Regional paleo-environment for Carbonates Aptian Reservoirs at Campos, Santos and Espírito Santo Basins.

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Abstract

Nowadays, it is well known that the comprehension of the tectonic-structural evolution and the processes that determines the presence of a carbonatic reservoir facies, will be a technical way to understand depositional and diagenetic process; and as consequence, the hydrocarbon habitat for this kind of play would be defined. The objective is to define the hydrocarbon habitat at the Aptian levels of Campos, Santos and Espirito Santo basins, all the analysis based on tectonic-sedimentary techniques, seismic attributes, and seismic interpretation integrated with petrographic and petrophysical data. The regional seismic interpretation verified: a.- the presence of a proximal high confirmed at the gravimetric map; b.- The rift structures deforming stratigraphic levels older than Aptian; c.- the ends of the Aptian age is represented by a transition phase identified at the literature as "sag". When evaluated the tectonic-structural context at the rift phase using geophysical data gravimetric map (Bouguer Anomalies) and seismic data, it is possible to define mainly three production hydrocarbon systems: a.- Reservoirs in limestone – "Coquines" with good permeability and oil production initialized; b.- Reservoirs in limestone "Coquines" without initialized oil production; and, c.-Carbonates type limestone: stromatolites and laminated microbialites. Finally, the identification of a fault system that affected the Aptian level and the Post-Salt section were determinant for the oil migration at the basin, from the Jiquia Formation to the Aptian-Coquines and upper reservoirs.

Introduction

The understanding of the geological factors, that define the petroleum habitat for Albian Carbonates reservoirs, would be based on a geophysical vision.

The proposed research includes a regional (Santos, Campos and Espirito Santo Basins) geophysical interpretation with the aim of verify the paleo-geometry and paleo-bathymetric conditions of the basement and sedimentation along Aptian and Albian ages. The mentioned parameter could condition a carbonatic bank evolution or the sediment rework that nowadays is find in an oil accumulation.

This point of view will offer to geologists and geophysicists information about hydrocarbon habitat, and some hypotheses about paleo-environment necessary to understand to the permo-porous system will be related to this information.

The study area is located at the Santos, Campos and Espírito Santo basins, all of them knowledge as Brazilian marginal basins at the offshore region, as showed at the figure 1.

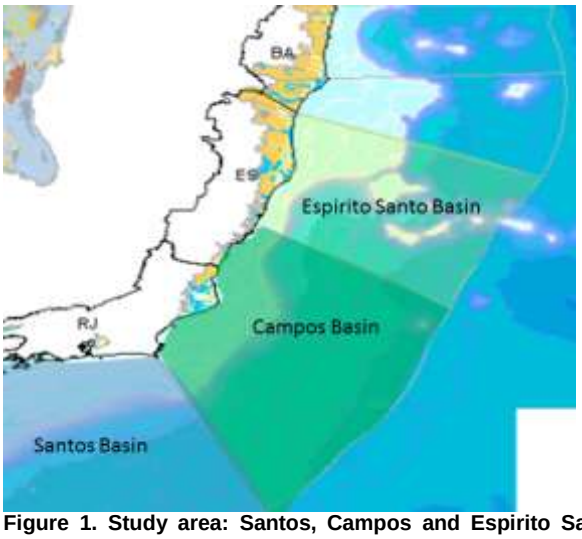

Figure 1. Study area: Santos, Campos and Espirito Santo basins.

At Campos basin the main region that produce hydrocarbon from "Coquina" reservoirs is related to the trend Enchova-Linguado-Trilha and Pampo. Vincentelli, et al. (2016) defined the lateral boarder of this province with two fault systems with tectonic reactivation: Alegre fault (at Northeast) and High Cabo Frio 2 fault (at Southwest); in addition, the authors call the attention to Polvo oil field that produce from Quissamã Fm. (Albian – Calcarenites), and it is located at the junction of the last mentioned fault and Marlin fault (defined at the same research), with azimuth NE-SW

Currently, it is well known that the comprehension of the tectonic-structural evolution and the processes that

determines the presence of a carbonate reservoir facies, will be a technical way to understand depositional and diagenetic process, and as consequence the hydrocarbon habitat for this kind of play will be defined.

The main objective is to define the hydrocarbon habitat at the Aptian levels of Campos, Santos and Espirito Santo basins, all the analysis based on tectonic-sedimentary techniques, seismic attributes, and seismic interpretation integrated with petrographic and petrophysical data.

The evolution of the Brazilian offshore basins, started with the Gondwana breaking and as consequence the Atlantic Ocean opens and the American and African continent were separated. Until today, multiples studies oriented to define evolutive and sedimentary geological models based on the geological geophysical integration have been done, but a specifically study related to define pelo-environments base on the mentioned data has not yet been performed

The importance of integrated structural and stratigraphic models is related to the genesis of the own basin, because it represents the basement evolution history, fundamental in the comprehension of paleo-environment conditions to development carbonate reservoir like Coquinas at the Aptian age. At the next paragraphs some important consideration that justify this research are described:

Castro (2006) shows the importance of the pre-salt section analysis at Campos basins that contains some analogies with Santos basin as follow: : "*... the coquina reservoir at Laoga Feia Formation, in the Badejo, Pampo and Linguado oil fields, is considered a unique oil trap, where the control is mixed, in other words structural and stratigraphic and mainly diagenetic. The antithetic faults, inherited from the post-basalt rift, conditioned the coquina distribution, promoting the section growing at the hanging wall, and it acts as conduct for the circulation of meteoric water associated with the post-coquine unconformity that aids the secondary porosity by dissolution and creation of it"*

At the case of erosive processes, it may be originated by environment changes as marine regressions or by gravitational mechanism as submarine flux of rock. This effects change the topography's geometry, but it can be reproduced in paleo-environment maps.

Among other factors, it is widely known that the tectonic processes are the main factor that deforms stratigraphic layers in sedimentary basins as Campos, Santos and Espirito Santo; this condition justified the cinematic analysis of its paleo-environment evolution. These basins initially were deformed by the rift phase and after an intense halokinetic deformation was register, dated by Vincentelli & Barbosa (2008) from Upper Albian (about 100 My) to the Miocene (35 My). The mentioned authors also say that the halokinetic deformation was not continue along the geological time, but it defined geometries in the basin that created accommodation spaces that allowed the turbiditic bodies (main recognized reservoir at the basins) sedimentation.

Rangel & Martins (1998) defined the main structural features identified at the rift phase of these basins as showed at the figure 2. The Badejo High, big horst with main azimuth Northeast-Southwest, controlled the sedimentation between the middle and external platform at the South and Southwest of Campos basin. In a parallel position of Badejo High the Central and External highs were defined as horsts structures, separated by normal faults that shows vertical slip until 2500 meters. The azimuth of the main fault system is NE-SW, the same that the Pre-Cambrian recognized lineaments. Adjacent to the main structural highs some structural lows like *Corvina-Paraty* and *São João da Barra*, were described.

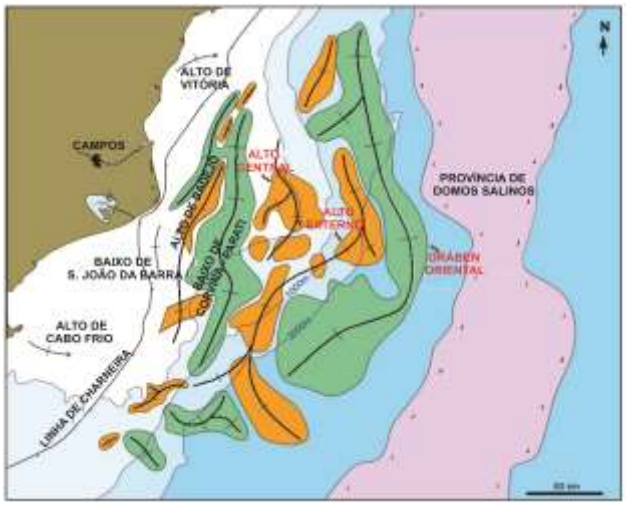

Figure 2: Main structural features identified at the rift phase of the study basins. Rangel & Martins. (1998).

Database and Methods

2D regional seismic lines were interpreted joint with 3D seismic volumes available for academic researchers from de Petroleum Nacional Agency (ANP) at the LISG-UNESPetro-UNESP. The database is formed by 2D and 3D seismic data in a total area of 850 Km², in 8 *bits*, and well data information of 20 wells.

The basement geometry was defined based on the gravimetric map of the CPRM. Based on the geographical position of the *trend* Linguado-Trilha and Pampo, a qualitative analysis about the presence of basement highs and its relationship with the existence of carbonatic reservoirs: Aptian and Albian, were done; this analysis is justified because, it is possible that the evolution of any carbonate shoal is conditioned by the presence of basement paleo-highs.

With the aim of verify the regional distribution of the main carbonate reservoirs: Albian (Calcarenites- Quissamã Fm.) and Aptian ("Coquines" – Lagoa Feia Fm, regional geological sections were elaborated and its geographic position was defined based on the gravimetric map of the three study basins. These geological sections allowed the basement paleo-highs visualization, geological feature that may condition the "Coquina" reservoir distribution. By

the use of back-stripping technique it is expected to reproduce the environment conditions that define the "Coquina" as reservoir (when de permo-porous system is interconnected), or when the "Coquina" is found as a rework rock without reservoir conditions.

At the seismic interpretation, six stratigraphic level were mapped: Lagoa Feia Fm. top, salt top, Albian top, Upper Cretaceous top (Maastrichtian), Oligocene-Miocene (blue mark) and Sea Bottom. After, the seismic sections were time to depth converted using interval velocities and the geological section was retrodeformed with the aim of verify if the currently basement structural highs were the same in the Aptian age. Evidence of marine transgressions at the identified paleo-lakes and available spaces for sedimentation was also considered.

Results

The figure 3 shows a geophysical section through the onshore and offshore regions of Espirito Santo Basin. This section shows the Proterozoic domain at the outcropping area, with a detachment fault of the compressive phase associated with this geological age. The mentioned geological feature is limited by the boarder fault that separates the onshore to the offshore tectonics domains. The continuity of the Miocene reflector is observed at both domains and the deformation of the basement at the phase rift is clear at the interpreted horst structures. Nevertheless, the thickness of the rift sequence appear to be not too thick to development coquine reservoir facies at the Aptian of Espirito Santo Basin, in another words this place does not represent the same geological characteristics of the *trend* Linguado-Badejo-Pampo.

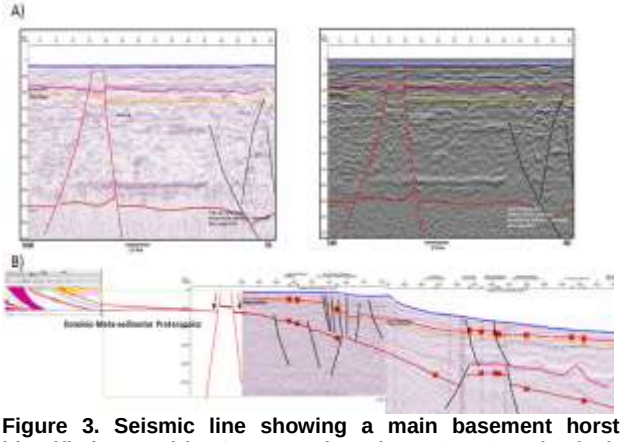

Figure 3. Seismic line showing a main basement horst identified at Espirito Santo Basin. Figure 3-B. Geophysical-Geological profile A (*onshore*) - A´(*offshore*), that shows the basement high at Espirito Santo basin equivalent to Badejo High, and the configuration of the basement deformation.

At the regional interpretation involving the three basins it was verified: a.- the presence of a proximal high confirmed at the gravimetric map; b.- The rift structures deforming stratigraphic levels older than Aptian; c.- the ends of the Aptian age is represented by a transition phase identified at the literature as "sag"(Winter , 2007).

The South of the study area (Santos Basin) shows a Proximal and Central basement to Aptian highs identified on seismic interpretation. It is important to mention that for Aptian age the main carbonate reservoirs for these basins were recognized until now.

The Albian regional map indicates that the carbonate banks are absent at the distal portion of the basins, mainly at the deep and ultra-deep water regions, mainly dislocated by the salt domes that configure two bands: one at the proximal region that covers the Central High at Santos Basin – position that is different at Campos and Espirito Santo were the salt domes are localized – and another distal, located at the deep water in a band from Santos to Campos Basin, with total absence of Albian level because two factors: an hiatus of the sequence or movement of the carbonate blocks caused by halokinetics at these two basins.

Contour structural maps at the region of Badejo High, indicates: the structural traps are associated with the carbonate´s bank evolution for the Albian (Macaé Group – Figure 4) and for Lagoa Feia Gr (Aptian – figure 5). The main azimuth of the carbonate banks is N15W and N35wm and the system faults shows the main azimuth NE-SW related to the rift phase.

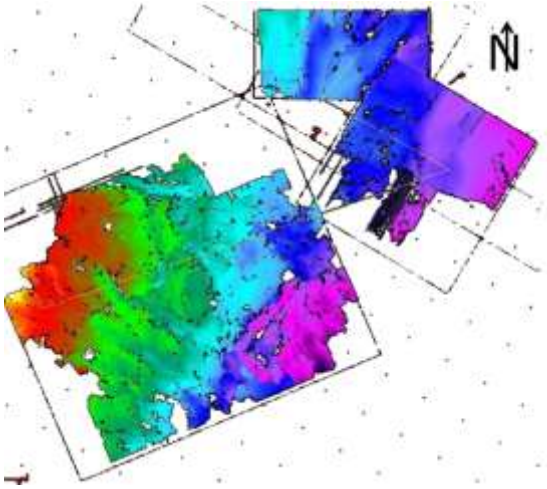

Figure 4.- Albian (Macaé Group) Contour structural map at the region of Badejo High. (hot colors at the map represents structural highs)

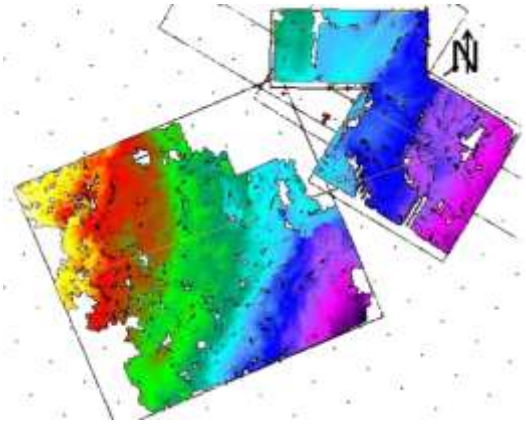

Figure 5.- Aptian (Lagoa Feia Group) Contour structural map at the region of Badejo High. (hot colors at the map represents structural highs)

The structural pattern observed at the top of Cabiúnas Formation (Figure 6) indicates a general dip EWE with a fault system with NE-SW direction. These features are related to the Gondwana Supercontinent fragmentation initialized at Upper Jurassic. An secondary faults system, with azimuth WNW-ESE, is also observed and represents transfer zones generated for the extensional process own of the continent´s separation.

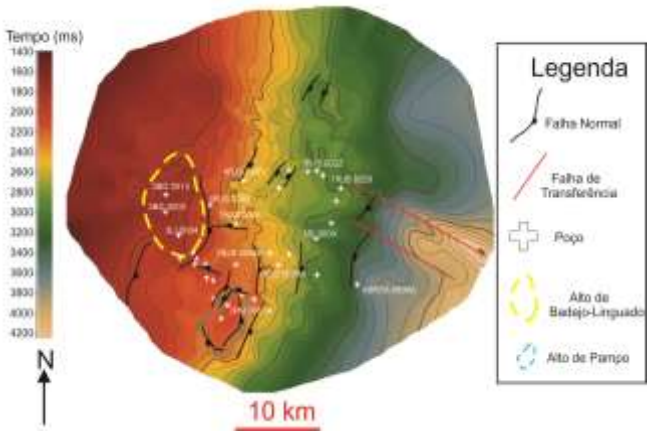

Figure 6: Contour Structural map of Cabiunas Formation at the region of Badejo High.

When evaluated the tectonic-structural context at the rift phase of Santos, Campos and Espirito Santo basins – using geophysical data, potential maps methods (gravimetric map – Bouguer Anomalies) and seismic data, integrated with ANP data and "informal" communication like conferences and non-technical journals, among others, about oil fields and potential reservoirs Aptian levels; It is possible to define mainly three production hydrocarbon systems with its area indicated at the squares of the figure 7:

a.- Reservoirs in limestone – "Coquines" with good permeability and oil production initialized:

a.1.- Black square: area of the *trend* Linguado-Badejo- Pampo.

a.2.- Blue dark squares: upper square, area of Jubarte –Espirito Santo Basin - oil field; lower square, Buzios – Santos Basin).

b.- Reservoirs in limestone "Coquines" without initialized oil production – blue light square: Libra oil field.

c.- Carbonates type limestone: stromatolites and laminated microbialites – green square: area of Lula and Sapinhoá fields.

Until now two of these production poles are reference in Brazil: the traditional one is related to Badejo High (Rangel & Martins, 1998, Figure 7), where the main reservoir shows high porosity and permeability mainly at Pampo oil field, with oil production until today, localized at the higher position of a previous paleo-basement high, geological condition favorable to the main reservoir evolution, but its oil volume is less than the Pre-salt reservoirs because its structural dimension.

As defined by Vincentelli et al. (2016), the Alegre fault at its offshore position, shows a sinistral movement for the rift section at Campos Basin Campos (North) and shows neotectonic reactivation. This fault separates two oil provinces (the *trend* Linguado-Badejo-Pampo from Parque das Baleias region).

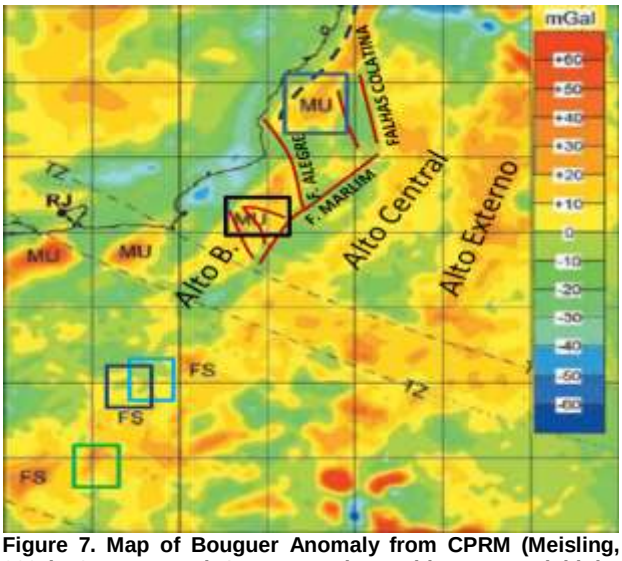

Figure 7. Map of Bouguer Anomaly from CPRM (Meisling, 2001), Campos and Santos Basins. With structural highs defined by Rangel & Martins (1998) and system faults defined by Vincentelli et al. (2016). The map shows the Santos Basin at the South and Campos basin at the North. The highlighted squares areas show the main identified carbonate reservoirs at Aptian ages: Blue dark –Jubarte oil field (at North region) and Búzios oil field; blue light –Libra field; green – Lula/Sapinhoá. The main anomalies represents: Moho closed to the coast (MU); footwall blocks while Ocean Opening (FS). The main transfer faults (TZ).

Another structural limit of petroleum provinces is defined by Marlin fault as characterized by Vincentelli et al. (2016), this structural feature represents the structural limit between the Badejo High and the Corvina-Parati Low as defined by Rangel and Martins (1998). At the Southeast of Marlim fault turbidites reservoirs are the dominant play.

Conclusions

The seismic data interpretation and regional maps show the same structural patterns; with the main faults normal showing an azimuth of NE-SW, and transfer fault zones oriented NW-SE. At the Southwest portion of the study area an important dome feature was characterized at Quissama Formation level (Albian) and it corresponds to Pampo Dome. A similar structure but in less scale was identified at the South of Bonito oil field, associated with normal synthetic and antithetic faults that condition the oil production at this field. It was also possible the identification of fault system that affected the Aptian level

and the Post-Salt section exemplified at the fault that separates the fields Bicudo – Pampo and Badejo – Trilha; it was interpretded that this fault system were determinant for the oil migration at the basin from the Jiquia to the Aptian-Coquines and upper reservoirs.

The regional seismic interpretation verified: a.- the presence of a proximal high confirmed at the gravimetric map; b.- The rift structures deforming stratigraphic levels older than Aptian; c.- the ends of the Aptian age is represented by a transition phase identified at the literature as “sag”.

When evaluated the tectonic-structural context at the rift phase using geophysical data gravimetric map (Bouguer Anomalies) and seismic data, it is possible to define mainly three production hydrocarbon systems: a.- Reservoirs in limestone – “Coquines” with good permeability and oil production initialized; b.- Reservoirs in limestone “Coquines” without initialized oil production; and, c.-Carbonates type limestone: stromatolites and laminated microbialites. Finally, the identification of a fault system that affected the Aptian level and the Post-Salt section were determinant for the oil migration at the basin, from the Jiquia Formation to the Aptian-Coquines and upper reservoirs.

Acknowledgments

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