reservoir volume. One more advantage of the improved low frequency content (below 10 Hz) in the broadband data is the better definition of geological bodies separated by faults; even if a fault is not included in the initial model, it makes the interpretation process easier and more reliable. This also can be seen in Figure 4 : the high impedance layer on the right side of the fault at time 3180ms corresponds to the same layer on the left side of the fault at time 3320ms. This is more clearly defined in the broadband inversion results.

In Figure 8 we show the quality control at well X and well Y. The broadband inversion gives a better match to the “blind” well Y – the inversion impedance is closer to the real log values, because of the presence of the low frequency content in the broadband seismic data. Then, we can see how these results affect a cascaded lithology and hydrocarbon classification: cross-plots are presented in Figure 9. On the horizontal axes there are acoustic impedance values (logs or inversion results) and the saturation and lithology are shown in color. This analysis was executed only for reservoir interval. In the initial cross-plot – (a) and (d) – we can see the excellent separation of oil and water saturated reservoir intervals. Analyzing the inversion results around well X – (b) and (c), used in the initial model, we can see that the overlap of the facies in terms of impedance values (horizontal axis) is larger on the conventional seismic inversion results, which means the uncertainty is greater. Then, making the same analysis for two wells: X and Y – (e) and (f), we can see more uncertainty, as expected, and again, for conventional seismic the uncertainty is so big that we cannot determine the cut-off value for oil and water saturated parts of reservoir.

In the pre-salt interval, not penetrated by wells, only a very general analysis could be carried-out. On Figure 10 display some time slices and sections corresponding to this interval. We observe the same effect of low frequencies making the geological bodies better defined in the broadband inversion results. The individual layers can be seen more clearly compared to the conventional inversion results, where separated by fault parts of geological bodies can be hardly interpreted as the single object. Taking into account the significant lateral changes in carbonate properties – important to emphasize the significance of the presence of low frequencies in the seismic data for a proper inversion calculation.

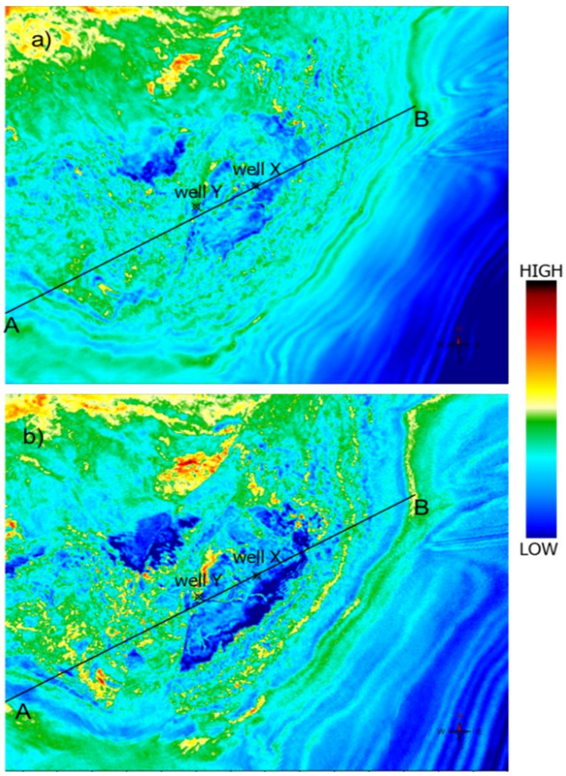

Figure 6. Acoustic inversion results for Eocene interval: a) horizontal slice through conventional data inversion result, b) horizontal slice through broadband data inversion result. The line AB represents the location of section on Figure 7.

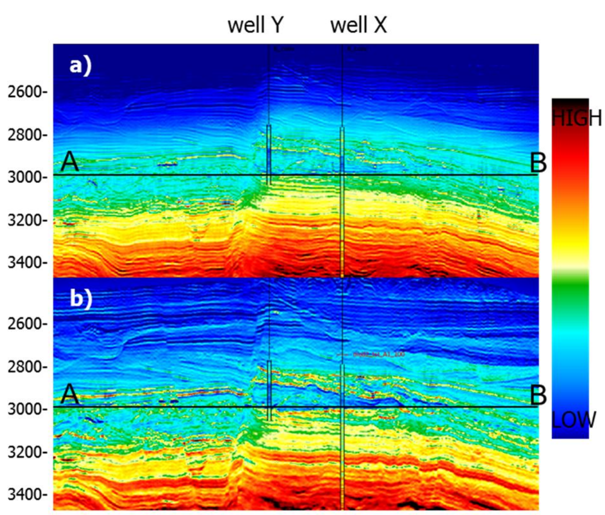

Figure 7. Acoustic inversion results for the Eocene interval: a) section through conventional data inversion result, b) section through broadband data inversion result. The line AB represents the level of slice on Figure 6.

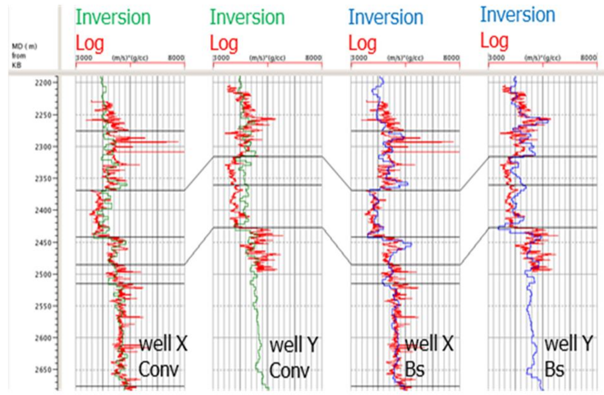

Figure 8. Well QC of inversion results.

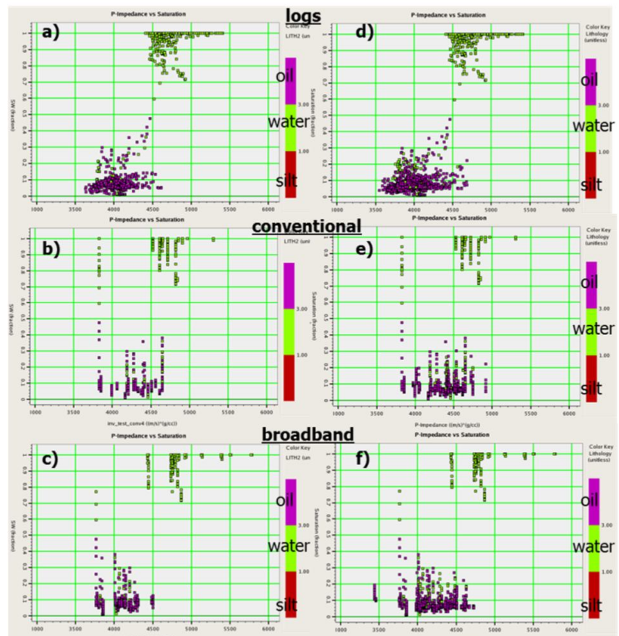

Figure 9. Cross-plot saturation log versus acoustic impedance: a), b), c) – only well X , d), e), f) – well X and well Y ("blind") are used in analysis.

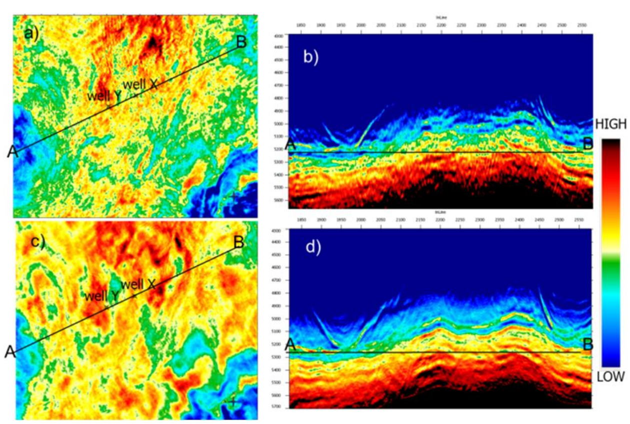

Figure 10. Acoustic inversion results for pre-salt interval : a) horizontal slice and b) section through conventional data inversion result, c) horizontal slice and d) section through broadband data inversion result

Conclusions

The lack of low frequencies in conventional seismic data usually makes us impose this part from an a priori initial model, which can be quite risky if the well information is sparse and the reservoir properties change laterally. Also, the low frequencies are very important for better estimation of the real, absolute impedance values. The described experiment shows the advantage of broadband variable depth streamer data for reservoir characterization, particularly for inversion and lithology classification. The variable depth streamer acquisition provides valuable information to constrain the inversion process and obtain accurate impedance estimates without using a log-derived low frequency model. The presence of low frequencies in the seismic data and absence of side lobes in the wavelet provides the following benefits:

1 – Better quality inversion results, proven by the "blind" well test

2 – Clearer definition determination of geo-bodies,

3 – Less uncertainty in lithology classification.

Acknowledges

The authors would like to thank ANP (Agência Nacional do Petróleo) and CGG for permission to publish this paper.

References

L. Michel, R. Hanumantha, F.Baillard, CGGVeritas, Variable Depth Streamer acquisition – benefits for rock property inversion, 2013. Abstract, PDGS2013 Petroleum Geoscience conference and Exhibition, Kuala Lumpur.

Soubaras, R. and Whiting, P., 2011, Variable depth streamer: The new broadband acquisition system. 81th SEG Annual Meeting, Expanded Abstracts 30, 4349-4353.