SBGf38199

Thin-Skinned Gravitational Transfer Zone in the Southern Part of Santos Basin

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INTRODUCTION

The sedimentary sequence of the Santos Basin (Fig. 1) is structured mainly by salt tectonics, with limited contribution of basement involved tectonics. The ductility of the salt, which permits it to flow at low pressures and temperatures, is well known; interaction between the ductile behavior of the salt and the brittle behavior of the overlying sediments controls salt tectonics.
Gliding and gravity spreading over the salt produce a good variety of structures such as listric faults with rollovers, salt walls, folds and thrusts. These structures are not evenly distributed in the Santos Basin but define distinct Salt Tectonic Provinces (Demercian and Szatmari, 1993; Demercian et al., 1993), each with its characteristic pattern of flow and structure. The limits between these Provinces (Fig. 1) are always parallel to the main direction of flow at that location; they are nearly linear and abrupt, satisfying the criteria of transfer zones. Three such transfer zones have been defined: those of Ilha Grande, Merluza, and Tubarão. Below we are going to focus on the Tubarão Transfer Zone that divides the Southern and Southwestern Provinces of the basin (S and SW in Fig. 1).
It is worth noting that our interest in identifying and analyzing these transfer zones derives from their providing long, nearly vertical fault planes which may act as important pathways in hydrocarbon migration and hence deserve the attention of explorationists.

PRE-SALT BASIN CONFIGURATION

When analyzing the southern Santos Basin, the first thing that draws our attention is the great difference in the intensity of structuring, and hence in mobility, between the Southern and Southwestern Provinces (Fig. 1), together with the marked NW - SE limit along which terminate, in this region, the cut-off lenses of the lower Albian (in blue). The contrast in deformation between the sedimentary sequences of the two provinces reflects their contrasting depositional history, largely controlled by the shape of the basin before salt deposition started.
The block diagram of Fig. 2 (based on the seismic mapping of the region by Demercian, 1996) shows the major features of this portion of the pre-salt Santos Basin.
The barrier formed by the Florianopolis High and the São Paulo Ridge defines the southern limit of the Aptian hypersaline sea (Gambôa & Rabinowitz, 1981). The depositional limit of the evaporites trends E - W, accompanying this barrier. The pre-salt relief, however, has its highest gradient in a NW - SE direction (also shown on Fig. 2), and it was this gradient that controlled the change in the thickness of the Aptian salt sequence.
Thus, the salt filled a basin whose shape resembled the one shown in Fig. 2. In the northern portion of this area, where the basin was deeper, the salt is thick (more than 2000 m in the depocenters); whereas in the south, where the basin was much shallower so that less space was available, only thin salt deposited, which thinned still further toward its depositional limit in the south.
Therefore the sediments derived from the coast, or increasing along the coast accompanying the paleo-bathymetry, prograde over the salt from NW to SE in both provinces. In the south, where the salt is nearly or completely absent, the sedimentary sequence is more stable, harder to dislocate, hence no major faults form and the geometry of the depositional sequences is readily characterized. In the area where the salt is thick, on the other hand, the sedimentary sequence is much more mobile, so that it readily glides or becomes extended, forming abundant faults that allow the rise of high salt walls.

IMAGING TWO STAGES IN THE EVOLUTION OF THE SOUTHERN SANTOS BASIN

The block diagrams of Figs. 3 & 4 (both based on seismic mapping of the region and horizontal reconstruction by Demercian, 1996) show the general structure of the major sedimentary sequences which became deformed in the area, without including unnecessary details.
Fig. 3 shows the southern portion of the Santos Basin at the end of the deposition of the mid-Albian carbonate shelf. The first normal antithetic (counterregional) fault in the area was already active and fine sediments (calcilutitites) were depositing along it, in the space created in the hanging wall of the fault. The carbonate shelf margin that developed in the region during Albian times already started to become inflected to the east, deformed by gliding to the southeast of that part of the carbonate ramp which had been originally deposited over thicker salt. The outlines of the first salt wall are already perceptible.
Fig. 4 shows what the present configuration of the area would be if the entire sedimentary sequence deposited after the mid-Albian carbonate ramp were removed. The southern portion of the area continues essentially undeformed, as in the

previous figure showing the mid-Albian state; there are only salt pillows up to 200 m thick and very few faults. In the northern portion of the area, however, where deformation was intense, salt walls are already fully formed (reaching, in reality, up to 4 to 6 km in height) and between the salt walls there are the fragmented pieces of what was, originally, a continuous Albian carbonate shelf. These fragments would thus be analogous to the rafts defined by Duval et al. (1992) in the Kwanza Basin. The carbonate shelf margin, which was already being deflected to the east in the previous figure, here has a major deflection exceeding 50 km. It is worth nothing that the salt walls that are further to the SE are somewhat recumbent, owing to the contractional regime that directly preceded the formation of the Avedis Volcanic Chain, a pre-salt volcanic construction mapped by Demercian (1996).

TUBARÃO TRANSFER ZONE

We have seen that in the southern portion of the Santos Basin two tectonic provinces exist side by side, each with different characteristics and degree of deformation. The juxtaposition of two deformational domains which differ so much from each other, the abruptness of the change between them at the boundary, the linearity of this boundary, the general trend of deformation (NW - SE) parallel to it, and the near-vertical position of the salt walls at several points along it, are sufficient to characterize a transfer zone (Christie-Blick & Biddie, 19055; Zalán, 1986a, 1986b; Sylvester, 1988; Milani, 1989) that affected both the salt and post-salt sequences and separated the Southern and Southwestern Provinces of the Santos Basin. We have defined this zone as the Tubarão Transfer Zone.

CONCLUSIONS

The Santos Basin can be divided into distinct salt tectonic provinces, each having distinct, characteristic features. These provinces are separated by several transfer zones, one of which is the Tubarão Transfer Zone. This major transfer zone is directly related to the pre-salt relief of the southern portion of the Santos Basin, and is readily observed on our seismic maps and in 3-D images based on these maps. The high potential of these transfer zones as migration routes for hydrocarbons, owing to their near-vertical planes and the great thickness of the sediments affected by them, provides a major incentive for their study by explorationists.

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ACKNOWLEDGMENTS

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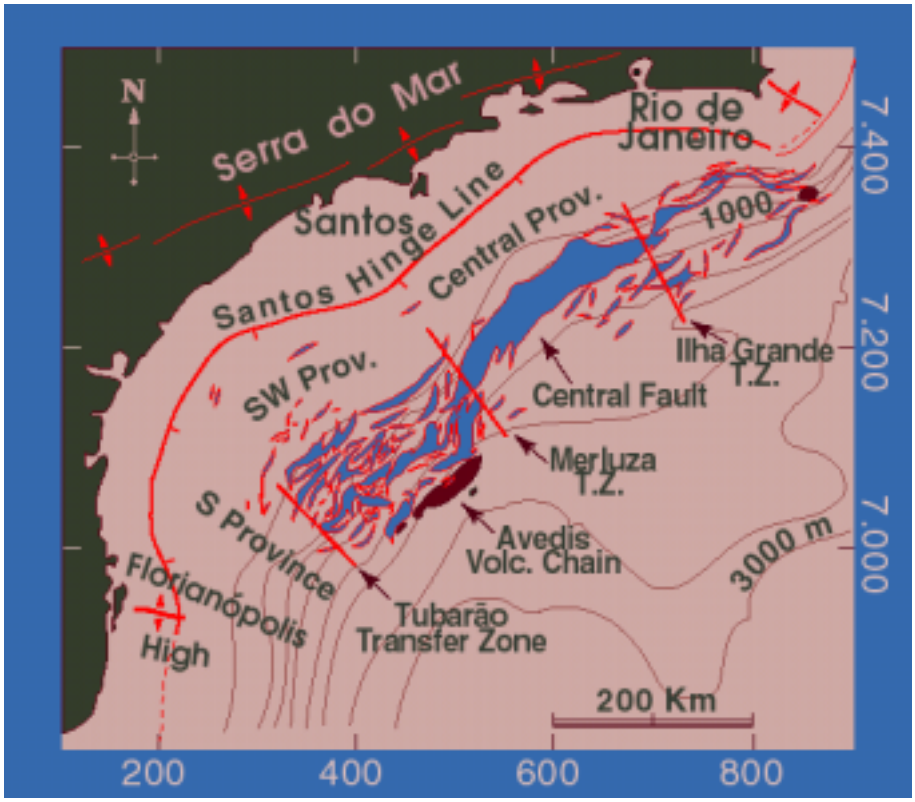

Figure 1 — Outlines and subdivisions of the Santos Basin in SE-Brazil, based on salt flow patterns, defined by Demercian & Szatmari, 1993. Faults of salt tectonic origin in the Lower Albian are shown in blue. The Tubarão, Merluza and Ilha Grande Transfer zones are also indicated (Demercian, 1996).

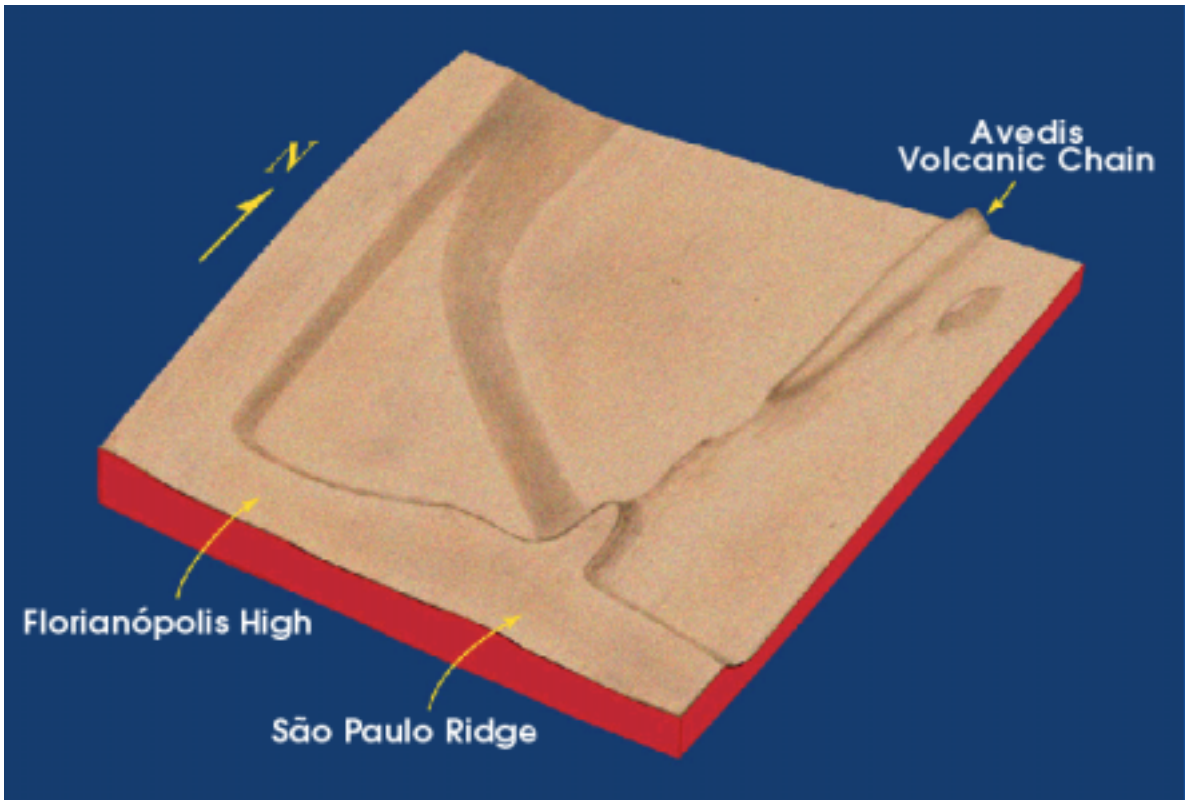

Figure 2 — Pre-Aptian structural pattern of the southern portion of the Santos Basin, based on seismic surveys (Demercian, 1996).

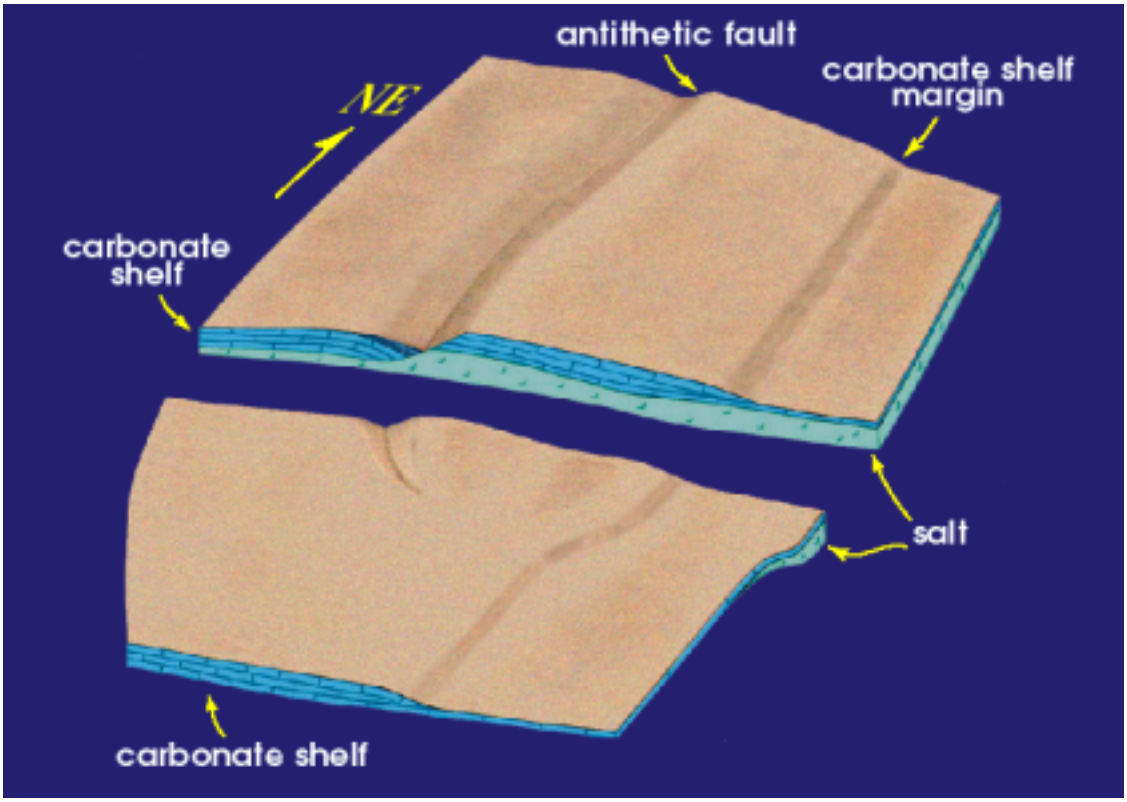

Figure 3 — Structural pattern of the southern Santos Basin at the start of major salt tectonic activity, based on seismic surveys (Demercian, 1996).

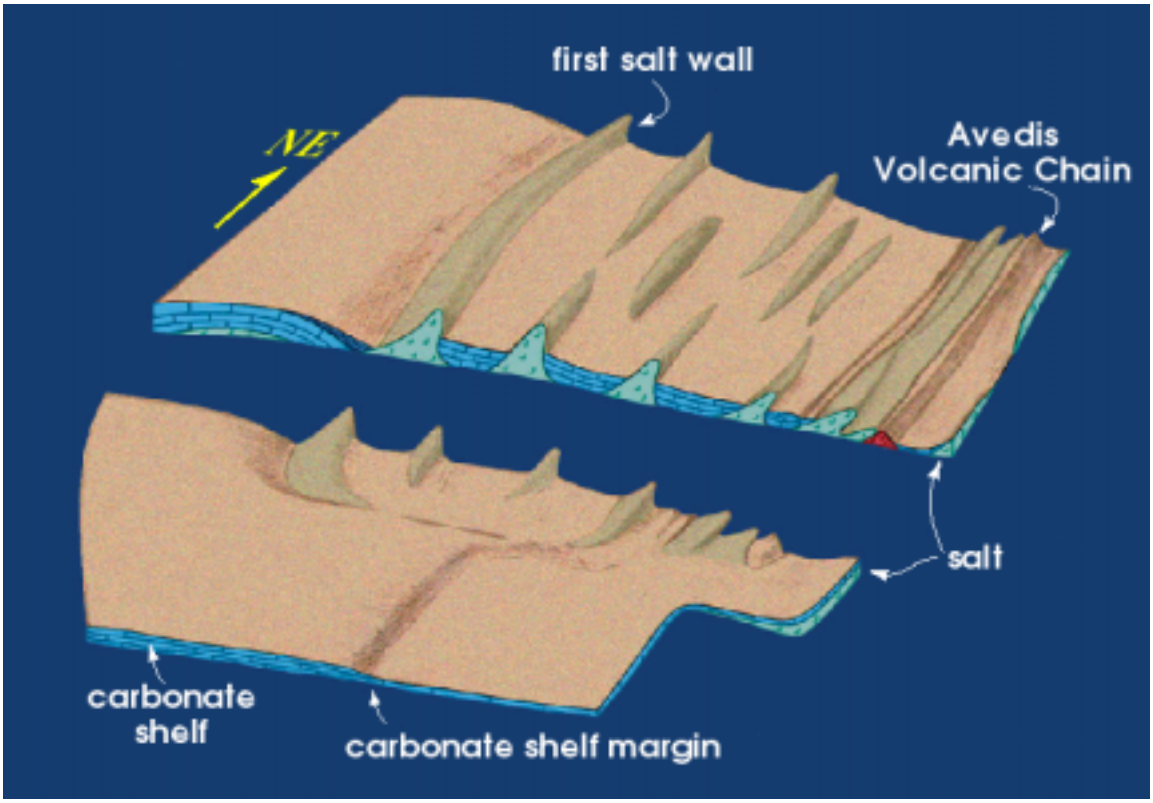

Figure 4 — Present structural pattern of the southern Santos Basin, based on seismic surveys. All sediments younger than the Albian carbonate shelf have been removed (Demercian, 1996).