Tectonic Characterization of the Southeastern Brazilian Continental Margin in the Region of the Cabo Frio High and its Influence on the Structure of the Campos and Santos Basins.

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Abstract

This study aims an analysis and interpretation of the Southeastern Brazilian Continental Margin in the region of the Cabo Frio High answering important questions regarding its origin, evolution and morphotectonic influence on the formation of the Campos and Santos basins. The work involved the analysis and interpretation of seismic lines and well data. From the results obtained by the seismic interpretation was observed that the Cabo Frio High is composed of two domains, one proximal, of Cambrian age, represented by Structural Platform of Cabo Frio and a distal, of Neocomian age, composed by the External High of Cabo Frio. It was found that they exert the role of preventing sedimentation between the Campos and Santos basins in their proximal and distal portions, respectively. Structural and Isopach maps generated from the interpolation of the interpreted horizons indicated that the region composed by the Structural Platform and the External High of Cabo Frio served as an effective sediment barrier during the entire rift phase. A tectonic evolution model is proposed based on Riedel's fractures system which indicated that the southeastern continental margin in the region of the Cabo Frio High has evolved by distensional deformation, marked by a sinistral transtensional system, preferably oriented NE-SW. From the Total Isopach Map we observed that tectonically the Southeastern Brazilian Continental Margin was strongly influenced by the rift phase deformation since the proposed model for the basement´s characterization is still compatible with the structural configuration of the deposits so far.

Introduction

The Southeastern Brazilian Continental Margin has been under intense evolutionary studies since the 1970s, from the Discovery of oil in the Campos basin. With the recent significant discoveries of giant fields in the regions of the Campos and Santos basins have become a challenge of strategic importance for the Brazilian economy clearly understand the origin and geological evolution of this site (Fig. 1).

The Cabo Frio High is a basement's upright region that segments the Campos and Santos basins (Ponte & Asmus 1976; Asmus, 1984; Viviers & Azevedo, 1988; Dias, 1991; Mohriak *et al.,* 1995; Pedro, 2005; Stanton, 2009; Silva 2010; Silva et al., 2010). According to Silva (2010) and Silva *et al.,* (2010), it consists of a proximal component composed by a Cambrian granite-gneiss complex (Structural Platform of Cabo Frio) and a distal portion of volcanic composition from the Neocomian (External High of Cabo Frio).

In this work we present the morphotectonic characterization of the southeastern margin surrounding the Cabo Frio High based on the interpretation of structural and isopach maps generated from the interpolation 2D seismic and vertical well data.

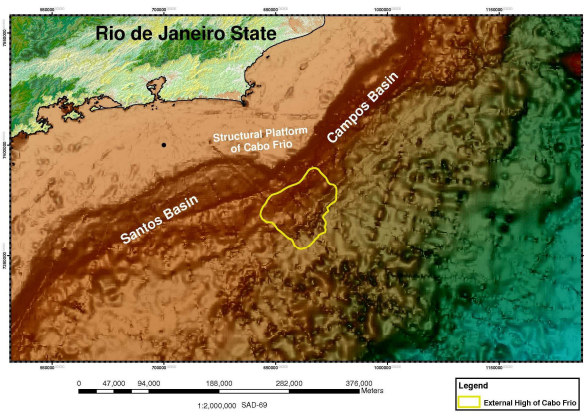

Fig. 1 *– Bathymetric Map of the Brazilian Southeastern Continental Margin showing the Campos and Satos Basins and the Cabo Frio High.*

Method

The database available for this work hás 305 2D multichannel seismic lines and 21 vertical wells (sampling and geophysical logs) bought from the Brazilian Database of Exploration and Production (BDEP – ANP) (Fig. 2). The seismic data interpretation was made by using the *SMT Kingdom 8.5* software.

The methodology used to perform the seismic interpretation was based on the concepts of seismic stratigraphy (Mitchum & Vail, 1977), that consider the geometry of the inner and outer layers, the continuity and the acoustic standard of the reflectors. For structural characterization were considered the methodology of

Brown (1993). To calibrate the intervals interpreted on the seismic lines and match them accurately to the phases of stratal deposition, we used vertical well data.

After the interpretation of the seismic lines, was performed with aid of *GOCAD Suite 2.5.2* software, the geostatistical operation of interpolation by the nearest neighbors method the following horizons: Basement, Rift Sequence's Top and Water Bottom. With this were generated structural maps that mark the tops of those horizons. Using calculations of vertical thickness variation between these structural maps were prepared the Rift Sequence's and Total Isopach Maps.

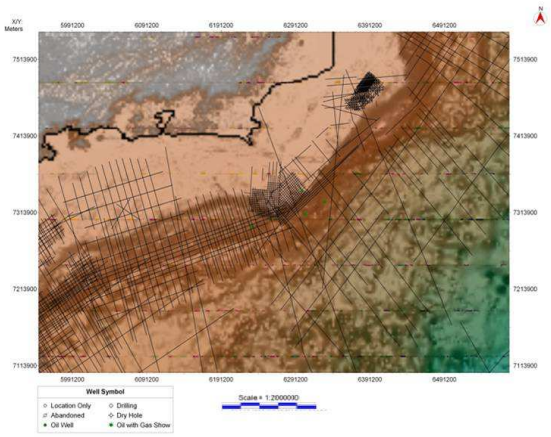

Fig. 2 – *Bathymetric map of the southeastern Brazilian margin showing the database available to seismic analysis in the region of the Campos and Santos basins.*

Structural maps consist of spatial redistribution of acoustic depths of a given horizon mapped in a regular seismic mesh. The Isopach maps are thickness demarcations of a given layer or sequence generated based on the subtraction function in time interval that marks the top of the package by its bottom. From these maps we can identify the location of depocenters and possible topographic barriers relying on the regional distribution of sediment thicknesses and on the tectonic-stratigraphic evolution of the area.

Results

The seismic-stratigraphic analysis integrated with well data led to the determination of the chronostratigraphic domains Basement, Rift Sequence's Top, Aptian Top, Albian Top, Paleocene – Eocene, Oligocene Top and Water Bottom (Fig. 3). These were mapped based on discontinuities and flooding surfaces.

According to Silva (2010) and Silva *et al*., (2010), the region that makes up the Cabo Frio High can be interpreted as a broad plateau located in the Cabo Frio region, consisting of basement rocks whose elevation is higher than its surroundings, made by two domains, a proximal and a distal. The proximal part, the Structural Platform of Cabo Frio, is located west of the Cretaceous hinge line and is composed by the Cambrian basement (Ponte & Asmus 1976; Asmus, 1984; Viviers & Azevedo, 1988; Dias, 1991; Mohriak *et al*., 1995; Schmidt *et al*, 2005). From the seismic mapping is observed that the hinge line remained exposed until the Miocene. Thus, the major transgressions occurred in the Tertiary were not bulky enough to overcome the Structural Platform of Cabo Frio (Silva, 2010; Silva *et al.*, 2010). The distal component is composed by spills of magmatic sequences related to Camboriú (Santos basin) and Cabiúnas (Campos basin) Formations from the Neocomian (144 – 130 Ma), located east of the hinge line.

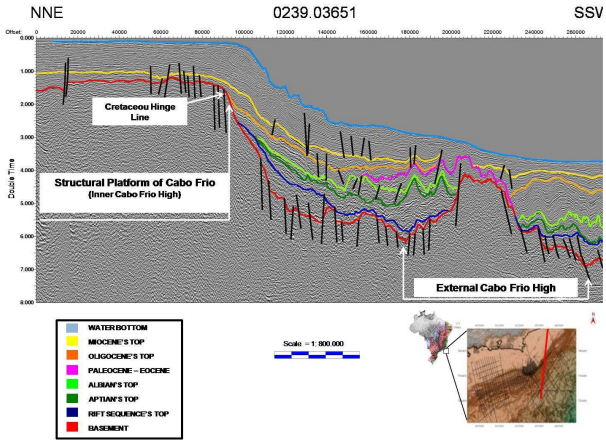

Fig. 3 *– Example of 2D seismic section defining the Cabo Frio High in proximal and distal components.*

According to Silva (2010) and Silva *et al*., (2010), the volcanic portion of that High begins soon after the breakup of the hinge line and extends toward the Santos basin. In the center of this region, there are elevations in the form of cones whose physiographic structure allows interpret them as volcanic plugs (Fig. 3). According to these authors, on his High it's also observed volcanic spills from Paleogene which enhance its altimetry. These volcanic plugs may have acted as carriers of mantle material during the Cretaceous – Tertiary period. The External High of Cabo Frio in conjunction with the floodings of volcanics from Paleogene may have acted as a local barrier preventing the free circulation of sediments until the Miocene or until the Neogene (Silva, 2010).

The effective influence of the inner and outer Cabo Frio High in the sedimentation of the Campos and Santos basins can be observed in regional and local character from that structural and isopach maps. From the analysis of these maps were possible estimate the sediment load deposited in each of the mentioned intervals and how long the contribution of the inner and outer Cabo Frio High was effective in the sedimentation of the Campos and Santos basins.

Analysis of the Basement's Structural Map shows, by altitude differences, that the External High of Cabo Frio was present since the beginning of the Gondwanaland disruption (Fig. 4). This is because there is a remarkable elevation of the basement in the region defined as external high separating large regions with much lower levels of depth.

With respect to their structural partitioning the region analyzed shows have shows have evolved by tectonics dominated by a distensional regime marked by a sinistral transtensional system, preferably oriented NE-SW. This characterization suggests that the deployment of this region has been caused by the action of a directional field of paleostresses obtained in response to a shear binary oriented WNW-ESE.

The map region was analyzed based on the fracture system of Riedel (1929), in which a main fault zone can develop subsidiaries fractures that obey well-defined angles relative to the dominant structure. From this model the secondary discontinuities conjugated to the main faulting were interpreted as synthetic shear fractures (R), antithetic shear fractures (R') and tensional fractures (T), according to the terminology used by Petit (1987). Associated with this system there is a discordant tension structure oriented NE-SW semi-perpendicular to the direction of the tectonic band and parallel to R' which breaks the structural pattern of the rift in this region and move fault segments, defining thus a transfer fault. The implementation of this feature may be due to differences in angular velocities of the trajectory of the South-American Plate that may have favored this change in orientation of the strength regime (Ferrari, 2001).

Meisling *et al*., (2001) argue, based on gravity alignments, that the Southeastern Brazilian Continental Margin is characterized by dislocations of dextral transfer faults oriented NW-SE. According to these authors, these discontinuities would be old transform faults associated with aborted spreading centers.

In an attempt to define the chronological evolution of the structures identified on the map it is proposed that these have been started from the installation of a moderate deformation zone by simple shear (non-coaxial) resulting from the disruption process of the Gondwanaland in the Neocomian. This extentional component may have favored the rotation of the secondary structures (R, R' and T), decreasing their angles to the main faulting (Woodcock & Schubert, 1994). This breakup has produced a system of rift valleys oriented NE-SW in the Southeastern Brazilian Margin where were deposited siliciclastic and carbonate continental sediments from Lagoa Feia (Campos Basin) and Guaratiba (Santos Basin) Formations. It is understood that from the beginning of the deformation characterized by the moving of the main fault has been generated primarily the tensional fractures (T) (Wilcox *et al*., 1973). By rotating the rift blocks were originated initially the synthetic faults (R) and then, by continuing the rotational deformation, led to the formation of the antithetic faults (R'). Observe that the latter are directly influenced by the direction of the shear binary.

The structure marked on the map as T evidence tectonic movements related to the beginning of the process of continental disruption and formation of the margin and ocean floor in the region. It presents direction approximately N-S and is consistent with the Serra do Mar Dike Swarm (Valente *et al*., 2007; Tetzner e Almeida, 2003; Guedes *et al*., 2005; Corval, 2005; Stanton *et al*., 2006).

The synthetic faulting R oriented NE-SW located in the southern portion of the Campos Basin may have been favored by reactivations of preexisting zones of weakness of the Neo-Proterozoic - Cambrian related to the Ribeira Fold Belt (Cordani *et al*. 1973; Almeida *et al*., 1973; Heilbron *et al*., 1995; Cobbold *et al*., 2001) since its orientation is consistent to those structures observed in this band. The same discontinuity is also corresponding to the directions of displacements of the oceanic fracture zones that were active during the rifting in the Neocomian and evolved until about 80 Ma (Alves, 2002). Subsequently, the latter suffered an inflection of NE-SW to E-W and remain in that way until today (Alves, 2002). Conversely, the model proposed by Meisling *et al*., (2001) considers this feature as a transfer fault.

The great antithetic fault R' observed in the map that cuts through the region between the Structural Platform and the External High of Cabo Frio may have originated due to intense extrusion of Neocomian basalts. This would explain its manifestation took place on the Cabo Frio High, a region known to centralize the highest concentrations of magmatic floodings compared to other regions of the Campos and Santos basins (Mohriak *et al*., 1995).

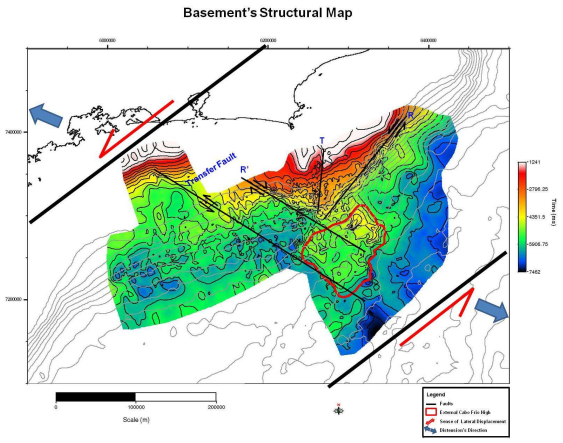

Fig. 4 *– Basement's Structural Map.*

The Structural Map of the Rift Sequence's Top characterized regionally the stratal surface behavior occurring shortly after the end of the rupture of Gondwanaland (Fig. 5). On this map it is observed that the area occupied by the Structural Platform and the External High of Cabo Frio still remains, mostly, elevated from their neighborhoods even thought there are some points where the altitude variation is no longer an additional factor of great nobility.

It is observed that the tectonic deformation observed in the Basement's Structural Map served during the entire rift phase since the shear model proposed for the region in Neocomian also fits to characterize the morphology of the same in the Eo-Aptian.

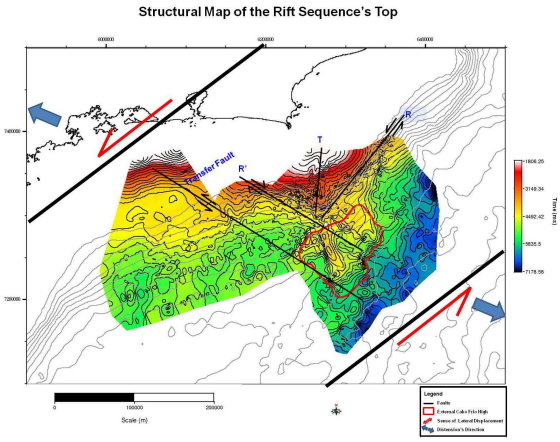

Fig. 5 *– Structural Map of the Rift Sequence's Top.*

The Isopach Map of the Rift Sequence represents the vertical thickness deposited from the Neocomian to the Eo-Aptian (Fig. 6). From the same can be seen that especially in the areas southwest of the External High of Cabo Frio the thicknesses of sediments are clearly superior to those found inside. From the tectonic model proposed for the study region can be visualized depocenter shiftings in the Santos basin in response to movement of R' and transfer faults. The voluminous amount of sediment observed in the same due to the high deposition of continental sediments from Guaratiba Formation. This information serves as a basis for defining the Structural Platform and the Structural High of Cabo Frio as an effective agent that limits the sediment transport between the Campos and Santos basins during the rift phase. This feature, if confirmed, could provide important data for the oil industry because that would indicate that the intercommunication between the source rocks of Guaratiba (Santos) and Lagoa Feia (Campos) Formations wouldn't exist or would be very limited. This interpretation suggests that these areas may come from different sources.

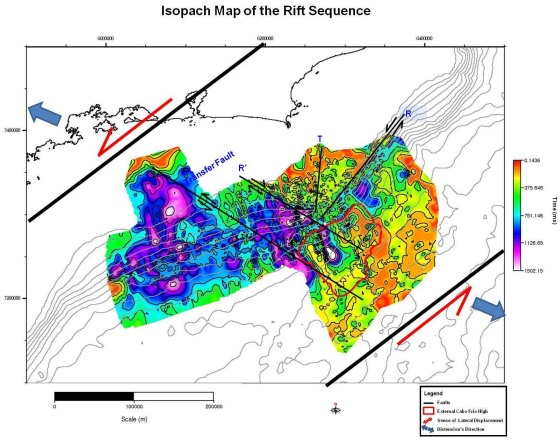

Fig. 6 *– Isopach Map of the Rift Sequence calculated from the difference in thickness between the horizons Basement and Rift Sequence's Top.*

The Total Isopach Map proposes an estimate of how is distributed the sediment deposition since the disruption of Gondwanaland to the present (Fig. 7). This map indicates where concentrate the highest elevations and regional depocenters taking into consideration the entire evolutionary history of the Campos and Santos basins and the Cabo Frio High. Based on the results obtained from this map we can conclude that the region occupied by the Structural Platform and by the External High of Cabo Frio served as features that can effectively segregate interbasin sediment transportation. Moreover, it is observed that the intermediate portion between them behaved like a real depocenter, taking into account the great sedimentary thickness to it overlapped. This is confirmed by the significant load of sediments deposited on the regions outer from the External High and that inside it. From this argument it is possible to describe the External High of Cabo Frio as a basement feature that directly influenced the sedimentation of the Campos and Santos basins preventing that much of the sediments circulate freely between them.

With regard to the tectonic characterization is observed that the Total Isopach Map (Fig. 7) is strongly influenced by the deformation occurred in the rift phase, since the proposed model to that period is still compatible with structural configuration of this phase (Fig. 5). This suggests that the tectonic that the tectonic events related to the transitional and post-rift phases were not as significant as to indicate a notable change in the structural regime of the area.

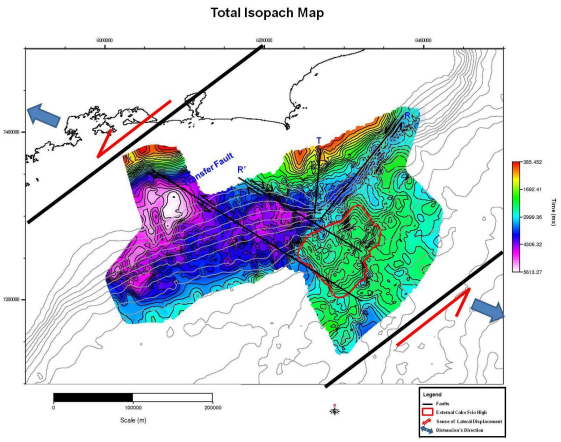

Fig. 7 *– Total isopach Map calculated from the difference in thickness between the horizons Basement and Water Bottom.*

Conclusions

It was noted that the analysis and interpretation of data from 2D seismic reflection and vertical wells allowed to obtain satisfactory results that permit us to understand the morphotectonic evolution of the southeastern Brazilian margin in the region of the Cabo Frio High and its contribution in the conditioning of the basins it limited.

From the structural maps can be observed that the region occupied by the Structural Platform and the External High of Cabo Frio significantly influenced in the configuration of sedimentary depositions in the Campos and Santos basins.

Structurally, the southeastern continental margin of Brazil, at least in the surroundings of the Cabo Frio High, shows have evolved by distensional tectonics, marked by a sinistral transtensional system, preferably oriented NE-SE. This indicates that this region has been originated by the action of a strike-slip field of paleostresses obtained in response to a shear binary WNW-ESE.

The study region, based on fracture system of Riedel (1929) presents secondary discontinuities conjugated to main faulting which were interpreted as synthetic shear fractures (R), antithetic shear fractures (R') and tensional fractures (T) (Petit, 1987). Associated with this system were observed a transfer fault represented by a NW-SE discordant tensional structure parallel to R' which breaks the structural arrangement of the rift and move fault segments. This tectonic structure acted during the entire rift phase since the deformation model proposed for this region in the Neocomian also fits perfectly to characterize the its morphology in the Eo-Aptian.

Analyzing the isopach maps observed that the thickness of sediments deposited within the domains of the Cabo Frio High is noticeably lower than that recorded in the regions adjacent to it. Based on the results shown by these maps it is possible to say that the External High of Cabo Frio served in its entirely as a topographic barrier preventing the movement of sediment between the Campos and Santos basins during the entire rift phase. This may represent an important consequence for the oil industry, as it suggest that there wasn't an intercommunication, or it was very narrow, between the source rocks of Guaratiba and Lagoa Feia Formations in Santos and Campos basins, respectively. This fact indicates that these can come from different areas.

The Total Isopach Maps shows that tectonically the southeastern Brazilian continental margin was strongly influenced by the deformation of the rift phase. This assertion is confirmed as the proposed model for the characterization of the basement is still compatible with the structural configuration of this map. This suggests that the tectonic events related to the transitional and post-rift phases were not significant enough to indicate a relevant change the geologic record of the area.

Acknowledgments

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