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# The Outer High of the Santos Basin, Southern São Paulo Plateau, Brazil: Tectonic Setting, Relation to Volcanic Events and some Comments on Hydrocarbon Potential

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## Introduction

The São Paulo Plateau is located in the southeastern Brazilian Continental Margin, comprising the deep-water setting of both Campos and Santos basins. In recent years, following the creation of the ANP (National Petroleum Agency), these basins have been regarded by the oil industry as the main exploration focus in Brazil.

Following the remarkable success that took place in the Campos Basin, mainly during the eighties (Guardado *et al.*, 1990) and mid nineties (Rangel *et al*., 1998), the expectations of the oil companies have shifted to the Santos Basin, where analogous petroleum systems were believed to occur. Regional tectonic and stratigraphic similarities between the Campos and Santos basins support this assumption (Pereira and Macedo, 1990; Mello *et al*., 2002).

However, despite the presence of an established and productive Albian carbonate play to the south (Ramos *et al.* 1998) and an emerging Eocene turbidite play in the north of the basin, where some important oil discoveries have been recently reported, the expectations are yet to be fulfilled. In this scenario, the ultra-deep water region of the Santos Basin still remains as a high potential frontier area for hydrocarbon exploration (Figure 1).

The easternmost portion of this frontier area, partially covered by block BM-S-22 (Amerada Hess/Ocean Energy), is distinguished by an outstanding basement high, which probably affected the evolution of the whole deep setting of the basin (Figs. 1 and 2). This structural high is also supposed to have acted as a regional focus for hydrocarbon migration, e.g. a gathering area for the oil generated in the thick pre-salt section of the Santos Basin.

This study introduces a regional tectonic setting for this feature, presents some possible origins for it and discusses its relationship with volcanic events and with some southwest-northeast trending positive gravity anomalies observed at the distal portion of São Paulo Plateau.

## Previous Work on the Evolution of São Paulo Plateau

The concept that the São Paulo Plateau is mostly underlain by extended continental crust was progressively strengthened by a number of studies during the last two decades (Kowsmann *et al.*, 1982; Macedo, 1990; Gomes *et al.*, 1993, Souza et al., 1993). More recently, some regional studies performed by Karner (2000) and Meisling *et al.* (2001) have introduced important advances on the understanding of the tectonic evolution of this marginal plateau. The former has presented an ocean-continent boundary based on the termination of fracture zone trends and on changing directions on gravity anomalies trends. Meisling *et al.* (*op. cit*.) have further developed some concepts conceived by Kumar and Gamboa (1979) and Demercian (1996), suggesting the presence of a southwest-northeast trending volcanic chain in the distal portion of São Paulo Plateau, corresponding to a failed spreading ridge implanted in a thinned continental crust domain.

## A Proto-Oceanic Crust in the Southern São Paulo Plateau

We would like to advance on this concept of an aborted sea-floor spreading center, suggesting that the large wedge-shaped positive gravity anomaly to the south of São Paulo Plateau (Fig. 1) is related to the emplacement of a proto-oceanic crust, as previously considered by Mohriak (2001). The so-called Avedis Volcanic Chain (Demercian, *op. cit*.) represents just the northernmost edge of that anomaly, which is mainly related to a structural low in the basement, as shown in Figure 2. The seismic character of the basement in this low domain clearly resembles that of typical oceanic crust and the range of Bouguer gravity anomalies is consistent to the presence of such crustal type. These events of spreading axis implantation/failure bring more complexity to the evolution of São Paulo Plateau, as they are not taken into account on those models which involve differential crustal stretching bounded by transfer or fracture zones zones (Macedo, 1990; Karner, 2001).

## The Outer High of the Santos Basin

The failed spreading axis from Meisling *et al.* (2001) is not restricted to the wedge shaped positive gravity anomaly that was discussed previously. According to their interpretation, the aborted feature continues its southwest-northeast trend and traverses all the deep Santos Basin domain of the São Paulo Plateau (Fig. 1).

However, those authors didn't point out to important structural variations along the distal SW-NE gravity trend. To the south of the transfer zone TF1 (Fig. 1), the gravity anomalies are related to a regional structural low (Fig. 2), and represents a Moho response, linked to the presence of oceanic crust, as discussed earlier. To the north of the transfer zone, lies the Avedis Volcanic Chain, and further north, another transfer zone strongly offsets the southwest-northeast trend (TF2 on Fig. 1). From this structural lineament to the northeast, the gravity anomalies are related to a huge basement high, here called the "outer high" of the Santos Basin (Fig. 2). The crestal portion of this structure has an approximate area of 1,500 $km^2$, and part of which was probably exposed during Aptian times. Both rift and sag sections pinch-out against the high, and its crest seems to be covered directly by the evaporitic sequence, which is at least partially allochthonous in this region.

The inevitable influence of such impressive structure on the paleobathymetry and paleogeography of the deep Santos Basin is yet to be fully understood. Nevertheless, one can observe in the regional seismic profile (Fig.2) that both the syn-rift and the Upper Cretaceous sections thin onto the basement high. Only the Tertiary section shows an approximately constant thickness along the profile. Seismic interpretation also indicates that the outer high was affected by a number of tectonic reactivations since its formation, which caused uplifting and faulting up until Early Tertiary times.

Two possible scenarios are suggested for the origin of this structure: the first one is a simple model of a pre-existing basement high, reactivated due to the sea-floor spreading process which, at that time, was in progress to the southwest. In a second model, the high would represent a hotspot-related syn-rift thermal dome, involving the uplifting of a highly stretched continental crust, possibly followed by an underplating process. In this case, the high would be part of the failed spreading ridge postulated by Meisling *et al.* (2001).

Aeromagnetic data recently acquired will provide more constraints on the crustal nature of the basement high. Regional 2D seismic and gravity interpretation suggests that the feature may be cored either by crystalline basement or volcanics related to the Serra Geral flood basalts (c. 130 Ma). In the same way, some opposite dipping reflectors observed near the crest of the structure can be interpreted either as a folded pre-rift crystalline basement or as juxtaposed seaward / landward-dipping reflectors wedges (Hinz, 1981) related to a failed spreading axis.

## Brief Comments on the Hydrocarbon Potential of the Outer High Area

According to our interpretation, the outer high was present as a positive structure in the Santos Basin at least since the Lower Aptian. Thus, as a long-lived feature, it can be regarded as

a regional focus for oil migration, as mentioned earlier. This assumption is valid not only for the hydrocarbon generated from lacustrine rift source rocks, but also from organic-rich shales related to a marine-influenced sag environment.

The main exploration risk in this frontier setting is related to reservoir presence and quality. Nevertheless, the outer high region has reservoir potential for both pre and post-salt sections. Thus, Upper Cretaceous turbidites are expected to be present, as well as high energy prograding sequences in the Barremian/Aptian sections.

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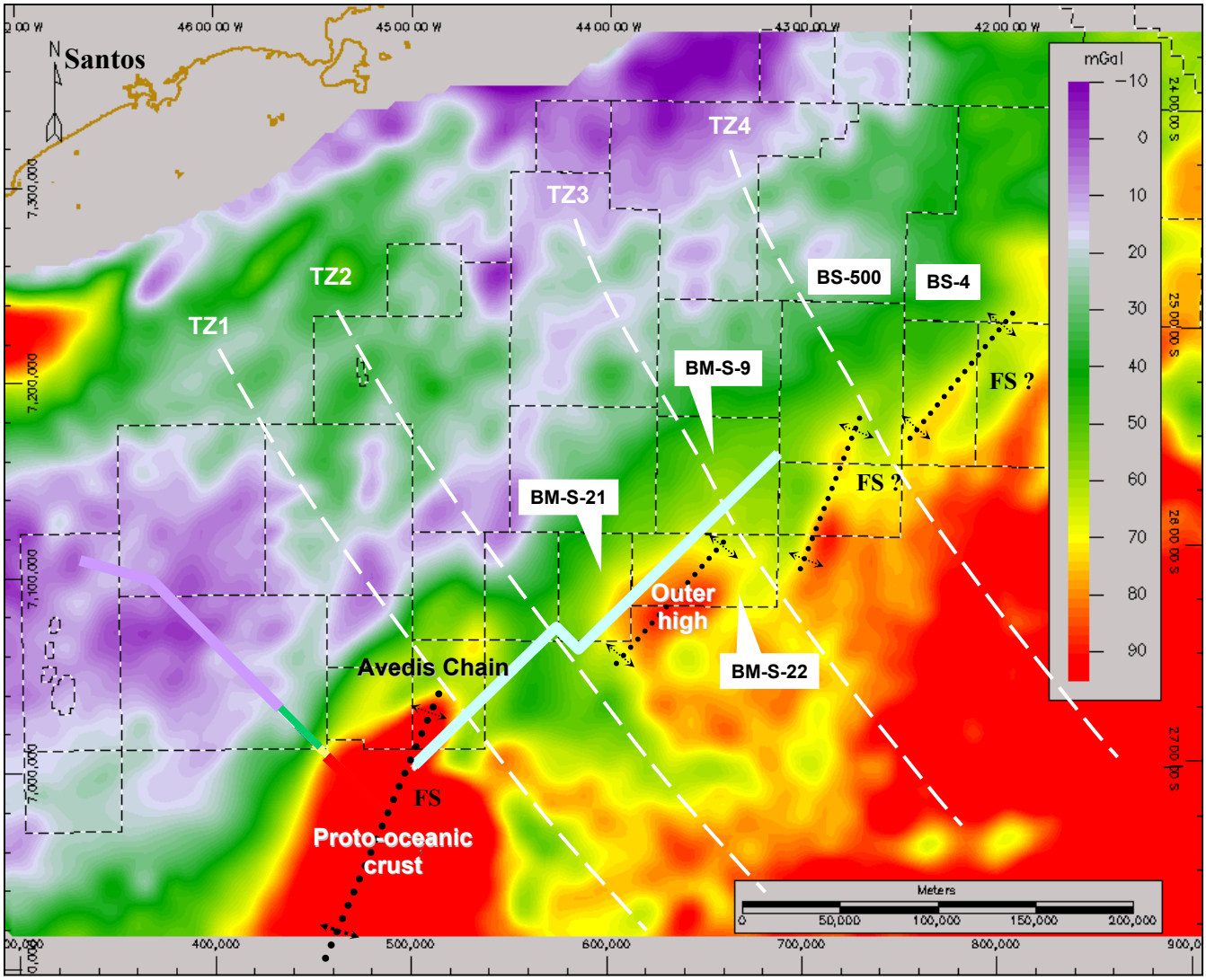


**Figure 1** –Bouguer gravity anomaly map of the southern São Paulo Plateau. The highlighted seismic path, which is displayed on Figure 2, crosses the outer high of the Santos Basin and goes through the very beginning of the wedge-shaped positive gravity anomaly interpreted as a proto-oceanic crust. The dashed lines are transfer zones (TZ) and the dotted lines represent the failed spreading ridge (FS) from Meisling *et al*. (2002). Avedis Volcanic Chain from Demercian (1996).

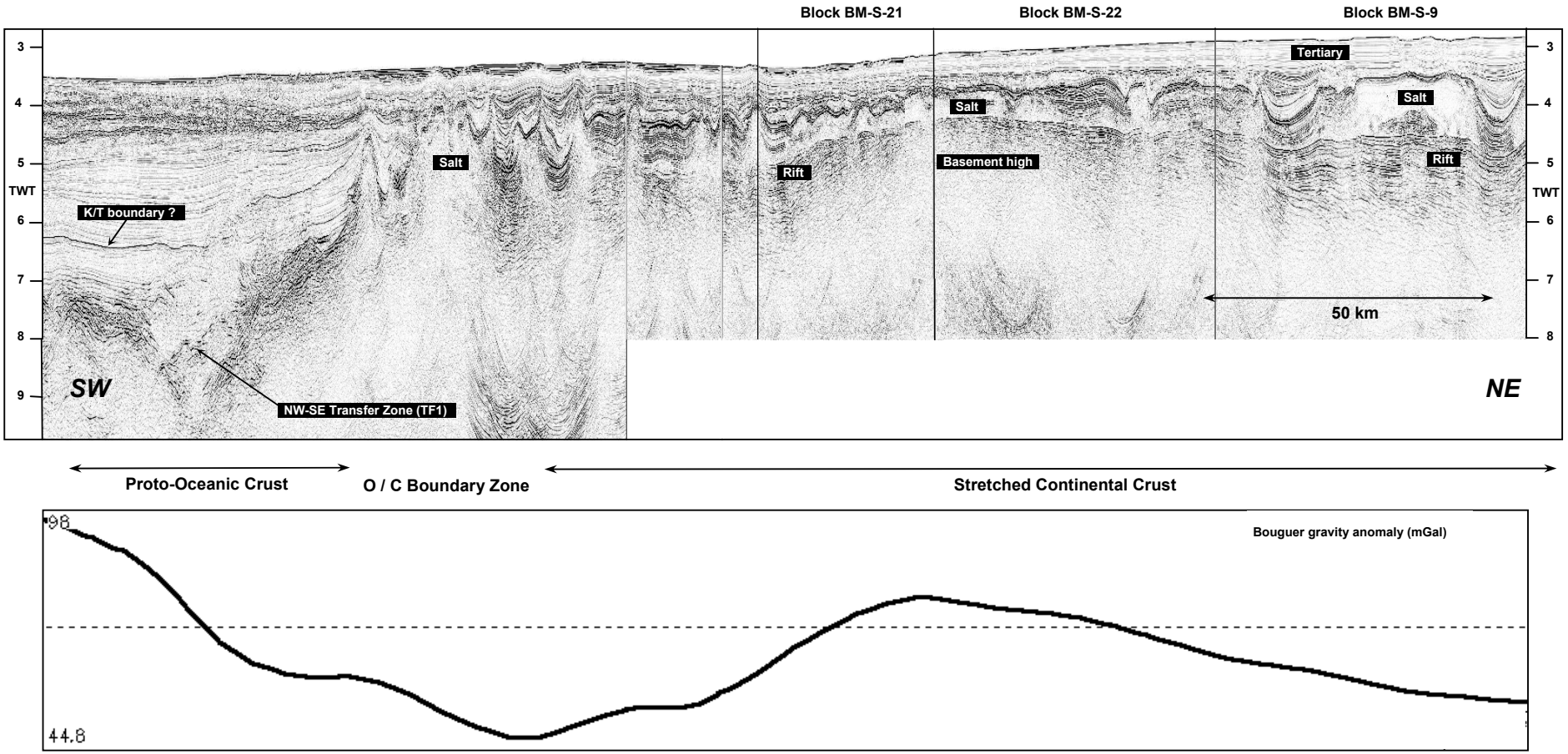


**Figure 2** – Regional strike seismic profile in the southern São Paulo Plateau (see Fig. 1 for location). The outer high of the Santos Basin is an outstanding basement structure, covered by blocks BM-S-21 and BM-S-22. Note that the rift section onlaps and pinches-out towards both sides of the structural high, which acts as a regional focus for oil migration. An impressive basement structural low can be observed in the southwestern edge of the seismic image. This region is related to the steep gradient observed in the Bouguer gravity anomaly profile, and is interpreted as the very beginning of the proto-oceanic crust region indicated in Figure 1.