3D Seismic Interpretation of Low Reflectivities in the Pre-Salt of Buzios Field, Santos Basin

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Abstract

Seismic reflectivity from compressional waves, commonly used in the oil industry, has not only geology-related information, but also signals referring to coherent and random noise. These noises affect the primary wave responses, contaminating mainly those related to background amplitudes. This work seeks to follow two strands: Interpret data where seismic qualification is applied, providing a more balanced spectrum of amplitudes at all frequencies, and perform acoustic inversion modeling. The goal is based on highlighting events correlated to low reflectivities that can differentiate fluids from rocks. These concepts were applied in the Buzios Field, Santos Basin, for the interpretation of a post-stack 3D seismic data.

Introduction

The evaluation process of an oil field, from exploration to abandonment, may involve, in several stages, the use of geophysical methods. Seismic interpretation plays a fundamental role, since its wide range of applications goes from the identification of targets of regional economic interest to the knowledge of petrophysical properties and the understanding of fluid dynamics within a reservoir.

In a seismic interpretation flow, it is often necessary to use filters that highlight information of interest implicit in the data. To achieve this goal, different decompositions of the seismic signal have been used.

Based on the concept of decomposition of the frequency spectrum, Gridley and Partyka (1997) interpreted a seismic data as a function of amplitude and phase, from a decomposition based on Fourier Transform (Khondi & Rastogi, 2013). Over the years, more robust methods have been developed.

Santos *et al.,* (2018) presented an amplitudes decomposition to incorporate magnitudes associated with a group known as background, in order to better reveal geological and petrophysical behaviors that tend to aggregate in the E&P industry.

Santos *et al.,* (2019) portrayed a new concept of seismic qualification, aiming to attenuate amplitudes directly in the time or depth domain, evidencing low reflectivities. This application aimed to identify fracture zones during interpretive processes.

In this work, we will analyze the response of a seismic data to which the reflectivity decomposition method described by Santos *et al.,* (2018) was applied. The aim is to highlight compressional wave responses associated with low reflectivities, possibly hidden by strong primary events or coherent noise. The application of the method was performed in the Buzios Field, Santos Basin, more specifically in the area highlighted in black on the map in Figure 1.

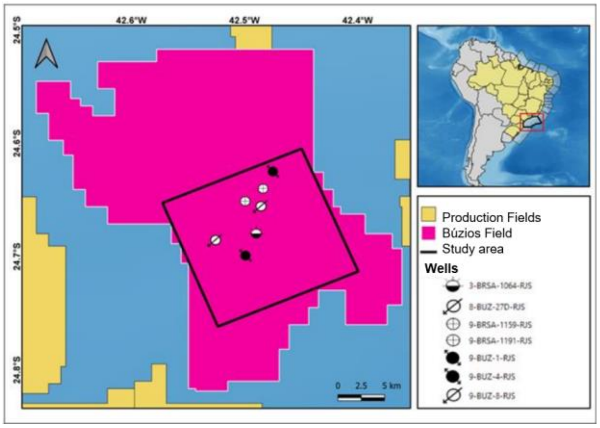

Figure 1 *– Study area location map.*

Geological Settings

Geologically, the Búzios Field, included in the Santos Basin, is inserted in the continuous system of sedimentary basins of extensional domain of the divergent margin of South America (Milani *et al.,* 2001). Its tectonic evolution is shown in Figure 2, composed of the lower rift, upper rift, sag and passive margin phases (Castro,2019).

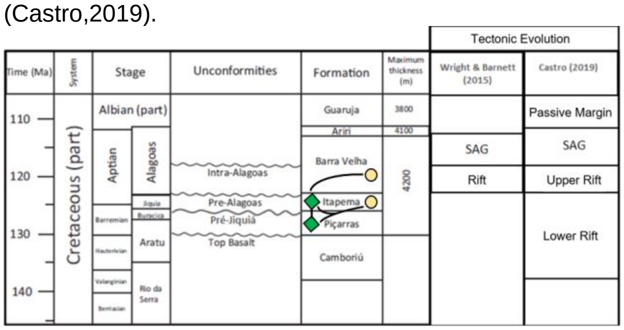

Figure 2 *– Tectonic evolution.*

The carbonatic reservoirs of the pre-salt section are formed by coquinas from bioaccumulation of the Itapema Fm and by mud, spherulites and shurbs of the Barra Velha Formation. These last are textural and facies classifications presented by Gomes *et al.,* (2020) and adopted in the present work, due to the uncertainties about the microbial nature or not of the carbonates from Fm. Barra Velha. According to Petrobras (2020), the mentioned reservoirs have excellent petrophysical conditions of porosity and permeability.

Method

Seismic Qualification Theory

Qualitative data preparation for interpretative tasks known as seismic conditioning generally involves the use of filters, whether static, residual, or other processes that tend to improve the signal-to-noise ratio in a data. Unlike conditioning, seismic qualification attenuates specific information, related to noise or unwanted seismic signals to the interpreter's objective. This procedure aims to improve the detection of heterogeneities associated with faults and fractures, facies, textures, and petrophysical parameters (Santos *et al.,* 2019). When working with background amplitudes, Santos *et al.,* (2018) states that the qualification smooths in a controlled way the amplitudes, reducing the effects of noise correlated to the higher magnitudes of the signal and improving the data in some points considered geologically critical.

Methodology

The adopted workflow can be seen in figure 3 and 4. Initially, from the psdm (post-stack depth migrated) seismic data and well data, the objective was to understand and map the main tectonostratigraphic phases of the Buzios Field, generate seismic attributes and make a proper correlation between seismic and well to perform a good inversion modeling.

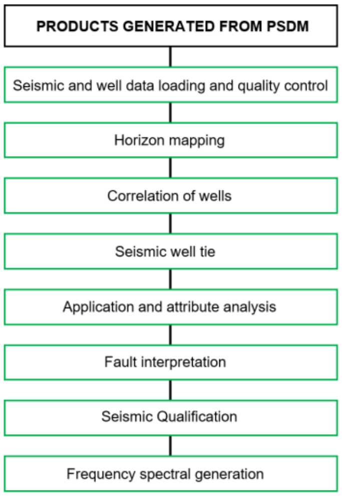

Figure 3 *– Workflow performed on the given psdm.*

Subsequently, to obtain the low reflectivities representative of the background, four attenuations (qualifications) were performed on the psdm data, of 23 dBs, 42 dBs, 65 dBs and 85 dBs, the latter being the one that best represented the responses relative to the background and was chosen to proceed in this work.

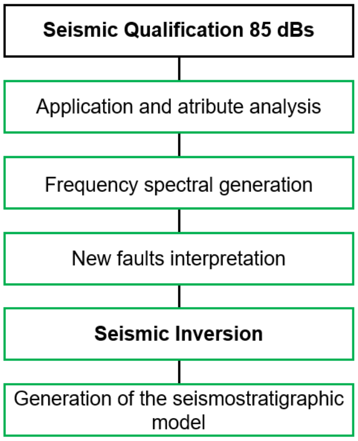

Figure 4 *– Workflow performed after seismic qualification.*

After quality control and generation of by-products, such as seismic attributes and the extraction of the amplitude spectrum from the 85 dB qualified data, a seismic inversion modeling was performed. As a result, we obtained a seismic cube of low reflectivities, which was used in the creation of a geometric model and interpretation of subtle and non-subtle anomalies related to lithologic and fluid responses.

The cube of low reflectivities, generated from the inversion described, can also be referred to as an effective DHI seismic cube. Such nomenclature is suggested by Santos *et al.,* (2022), as it is an effective indicator of all elements of the petroleum system. For this, one can consider the seismic responses as defined by Bortfeld (1961), where part of these is due to the fluid saturation factor and part to the rock stiffness factor, and that can be seen in equation 1. In this equation relationships are established between transmission and reflection coefficients of P and S waves with elastic properties.

$$R_{pp} = \underbrace{\frac{\rho_2 V_{p_2} cos\theta_1 - \rho_1 V_{p_1} cos\theta_2}{\rho_2 V_{p_2} cos\theta_1 + \rho_1 V_{p_1} cos\theta_2}}_{\text{Termo fluídico}} + \underbrace{\left(\frac{sen\theta_1}{V_{p_1}}\right)^2 [V_{S_1} + V_{S_2}]\left[3\left(V_{S_1} + V_{S_2}\right) + 2\left(\frac{V_{S_2}\rho_1 - V_{S_1}\rho_2}{\rho_1 + \rho_2}\right)\right]}_{\text{Termo de rigidez}} \quad (1)$$

Where,

$\rho 1$ - Density of layer 1;

$\rho 1$ - Density of layer 2;

$VP1$ - P-wave velocity in layer 1;

$VP2$ - P-wave velocity in layer 2;

$VS1$ - Velocity of the S-wave in layer 1;

$VS2$ - S-wave velocity in layer 2;

Results

Spectral Analysis

In our main target of study, the pre-salt, the input seismic sub-volume has its spectrum presented by the red curve, seen in Figure 5. Its range of significant frequencies varies from about 2 to 17 Hz and its peak is at 6 Hz. As the qualification was applied to the data, the energy for some frequencies has been recovered and the spectral amplified smoothing is quite characteristic. This last observation occurs from the target range of the study, which in the input data would go up to 17 Hz in the pre-salt and after the filter, when we look at the black curve relative to 85 dB, it went to about 25 Hz. When we look at the peaks of the filtered data relative to the original data, no considerable shift is noticeable, which affirms that the qualified data has equivalent phase to the input data.

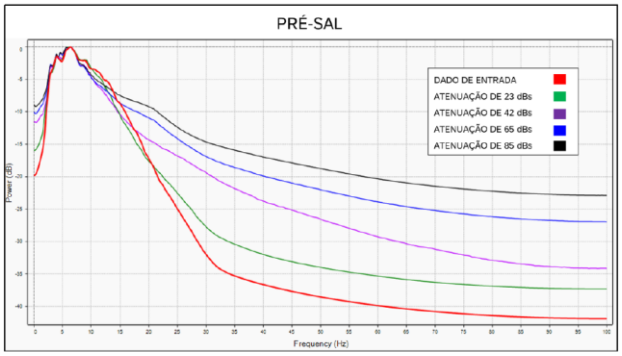

Figure 5 *– Frequency spectrum of the pre-salt sub-volume.*

Seismic Attributes

One of the advantages of seismic qualification is to obtain a spectrum with more balanced amplitudes among all recoverable frequencies in the oil prospecting seismic band. Santos *et al.,* (2019) shows that such qualification open the expectation of tracking subtle features with reflections associated with small faciologic modifications. Subtle seismic facies variations are of extreme importance in hydrocarbon prospecting, as often the seismic facies variations are of very small impedance differences, which generate very low amplitudes, but which can hold information of important hydrocarbon volumes. Figure 6-B illustrates the subtle fluctuations observed by the qualified data with the application of a heterogeneity identification attribute. One can notice a relevant gain of information, mainly associated with smaller acoustic impedance contrasts, if compared to the original input data, shown in figure 6-A, with the same attribute and parameters applied.

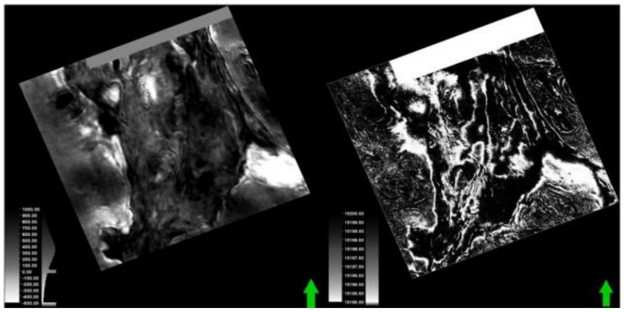

Figure 6 *– Original data shown in 6-A with attribute, and in 6-B, the resolution gain for subtle facies after seismic qualification and application of the heterogeneity identification attribute.*

Petroleum System Indicators

One way to identify the presence of seismically effective DHI cube generators is by following the onset of the secondary migration process. In general, such generating bodies show circular anomalies and geographically originate from possible structural lows, where they are formed by fines with sealing characteristics. Figure 7 shows textures with lower magnitude values of the indicator, positive or negative, being associated with such generators(low permeabilities).

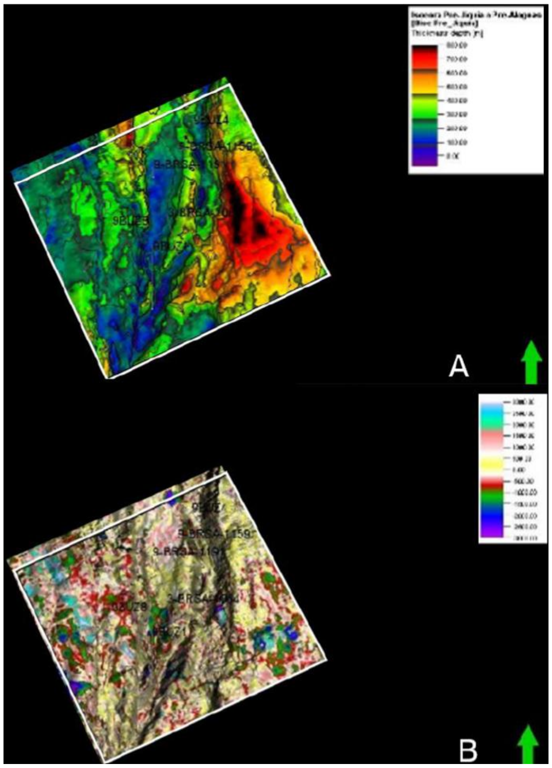

Figure 7 ***-*** *A-Isocore between the Pre-Jiquia and Pre-Alagoas discordances, indicating possible regions of generative kitchens. B - DHI model facies ten layers below the Pre-Jiquia discordance, illustrating the textures with the lowest DHI indicator values of low reflectivities (very low permeabilities).*

Low magnitudes of reflectivities derived from effective DHI cubes may indicate the presence of sedimentary or volcanic materials of very low permeability. To illustrate textures associated with seals or more pronounced impermeabilities, in the DHI model of Figure 8, the lower magnitude values (around zero) are marked, i.e., the input and output have no marked seismic response variations.

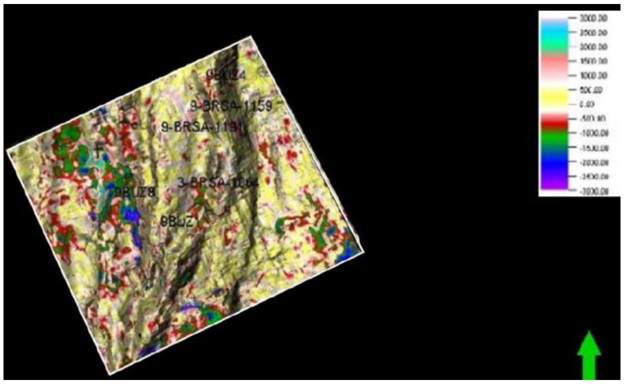

Figure 8 *– Stamps are indicated by low values close to 0 (yellow).*

The evaluation of the sealing behavior of a fault in an effective DHI cube can be analyzed as a function of the observed reflectivities at its gaps. For a sealing fault around both sides of the fault plane, the indicator response should be close to zero. Conversely, the more negative the DHI value, the greater the indication that such a fault would have an important fluid transmissibility factor, which would cause the impedance to decay along the fault plane. Some of these responses can be seen in Figure 9 below.

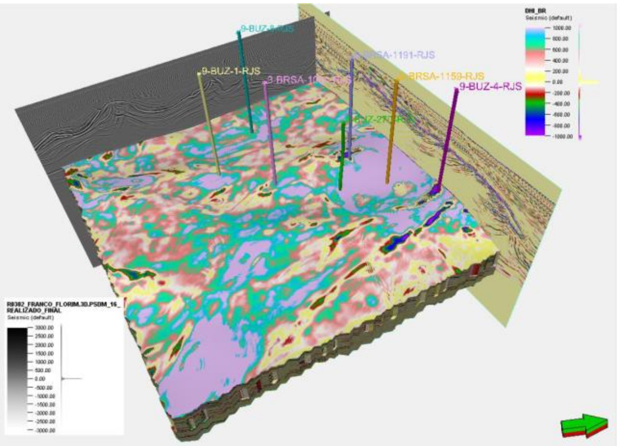

Figure 9 *– Geometric seismostratigraphic model showing the major faults that may show evidence of seal (yellow) or migration (violet, blue and green) within the Barra Velha Formation.*

Retention Indicators

In terms of magnitudes of reflectivities, good retention would be that indicated by low values but associated with adjacent homogeneous and impermeable sealing surfaces seismically indicated by values of reflectivities close to zero. An important geoscientific support to this determination of sealing potential of layers, supported by 3D seismic, can be established by algorithms that define seismic geometric coherence between features (Variance, Coherence, Semblance, among others). Figure 10 below illustrates the textures that may suggest fluid retention, following the same textural principle conceptually described for seals, but now for a low-reflectivity depth slice at a depth of 5850 meters in Búzios. By association with geological or petrophysical concepts, below or laterally to an important seal, the presence of a large volume of fluids is suggested, with a strong indication of retention pronounced by the violet, blue and green textures.

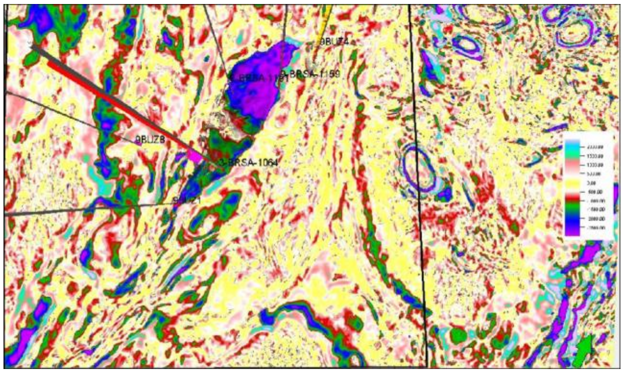

Figure 10 *– Depth Slice 5850 of the DHI cube indicating possible fluid retention in the violet-colored texture.*

Detection of Bodies Associated with the Presence of Fluids

In general, fluid-associated anomalies show up as amplitude flags, which are variations often positioned in regions of structural hinges, regions of faults, fractures, and anticlines. In general, fluids seek migration through regions of pressure relief, forming alignments that may be structural, associated with the just position of faults and fractures, and along sedimentary bodies whose depositional patterns are justified by continuities of permo-porosities, which line up along regions with pressure relief conditions and accelerate migrations according to internal depositional and petrophysical anisotropies, forming carrier beds. When such seismic flags are shown to be spatially connected, interpretative scenarios open up that make it possible to examine and evaluate possible migration routes. In general, such routes are triggered from hydrocarbon-generating kitchens or initiated from sweet spots near possible kitchens, which indicate spatial points of concentrated regions of fluid passage. Figure 11 shows a seismic detection, from the low reflectivities, that would possibly be correlated to reservoirs with hydrocarbons and zone or block with the presence of water. It is possible to see from the injection well 9-BUZ-8-RJS, dominant textures in blue and lilac, in the western part of the study area, possibly indicating water retention. In the eastern part, we observe good oil producing wells, such as 9-BUZ-1-RJS and 9-BRSA-1159-RJS, and notice textures predominantly in green and blue, allowing us to differentiate such accumulations.

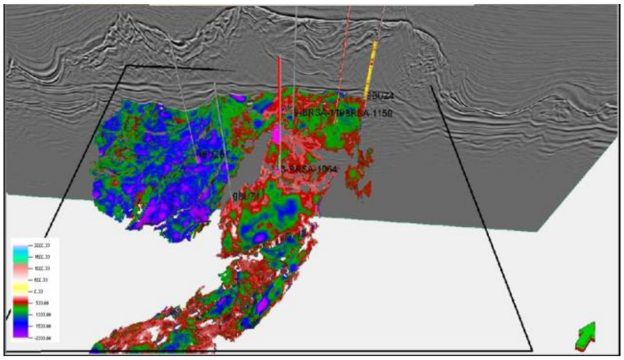

Figure 11 *– Detection of fluid-associated bodies from low reflectivity responses.*

Conclusions

The use of the proposed methodology showed us that the seismic qualification improved the response of the attributes used. In addition, it was possible to note that after the respective applications of seismic qualification, acoustic inversion and geometric modeling, it was possible to highlight subtle information related to low reflectivities, where the main elements of the petroleum system were highlighted. These results tend to corroborate with the mitigation of drilling errors of wells in exploratory phases and also add to the understanding of reservoirs during the development of production fields.

Acknowledgments

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