Attribute Analysis of an area below seismic resolution – a case history from the Peregrino field

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Abstract

The capability of interpreting a reservoir is highly dependent of seismic resolution. The Peregrino Field is challenging with a Carapebus sand reservoir on-lapping the Macaé Group. The stratigraphic trap gives a pinchout line length of approximately 30 km. The Top Macaé has strong acoustic impedance contrast with the layers above and dominates the seismic response, since the impedance contrast of the reservoir sands and the cap rock is much smaller.

Determining the pinch-out of the reservoir is very challenging due to the limitation in resolution. Two appraisal wells have proved good reservoir sands in the area below tuning thickness, and the aim of this paper is to demonstrate how the well data were used to perform synthetic seismic wedge modeling and how the results were applied in an attribute analysis study of the real seismic data.

Introduction

For seismic interpreters one of the most difficult challenges is to deal with seismic resolution limitations. Geological events that are closer than ¼ of the seismic wavelength cannot be accurately interpreted. Within this thickness, the top and bottom events interfere with each other. This interference can be either constructive or destructive, depending on the thickness of the bed and the acoustic impedance of the layers (Widess, 1973). The Peregrino Field brings several challenges to seismic interpretation in the area below seismic resolution (BSR), and this paper aims at demonstrating how attribute analysis and AVO helped to approach some of the challenges.

Geological concept - Peregrino Field

The Peregrino field is located in block BM-C-7, in the southernmost Campos Basin (Figure 1). The field is located 85 km southeast of the nearest coastline, approximately 100 km southeast of Macaé. The Peregrino field was discovered in 2004, and the production started in 2011. The water depth in the area varies from 95 to 135 meters, over an area of approximately 350 km2. The reservoir depth range between 2150 and 2350 meters TVD. The Peregrino Field is one of the offshore development with the heaviest oil (14°API) in Brazil.

The reservoir interval is the Carapebus Fm., with good quality Cretaceous sands deposited from gravity flows in deltaic and shallow marine environments. The upper and lower part of the reservoir is divided by a 5 m thick siltstone flooding surface. The caprock is a shale, the Tamoios Fm., and the formation below the reservoir is the Macae Group, which is composed mainly of marls and limestones in this area.

Figure 1: Location of Peregrino field

This study will focus on the most updip part of the reservoir structure. The isochron in Figure 2 illustrates the area of interest.

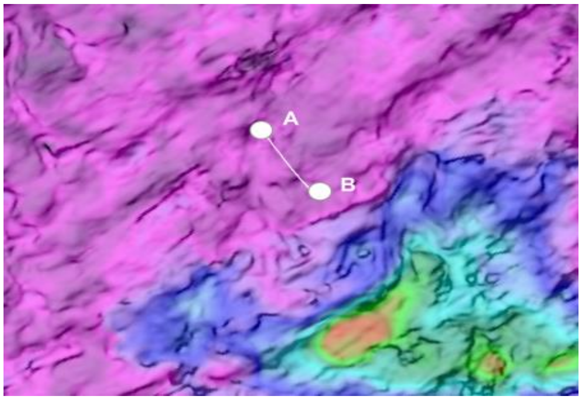


Figure 2: Isochron map in the Peregrino Field with semblance at Top Macaé in background, around the two appraisal wells A and B. The pink areas show where the interpreted top and base reservoir are less than 23ms thick.

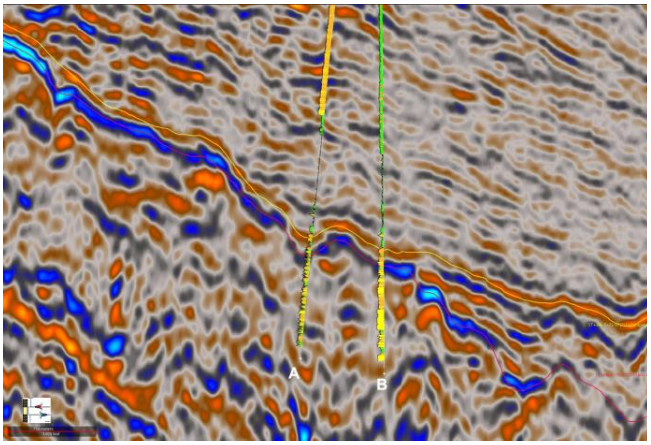


Figure 3: Seismic dip section along wells A and B. Carapebus onlaps onto Macaé.

Well data – AI and Vp/Vs

There are information about the AI and Vp/Vs ratio from the logs of the appraisal wells A and B.

The impedance contrast between the cap rock, Tamoios, and the reservoir is very small in comparison to the contrast between the reservoir sands and the limestones in the Macaé Gp. This makes the top Macaé event (bottom reservoir) the dominating event at the reservoir level, specifically in the tuning area. Thus it is possible to map the bottom of the reservoir, but this is not the case for the top of the reservoir. Therefore, predicting the pinchout of the reservoir is very challenging.

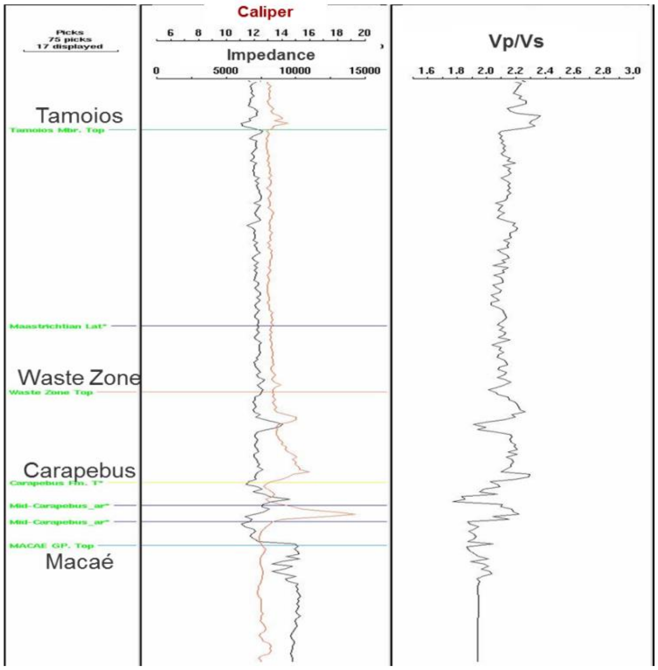
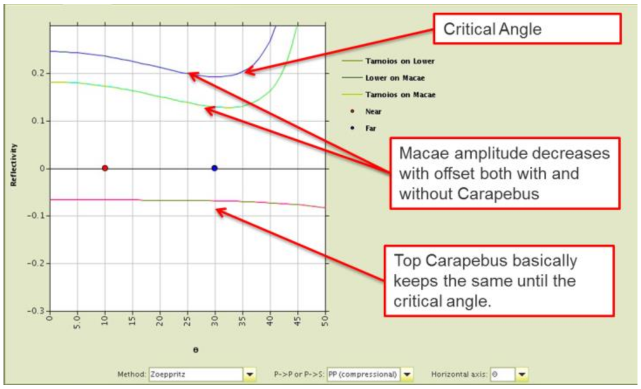


Figure 4: Acoustic Impedance and Vp/Vs in the appraisal well B.

Another observation from the well data is the expected seismic response of the Carapebus reservoir sands. The good and permeable sands show a decrease in acoustic impedance from Tamoios. This sand is present in the Lower part of the thin reservoir proved by A and B (Figure 4). However, the poorer Carapebus facies have almost no acoustic impedance contrast with Tamoios in comparison to the reservoir sands.

From the Vp/Vs-log shown in Figure 4 information about the expected AVO (amplitude versus offset) response can be extracted. The reflection of the dominant bottom event (Top Macaé) dims towards larger angles, but the Carapebus sands has an opposite behavior with almost constant AVO response (Figure 5).



Critical Angle

Macae amplitude decreases with offset both with and without Carapebus

Top Carapebus basically keeps the same until the critical angle.

Figure 5: Expected AVO behavior from average rock properties values.

Seismic PSDM data and its resolution

Peregrino has a 3D seismic dataset acquired in 2007, which was reprocessed in 2010 using prestack depth migration. For the Peregrino PSDM data the tuning of top and bottom reflectors begins whenever the isochron is equal to or smaller than 23ms TWT. The tuning thickness in the area below seismic resolution on Peregrino is 16ms (Figure 6).

The tuning thickness explains by itself the motivation for this work, as 16ms for a reservoir with velocity around 2900m/s means a potential 23m Carapebus thickness. Thus the ability of distinguishing the areas where the Carapebus sands are present from the areas where the seismic response is caused by the sidelobe of the Top Macaé would be valuable.

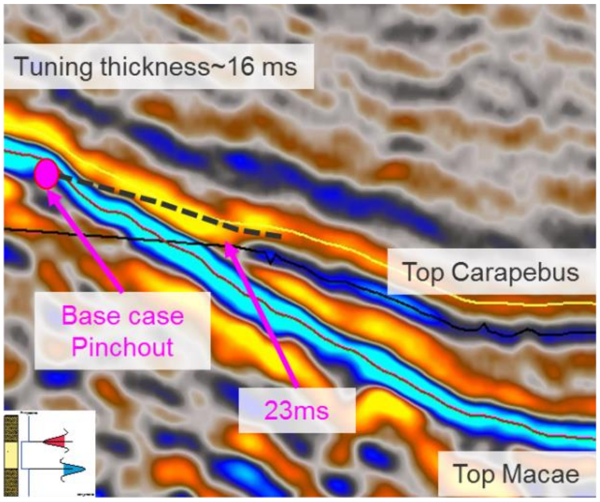


Figure 6: Time interpretation in the BSR area. Top Carapebus is interpreted in a trough and Top Macae in a peak, but in the BSR area this trough can be the sidelobe of the Macae reflection.

Well ties and wavelet extraction

To construct an accurate wedge model, the first step is to determine a proper seismic wavelet. In order to do that seismic well ties were performed. Wavelets were extracted using the wells and forward synthetic seismic modeling was performed to try to reproduce the real seismic data at the reservoir level.

Wavelet extraction from the Peregrino data has been a challenge. Despite the wells having reasonable well ties, the noise in the seismic data raises difficulties. By synthetic modeling we observe that the extracted wavelets do not represent the real signal at the reservoir level. Wavelet extraction was performed both in the overburden and in the reservoir. For the shallow reflectors the frequency content is higher than at the reservoir, and in the reservoir the quality of the extracted wavelet was very poor due to the noise content in the seismic data. Since both wavelets were noisy and the modeling using them was not considered representative, a bandpass wavelet with similar maximum frequency content as the extracted wavelet at the reservoir level was created. The minimum frequency was selected to fit the sidelobe of the extracted wavelets. The result was a smooth and controlled wavelet (Figure 7).

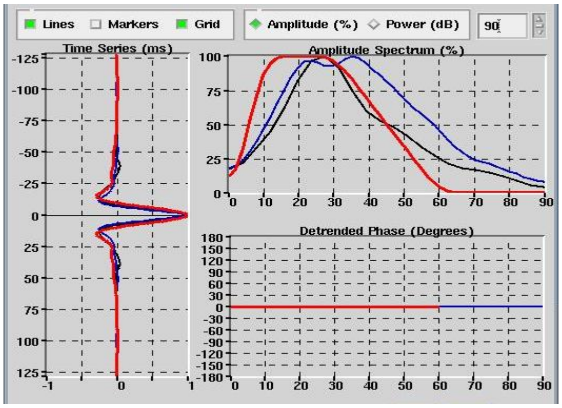


Figure 7: Extracted wavelets for shallow interval (blue), in the reservoir interval (black), and the bandpass wavelet (red).

Wedge Models

Wedge models were created using the bandpass wavelet. First, a simple model with only the good sands in the reservoir (Figure 8) was created. This model was created using the mean values for each lithology. In the wedge model, the thickness of the sands was varied in order to simulate the response of the tuning effect in (Figure 9).

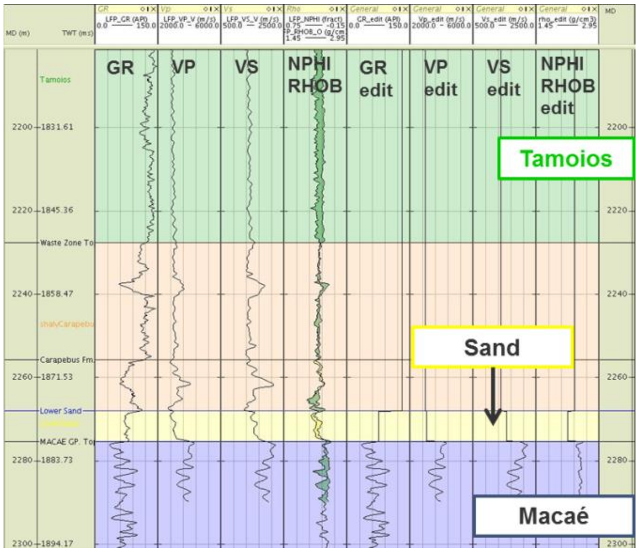


Figure 8: Logs from well B. The first (simple) wedge model was created using means values for Tamoios and for the good reservoir sand in Carapebus only (edited logs to the right). The second model used the entire logs, including poor sands and shales (pink colour).

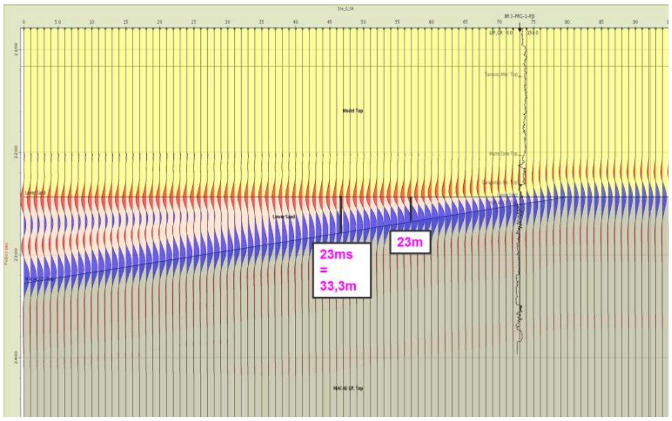


Figure 9: Wedge model varying the thickness of the simple sand model illustrated in Figure 7.

The gathers of each wedge model were analyzed in terms of amplitudes and AVO response of the Top Macaé peak and of the sidelobes.

From Figure 10 the difference in AVO response of the trough for different cases can be observed. The AVO effect of the peak (Top Macaé, in blue) is very similar for all cases.

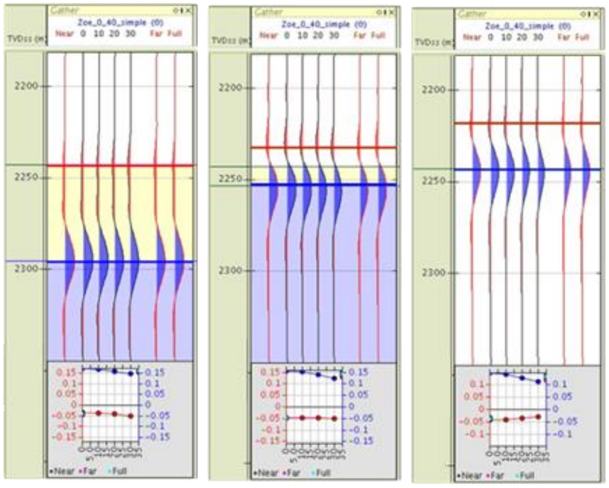


Figure 10: Angle gathers from the simple wedge model. The first gather is the case with thick sand layer (no tuning effect). The second gather is in tuning with a thin sand bed (7m), and the last is the case without sand (only Top Macae event).

In the second model, the real logs of well B were used, including poorer sands in the Carapebus reservoir, and a transition zone between Tamoios and the reservoir (Figure 8). The AI and Vp/Vs ratio of those shaly sands are different from the good reservoir sands tested alone in the first model.

In the synthetic seismic gathers of Figure 11 it can be observed that the AVO response with the poor shaly sands above the good sands is different from the simple model (Figure 8). In this scenario the expected AVO response for Top Carapebus is constant even without tuning. However, it is still possible to distinguish the cases with and without Carapebus sands in the model. This effect is also possible to observe in the stacked data, according to the modeling (Figure 12). It is only possible to distinguish sands thicker than 6m according to this model.

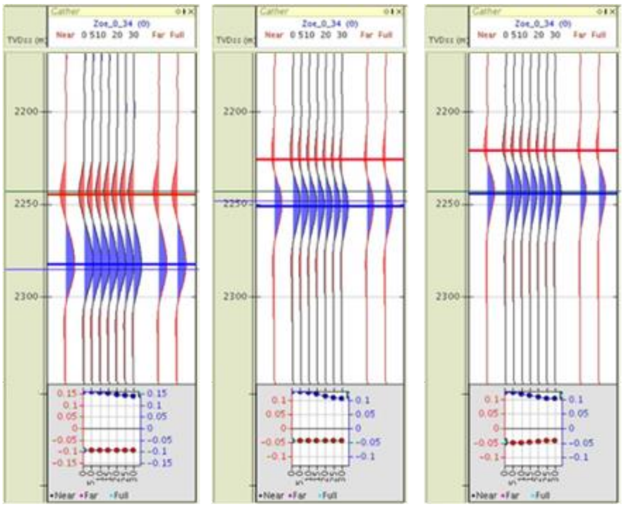


Figure 11: Angle gathers from the wedge model from well B logs. The first gather is the case with thicker Carapebus (no tuning effect), the second gather is with a thin Carapebus (tuning effect), and the last is the case without any Carapebus.

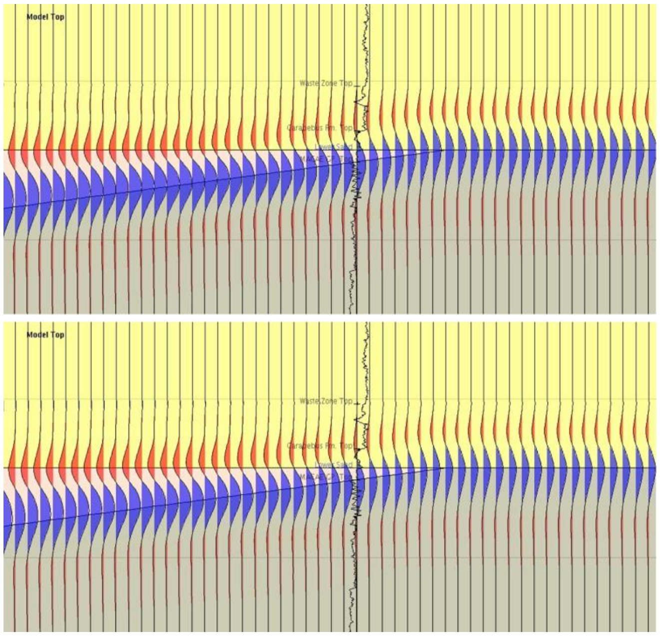


Figure 12: The near stack (0-15º) (above) and the far stack (below). The AVO dimming on the far stack is clear in the area without Carapebus (pink in the background).

Application on real seismic data

The seismic data on Peregrino has problems with residual multiples, causing near traces with too strong amplitudes. In addition, the noise content in the data is quite high in certain areas. This means that the AVO response in the seismic data is not preserved. It is only possible to observe a qualitative trends when examining the ratio between near and far offsets in the real data, with higher ratio between far and near stack where sands are present (Figure 13).

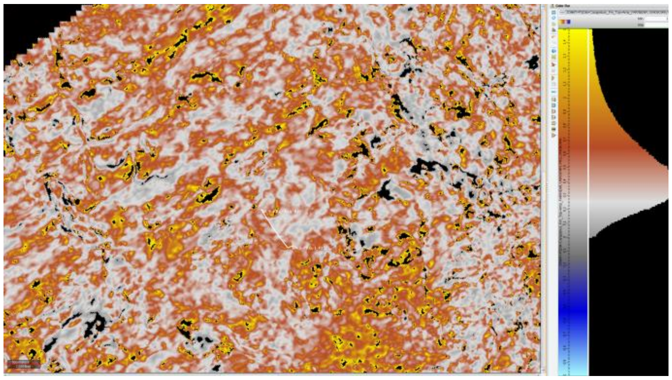


Figure 13: Ratio between Far and Near stack amplitudes.

Despite the noise contaminated near traces, it is still possible to use the relationships observed for the far stack amplitudes. According to the modeling results, the seismic amplitudes of the trough are constant if there are sands present. At the same time, the amplitudes of the peak dims in this case. When the sand is not present, the sidelobe of the peak dims following the peak AVO effect. Therefore, the ratio between the far offset amplitudes of the trough and the peak can differentiate scenarios with and without sand.

In addition to the larger difference between scenarios in the far stack, another advantage of using the far stack amplitudes alone is that the far stack is less noisy. Based on this, an amplitude ratio map was created by dividing the amplitude of the trough by the peak in the area Below Seismic Resolution - BSR (Figure 14).

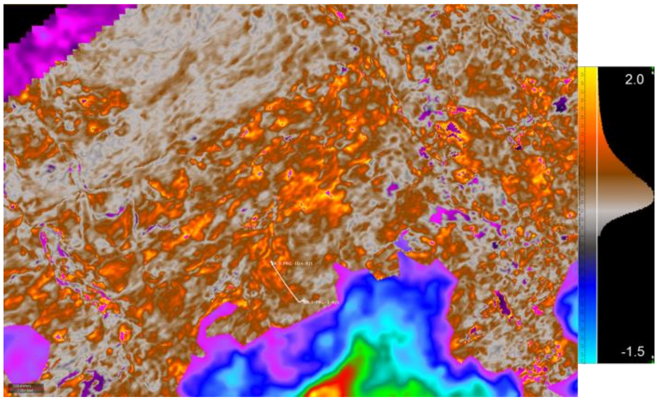


Figure 14: Amplitude ratio map in the BSR area using Far offset amplitudes. Isochron between Top Carapebus and Top Macaé is shown in the non-BSR area.

Conclusions

According to the modeling, it is could be possible to predict good sands beyond seismic resolution. The thickness limitation found in the modeling was 6m. Any sands thinner than this cannot be detected. The contrasts found in the modeling were not very large, thus it is not easy to use this directly when evaluating the real data.

Despite of this, it was still possible to use the result from the modeling by evaluating the far angle amplitudes alone. With the amplitude ratio attribute map (Figure 14) together with seismic dip interpretation (Figure 3) and the structures observed in Figure 2 it is possible to delimit pinchout lines and also identify possible new targets in the BSR area of Peregrino.

Acknowledgments

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The seismic data shown is proprietary to PGS.

References

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