Quantitative geophysical characterization of an aptian carbonate reservoir in Santos Basin

Maíra Izeli (Petrobras), Maria Gabriela C. Vincentelli (Unesp)

Abstract

Discoveries of large hydrocarbon reservoirs, associated with Aptian carbonate´s rocks, at ultra-deep waters of Santos Basin, generated a high expectation related to economic return for the oil industry. In order to better understand this kind of reservoirs and improve the process of geological facies definition, distribution and prediction, this study was carried out in an oil field of Santos basin. The study was based on wirelogs, 3D seismic cube in time and depth scale, 2D seismic lines and well core; as result, it was possible to obtain an understanding of this reservoir and the porosity distribution was estimated for an oil producer level at the area. To reach the proposed objective, a stratigraphic well correlation, petrophysical analyzes, well-seismic calibration, and seismic interpretation were performed, including generation of attribute maps that allow the comprehension of the porous system. The analysis of the seismic attributes with the reservoir properties correlation was performed in a quantified way, using crossplots between amplitude and rock property. From the stratigraphic sections generated, a structural high was observed in the Northeast portion of the studied area and an expressive low to the Southwest, with great increase of the thickness of the rift sequence zones in this direction. The 3D seismic cube structural interpretation suggested a division of the area in three blocks with NE-SW direction, separated by expressive normal faults, with dip to SE. The crossplots show, at the studied level, that the porosity is reflected by the attribute map of Maximum Negative Amplitude and the density property is reflected by the RMS attribute map (extracted from the acoustic impedance cube filtered, bandpass). Finally, it was possible to conclude that the porosity and density distribution follows the main trend of the NE-SW faults.

Introduction

The Santos Basin is located in the southeastern portion of the Brazilian continental margin, along the states of Rio de Janeiro, São Paulo, Paraná and Santa Catarina. It is limited to the South by the High of Florianópolis, which separates it from the Pelotas Basin. The North portion is bounded by the structural High of Cabo Frio, which separates this basin from the Campos Basin. The study area is inserted in the Northeast portion of the Basin, according to Figure 1.

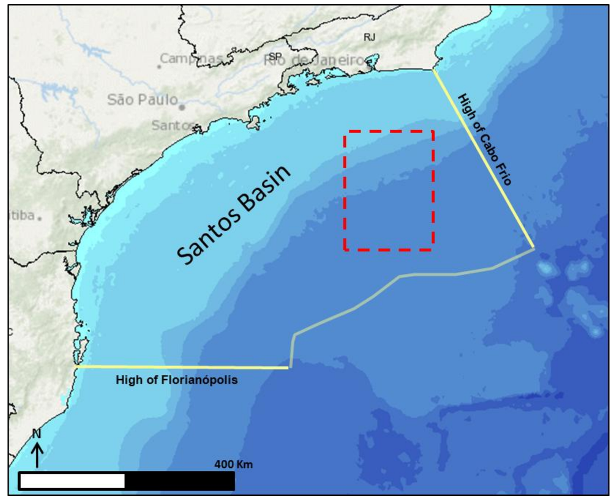

Figure 1 - *Santos Basin location. The dashed line in red indicates the window in which the study area is inserted (Map from BDEP website, November 2015).*

According to Moreira et al. (2007), the stratigraphic framework of the Santos Basin comprises three supersequences: Rifte, located at the lower portion, with normal faults involving crystalline basement and associated basic volcanism; Post-Rift (or Transitional); and Drift, with deposits related to the natural process of continental drift. The reservoirs object of this study are located at Post-rift Supersequence, corresponds to the Barra Velha and Ariri Formations, from the Guaratiba Group. The Barra Velha formation is subdivided into two sequences, upper and lower, deposited in a transitional environment between continental and shallow marine. The low sequence, Upper Aptian age, shows its lower limit defined by the pre-Alagoas unconformity represented by a reginal seismic reflector with strong positive amplitude. Stratigraphic sequence is characterized by microbial limestones, stromatolites and lamites in the proximal portions and shales at distal portions. At the top, evaporites of the Ariri Formation are found.
With the aim of understand the reservoir facies distribution based on porosity property through the core-log-seismic integration, a quantitative seismic interpretation of the study level reservoir where performed in order to determine the lateral variability of this rock characteristics.

Method

For the development of the research 2 seismic cubes were used in time and depth scales, each one showing an area of 400 Km^2, 30 seismic lines 2D, 5 wells with wirelogs and 200 meters of core from one of the wells. Initially, a stratigraphic correlation was performed between the wells to determine the main reservoir levels. From the calibration of the well with the seismic, the 3D seismic interpretation, petrophysical analysis and the seismic data acoustic inversion were carried out. Using amplitude and acoustic impedance seismic cubes, the seismic attributes maps were calculated. After, the attribute maps were correlated with the rock property that it represents by crossplot analysis calibrated by core observation.
The seismic attributes quantitative analysis was applied to the reservoir just below the salt layer, defined in this work as *Barra Velha Superior* 1 (BVE S1), which due to the tabular form of deposition with little thickness variation throughout the study area, allowed the split of the zone into bands of the same thickness in seismic time, increasing the number of sample points and allowing the analysis of the crossplot between the rock properties and the seismic answer.
Using top and base horizons of each zone, the attributes of Maximum Negative Amplitude, Maximum Positive Amplitude, Mean Amplitude, RMS, Negative Amplitude Sum, Positive Amplitude Sum, Total Energy, and Trace Power were calculated for windows between two horizons at seismic time. This stage had a preliminary qualitative evaluation relative to the most appropriate extraction windows and selection of the best attributes that represents a geological facies or feature. As a result, approximately 250 seismic attributes maps were extracted from the cube of amplitude and filtered acoustic impedance.
For the analysis of the relationship of each seismic attribute map with the rock properties, correlation crossplots were generated between amplitude/impedance Vs rock property measured on wirelogs. The rock properties used were porosity, density, velocity and acoustic impedance. To better represent the rock property value, for each represented reservoir interval, the mode value was selected.
After all correlation graphs were generated, a detailed analysis was performed for the selection of attributes with the best responses to the rock properties for the zones of interest.
The verification of the correspondence degree between the seismic attribute and the rock property was performed by the R^2 value (correlation factor) of the correlation line. For a better fit of the line, each graph was analyzed individually using geological criteria. The quantitative attribute analysis process is illustrated in Figures 2 to 5.
With the quantitative analysis result, maps of pseudo-property distribution were generated applying numerical inversion of the line equation, result of the crossplot for the BVE S1 zone.

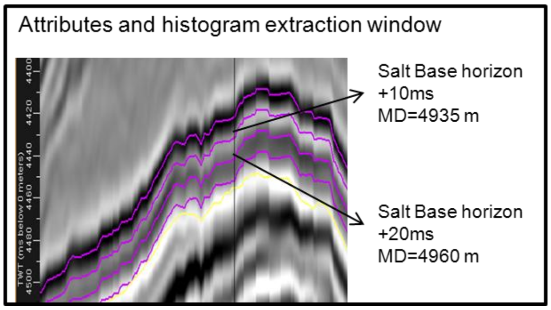

Figure 2- *Creation of horizons from time shift of the top of the reservoir (Salt base) and definition of the seismic attributes and properties histogram extraction window.*

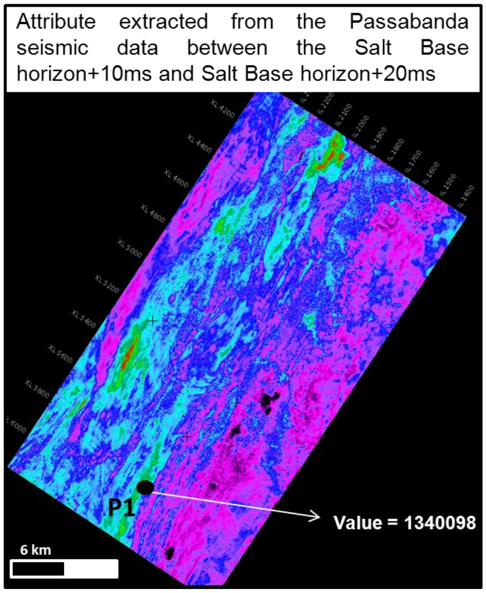

Figure 3- *Seismic attribute map, from where the attribute value in the well is taken to be used at the crossplot.*

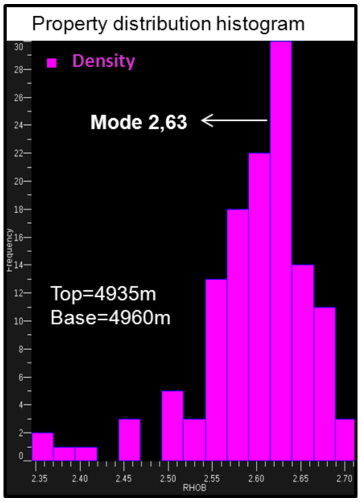

Figure 4- *Property distribution histogram to define the mode value to be used at the crossplot.*

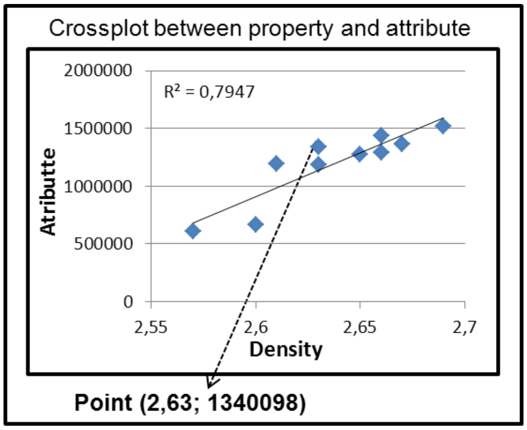

***Figure 5** – Crossplot between property values and attribute for each well.*

Results

From the stratigraphic correlation, it was possible to identify six stratigraphic levels: Upper Barra Velha 1 (BVE S1), Barra Velha Upper 2 (BVE S2), Barra Velha Lower (BVE I), Upper Itapema (ITP S), Lower Itapema (ITP I) and Piçarras (PÇR).
The stratigraphic mapping allowed the identification of ten reflectors that were interpreted in the 3D seismic cube, six of them below the salt layer of the Ariri Formation, with five well-defined stratigraphic zones in the seismic data (Figure 6).
The fault´s seismic interpretation on the 3D seismic cube showed expressive normal faults of direction NE-SW, with dip to the SE, that divides the area into three main blocks (figure 7).
The acoustic inversion allowed the understanding of the acoustic impedance variation in response to the porosity of the studied reservoir. During the viability stage process, a dual trend in this correlation was verified. Values outside the main correlation line are associated with probably more clay mineral assemblage, such as those in the PÇR zone for all wells and the BVE S2 zone in three wells structurally in lower positions.
At the petrophysical analysis the Gamma Ray Index, Porosity and Water Saturation logs were calculated. Comparing the histograms of total porosity and porosity corrected by the gamma ray index (P_{RG}), we highlight the large drop of corrected porosity (P_{RG}) in the BE S2 zone. This drop is very significant in structurally lower wells, with a total porosity of 9% and corrected porosity (PRG) of 5%, and may be associated with an increase in shale.
The seismic attributes quantitative study allowed the definition of the correlation of rock physical properties with attributes calculated on the seismic data. The generated crossplots indicate that for the BVE S1 zone in the area, the porosity is reflected by the Maximum Negative Amplitude attribute (Figure 8) and the density by the RMS attribute extracted from the filtered acoustic impedance cube (Figure 9).

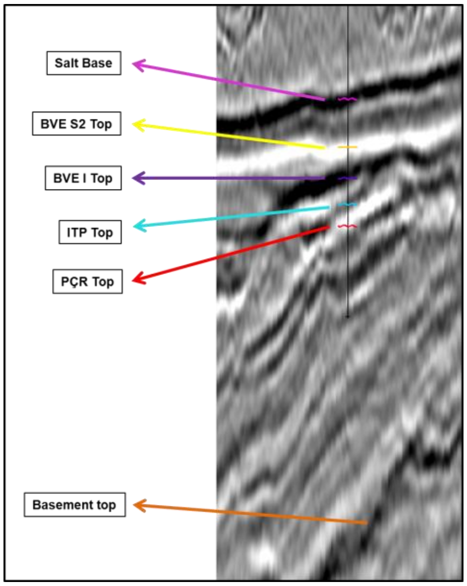

***Figure 6** - Interpreted horizons, between the base of the salt and the top of the igneous, highlighting the seismic response of each zone. Camboriú Formation Top (Basement Top); Piçarras Formation Top (PÇR); Upper Itapema Formation Top (ITP S); Barra Velha Inferior Formation Top (BVE I); Barra Velha Superior Formation 2 Top (BVE S2); Barra Velha Superior 1 Formation Top (BVE S1), which coincides with the Salt Base.*

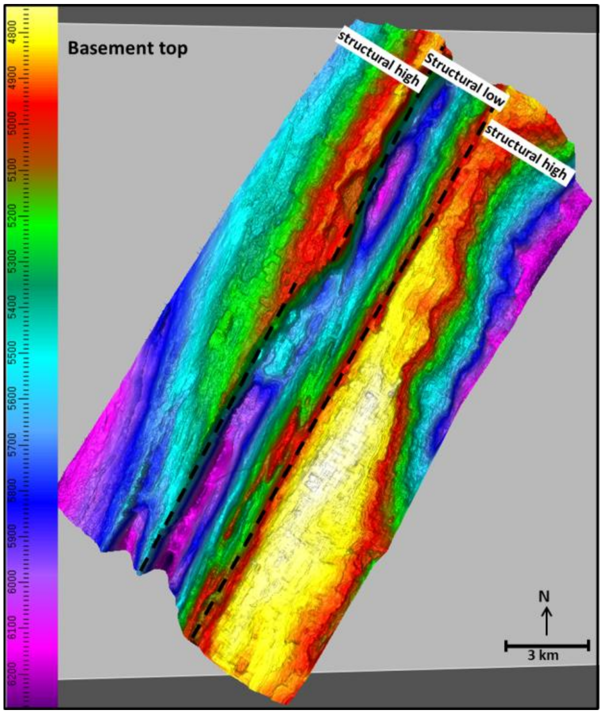

***Figure 7** – Basement top horizon, with the NE-SW main normal faults, that divides the area into three blocks.*

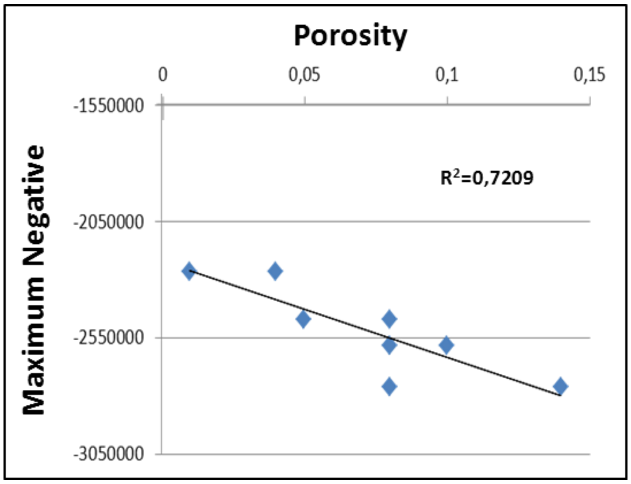

Figure 8 *- Crossplot of the porosity property with the Maximum Negative attribute, extracted from the filtered acoustic impedance cube.*

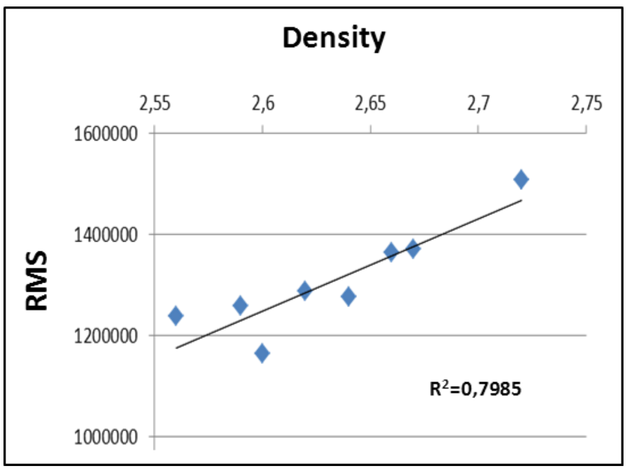

Figure 9 *- Crossplot of the density property with the RMS attribute, extracted from the filtered acoustic impedance cube.*

With the result of the crossplots correlations, a correlation line equation was created.

For porosity:

$$X=\frac{-2218466-Y}{4147988}$$

Where, X is porosity value and Y is attribute value.

For density:

$$X=\frac{Y+3512113}{1830807}$$

Where, X is density value and Y is attribute value.

These equations allow the obtainment of two pseudo-property distribution map, for porosity and density (figure 10 e 11).

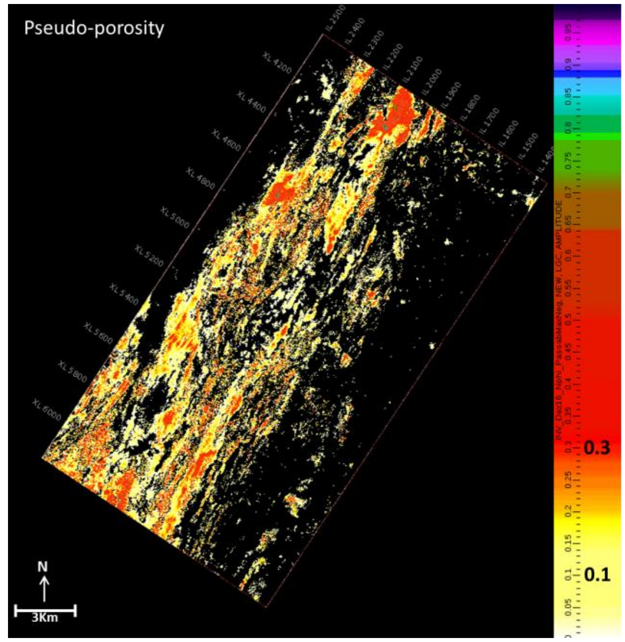

Figure 10 *- Pseudo-porosity distribution map calculated with the correlation line inversion generated from the crossplot between porosity and Maximum Negative attribute.*

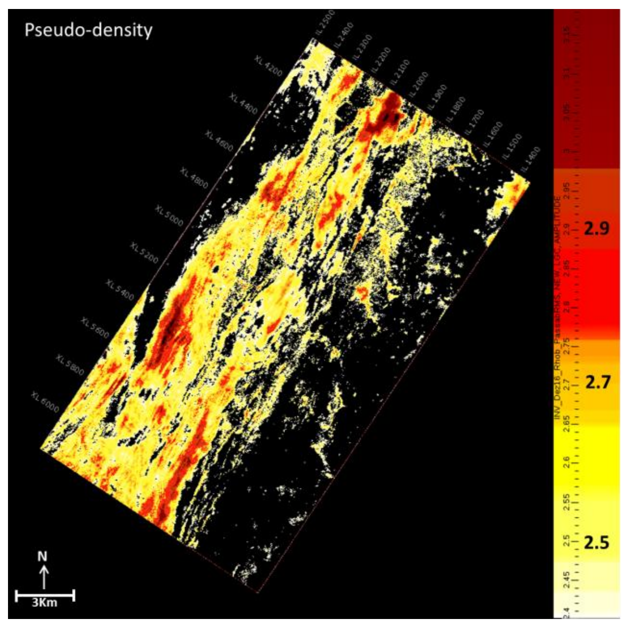

Figure 11 *- Pseudo-density distribution map calculated with the correlation line inversion generated from the crossplot between density and RMS attribute.*

Conclusions

From the stratigraphic sections and the seismic interpretation, a structural high is observed in the Northeast portion of the studied area and an expressive low to the Southwest, with a high increase of the thicknesses mainly of Upper Itapema, Lower Itapema and

Piçarras formations. The structural interpretation in the 3D seismic cube area shows that the area is divided into three blocks of NE-SW direction, separated by expressive normal faults, with dip to the SE.

The isopachs indicate expressive thickness variations close to the fault, of approximately 250m to the BVE I and ITP zones and 340m to the PÇR zone. The stratigraphycal growing observed at ITP and PÇR zones would indicate that the faults were active at the deposition moment of these sequences (syndepositional stratigraphic layers) of the rift phase. In the case of the BVE I zone, a growing section was also observed, and it is associated to the accommodation space generated by the active fault system, in which an ideal water and temperature blade condition was created for carbonate evolution, with subsequent failure and rotation of blocks. The tabular form of the layers in the BVE S1 and BVE S2 zones and the low thickness variation is the result of deposition in a tectonic environment characterized by thermal subsidence, interpreted as post-rift phase.

The attributes study indicates that the Maximum Negative Amplitude and RMS attributes maps could show porosity and density answer, respectively. Although the seismic data would be affected by illumination problems, with the largest amplitudes below the top of the salt, it is possible to conclude that the pseudo-porosity and pseudo-density distribution follows the main trend of the NE-SW direction faults.

Acknowledgments

This research was development at UNESPetro, Center of Geosciences Applied to Petroleum, UNESP, IGCE, Rio Claro – SP – Brazil. We would like to thank Petrobras for supporting this study and for allowing this publication. We are grateful to colleague Jorge Guida, Geophysicists at Petrobras for the acoustic seismic inversion study. We are very grateful to Sergio Contreras for all the geophysical help. And we also thank Unespetro and its entire staff for the physical structure for the development of this work.

References

MOREIRA, J. L. P.; MADEIRA, C. V.; GIL, J. A.; MACHADO, M. A. P. Bacia de Santos. **Boletim de Geociências da PETROBRAS**, v. 15, n. 2, p. 531-549, 2007