Carbonate Reservoir Characterization Case Study: Pampo Field, Campos Basin

Danilo Jotta Ariza Ferreira (UFF) and Wagner Moreira Lupinacci (UFF)

Abstract

In this paper, the main objective is to propose a workflow to aid in carbonate reservoir characterization of the Quissamã Formation (Macaé Group) in the Pampo field located in the Campos Basin. In carbonate rock, spatial distribution models of reservoir and elastic properties are more complex due to diagenetic processes and mineralogical composition, which directly interfere in variation of the pores shape and interconnection. So, Model-based seismic inversion and sequential gaussian simulation with co-kriging for porosity estimation were used to characterize the carbonate reservoirs. The results showed that the carbonate plataform is located between the Neo-Alagoas and the Eo-Albian seismic surfaces. The inversion allowed the identification of low acoustic impedance in structural highs were most producing wells were drilled and the interpretation of a new surface Intra-Albian. And the porosity estimation showed that higher porosity values are located mainly in the region between Eo-Albian and Intra-Albian surfaces and also in structural highs.

Introduction

The reservoir characterization process consists in the three-dimensional determination of the structures and properties of the rocks of an oil field. The objective is to construct a model where all the information and data available can be incorporated. These models are extremely important to predict, monitor and optimize the performance of a field during its production (Sancevero et al., 2006).

In carbonate rock, spatial distribution models of reservoir and elastic properties are more complex, due to the intrinsic characteristics of these rocks. Elastic properties in carbonates are highly dependent on the diagenetic processes and mineralogical composition, which directly interfere in variation of the pores shape and interconnection (Lucia, 2007). These factors make it more difficult to identify and characterize the carbonate reservoirs.

Seismic inversion is a technique widely used in the reservoir characterization. It converts seismic data from interface properties to layer properties. The input data in the inversion process is the compressional wave and density well logs and post-stack seismic data that we estimate the acoustic impedance. It is also common to use correlations between acoustic impedance values with other lithological properties such as facies and porosity. Normally, these correlations are obtained from well logs and then extrapolated to the volume (Savic et al., 2000). These layer properties increase the reliability for the interpretation and characterization of the geological environment.

The main objective of this work is to propose a workflow to aid in carbonate reservoir characterization of the Quissamã Formation (Macaé Group) in Pampo field, Campos Basin (Figure 1), using the estimation of acoustic impedance and porosity.

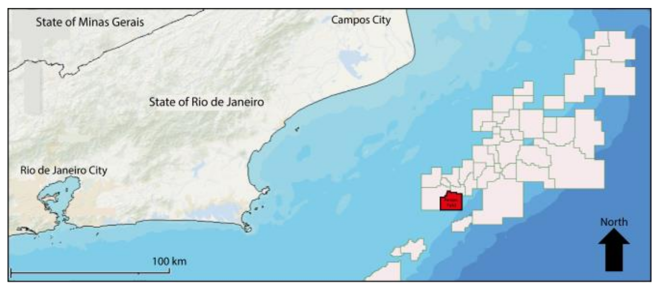

Figure 1: *Localization of the Pampo Field, Campos Basin.*

Method

The data used in this work consisted of a post-stack seismic volume and well logs of ten wells. The seismic survey region and the location of these wells are showed in Figure 2. The reservoirs of the Quissamã formation in the study area are predominantly classified as oncolytic packstones with porosities varying between 18% and 30%, mean permeability of 200 md and 20º API oil (Carozzi and Falkenhein, 1985; Okubo et al., 2015).

A preconditioning workflow was applied before the seismic inversion to improve the resolution and increase signal-to-noise ratio of the seismic data. This routine consisted in the use of filters to remove noise and to recover the attenuation effects (Lupinacci et al., 2017). It is worth mentioning that the mapping of the horizons and faults were done in the original seismic data, and the other steps of the workflow were done in the filtered data.

Seismic interpretation was performed according to seismic reflection termination patterns, which indicate sequence limits and surfaces that delimit seismic units and depositional systems tracts, with the most commonly used being onlap, downlap, toplap, lapout, truncation and conformity. Seismic reflections preserve the geological factors that generated them, such as: stratification, lithology and depositional features (Brown Jr. and Fisher, 1977).

In this work, nine seismic-stratigraphic sequences were interpreted, from the seabed to the commercial basement of the basin. However, the area of interest is the top and bottom of the Albian carbonate platform.

The wavelet used in the seismic trace modeling was extracted from the seismic traces in the vicinity of each well. The well tie was performed through shifts, stretches

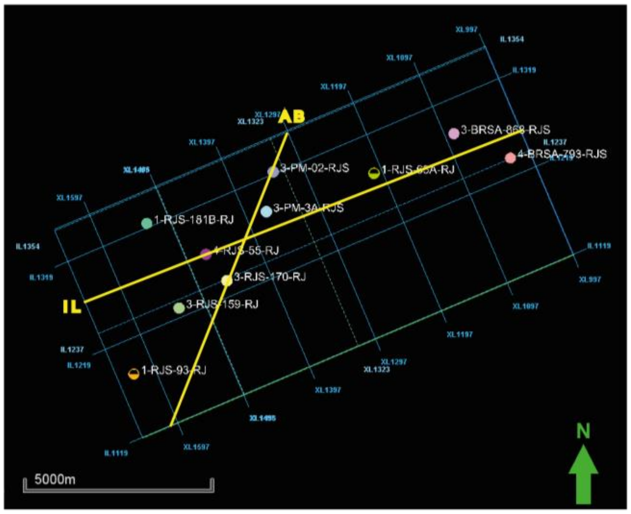

Figure 2: *Data available for the study. The seismic cube survey is represented by the blue polygon, the wells are represented by colored circles and the acoustic impedance sections shown in Figures 5 and 6 are the yellow lines IL and AB, representing the inlne 1260 and an arbitrary line respectively.*

and squeezes comparing the real and synthetic seismic traces in the area of each well, with the aid of the interpreted seismic surfaces and the chronostratigraphic markers of the wells.

In order to increase the correlation between the real and synthetic traces, a quality control was applied to re-tie the wells in the regions between the top and the base of the Albian carbonate platform. For this, new wavelets were estimated in the interval of 1500 to 3000ms using a statistical method defined by Hampson and Galbraith (1981). The correlation coefficients of the wells re-tie can be seen in Table 1.

The background model was built by extrapolating the smoothed acoustic impedance logs, following the seismic horizons of the top and bottom of the carbonate platform. The wavelet used in the inversion was estimated by the arithmetic mean of all wavelets that have a correlation factor above 60%.

The model-based inversion was used for seismic inversion (Russell and Hampson, 1991). This method uses the generalized linear inversion (GLI) algorithm, which consists of a process that starts with an initial impedance geologic model and a pre-defined wavelet. Then, it calculates for each acoustic impedance trace from the initial model a synthetic seismogram using the pre-defined wavelet. The impedance values are then modified gradually until the synthetic traces approach the original seismic trace within acceptable limits parameterized by the user.

Table 1: *Correlation factor of the wells tie.*

Wells	Correlation Factor (%)
1-RJS-181B-RJ	58
1-RJS-63A-RJ	72
1-RJS-93-RJ	74
3-BRSA-868-RJS	89
3-PM-2A-RJS	53
3-PM-3A-RJS	60
3-RJS-159-RJ	68
3-RJS-170-RJ	51
4-BRSA-868-RJS	79
4-RJS-55-RJ	64

The seismic inversion was constraint by the Hard Constrained Model. This consisted in limiting the variations of the acoustic impedance values based on the well information. Finally, the porosity modeling was performed through the Sequential Gaussian Simulation method using colocalized co-kriging with the acoustic impedance volume as the secondary variable (Nikravesh and Aminzadeh, 2003). The workflow used in this work is showed in Figure 3.

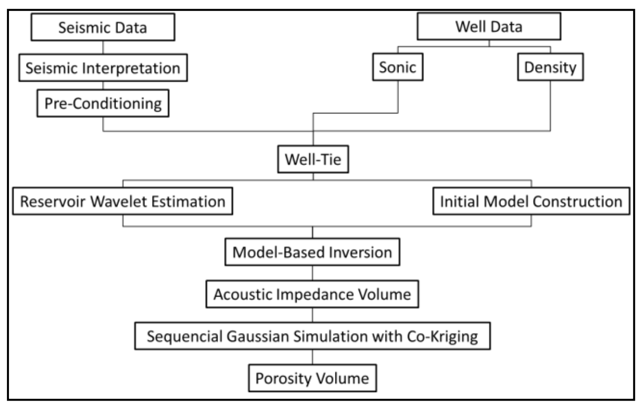

Figure 3: *Workflow used to characterize the carbonate reservoirs of Pampo Field.*

Results

The seismic-stratigraphic sequences interpreted are shown in Figure 4. These sequences represent: the basement of the basin (Cambiúnas Formation), the sequence between the basement and the Neo-Alagoas surface (Lagoa Feia Group) defined in Winter *et al.* (2007); the sequence between the Neo-Alagoas and the Eo-Albian (Quissamã Formation), the sequence between the Eo-Albian and the Cenomanian (Outeiro Formation), the sequence between the Cenomanian and the Maastrichtian (Imbetiba Formation) and the sequences between Maastrichtian and Sea Floor (intercalations between the Carapebus, Ubatuba and Grussaí

Formations). Also, it is important to highlight that in terms of geotectonic timing the sequences between the basement and the Neo-Alagoas surface comprehend the rift and post-rift sedimentation and the sequences between the Neo-Alagoas surface until the seafloor comprehend the drift sedimentation of the basin.

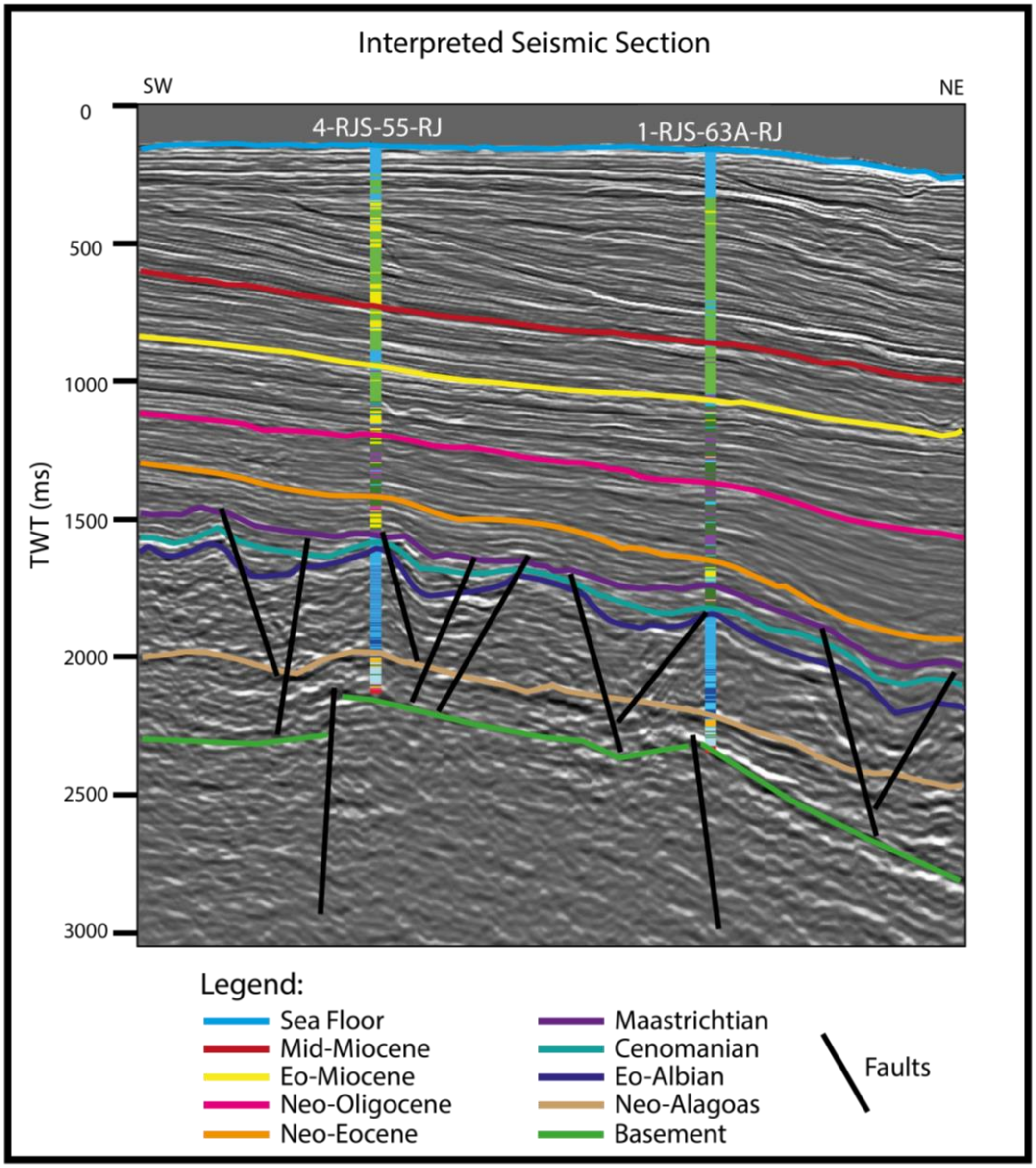

Figure 4: *Seismic Interpretation in the Inline 1260.*

The acoustic inversion was performed with focus on the Albian carbonate platform, which is comprised between the Neo-Alagoas and Eo-Albian seismic horizons. The inline 1260 and an arbitrary line of the acoustic impedance volume are represented, respectively, in Figures 4 and 5. In these sections, the faults identified are displayed in black lines and the acoustic impedances logs are illustrated for help in quality control.

The lower acoustic impedance values between the Neo-Alagoas and Eo-Albian horizons were observed mainly near the top of this sequence and at the structural highs. The result allowed to delimit a new horizon (Intra-Albian), which separates the lower impedance carbonate facies at the platform top from the higher impedances facies at the platform base.

Mud-logs information showed that the carbonate facies above the Intra-Albian are composed of packstones and wackstones intercalated, with medium to high porosity and little or no cementation, being characterized as the Albian reservoirs. The carbonate facies below the Intra-Albian horizon are composed of dolomitized packstones, wackestones and mudstones. These facies have low porosity, mainly due to the dolomitization process.

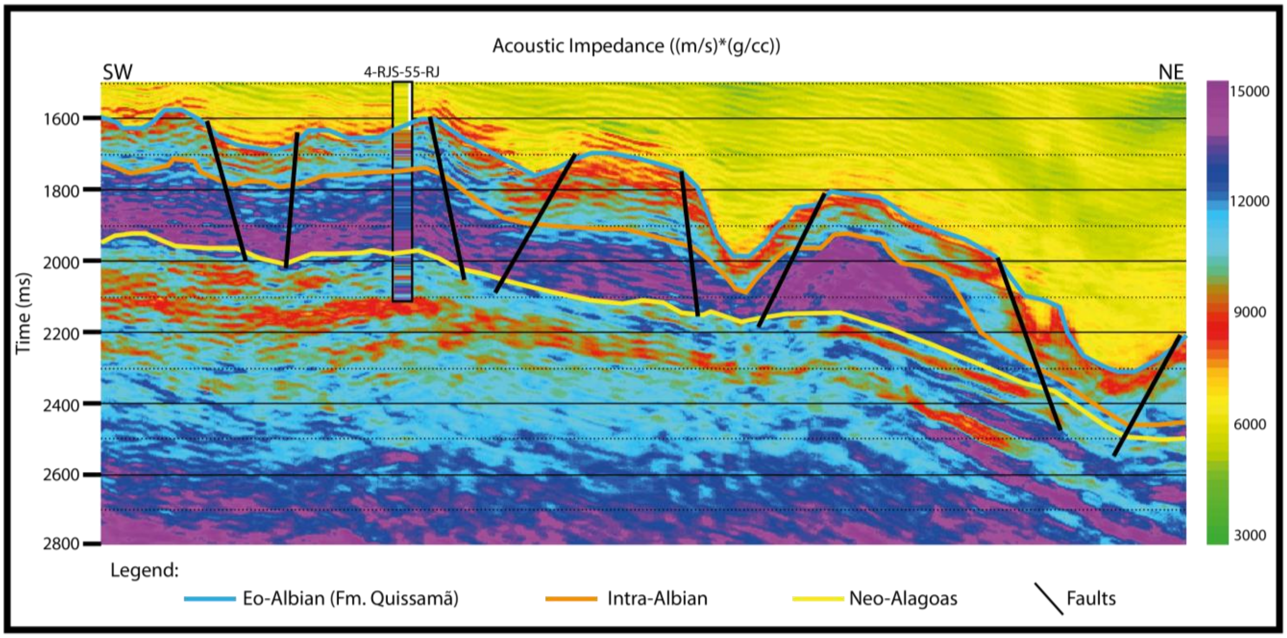

Figure 5: *Acoustic impedance values (inline 1260). The Eo-Albian, Intra-Albian and Neo-Alagoas seismic horizons are represented, respectively, by the lines in blue, orange and yellow. Faults are represented in black lines. The acoustic impedance logs of well 4-RJS-55-RJ can also be observed.*

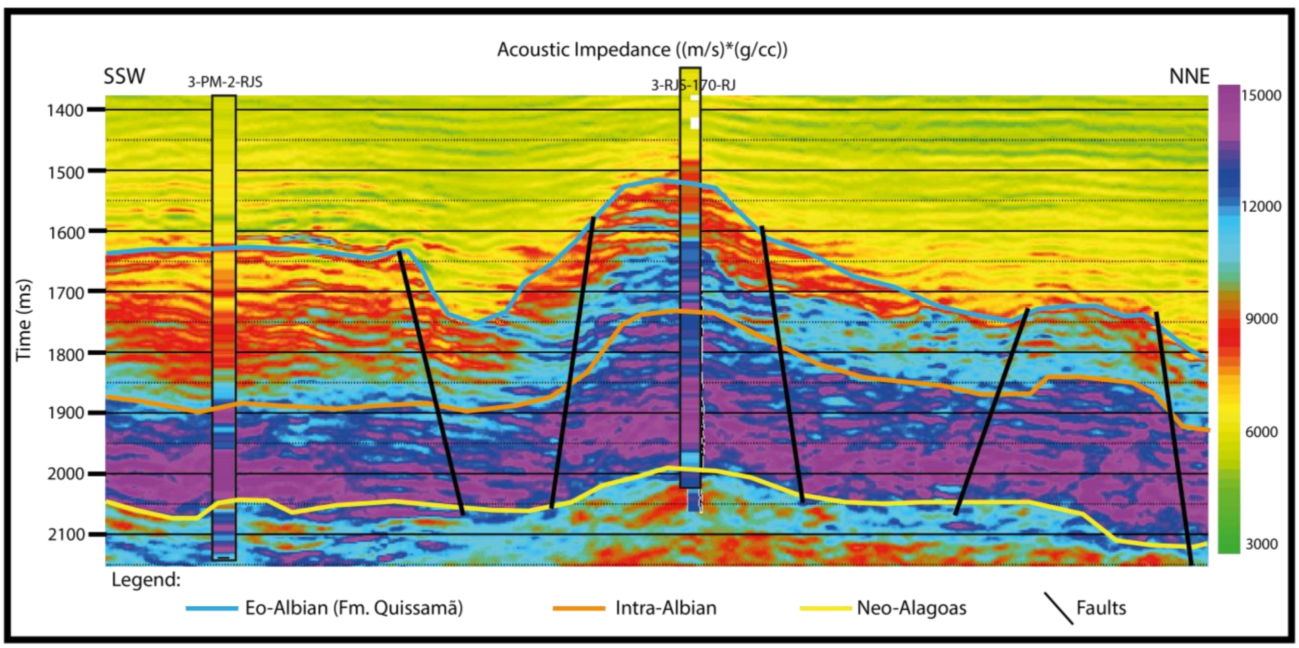

Figure 6: *Acoustic impedance values in the arbitrary line 1. The Eo-Albian, Intra-Albian and Neo-Alagoas seismic horizons are represented, respectively, by the lines in blue, orange and yellow. Faults are represented in black lines. The acoustic impedance logs of the 3-PM-2-RJS and 3-RJS-170-RJ wells are also shown.*

The acoustic impedance attribute map on the surface of the Eo-Albian is showed in Figure 6. All wells represented in this figure are oil producers, except well 1-RJS-63A-RJ that is a sub-commercial well. This map show that the reservoir facies are in the structural highs and in regions with the lowest acoustic impedance values. It is also highlighted that the sub-commercial well was drilled in a high acoustic impedance region.

Figure 7 illustrates the porosity values obtained using the acoustic impedance volume in the sequential gaussian simulation with colocalized co-kriging between the Eo-Albian and Intra-Albian surfaces. As can be seen, the higher porosity values are located mainly in the region between Eo-Albian and Intra-Albian. It is also highlighted that the producing wells are in high porosity regions and that the sub-commercial well is in a region with lower porosities.

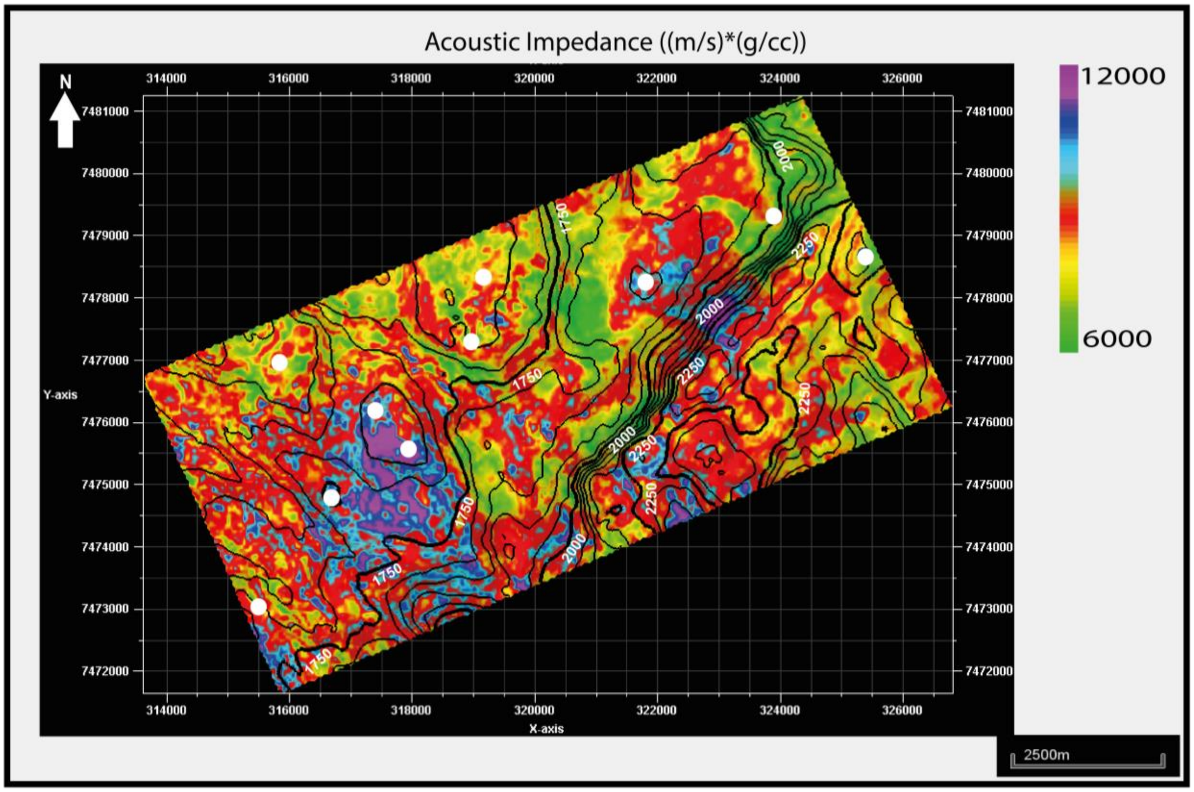

***Figure 7**: Acoustic impedance attribute map on the Eo-Albian surface. White circles represent the wells.*

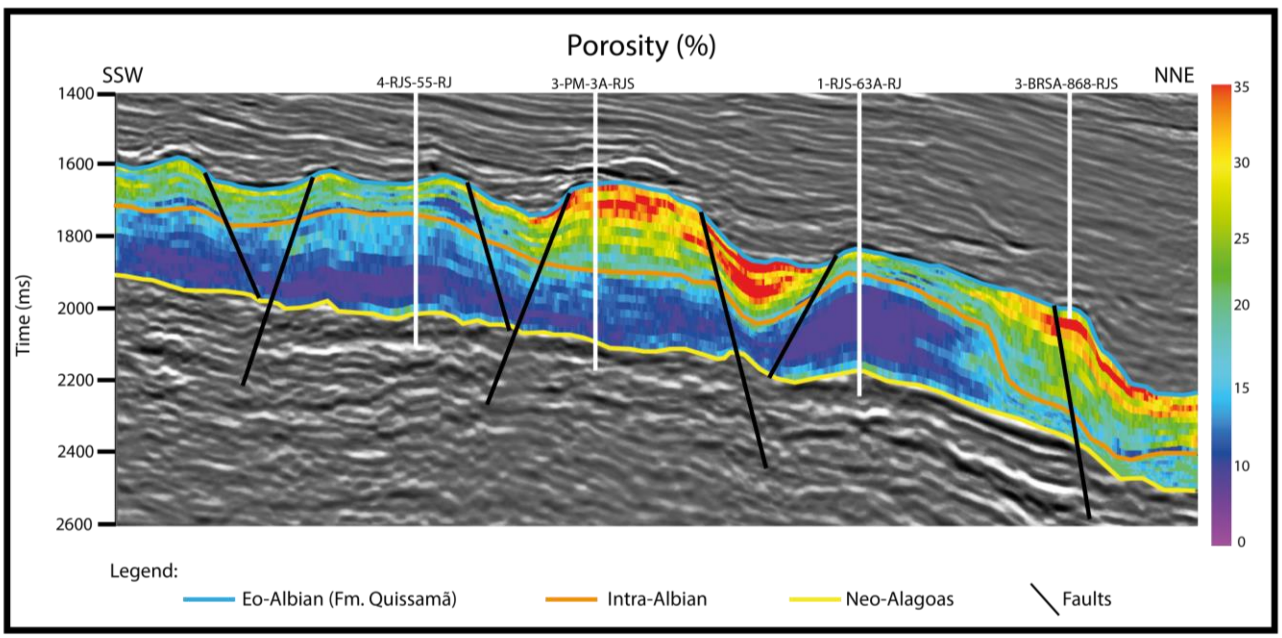

***Figure 8:** Porosity modelling in inline 1279. The Lower Albian, Intra-Albian and Upper Alagoas seismic horizons are represented, respectively, by the lines in blue, orange and yellow. Faults are represented in black lines. The well path of the wells that intersect or are located near the inline can also be observed.*

It is also possible to identify regions of structural highs with low acoustic impedance and high porosity values that have not yet been explored from the inversion and the porosity modeling results.

Conclusions

The proposed workflow allowed a better characterization of the Albian carbonate platform. The results confirmed the location of the producing wells in the structural highs that are also locations with the lowest acoustic impedance values and the highest porosity values. On account of with this study, it was also possible to interpret a new seismic-stratigraphic horizon, to delimit the reservoir facies and identify new promising areas for exploration.

Acknowledgments

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