Seismic interpretation and geological facies distribution analysis for carbonate´s reservoirs (Albian) at Enchova oil field.

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Abstract

Nowadays, it is necessary to better understand the geological facies distribution on potential carbonate´s reservoirs; this process will help the exploratory process on this kind of play. The main objective is to determine the geological facies reservoir and non-reservoir in Enchova oil field Albian carbonate bank. The study was based on the use of seismic attribute maps calibrated by rock information (cores and well logs), and the applied method includes the use of petrography and qualitative description of the reservoir through the interpretation of the attribute´s map (energy, root mean square, mean amplitude, maximum negative amplitude, among others), all of them calculated for the Albian level. As result, it was obtained the tectonic-stratigraphic geometry of the analyzed carbonatic oil reservoir, where the presence of basement structural paleo-highs were determinant for the development of reservoir facies (grainstone), identify at seismic attribute maps and verified by petrographycal information. The attribute´s map answer related to reservoir quality (as verified at the correlation cross-plot) at its principal reservoir indicates best reservoir´s quality at the North, center and South of the studied area, and these anomalies are reflecting the paleo geographic conditions. Such areal differentiation may explain the observed difference between the hydrocarbon production´s curves associated to each of these regions.

Introduction

The geophysical analysis of carbonate´s reservoir is limited by its own resolution; on this sense, the high heterogeneities related to this kind of reservoirs oriented geological and geophysical reservoirs to improve the visualization of geophysical facies and calibrate this facies with geological facies that may be simplified in reservoir and non-reservoir facies.

The method proposed here will help on the determination of the permo-porous system with less geological uncertainly. In another way, this work applies geological scale´s transfer between well data scale (centimeters and meters) and the seismic scale (tens and hundreds of meters). With the aim of minimize the error and better control the rock properties along the reservoir, this method uses geological and geophysical analysis based on seismic volumetric interpretation that allows an indirect visualization of the reservoir heterogeneities.

The study area is localized corresponds to Albian Enchova oil field at the meridional portion of Campos Basin (figure 1). The Campos Basin extends from the North of Rio de Janeiro State (Cabo Frio High) where it limits with Santos Basin, at the limit of the Espirito Santo State (Vitoria High), limiting with Espirito Santo Basin.

Figure 1.- Map with the localization of Campos Basin showing the main hydrocarbon oil fields, the study oil field being located inside the red square. Modified of Bruhn et al.(2003).

The main objective is the geophysical and geological characterization of the reservoir and non-reservoir facies of a hydrocarbon producer carbonate´s bank. In order to achieve the goal geological data were integrated with the tectonic and sedimentary evolution defined by surface´s seismic attributes created for each bank´s development stratigraphic unit, previously defined by the petrographic description (upscaling of the data – micro/meso to macro scales).

One of the latest synthesis about tectonic-sedimentary evolution of Campos basin´s, published by Winter et al. (2007 – figure 2), defines its evolution in three super sequences: Rift, Transitional and Passive Margin. The passive margin (Albian to Quaternary) highlights the starting the marine sedimentation (carbonatic at the beginning, followed by mainly siliciclastic sedimentation), after deformed by an intense halokinetic´s tectonic. The synthesis by Winter et al. (2007) has been discussed by many authors, such as Asmus, 1975; Asmus & Guazeli, 1981; Azevedo et al 1987; Guardado et al. 1989; Dias et al. 1990; Mohriak et al. 1990; Chang et al. 1992; Cainelli & Mohriak, 1998 ; Guardado, 2000; Azevedo, 2001, among others.

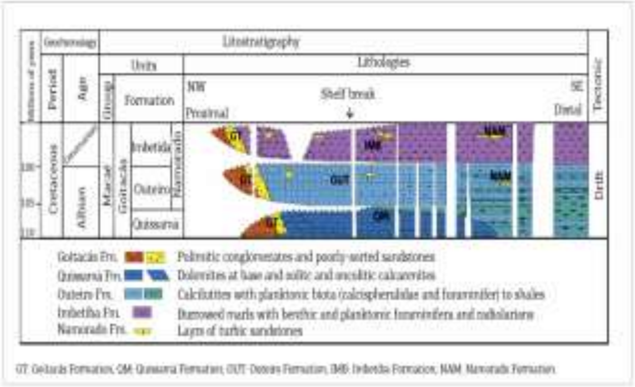

Figure 2: Stratigraphic chart showing the Albian interval at Campos Basin (Fonte: Winter et al. 2007).

The Quissamã Fm. is characterized by carbonate´s banks with main azimuth NE –SW (Guardado et al. 1989), deposited in environment of high to moderate energy. The lithological composition is mainly grainstone and packstone, formed by oncoids, ooids, peloids and bioclasts according to description showed at the table 1 (Spadini et al., 1988; Favoreto, 2014; Favoreto et al., 2016).

The Outeiro Fm. is formed by fine grained carbonates intercalated by marls and shale, which occurs as the answer at the progressive sea level rises. This carbonates are rich in pelagic microfossils as well as calciferous (Pithonella), planktonic foraminifera, and radiolarians (Dias-Brito, 1982; Favoreto, 2014; Favoreto et al., 2016).

Methods

The method was based on the integration of geological and geophysical data in the study area; for this, petrographic analysis, paleogeografic and seismic attributes maps were done and interpreted.

Wire logs were used (28 wells with wirelogs of Gamma Ray, density, neutron, and sonic among others) with the aim to perform the rock-wirelog and wirelog-seismic calibrations; in addition 30 km² of tridimensional seismic data was used. It is important to mention that all these data are homogeneously distributed in the study area.

The spatial distribution and paleo-sedimentary environment evolution of the different geological facies were done based on the following aspects: type of grain that formed the rock, micrite´s presence, diagenetic features and fossiliferous register, when available. The vertical facies relationship and its spatial distribution with use of well stratigraphic correlation (depositional trends) and maps of facies proportion were also analyzed.

All the recognized depositional sequences were evaluated by the seismic perspective through the use of attributes maps.

At the geophysical study a cross validation between wirelog data and seismic amplitude was done; in other words, the possible Quissamã´s reservoirs were identified at the wire log and its amplitude signature. From this test, each core´s interval was checked with its correlated electro facies and seismic amplitude, with the purpose to verify the seismic signal for each phase.

Having as a goal to define the geological development model, based on the seismic attributes study, each validated stratigraphic level was interpreted at the seismic volume. As a result, four surfaces related to top and base of each depositional sequence were generated at the interest interval.

The seismic attribute maps were calculated on the seismic volume, using as reference the structural interpretation (of previously created surfaces); as product pseudo-structural maps (in time) at the top of each sequence, attributes maps were obtained in order to get amplitude anomalies. The structural maps are called pseudo structural maps, since they are shown in time scale, due to the fact that the water layer is almost constant along the area (120 m) and there are not important changes in the velocity field caused by geological structures. As a consequence, the contour structural map is almost showing a geometry related to the structural map.

The amplitude anomalies were determined by the use of the calculated attributes maps (*Root Mean Square*, *mean amplitude*, *average amplitude*, *energy*, among others) for each top of interpreted sequence and at the intra-sequence levels.

Applying the seismic attributes maps, the described geological facies were statistically evaluated using correlation´s cross-plots of amplitude anomaly vs facies (Figure 3), in order to obtain a characterization of facies distribution along the study of the oil fields.

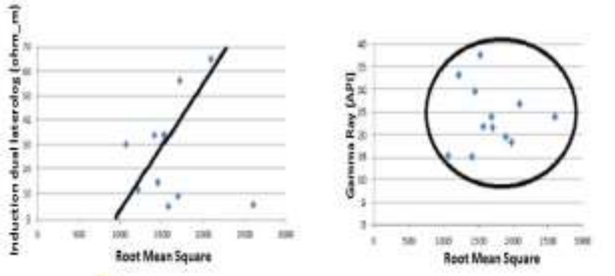

Figure 3 - Graphic of cross-correlation of amplitude Vs rock attribute.

When the rock attribute´s value shows a linear relationship to the value of the seismic attribute, it is interpreted that it is possible to predict a specific rock property using seismic attributes maps; but, if the graphic shows a high dispersion (without linear correlation), it means that the selected rock property is not represented at the attribute map.

Results

The carbonaitc bank, object of this research, evolved into a rift sequence´s paleo-highs from the Aptian age; this geological feature was visualized at the South-West region as shown in the maps of figure 4. The seismic data interpretation determined that the mentioned Aptian paleo-highs were conditioned by fault's basement. The real geometry of the evaluated carbonate´s bank was strongly dominated by the halokinetics system, that configures structures like rollovers at the West (see this geometry at the top of Macaé Group –seismic interpretation at figure 4), and it also determines an internal fault´s own system of the rheology of the carbonate´s bank with a regional ductile compensation at the evaporitic sequence (Retiro Fm. Aptian top)

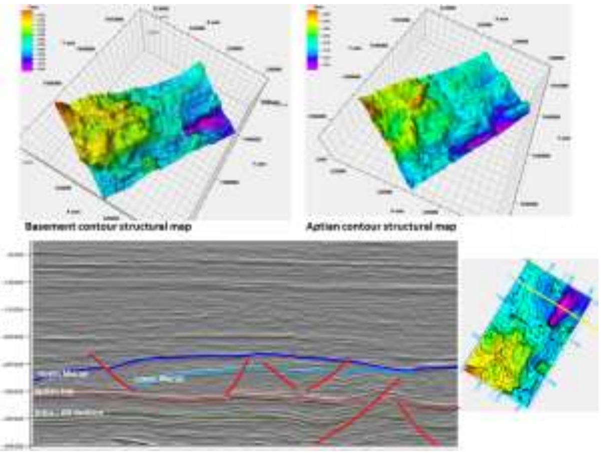

Figure 4.- **Seismic interpretation and contour structural maps of basement and Aptian showing the structural paleo-highs at the South-West region of the studied area.**

At the seismic line of figure 4, it is observed the upper rift´s sequence (between green and red horizons), and at the SE portion the horst shows a dip slip of 380 meters approximately, the structural deformation is highly influenced by basement's highs and lows related to Gondwana opening (see the contour structural map at the right of the seismic line – figure 4).

The Aptian structural configuration has provided the simultaneously evolution of two carbonate banks at the Albian age. This fact was verified at the seismic interpretation and visualized at the opacity and transparence volumetric seismic attributes at the sweetness cube, this last being a seismic volumetric attribute that allows the lateral continuity of the carbonatic reservoir, as defined by Vincentelli et al (2015-figure 5). The substrate would be interpreted as approximately the same for both banks, but with a geological division caused by a normal fault system observed from the basement, with azimuth parallel to the conjugate´s deformation system at Campos Basin with main direction NW-SE. This fault system separates the footwall (the high block) of the hanging wall (low structural block) located at the north portion of the evaluated area, the dip slip between the blocks was measured in 150 meters; it was also observed that this fault system was active along the whole phases of the carbonate´s bank evolution, for it is considered that these two main structural features determine the differential distribution of oil production and petrophysical properties characterizing the North region to the South.

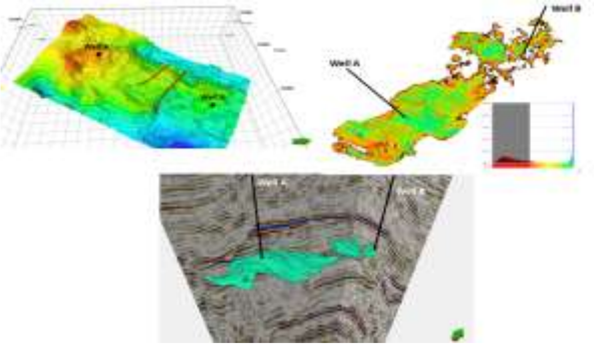

Figure 5.- At the left top: seismic interpretation of the two carbonatic banks, each one characterized by wells A and B, respectively projected at the first reservoir sequence structural map (top of phase 3 and base of the phase 4). At the upper right position of the figure it is shown the continuity visualization of the reservoir rock highlighted by the sweetness volumetric attribute. At the low figure: the main carbonatic reservoir distribution, tested at the wells A and B, is shown - here; this reservoir level is related to the phase 4 of the carbonatic bank.

The carbonatic bank of the Albian (Enchova oil field) shows five evolution stratigraphic phase, identified as Sequence 3 (Figure 6), and associated with the substratum of the main oil producer level (sequence 4), the deposition of the peloidal packstone facies - with rudaceous oncoids were possible to find, in a preserved environment conditions created by barriers or local lows adjacent to the bank; this pervious condition is confirmed by the structural map where one can observe its main direction NE-SW, with structural lows on the same direction (Figure 6-A). This last feature represents "mini-basins". The relative oscillation of the main sea level caused the bank´s subaerial exposition that generates a meteoric vadose diagenetic environment, with partial moldy porosity to the ooids and oncoids grains. (Figure 6-B).

On the mean amplitude seismic attribute map (Figure 6-C) is possible to verify the internal carbonatic reservoir heterogeneity caused by the diagenesis development. The seismic anomalies of the green color are modified by mainly blue and red anomalies. These anomalies would indicate regions with more (green regions) and less diagenesis (blue and red regions), respectively.

At this phase, it is confirmed a carbonatic bank with azimuth of NE-SW in the structural contour map (figure 6-A) as well as at the seismic attribute map (figure 6-C), with extension of approximately 6 km.

The paleogeographic condition of phase 3 is agains tthe Depositional Sequence 5 (phase 5), thus represented by the mudstones of the Outeiro Formation at well A (Figure 7). At phase 5, in the South region, the rising of the sea level creates paleo-environment conditions that do not support high energy conditions and it is not possible to hold environment conditions to the carbonate´s bank evolution. At the North position (well B), it was possible the conservation of primary porosity, due to the structural conditions favorable for the reservoir deposition (grain stone verified at the well) at the structural high of the carbonatic platform.

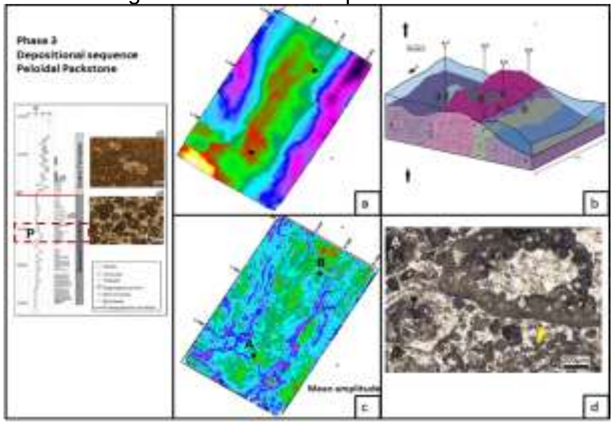

Figure 6: Characterization of the facie peloidal packstone main substrate for the carbonatic bank evolution (facie Grainstone); a) Contour structural map of the depositional sequence 3; b) Diagram block of the paleo-faciological condition of this region; c) seismic attribute map showing the distribution of the peloidal packstone facie, showing a green color anomaly; d) Photomicrograph of peloidal packstone facie representative of the stratigraphic interval showed at the well profile at the left of the global figure at the well A

At the same attribute map (Figure 7-C), of maximum negative amplitude, one can observe more heterogeneities of the reservoir facies (green facies) with initial diagenesis visualized at the well B; this fact being directly related to the reservoir quality as verified at the correlation cross plot of the figure 8. The yellow and red anomalies represent the mudstones and Wackestone facies of the Outeiro Fm.

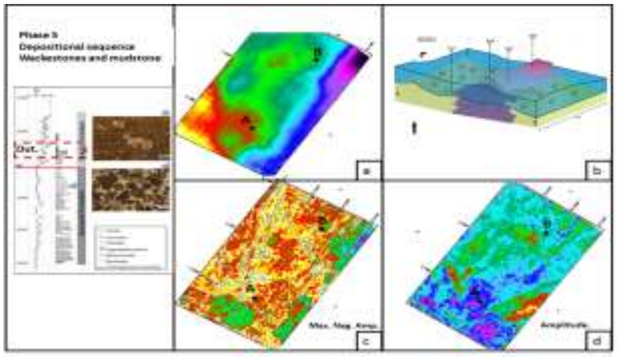

Figure 7: Characterization of the facie Wackestone and bioclastic´s mudstone representative of the Outeiro Fm, an image of thin section at the picture 1; a) Contour structural map of the depositional sequence 5; b) Diagram block of the paleo-faciological condition at phase 5;c) seismic attribute map of maximum negative amplitude representing the heterogeneities of the Wackestone and mudstone facies, with green and red anomalies; d) seismic attribute map showing the heterogeneities fo the bioclastic mudstone and Wackestone facies, with grainstone development at regions with high energies at the deposition ages, with green and red anomalies.

The cycles of the rising sea level were the key to each reservoir configuration, since this event would remove some regions of the carbonatic bank and formed channels to connect the open sea shelf with the restricted circulation shelf as verified at the attribute map of the figure 9, where is shown the Depositional Sequence 4 or phase 4. The amplitude anomalies are shown on the mean amplitude and maximum negative amplitude map, and the created channels that allow the circulation of marine currents are clear at the image.

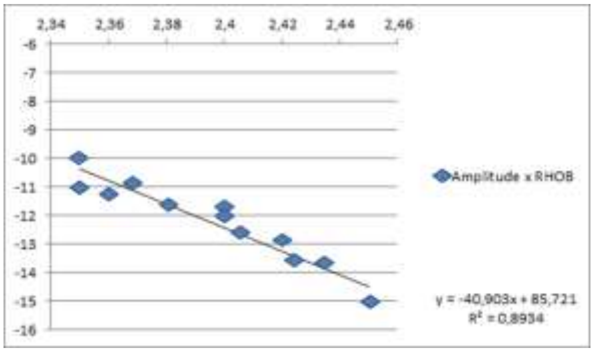

Figure 8.- Cross-plot of correlation of amplitude Vs rock density (reservoir quality) showing a linear relationship between the seismic attribute and the carbonatic rock type effectively reservoir.

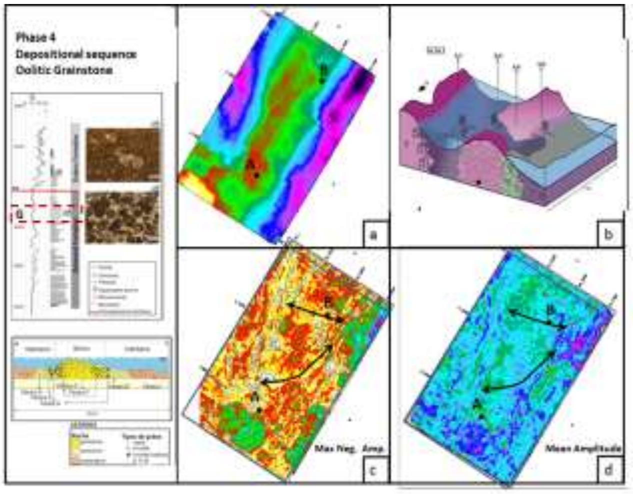

Figure 9: Characterization of the facie Oolitic grainstone at the main reservoir, image of thin section at the picture 2; a) Contour structural map of the depositional sequence 4; b) Diagram block of the paleo faciological condition at the phase 4;c) seismic attribute map of maximum negative amplitude representing the heterogeneities of grainstone facies with the paleo-channels that connected the open sea shelf to the restricted circulation shelf (the paleo-channels are represented by the yellow anomaly and arrows); d) in seismic attribute map of main amplitude, showing the grain stone facies heterogeneities, it was considered that the best reservoir facies is the green anomaly.

Sequence 4 above, which represents the top of the Quissamã Formation, with deposits of high and moderate environment´s energy, a marine transgression of Outeiro Fmoccurs. For this facies — like bioclastic Wackestone, mudstone and bioclastic´s peloidal

Wackestone suffering marl interference on phase 5 were deposited as previously explained. These facies are rich in pithonelids, radiolarians and *Favusella washitensis*, showing open sea conditions. The marl interference indicates geological events with high terrigenous of the basin, as well as the glauconite presence indicates less sediments contribution and anoxic conditions.

The older facies at the sequence 3 are the packstones facies (phase 1), representing a lower substrate of the carbonatic bank; after that it was observed the development of a grain stone facie of the sequence 2 (phase 2) of less reservoir quality when compared with the grains tone facie of the phase 3, but its regional distribution is more homogeneous due to the fact that the crest of the bank was located approximately at the same water depth along the main structure.

Conclusions

The seismic interpretation confirmed the presence of a paleo-highs basement, on the direction of the main rift structures of Campos basin, controlling favorable conditions for the carbonatic bank evolution; but the deposition of the effective reservoir facies depends on the high energy conditions created by adjacent mini-basins to the main bank. These conditions favor the development of packstone facies that originate the necessary substrate for the main reservoir deposition; for the studied oil region only two areas show the necessary environment conditions in a paleo-structural highs associated with an extensional deformation system related to the first halokinetics stages of the basin, in a fault system at the antithetic direction (NW-SE) at the main structural rift´s deformation system (NE-SW) .

Therefore, the integration of rock analysis (core description), combined with the determination of facies distribution based on seismic attribute maps, would reduce the uncertainty related to the few geological and geophysical data available to evaluate most of the carbonatic reservoirs along the World. A reservoir properties description, including seismic attributes, allow the implementation of a controlled upscaling from rock scale (macro and microscopic scales) to seismic scale (tens of meters); as a result, it is expected a better reservoir´s heterogeneities control in a quantify form, and, as a consequence, a better control of the reservoir flux units would be obtained.

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References

Asmus, H. E. 1975. Controle estrutural da deposição mesozóica nas Bacias da margem continental brasileira. Revista Brasileira de Geociências 5:160 –175.

Asmus, H. E.; Guazelli, M. 1981. Descrição sumária das estruturas da margem continental brasileira e das áreas oceânicas e continentais adjacentes. Projeto Remac. 9: 187 – 269.

Azevedo, R.L.M. 2001. O Albiano no Atlântico Sul: Estratigrafia, Paleoceanografia e relações globais. 2001. 265 p. Tese de Doutorado. Instituto de Geociências, Curso de Pós-Graduação em Geociênicas, Universidade Federal do Rio Grande do Sul, Porto Alegre.

Azevedo R.L.M., Gomide J., Viviers M.C. 1987. Geo-história da Bacia de Campos: do Albiano ao Maastrichtiano. Revista Brasileira de Geociências, 17(2):139-146.

Bruhn C.H.L., Gomes J.A.T., Lucchese C.D., Johann P.R.S. 2003. Campos basin: reservoir characterization and management - Historical overview and future challenges. In: Paper OTC 15220 presented at the Offshore Technology Conference, Houston, Texas: 14 p.

Cainelli, C. & Mohriak, W. U. 1998. Geology of Atlantic eastern Brazilian basins. *In:* 1998 AAPG-International Conference & Exhibition, Rio de Janeiro, v. Brazilian Geology 2, p.66.

Chang, H. K.; Kowsmann, R. O.; Figueiredo, A. M. F.; Bender, A. 1992. Tectonics and stratigraphy of the east Brazil rift system: An Overview. Tectonophysics, p.97-138.

Dias J.L., Scarton J.C., Esteves F.R., Carminatti M., Guardado L.R. 1990. Aspectos da evolução tectono-sedimentar e a ocorrência de hidrocarbonetos na Bacia de Campos. In: Raja Gabaglia G.P. & Milani E.J. (Coords.) Origem e evolução de Bacias Sedimentares. Rio de Janeiro, PETROBRAS: p. 333-360.

Guardado, L.R., Mello, M. R., Spadini, A. R., Brandão, J. S. L. 2000. Petroleum System of the Campos Basin, Brazil: AAPG memoir 73.

Guardado L.R., Gamboa L.A.P., Lucchesi C.F. 1989. Petroleum Geology of the Campos Basin, Brazil, a Model for a Producing Atlantic Type Basin. In: Edwards J.C. & Santogrossi P.A. (Eds.) Divergent/passive margin basin. tulsa, aapg memoir 48, p. 3-79.

Favoreto, J. 2014. Modelo deposicional de carbonatos Albianos da Formação Quissamã: análise faciológica, diagenética e estratigráfica de um campo de óleo na porção meridional da Bacia de Campos. 156p. Dissertação de mestrado em Universidade Estadual "Julio de Mesquita Filho".

Favoreto, J.; Rohn, R.; Lykawa, R.; Okubo,J. 2016. **Caracterização sedimentológica dos carbonatos Albianos do reservatório Quissamã na porção meridional da Bacia de Campos. Revista Geociências. V.35(1).**

Mohriak, W. E.; Mello, M. R.; Dewey, J. F.; Maxwell, J. R. 1990. Petroleum Geology of the Campos Basin, offshore Brazil. Classic Petroleum Provinces, 50:p.119-141.

Rangel, H. D.; Martins, F. A. L.; Esteves, F. R.; Feijó, F.J. Bacia de Campos. Boletim de Geociências da Petrobras, Rio de Janeiro, v.8, n.1. p. 2003-218, 1994.

Spadini A.R., Esteves F.R., Dias-Brito D., Azevedo R.L.M., Rodrigues R. 1988. The Macaé Formation, Campos basin, Brazil: Its evolution in the context of the initial history of the South Atlantic. Revista Brasileira de Geociências, 18(3):261-272.

Vincentelli.C,M.G; Cáceres, S.; Uchoa, M. 2014. **Geophysical characterization of Albia Carbonates reservoirs in Brazilian Basins: The Sweetness as a toll for carbonate reservoirs definition. Revista Brasileira de Geofísica. V.32, p 695-705.**

Winter W.R., Jahnert R.J., França A.B. 2007. Bacia de Campos. Boletim de Geociências da Petrobras, 15:511-529.