Pseudoporosity Calculation based on Seismic Attributes Analysis in Albian Carbonate Reservoirs – SW of Campos Basin (Rio de Janeiro – Brazil)

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This paper was prepared for presentation during the 15th International Congress of the Brazilian Geophysical Society held in Rio de Janeiro, Brazil, 31 July to 3 August, 2017.

Abstract

Carbonates reservoirs are a challenge for oil exploration considering that this rock presents high variation of its properties, including their porosity that influence directly in calculation of reserves. So, in order to decrease the geological uncertainty about such heterogeneous rock, this work presents a method to represent the pseudoporosity of two carbonate reservoirs (Albian age) based on quantitative analysis of seismic attributes and its integration with the 3D geological modeling. The method includes definition of the reservoir intervals based on wirelogs, seismic interpretation, analysis of seismic attributes and a 3D geological modeling of porosity. As a result, stratigraphic attributes, such as Maximum Negative Amplitude and Total Energy, were effective in highlight high porosity facies in the reservoir levels with correlation about $R^2 > 0,74$. These maps were used as a tool to validate a 3D geological model, making sure that is consistent with the geological data previously analyzed.

Introduction

The studied area is a hydrocarbon field located in Southwest of Campos Basin, which has its geotectonic history associated to the breakup of Gondwana about 130 Ma ago (Dias et al., 1990) (Figure 1).

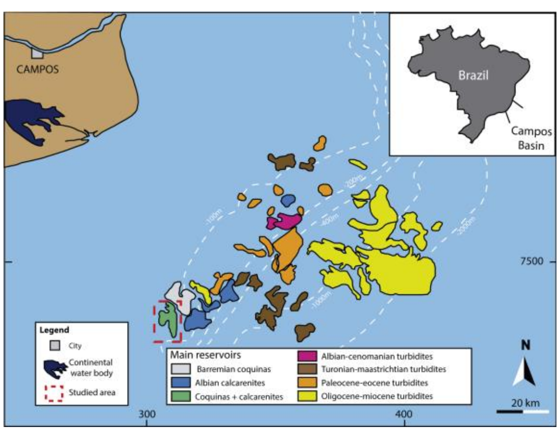

Figure 1: Studied area location (Bruhn et al., 2003 modified by Okubo et al., 2015).

This field has been producing oil over 40 years from four different stratigraphic levels: fractured basalts from Cabiunas Formation, coquines from Lagoa Feia Group, carbonates of Macae Group and turbidites from Campos Group (Horschutz et al., 1992).

The Macae Group includes the Quissamã Formation that represents carbonates deposited on shallow water conditions. In this stratigraphic level, the shoals were deposited in the NE-SW trend, parallel to the shoreline, and in the crests of the banks the high energy facies were accumulated (Guardado et al., 1989, Okubo, 2014).

The studied reservoir presents essentially high and moderate energy facies: oolitic and oncolitic grainstones, and oncolitic packstones. It is not always they show high porosity because they were under the influence of diagenetic process, mainly cementation as described by Okubo, 2014. So, in order to highlight the high porosity reservoir facies, seismic attributes were applied on the interpreted surface in seismic data that corresponds to the reservoirs.

The used seismic attributes are stratigraphic, such as Maximum Negative Amplitude, Amplitude RMS, Mean Amplitude, among others. This kind of tool has shown a high correlation between the amplitude value and the rock porosity in previous works, as Vincentelli et al. (2007), Vincentelli & Barbosa (2008) and Nascimento & Vicentelli (2015), resulting in a pseudoporosity map.

The distribution of this property is important to improve hydrocarbon carbonate reservoir analysis. Also, the attributes could be used as a tool to validate 3D geological modeling that interpolates unknown values of the reservoir property, since that the attribute maps reveals the locations of high porosity in the undrilled areas.

Objective

This work aims to represent the distribution of porosity of a carbonate reservoir through de use of seismic attributes and also test these tools to validate a geological scenario of a 3D porosity model.

Method

This work was developed by using a set of 19 wells and their logs (density, porosity, gamma ray, resistivity and sonic), and a seismic cube (50 km^2) (Figure 2). This database was provided by the Petroleum National Agency (ANP) and Petrobras and this work was performed in Unespetro – Center of Geosciences applied to Petroleum, UNESP (Rio Claro – SP).

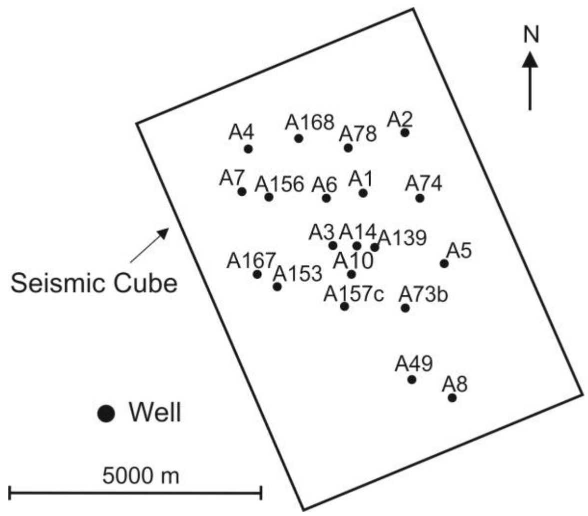

Figure 2: Distribution of the database.

In order to achieve the objective, this research had four subsequent steps:

1. Well correlation

The reservoir was identified by the change of the gamma ray log and secondarily, density and neutron porosity. The stratigraphic level was correlated along the study area through the similar response of the geophysical wirelogs to verify the lateral continuity of the layer.

2. Seismic Interpretation

The seismic was calibrated with the well data using the synthetic seismogram. Then, the identified stratigraphic horizon was interpreted in a grid of 5x5, interpolated and smoothed, resulting in the pseudostructural maps of the reservoir levels. Also, the main faults systems were interpreted.

3. Seismic Attributes Analysis

On the structural maps of the R1 and R2 reservoirs top, 13 stratigraphic seismic attributes were applied to verify if they could highlight an amplitude anomaly associated to some rock property measured in the wirelog. The attributes are: Amplitude RMS, Mean Amplitude, Mean Absolute Amplitude, Maximum Positive Amplitude, Maximum Negative Amplitude, Maximum Absolute Amplitude, Maximum Amplitude, Minimum Amplitude, Sum of Positive Amplitudes, Sum of Negative Amplitudes, Sum of Absolute Amplitudes, Total Energy and Maximum Peak Amplitude.

At first, this analysis was qualitative and then, it was quantified by the construction of cross plots, which has the rock property in x axis and the amplitude values in y axis in order to find the correlation between them.

4. Geological Modeling

The structural maps were converted to depth by using a velocity model based on sonic log of the wells. After, they formed a grid with 474240 cells, each one with dimensions 100 x 100 x 1 m (x;y;z axis). The porosity profile (Nphi) was upscaled to fill the cell with the arithmetic media every 1 meter.

Then, the used area to build the 3D model was delimited and a geostatistical analysis was made by experimental and theoretical variograms, definition of the azimuth and the application of Sequential Gaussian Simulation.

Thirty realizations were made and they were analysed according to the previously known results in order to choose the model that would be closer to the geological settings of the study area and then, validate the built model.

Results

In the well correlation, four stratigraphic levels were interpreted based on the wirelogs: Outeiro Formation, Q1 (transition of Quissamã and Outeiro formations), R1 and R2 (main reservoirs) (Figure 3).

This work is going to emphasize in the reservoir levels, which are characterized by gamma ray until 23 API and density around 2,3 g/cm^3.

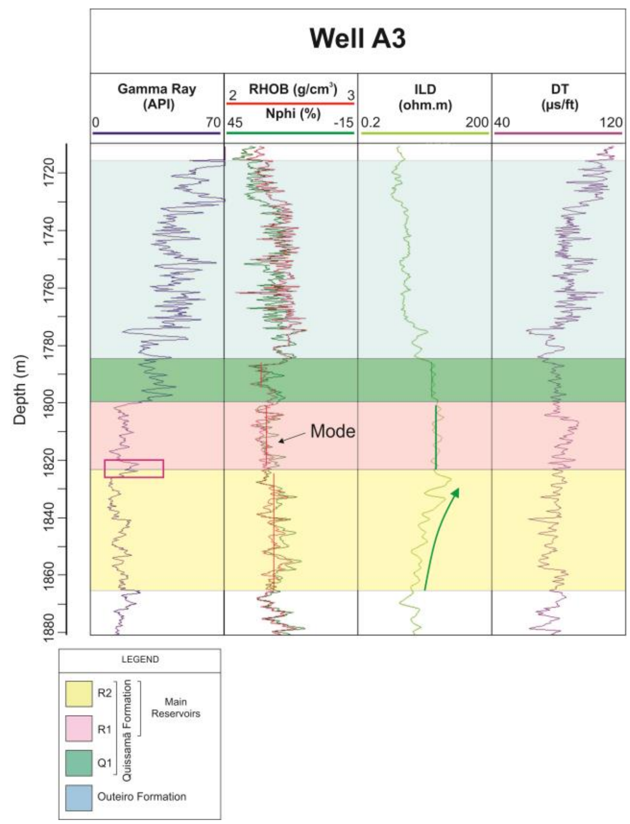

Figure 3: Definition of the reservoirs levels based on the wirelogs.

In the correlation between wells A3 and A10, two different reservoirs are filled with oil in the Upper Formation Quissamã, as resistivity log shows (> 80 ohm. m) (Figure 4). It is also possible to observe in the structural section that the oil producer wells are in a structural high.

By the analysis of the geophysical profiles, the density increases for the West and North of the studied area, and consequently these locations presents low porosity, as represented in Figure 5.

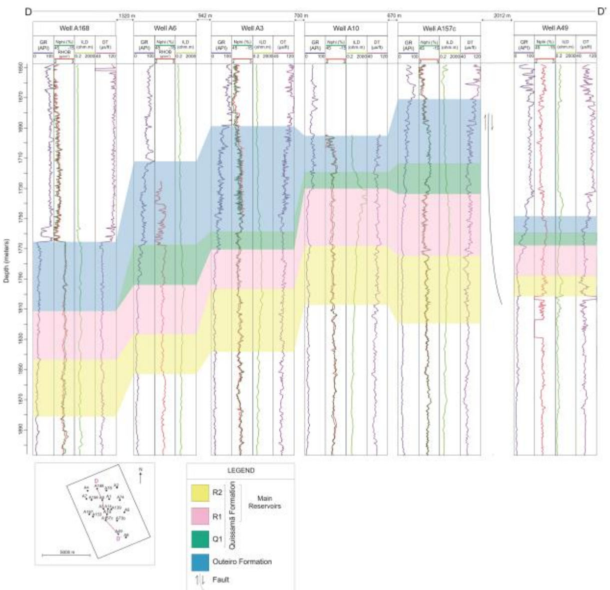

Figure 4: Well correlation D-D'.

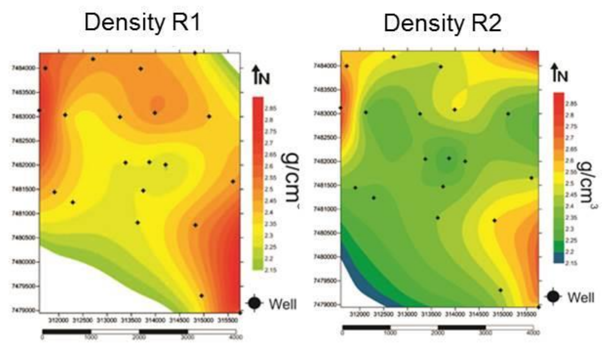

Figure 5: Density distribution map of the reservoir R1 and R2.

In the seismic section, it is possible to observe the structural high (central) as a horst, and other structures, as a rollover in the North of the area. Although this kind of structure is common in Albian reservoirs, this rollover does not present oil because the fault Ff separates the central horst oil producer in the studied area (Figure 6).

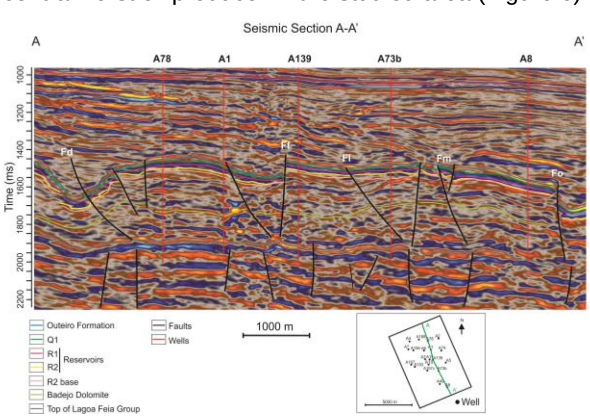

Figure 6: Interpreted seismic section.

This central structural high presents a main axis in direction NW-SE. It is delimited by faults (to the Southwest, Southeast and Northeast) and variation to higher density facies to the Northwest showing a structural-stratigraphic trap.

The main fault system in the study area is NW-SE. Also, there are faults in directions E-W, NE-SW and N-S (Figure 7). They are post depositional, what results in a similar structural configuration of both reservoir intervals (Figure 8).

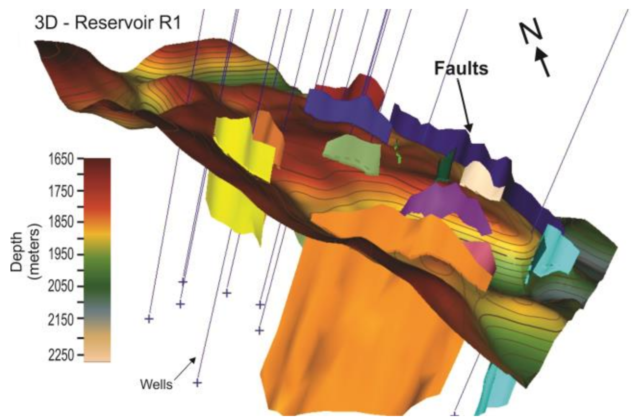

Figure 7: Main fault systems in the reservoir R1.

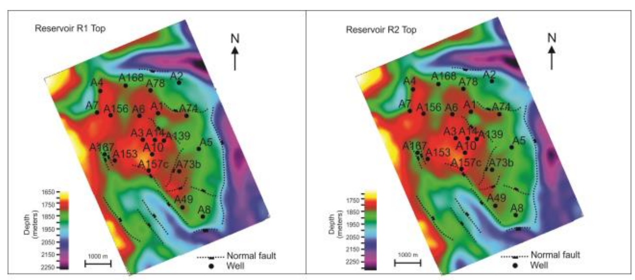

Figure 8: Structural maps of the reservoirs R1 and R2 tops.

When applied the seismic attributes on these structural maps, an amplitude anomaly was associated to the central structural high, standing out from the rest of the area (Figure 9). The cross plots showed that there is a relation about this highlighted amplitude and high values of porosity or low values of density.

The attributes that showed this relation for the reservoir R1 were Maximum Negative Amplitude and Maximum Absolute Amplitude, Minimum Amplitude and Trace Power with linear correlation $R^2>0{,}74$; with lower correlation ($R^2 > 0{,}65$), there are the Total Energy and Amplitude RMS.

In the Maximum Negative Amplitude Map, the amplitude anomalies in blue and green are delimited by faults (black lines) (Figure 9). In the cross plots (Figures 10 and 11), the relation between high values of porosity (or low values of density) and negative amplitude is explicit.

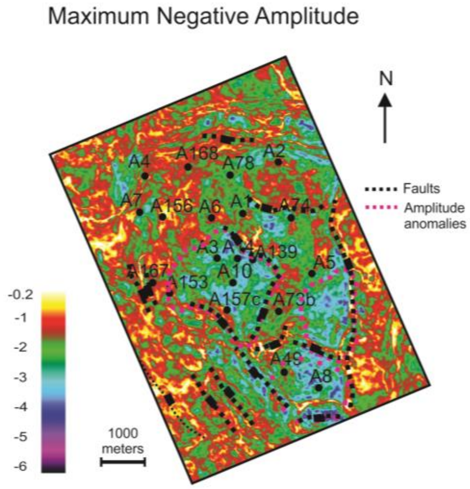

Figure 9: Maximum Negative Amplitude map applied on the reservoir R1. The black lines represent the faults that are the limits to some anomalies.

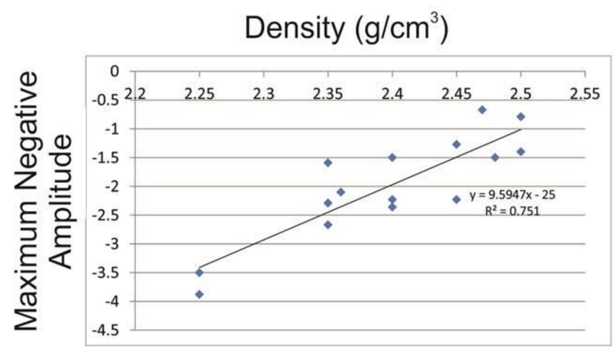

Figure 10: Cross plot between reservoir R1 density and the attribute Maximum Negative Amplitude.

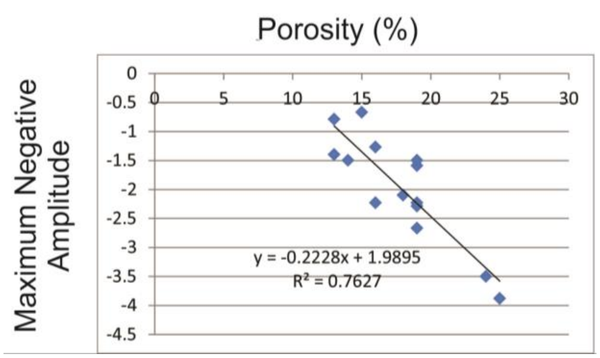

Figure 11: Cross plot between reservoir R1 porosity and the attribute Maximum Negative Amplitude.

For reservoir R1, this similar anomaly shape can be observed in the Minimum Amplitude map (Figure 12) with linear correlation to porosity (Figure 13).

For reservoir R2, the attributes show more dispersion in the correlation with coefficient R^2 = 0,65 (Figures 14 and 15), as shown in Sum of Negative Amplitudes map. Also the Minimum Amplitude and Amplitude RMS showed this association to porosity (Nascimento, 2016).

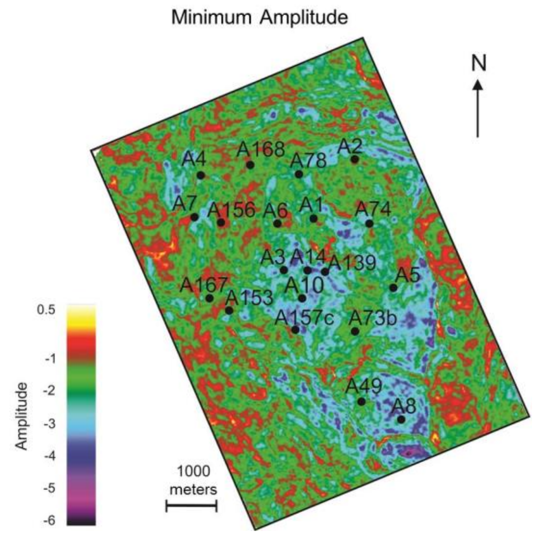

Figure 12: Minimum Amplitude attribute on the reservoir R1.

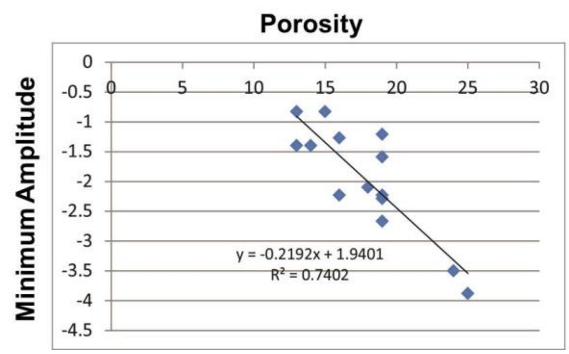

Figure 13: Cross plot between reservoir R1 porosity and the attribute Minimum Amplitude.

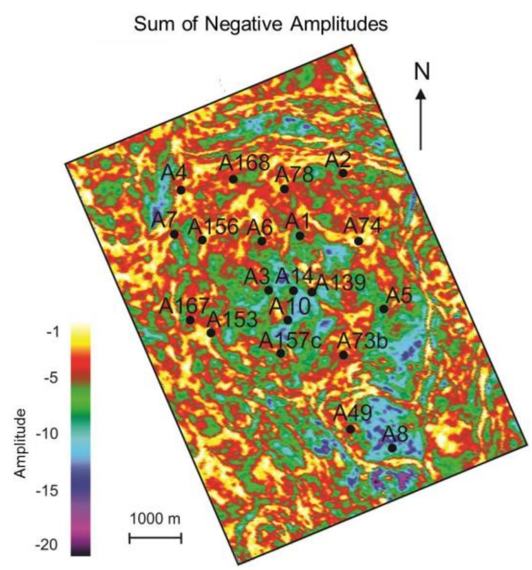

Figure 14: Sum of Negative Amplitudes Attribute Map of the reservoir R2.

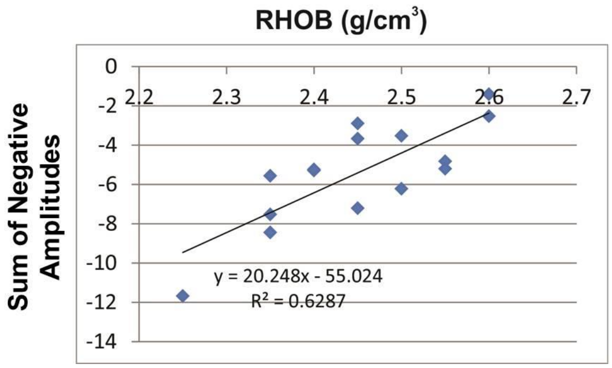

Figure 15: Cross plot between reservoir R2 density and the attribute Sum of Negative Amplitude.

In view of all these geological settings, and having a pseudoporosity map (attribute map), the 3D model was built in order to represent the porosity distribution among the wells.

In 30 realizations, it was observed that the central structural high presented high values of porosity (>20%) in all of them. It happened because this area has more information with nearby wells. The models that presented high porosity also in Southeast and South corresponds to only 7 in 30 scenarios (23%).

In this phase, the attributes maps were essential as a criterion to choose the model that would better represent the studied reservoir.

So, in the model it is possible to observe the high porosity values (red and yellow colors) predominantly in central, Southeast and South of the reservoir R1 and R2 (Figures 16 and 17) as showed in the attribute maps.

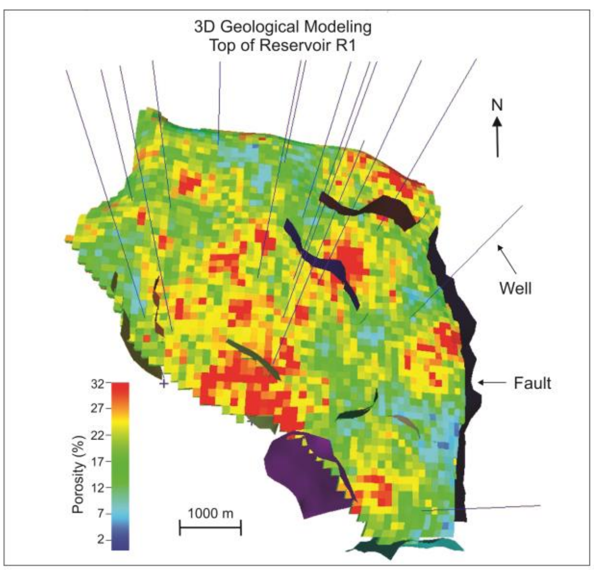

Figure 16: 3D porosity model of reservoir R1.

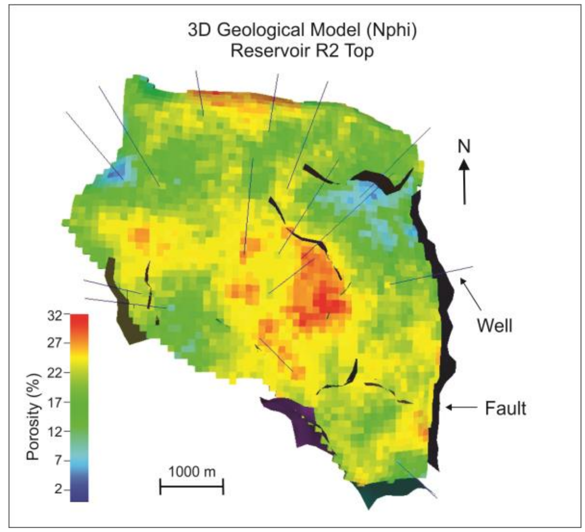

Figure 17: 3D porosity model of reservoir R2.

The petrophysical maps and the geological model show the diminution of porosity and increasing of density to the North and Northwest of the area, what reaffirms the analysis about the decrease of the reservoir quality to these directions (Figure 18).

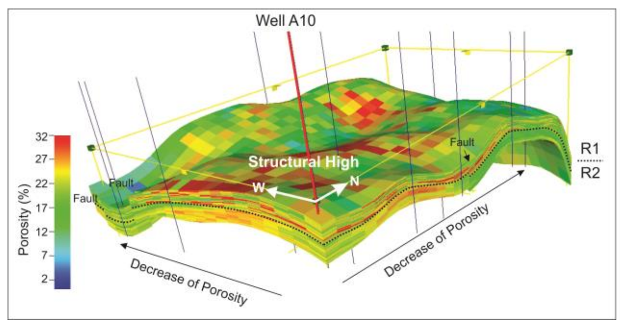

Figure 18: Section of 3D porosity model with reservoirs R1 and R2.

Conclusions

The application of seismic attributes for the Albian carbonates in the studied area is an effective method to highlight the quality of the reservoir rock by differentiating high values of porosity and low density.

For the Albian carbonates in Southwest of Campos Basin the Maximum Negative Amplitude, Minimum Amplitude, Trace Power, Maximum Absolute Amplitude attributes presents high correlation (R^2 > 0,74) with density and porosity. Also, the Amplitude RMS and Total Energy still highlights the interested areas, but with lower correlation index (higher dispersion).

Besides the central structural high, the attributes showed high porosity in Southeast and South of the area.

In addition, the attributes analysis showed an efficient tool to choose the 3D geological model closer to the available data set, which helps to decrease the geological uncertainty in the undrilled areas.

Acknowledgments

The authors would like to thank the Landmark for providing the licence of Decision Space software. Also, we wish to thank the ANP and Petrobras for providing the database. This research was developed in the laboratory of Geology and Seismic Integration (LISG) in Center for Geosciences applied to Petroleum - UNESPetro, UNESP, Rio Claro.

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