Geophysical analysis in multi-disciplinary well construction on the Peregrino field

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Abstract

Seismic data is extensively used in structural interpretation, lithology prediction and geosteering in well planning and operations on the Peregrino field. However, the quality of the seismic data in the area varies dramatically, making quantitative analysis and detailed planning challenging.

The aim of this paper is to demonstrate how seismic data is widely used as part of a multidisciplinary workflow. Seismic datasets are used to condition reservoir models, drive drainage strategy and well placement and to support geosteering decisions in combination with LWD tools.

Introduction

The Peregrino field is located in shallow water (around 130m of depth) in the Campos Basin, offshore Brazil. The reservoir consists of highly heterogeneous turbiditic sandstones, composing a stratigraphic trap that onlaps the carbonate sequence of the Macaé Group (**Figure 1**).

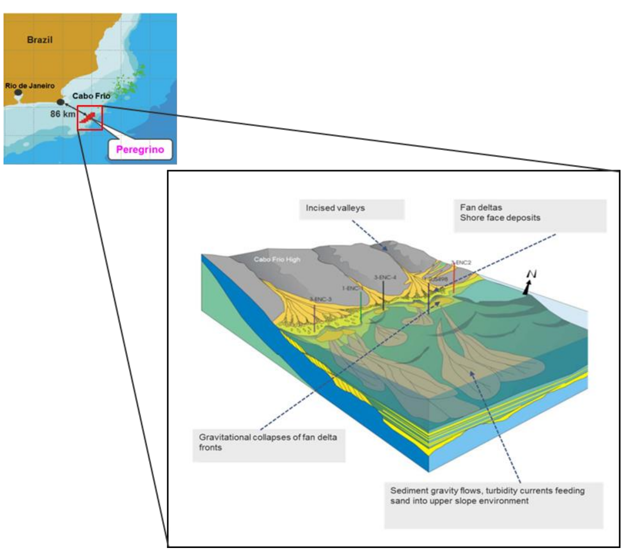

Figure 1 Geological concept of the Peregrino field

Being a heavy oil field, with oil API gravity varying from 13º-15º, the exposure of the producer wells to good reservoir quality is critical for production. The drainage strategy consists of several long horizontal wells, and fast drilling to keep up with the high production expectations.

The current seismic dataset has severe multiple residuals in the near traces and for this reason amplitude preservation is not optimal for AVO studies. Challenging overburden features such as progrades, large canyons and a seabed reef badly affects the signal-to-noise ratio for key areas. Additionally, due to the reservoir configuration, seismic data is not able to successfully resolve top and base reservoir in certain areas. For all these reasons, reservoir characterization studies in Peregrino require different geophysical analysis.

The well planning workflow

This paper intends to summarize the geophysical input and analysis prior to drilling production wells on the Peregrino field. The main aspects to be discussed are:

- Geophysical input to the reservoir model
- Target qualification
- Detailed cross-disciplinary target definition
- Geosteering during reservoir drilling

Geophysical input to reservoir model

The reservoir model is the starting point for the well construction workflow. The geophysical input is present throughout the whole process; starting from the structural framework (horizons, faults, etc.) up to the facies modelling and reservoir properties conditioning. At an early stage, seismic structural interpretation and time-to-depth conversion based on velocity analysis are used to create the fundamental structural framework of the field. Secondly, rock physics analysis, use of seismic inversion and amplitude analysis establish the main trends to populate the lithology facies into the model grid (**Figure 2**).

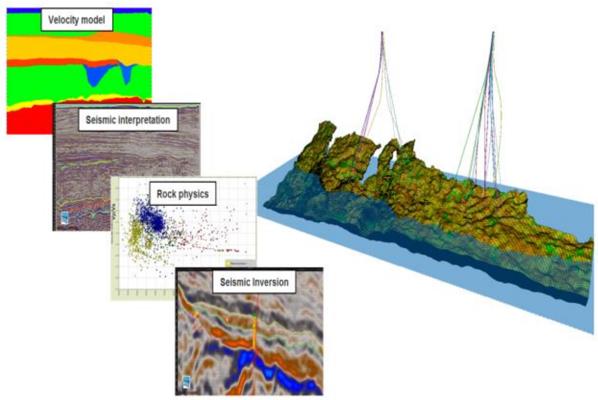

Figure 2 Geophysical inputs to the reservoir model

Rock physics analysis performed in Peregrino, using exploration wells, has been successful to highlight reservoir facies from non-reservoir facies in the Vp/Vs (velocity ratio) vs. AI (acoustic impedance) cross-plots domain (**Figure 3**). In general, Peregrino wells present a clear rock property contrast between good quality sandstones with both lower AI and Vp/Vs values from: a. overlying shales from the Tamoios Member; b. intra-reservoir siltstone; and c. underlying carbonates of the Macaé Group, all of which present higher Vp/Vs or AI values.

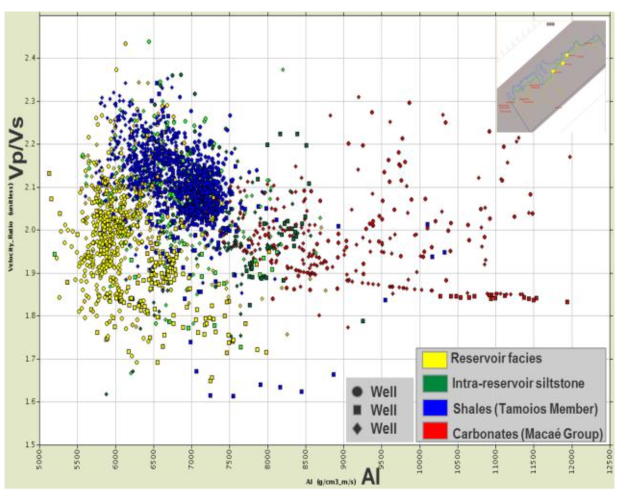

Figure 3 Vp/Vs vs AI cross-plot of three wells from Peregrino showing separation between reservoir (oil case) and non-reservoir facies.

Normally, seismic inversion derived attributes are used to classify seismic data into the same rock property domain and facies. The final goal is then to measure the probability of the occurrence of each facies across the study area. Peregrino seismic dataset limitations, such as poor amplitude preservation, strong side lobe effect from the Top Macaé Group (base reservoir) and challenging low frequency model issues (large heterogeneous field with sparse well log data), did not yield successful pre-stack inversion results. However, the use of full-stack relative acoustic impedance for Peregrino has been a practical solution to represent facies distribution among wells.

Internal pre-stack inversion software uses the best part of the seismic offset range and a selected wavelet to compute relative acoustic impedance contrasts. The impedance contrasts show good correlation with the reservoir facies from selected well locations in Peregrino, indicating that low relative acoustic impedance values correspond to a higher probability of good quality sand occurrence and high relative acoustic impedance corresponds to non-reservoir associated lithologies occurrence, see **Figure 4**.

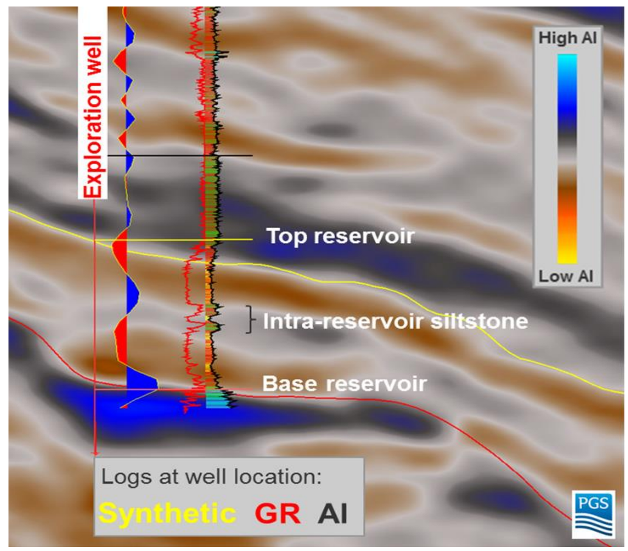

Figure 4 Seismic to well tie of vertical exploration well. Low acoustic impedance (AI) and gamma ray (GR) is associated with high quality reservoir sands.

This relative acoustic impedance values calibration to well log facies is the origin of probability density functions (PDF´s) and through them it was possible to statistically generate relative probability occurrence of reservoir and non-reservoir cubes. These cubes are used as a main trend for sand distribution in the reservoir model.

Target qualification

This stage consists of locating possible targets as a result of multidisciplinary screening and ranking, where both geoscientific and reservoir engineering inputs are taken into account and discussed with drilling and well engineers to come up with good areas to place wells optimally. Initially, the dynamic model depicts the preferential locations for higher production potential targets, followed by a fast-track geoscientific validation.

Detailed cross-disciplinary target definition

At this stage, the concept of the target area should be defined with a high level of detail using a cross-disciplinary approach. Different seismic attributes and techniques are used in order to reduce uncertainties in terms of structure and lateral continuity of sands, reservoir thickness and properties, distance from the aquifer and time-depth conversion issues.

The topography of the Macaé Group carbonates, at base reservoir, and the way this controlled sand deposition in Peregrino, is a very important aspect of the geological understanding. This is why structural attributes such as semblance and dip-azimuth maps are key tools to identify and characterize sand prone areas and avoid faults and escarpments (**Figure 5**).

RMS amplitudes as well as acoustic impedance maps (derived from seismic inversion), are used to identify and refine interpretation of sand bodies and indicate possible stratigraphic discontinuities (**Figure 5**).

Seismic amplitudes are calibrated and validated through existing seismic to well ties; this helps to avoid common pitfalls, such as focusing on bright spots that do not indicate good sand presence and highlight seismic resolution limitations. Additionally, seismic forward modelling brings information about reservoir thickness sensitivities and seismic response interference between reservoir and non-reservoir associated amplitudes. This analysis is used to support and increase the confidence in the seismic interpretation (**Figure 6**).

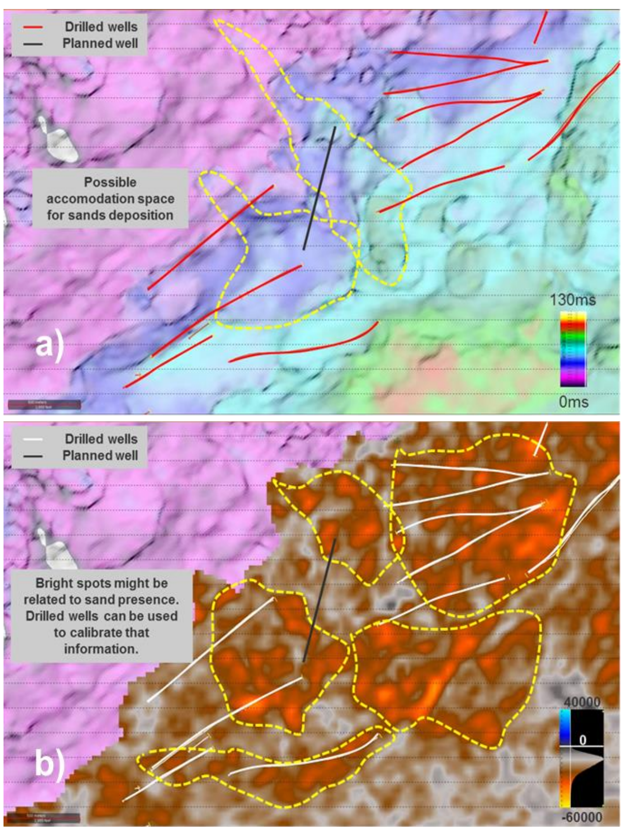

Figure 5 a) Isochron map between top and base of reservoir blended with semblance map at base of reservoir, highlighting the correlation of sand deposition and structure. b) Amplitude map at top of reservoir.

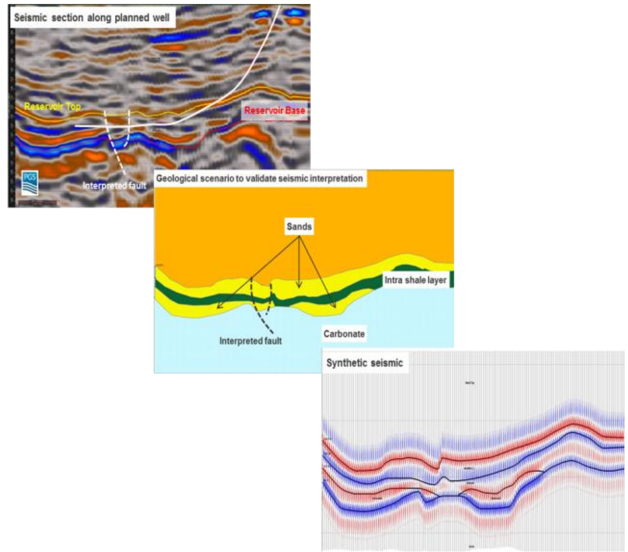

Figure 6 Diagram regarding the validation of interpretation through seismic forward modelling

Uncertainty analysis carried out during well planning takes into account seismic interpretation, velocity and well survey data among other parameters to estimate uncertainty values for a given well-path (**Figure 7**).

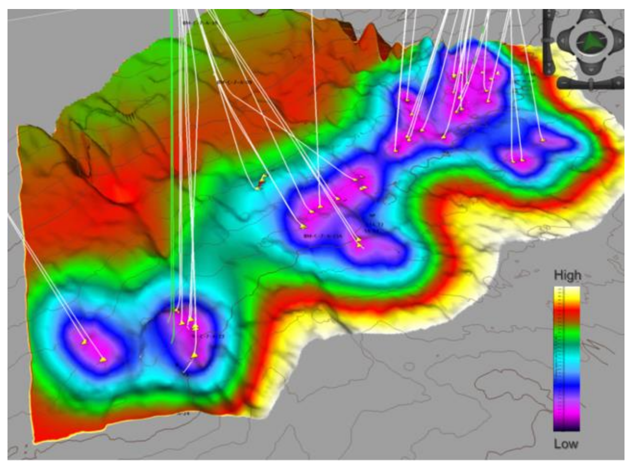

Figure 7 General view of the depth uncertainty map at top reservoir

After analysis and detailed interpretation of all collected data, it is possible to come up with a final trajectory which could endorse a location for the well to be drilled. The drilling engineering involvement is crucial to ensure the well is drillable and all operational risks are evaluated.

Operations and geosteering

During the drilling of the reservoir section, the main objective of the geosteering is to maximize good quality sand exposure. Standard LWD (Logging While Drilling) data such as gamma-ray, density neutron and resistivity give insight to reservoir properties during operations.

In addition, azimuthal resistivity measurements are acquired and processed real time to be used in geosteering decisions. This information is combined with the detailed seismic knowledge of the area and the seismic interpretation may be updated as the well encounters new geological information. The great benefit of this combination is the high resolution sampling around the borehole and the vast amount of structural information and understanding of layering continuity that comes from the seismic data.

In complex areas of Peregrino, where the structure is very irregular, the limitation of the azimuthal resistivity tools due to the sensor offset (~30m) make the reservoir exposure even more challenging. **Figure 8** shows an example of a well with insufficient sand exposure that had to be sidetracked, after subsurface evaluations. The final well used the high resolution deep resistivity inversions in combination with the seismic data that allowed placement of the well exactly within the reservoir sands.

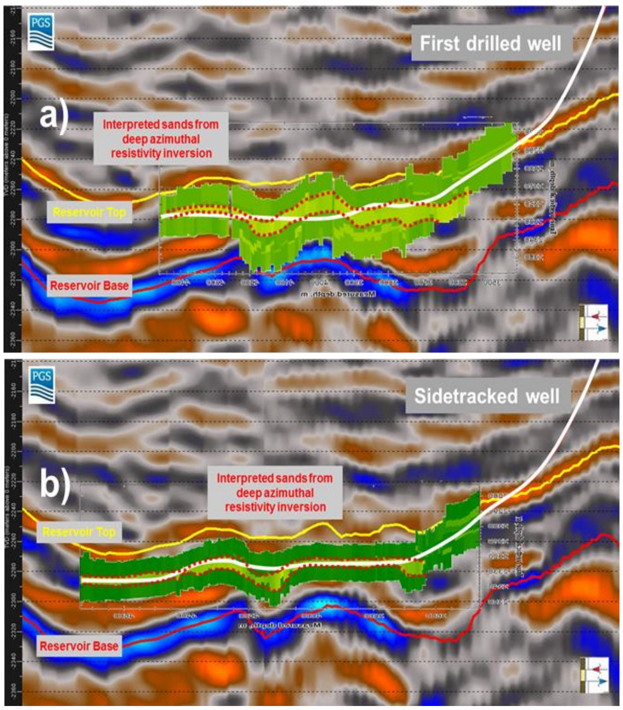

Figure 8 a) Seismic section along the drilled well with deep azimuthal resistivity inversion. b) Seismic section along the sidetracked well planned based on the first well results. Notice the significant increase in the reservoir exposure.

Conclusions

On the Peregrino field, geophysical data is intensely used to understand the reservoir and plan production wells optimally. Detailed structural information in combination with sand prediction analysis is crucial input to well construction. This process is done as part of a multidisciplinary workflow that involves both subsurface and drilling team in a highly dynamic way (geoscience, reservoir, production, drilling and completion engineering).

During operations, the communication among the disciplines needs to be effective in order to make good real-time decisions. For example, in the case mentioned in this abstract the results from the first well were not as expected. As a consequence a sidetrack was planned, and it successfully increased the sand exposure using the same target location, increasing the probability of good productivity.

Subsurface evaluations in the Peregrino asset are done in a continuous and effective way. New data, improved analysis and well results are used to update the reservoir model in order to optimize desired outcomes.

Acknowledgments

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References

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