45 mm

THE BRAZILIAN ESTUARIES: ARE THEY EXPRESSIONS OF TECTONICALLY CONTROLLED LOCAL SUBSIDENCE?

Guilherme C. Lessa[1]; Luiz César Correa-Gomes[1]
glcessa@gmail.com, lccgomes@gmai1.com
[1]- Instituto de Geociências, UFBA
Universidade Federal da Bahia
Campus Ondina, Salvador (BA), Brasil, 40.170-020

Palavras-chave: estuaries, neotectonics, coastal subsidence, grabens

INTRODUCTION

The Brazilian coast has undergone a relative fall of sea level of 1.5 to 3.5 m in the last 6000 years (Angulo et al., 2006), and as a result large scale coastal progradation and infilling of fluvial valleys with large sediment yield are widespread. Therefore, classical coastal plain estuaries no longer exist along the Brazilian coast, with the exception of the Eastern Pará coastal sector where large-scale subsidence has apparently occurred throughout the Holocene (Souza Filho et al., 2009).

In spite of this regressive scenario and attendant large scale coastal progradation, large estuaries in the form of large tidal bays are still observed along the coast. Lessa (2005) have suggested that local subsidence might have offset the Holocene sea level fall within the eastern Brazilian estuaries. Geomorphological and sedimentological evidence point to Late Quaternary tectonic activity in several sectors of the Brazilian coast (Martin et al., 1986; Rossetti et al., 2008; Souza Filho et al., 2009, amongst others) as well as in small Tertiary rifted basins lying at or very close to the coast (Souza et al., 1996; Ferrari 2001).

A strong correlation exists between the position of the coastal bays and the location of the coastal sedimentary basins, with the bays normally occurring in the central section of the basins. Correa-Gomes *et al*. (2005**)** have shown that the tectonic regime of some coastal sedimentary basins in Brazil have changed from extensive into a more transextensive regime. It means that the main far-field tectonic tensor (σ_1) has changed from vertical to horizontal, creating local tectonic conditions for tilting of faulted blocks. This causes local subsidence, and relative sea level changes, at least in the sector of the crustal block that is moving downwards.

The purpose of this paper is to: i) propose a tectonic model in which fault blocks produce local subsidence processes that offset, totally or partially, the Late Holocene sea level fall, and ii) discuss evidence of recent tectonic activity and subsidence, on local and regional basis, that may explain the existence and preservation of large Brazilian estuaries.

45 mm

SUBSIDENCE MODELS ASSOCIATED WITH RIFTED BLOCKS

We argue that the main factors influencing the recent sedimentary basin motion are: i) the throw between the set of fault planes that compartmentalize the fault blocks, and ii) the relative orientation of the stress field vectors in regard to the fault planes (Figure 1). This model also incorporates the presence of longitudinal and transverse faults. Given the elements listed herein, there are four possible scenarios for tectonic motions and consequent basin geometries in a rifted basin: **1) *Coaxial balance model***: Extension is parallel to the longitudinal fault strikes, and the orthogonal faults that laterally limit the fault block have throws of similar displacement. The downthrown block undergoes an even motion, and subsidence rates and sediment fill thicknesses are spatially uniform. **2) *Non-coaxial orthogonal extension model****:* Extension is orthogonal to the longitudinal fault strikes, but the throw at the longitudinal fault is larger than its counterpart. Subsidence rates are thus higher and sedimentary sequences thicker at the side of larger throw. 3) ***Non-coaxial longitudinal extension****:* Extension is parallel to the longitudinal fault strikes, but with no coaxial compensation. Hence, the throw at one orthogonal fault will be larger than at the other, with higher subsidence rates at the side with larger throw. **4) *Non-coaxial diagonal extension:*** Extension is diagonal to the longitudinal fault strikes, with no coaxial compensation. The throw may vary laterally (rotational faults) resulting in an asymmetrical basin with triclinic geometry. Subsidence rates will be higher at the sides with larger throws, where sedimentary strata will also be thicker.

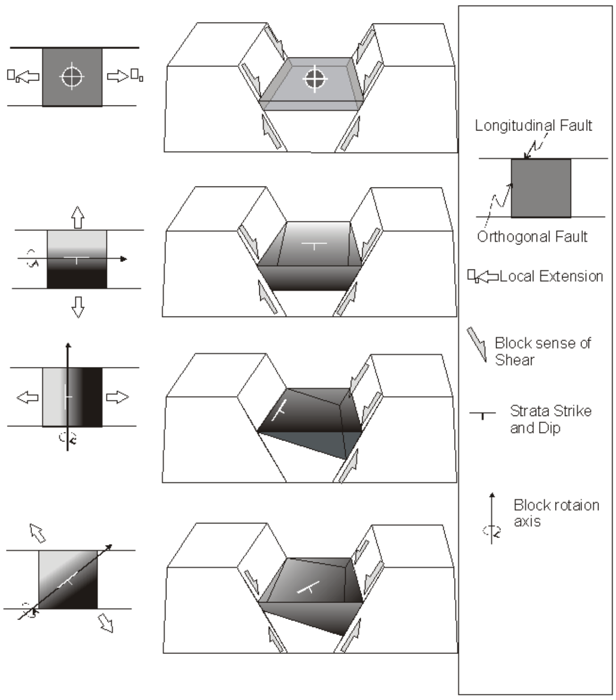

Figure 1 - Four tectonic scenarios for basin geometry given different orientation of the stress vectors, different throw magnitudes at opposite fault planes and the existence, or not, of coaxial compensation to the fault motion. The final geometry incorporates the organization of the sedimentary packages. 1) coaxial balance, 2) non-coaxial orthogonal extension, 3) model of non-coaxial longitudinal extension, 4) model of non-coaxial diagonal extension.

STRUCTURAL FRAMEWORK OF COASTAL SECTORS WITH LARGE ESTUARIES

45 mm

Northern Coast

Between the Amazon River and Turiaçu Bay the coast is 580 km long and harbors 28 estuaries within the Pará-Maranhão and São Luiz basins. The structural framework of the continental margin is characterized by several structural compartments (Souza Filho 2000). Warped blocks form a series of horsts and grabens that are associated with sedimentary basins such as the Bragança-Viseu and São Luís Equatorial basins.

Most of the western side of the coastal plain runs along a paleo-cliff 1 m to 3 m in height that is parallel to the coast and abuts the horsts that define the Bragança-Viseu and São Luiz sedimentary basins. This paleo-cliff is potentially a throw of an active fault associated with the downward movement of a block that supports the coastal plain. GPR profiles from the western side of the coast (Rossetti 2003) show a myriad of small scale normal faults with strike angles parallel to coastline and fault blocks intersecting the paleo-cliff. At the eastern side of the coastal plain, already in the domain of São Luiz Basin, Ferreira Jr. et al. (1996) have shown sets of strike-slip faults with meter scale throws, bordering São Luiz horst. The tectonic apparently extends all the way to the mouth the Amazon River (Rossetti et al 2008). Depending on the local orientation of the longitudinal and orthogonal faults, the subsidence models presented in Figure 1 could indeed be applicable to the local geometric rearrangements of the faulted blocks.

Souza Filho et al. (2009) have shown that the coastal evolution of the North Brazilian coast during the Mid- to Late Holocene has been modulated by apparent small scale subsidence events, with the onset of three phases of barrier development. There is no record of any higher sea level position in the last 6000 years, and transgression is apparently a still ongoing process, as indicated by several geomorphological evidences.

The southern Northeast Brazilian coast

Five estuaries are located within 3 sedimentary basins in the southern section of the northeast coast. The largest of these estuaries, Todos os Santos Bay, lay in the Recôncavo Basin, delimited in the East and West by the Salvador and Maragojipe faults, respectively, with scarps up to 100 m high. The Maragojipe scarp extends south towards Camamú Bay, forming a line between Cretacic sedimentary and pre-Cambrian crystalline rocks that is dotted with rapids and waterfalls. Pleistocene marine terraces are restricted to the southern side of Todos os Santos Bay, suggesting that it is tilting northwards in its central section (Martin et al 1986). In the northern bay margin, paleo-sea level indicators are vertically offset in relation to a reference paleo-sea level curve established for the open coast, and indicate varying degrees of submergence. In the western side of the bay Carvalho (2000) reported that sea level rose at a rate of about 2.8 mm/y between 9,200 and 7400 cal years B.P., and that no radiocarbon dating nor geomorphological features indicate sea levels higher than today's. Besides, depressed elevation of intertidal facies and a 20 m difference of the Paraguaçu River substrate depth across the Maragojipe fault, as it reaches the bay, would also indicate that the bay is sinking.

45 mm

The Southern Coast

The southeast Brazilian coast, between the States of Rio de Janeiro and Santa Catarina, present seven important estuaries. Despite the extensive system of grabens, neotectonic movements have only been reported in the Guanabara and Taubaté (inland) grabens (geological evidence), but also suggested on the basis of GPS measurements at Cananéia estuary. In the Guanabara graben, Ferrari (2001**)** identified two Quaternary tectonic events, the penultimate one in the Pleistocene and the last in the Holocene, responsible for the segmentation of Cenozoic sedimentary deposits, and deformation of alkaline rocks and sediment fills.

The Cananéia (hemi)graben is delimited by a normal fault at the NW flank (Souza et al. 1996). The graben is apparently tilted to the southwest where the sedimentary column (550 m deep) is about 350 m thicker than that at the northeast end. This graben geometry corresponds to the *Non-coaxial diagonal extension* model in Figure 1. Mesquita et al. (2005a,b) show that relative sea level is rising at 5,6 mm y^{-1} (years 2002 to 2005), whereas the land is subsiding 3.8 mm y^{-1}. This means that more than 65% of the measured sea level rise is explained by subsidence within Cananéia graben.

DISCUSSION AND CONCLUSION

The Brazilian continental margin is segmented in 17 rifted Cenozoic sedimentary basins parallel to the coast, whose architecture is clearly controlled by older structures inherited from the crystalline basement. The present orientation of the regional far-field tensor is conducive to tilting of tectonic blocks and can cause regional and local changes of the relative sea level position.

Cananéia and Todos os Santos Bay, besides the transgressive north Brazilian coast, are the only sites with documented evidence of subsidence during the Holocene. Several of the others estuaries display spatial asymmetries in the distribution of paleo and actual beach and estuarine deposits, suggesting that uneven rates of sea level fall have occurred within the estuary. It is likely that not all of the existing large estuaries are bound by tectonic forces. We believe, however, that tectonic subsidence could be an initial working hypothesis for geomorphological studies inside estuarine systems. Based on the paleo sea level data published by Angulo et al (2006) for the Brazilian coast, there are only 10 samples with time and space controls collected inside the large estuaries (Baia de Guaratuba, Baia de Sepetiba and Baia de Todos os Santos). Although some of these samples were indeed used by Martin et al. (1986) to suggest subsidence of Baia de Todos os Santos, there are not yet enough indicators to evaluate how estuarine mean sea levels plot in relation to those obtained in the neighboring open coast. The possibility that local subsidence is accentuating ongoing sea level rising rates deserves due consideration, as long term planning for urban and industrial accommodation of the predicted eustatic sea level rise are generally based upon open-coast sea level data.

45 mm

REFERENCES

Corrêa-Gomes, L. C. , Dominguez, J. M. L. , Barbosa, J. S. F. & Silva, I. C. da, 2005. Padrões de orientações dos campos de tensão, estruturas, herança do embasamento e evolução tectônica das Bacias de Camamú e porção Sul do Recôncavo, Costa do Dendê, Bahia, Brasil. *Revista Brasileira de Geociências* 25,4, pp 34-45.

Ferrari, A.L., 2001. *Evolução Tectônica do Graben da Guanabara*. PhD Thesis, Instituto de Geociências, Universidade de São Paulo, Brasil, 412 p.

Ferreira Jr., C.R.P., Costa, J.B.S., Bermerguy, R.L. & Hasui, Y., 1996. Neotectônica na área da Bacia de São Luís. Revista Geociências 15, pp 185–208.

Lessa, G.C., 2005. Baías Brasileiras: grandes estuários em uma costa regressiva? Proceedings 10th Congress Brazilian Association for Quaternary Studies (ABEQUA), Guarapari, Brasil, 5p (CD-ROM).

Martin, L., Bittencourt, A.C.S.P., Flexor, J.M., Suguio, K. & Dominguez, J.M.L., 1986. Neotectonic movements on a passive continental margin: Salvador region, Brazil. Neotectonics 1,1, pp87-103.

Rossetti, D.F., 2003. Delineating shallow Neogene deformation structures in northeastern Pará State using Ground Penetrating Radar. Anais Academia Brasileira de Ciências 75, pp 235–248.

Rossetti, D.F., Goes A.M., Valeriano, M.M. & Miranda, A.C.C., 2008. Quaternary tectonics in a passive margin: Marajó Island, northern Brazil. Journal of Quaternary Science 23,2, pp 121–135.

Souza-Filho, P.W.M., 2000. Tectonic control on the coastal zone geomorphology of the northeastern pará state. Revista Brasileria de Geociências, 30,3, pp 527-530.

Souza Filho, P.W., Lessa, G. C., Cohen, M.C.L. & Lara, R., 2009. Trangressive barrier estuarine systems of the Eastern Amazon coast, Northern Brazil. In: Dillemburg S., Hesp, P. (Eds.), Geology and Geomorphology of Holocene Coastal Barriers of Brazil. Lecture Notes in Earth Sciences, Springer, v. 107, pp. 347-375.

Souza, L.A.P., Tessler, M.G., Galli, V.L., 1996. O graben de Cananéia. Revista Brasileira de Geociências 26,3, pp139-150.