

THE ROLE OF NEOTECTONICS IN THE EVOLUTION OF THE BRAZILIAN COAST

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RESUMO

Embora alguns trabalhos pioneiros sobre a neotectônica no Brasil tenham vindo a lume há mais de 40 anos, o real interesse por este assunto foi despertado somente na década de 70 devido à construção de numerosas e gigantescas obras de engenharia civil, tais como as usinas hidrelétricas e termoeletricas.

O papel mais relevante da neotectônica na evolução do litoral brasileiro pode ser demonstrado, de maneira inquestionável, pelas bacias marginais, que são uma evidência de macro-escala (ou escala continental). Essas bacias foram mais ativas do Cretáceo ao Terciário, mas as falhas principais estão ativas até hoje.

O *Rift* Continental do Sudeste Brasileiro, compreendendo as bacias de Curitiba, São Paulo, Taubaté, Resende e Volta Redonda, representaria outro importante testemunho de meso-escala (ou escala regional) do papel da neotectônica na evolução da costa brasileira. Esta feição foi originada durante o Paleógeno e continuou ativa durante o Neógeno e Quaternário até hoje, como uma manifestação tardia e mais interior da *Reativação Pós-paleozóica*, cuja consequência mais importante foi a origem do Oceano Atlântico Sul, simultaneamente à formação das bacias marginais.

Além disso, as origens das nítidas diferenciações entre as porções norte e sul da linha costeira paulista, bem como da zona deprimida do Gráben da Guanabara, ou as impressionantes feições do tipo-ria do NE da costa do Pará e os afloramentos suspensos de rochas praias do litoral norte-riograndense poderiam estar relacionadas a movimentos neotectônicos de micro-escala (ou escala local), mas elas necessitam de estudos mais específicos e detalhados.

Aparentemente não há dúvida sobre a relevância do papel desempenhado pela neotectônica na evolução do litoral brasileiro, no entanto muitos setores desta costa ainda não foram suficientemente estudados. Por outro lado, deve-se reconhecer que muitas dessas feições representam fenômeno de tectônica ressurgente, cuja origem remonta ao Pré-cambriano.

INTRODUCTION

Neotectonics is a subject of geological studies since the last century (Gerbova & Tikhomirov 1982), with a complete reconnaissance of its importance and understanding of its theoretical and practical significances, but many are the inconsistencies in opinion, even on its definition. According to Obruchev (1948), author of this word, it would represent "recent tectonic movements occurred in the upper part of Tertiary (Neogene) and in the Quaternary, which played an essential role in the origin of the contemporaneous topography". For Mörner (1989), the neotectonics would be understood as "any Earth movement or deformation of the geodetic reference level, their mechanisms, their origins and practical applications, and their future extrapolations". In this case, the word neotectonics would be destituted of chronological implications, comprising since instantaneous movements (seismic) until that occurred 10^7 years ago. In this paper, the concept originally proposed by Obruchev (op. cit.) will be adopted. On the other hand, dealing with neotectonics, closely implied is the idea of seismicity (Hasui & Ponçano 1978; Hasui 1979; Mito 1993). Considering its huge area, Brazil is one of the countries characterized by a major seismic stability in the world (Assumpção *et al.* 1979), nevertheless, this tenuous and sporadic intraplate

seismicity focused attention of some scientists, like Branner (1920), since beginning of this century.

MEGASCALE NEOTECTONICS

Dealing with megascale (or continental scale) neotectonics, the role of marginal basins, as a neotectonic agent in the evolution of the Brazilian coast, must be considered. In chronological terms, it is necessary to go back in geological time scale, at least, to the end of Jurassic (about 150 my ago) for a better understanding of these basins. At that time, simultaneously to the persistence of huge synclises (Amazon, Paraná, and Paraíba intracratonic basins), Gondwana supercontinent fragmentation was initiated, followed by an amazing tectono-magmatic-sedimentary event. It was originally named *Wealdenian Reactivation* by Almeida (1967), which was replaced by *South-Atlantic Event* by Schobbenhaus *et al.* (1984) and, finally, Almeida & Carneiro (1987) called *Postpaleozoic Reactivation*. Independently of its denomination, this geological phenomenon was the great responsible for the formation of Brazilian marginal basins, as well as for the origin of South-Atlantic Ocean, besides innumerable geological phenomena which occurred in several time and space scales (Fig. 1).

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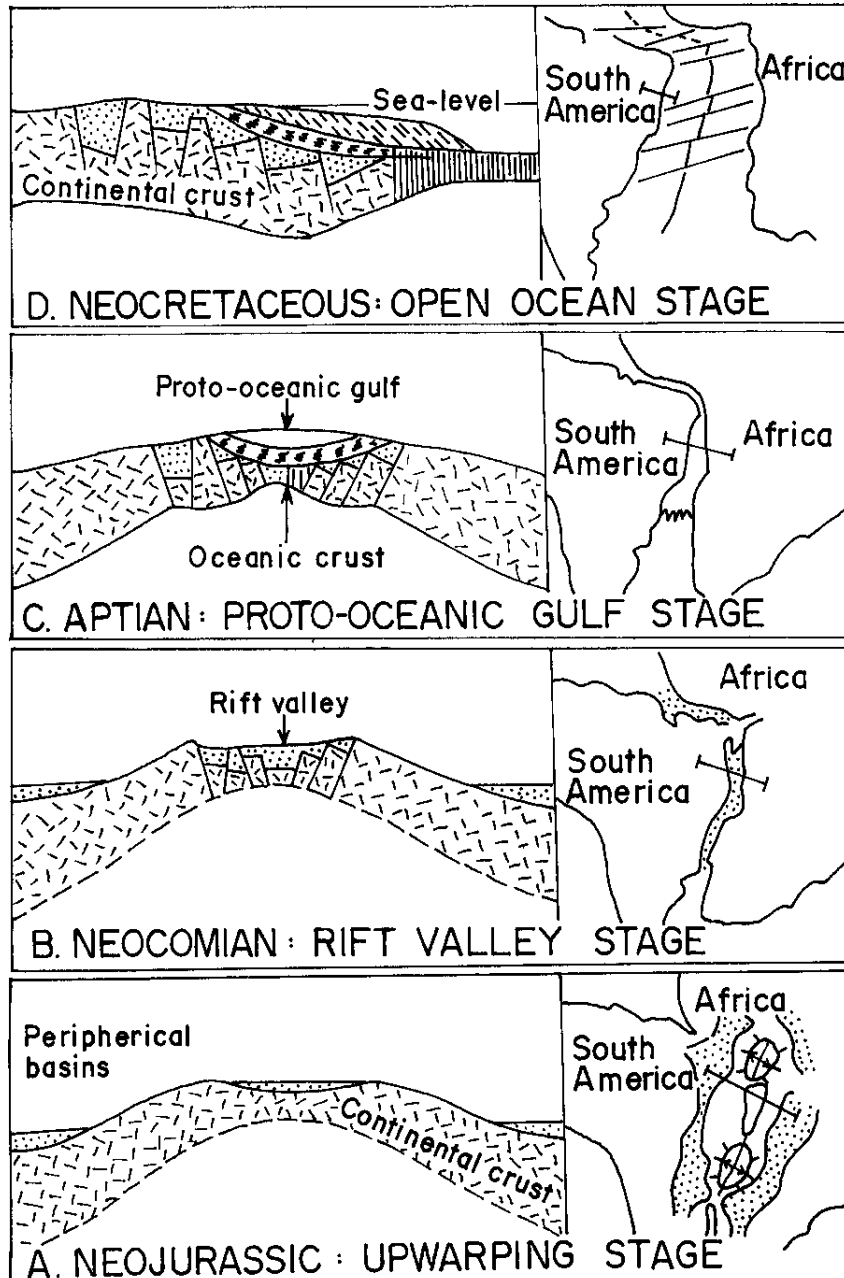


Figure 1: Scheme of geologic evolution of the Brazilian Marginal basins, simultaneously to the continental drift and consequent origin of the Atlantic Ocean (modif. from Ponte & Asmus, 1978).

In terms of areal extent, it is necessary to embrace not only the coastal plain but, at least, the adjacent continental shelf where is situated part of the marginal basins. The origin and evolution of these sedimentary basins were understood, according to the model of Atlantic-type continental margin (Asmus & Porto 1972), only after comprehension of African and South American continental plates separation processes, after fragmentation stage followed by continental drift.

Taking into account the evolutionary history of these basins, some of their peculiarities allowed to classify them in two groups: eastern and equatorial marginal basins. The first group is geographically limited between Rio Grande do Sul (Pelotas basin) and Alagoas (Sergipe-Alagoas basin) states. The second one begins in

Pernambuco (Pernambuco-Paraíba basin) and finishes in the Amapá state continental shelf (Fig. 2).

These basins, according to Klemme's (1971) classification, would evolve according to Asmus & Porto (1972), from the beginning of their formation until today, through two or three of following types: (a) *Type I* - simple intracratonic basin, (b) *Type III* - rift valley, and (c) *Type V* - opened marginal basin (Fig. 3). From Cretaceous to Tertiary, these basins evolved through the following sedimentary environments: lacustrine to deltaic, restricted marine to transitional, continental slope, continental slope and shelf and finally littoral. Changes in basin types and sedimentary environments through Cretaceous to Tertiary, respectively with 80 and 65 my of duration, have been controlled mostly by alterations

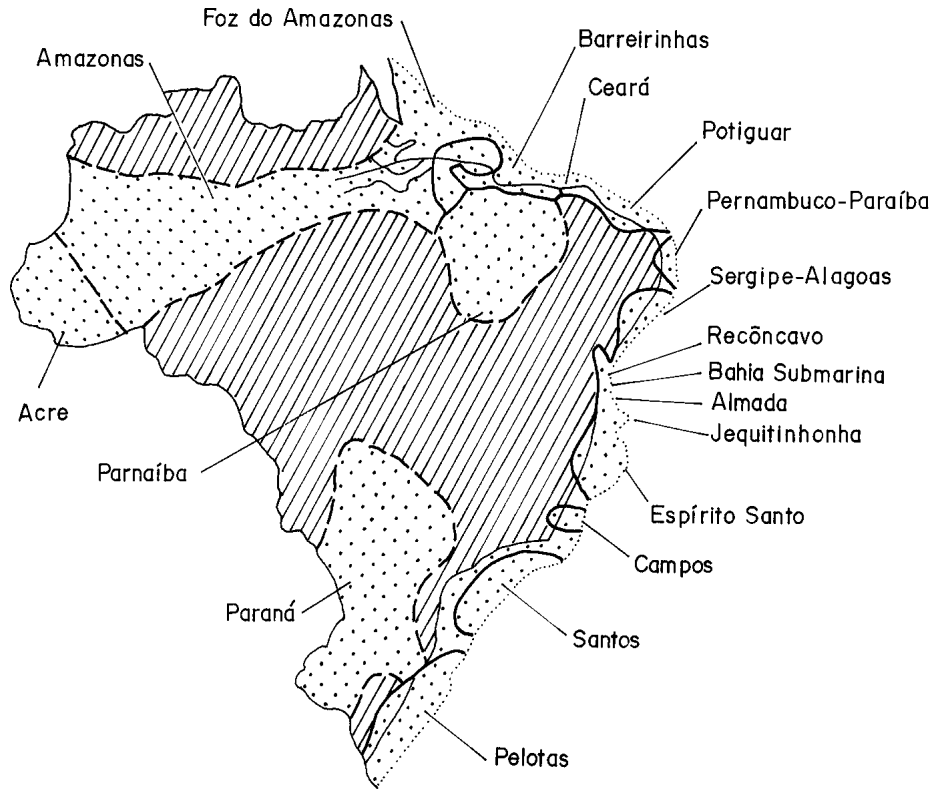


Figure 2: Locations of the Brazilian marginal basins and the Amazonas, Paran and Parnaba intracratonic basins.

in intensities of tectonic activities (thermal subsidence), as well as by negative eustatic fluctuations of sea-level (Fig. 4). Tectonic movements within these basins, even tremendously weakened than during Cretaceous and Tertiary, are still active presently (Suguio & Martin 1976; Martin & Suguio 1976 a, b; Martin *et al.* 1984 a, b; 1996).

Geometrical configuration of the Brazilian coast, in terms of shoreline orientation in relation to oceanographic factors (waves, tides, marine currents, etc.), as well as its geographic position and physiographic characteristics, represent a consequence of already mentioned

Postpaleozoic Reactivation, which explains the formation of marginal basins and the origin of the South-Atlantic Ocean (Fig. 5)

MESOSCALE NEOTECTONICS

Concerning to the mesoscale (or regional scale) neotectonics, the most representative examples are the Southeastern Brazilian Continental Rift (Riccomini 1989), and state of So Paulo coast (Suguio & Martin 1978).

AGE	LITHOLOGY	SEDIMENTARY ENVIRONMENT	DEPOSITIONAL SEQUENCE
Tertiary	Terrigenous regressive deposits	Littoral and continental shelf and slope	Marine
Cretaceous	Upper Transgressive shales	Continental slope	
	Middle Limestones	Shallow continental shelf	
	Lower Evaporites	Restricted marine and transitional	Gulf
		Conglomerates, sandstones and pelites	Lacustrine/deltaic
Jurassic	Terrigenous deposits	Fluviatile-lacustrine	Continental

Figure 3: General stratigraphic column of the Brazilian marginal basins, with indications of ages, lithologies, sedimentary environments and depositional sequences (Ponte *et al.* 1978).

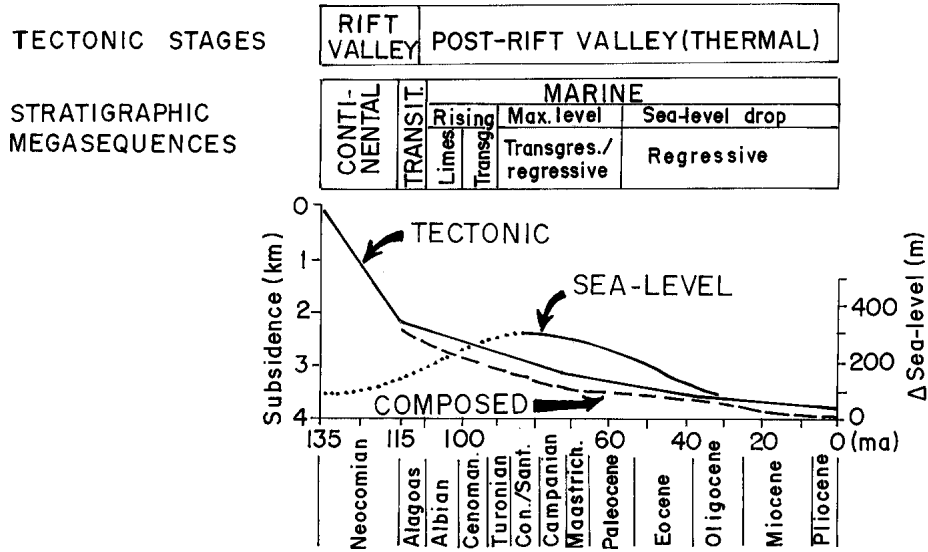


Figure 4: Curves of tectonic subsidence (thermal) and of sea-level changes, during Cretaceous and Tertiary, along the Brazilian coast. The sea-level fluctuations were based on Vail & Mitchum Jr. (1977) and Pitman III (1978).

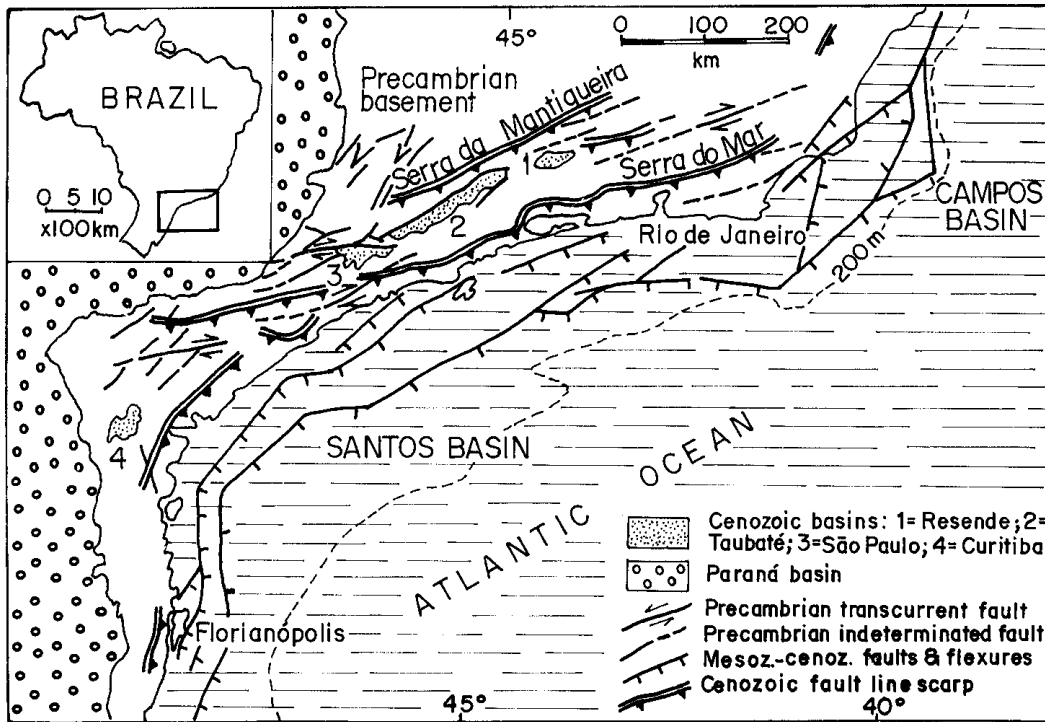


Figure 5: Tectonic framework of Southeastern Brazil (based on Almeida, 1976 and Asmus & Ferrari, 1978) showing the parallelism between some of the structural alignments in the continent and in the adjacent continental shelf.

Southeastern Brazilian Continental Rift

It was previously known as the Continental Rift Systems of the “Serra do Mar” (Almeida 1976). This continental rift is represented by Curitiba, So Paulo, Taubat, Resende and Volta Redonda basins (Fig. 5), which were originated during Eocene-Oligocene times, as the nearest inland delayed reflection of the previously mentioned *Postpaleozoic Reactivation*.

According to Riccomini (1989), they have been filled by braided and meandering fluvial deposits intertonguing with lacustrine deposits, as a consequence

of changeable tectonic and sedimentation rates influenced by climatic oscillations since the Paleogene to the Quaternary.

The morphostructural studies and Quaternary sedimentary deposits characterization (Mancini 1995), in connection with brittle tectonic structures of the Queluz structural high (Salvador 1994), near the states of Rio de Janeiro and So Paulo limit, allowed Salvador & Riccomini (1996) to recognize three stages of neotectonic movements. The oldest one is related to a NW - SE compressive stress field, probably during the Pleistocene, associated with an E-W right-lateral

transcurrent binary, which probably worked upon colluvial and stoneline deposits, frequently overthrust by blocks of basement rocks along faults trending NE to ENE. The origin of N-S trending grabens with syntectonic sedimentary filling, probably at the beginning of the Holocene, would be accountable to a change in the stress field to an E-W extensional regime. Finally, conspicuous and widespread shear joint families, systematically oriented ENE and WNW influencing alluvial, colluvial and alluvial-colluvial deposits, could be considered as a consequence of a new change in the stress field.

The State of São Paulo coast

The portion of the Brazilian coast, here focused, has a NE-SW trend and is situated between longitudes 44° 45' and 48° 00' W. It includes the state of São Paulo coast which, in a straight line, is longer than 400 km. Using the Silveira's (1964) classification, this portion could be considered as a crystalline coastline, characterized by the omnipresence of the "Serra do Mar" (Coastal Range). Freitas (1951) was probably the first author to emphasize possible tectonic movements as responsible for differences in coastal morphology between northern and southern parts, nevertheless this differentiation has been perceived since the beginning of this century. From a geomorphological viewpoint, Martin & Suguio (1975; 1976a, b) recognized a submersion coast at the north, and an emersion coast at the south. This idea was previously proposed by Fúlfaro & Ponçano (1974), following the Johnson's (1919) classification of shorelines. In fact, at north the crystalline basement reaches almost continuously the sea, excluding in front of restricted plains, whose inner portion is constituted by continental deposits and outer portion by marine sediments. Disregarding the presence of more conspicuous sedimentary deposits at south, this coastline is very homogeneous in its morphological features. For example, isolated hills of Precambrian rocks very commonly found at southern coastal plains could be easily compared with islands frequently found at northern coast.

The noticeable morphological differentiation between northern and southern portions could be explained by differences in sedimentation dynamics as well as by tectonic influence. So, it could be postulated that sediment supply has been more important at south than at north, or that southern half was uplifted and northern half was subsided. As the majority of rivers in this area flows from "Serra do Mar" (Coastal Range) to inland, excepting Ribeira de Iguape river, the first hypothesis seems to be unacceptable and could not explain the differences in distribution of Quaternary sediments. If the second hypothesis is correct, the coastline would show a tendency for submersion at north and for emersion at south, as assumed by some authors. This differentiation between northern and southern sectors could be observed even in width and declivity of the continental shelf. In front of the hilly Parati region (state of Rio de Janeiro), at north, to isobath of 50m is situated 8 km from the shoreline, while in Santos is about

30 km and in Cananéia (state of São Paulo) is placed 50 km. Analogously, higher altitudes occur nearer the shoreline at north than at south.

It is also interesting to verify that the transition between emersion and submersion zones is rather gradual than abrupt. This seems to eliminate the hypothesis of morphological differentiation due to tectonic interactions between fault blocks, separated by discontinuities normal to the coastline, being necessary to obtain the aid of the differential continental flexure mechanism (Bourcart 1949) to explain the observed differences. Assuming this hypothesis as true, Suguio & Martin (1978, 1994) admitted the following possibilities (Fig. 6):

a) If shoreline is situated at left side of flexure line, that is within uplifting zone, the coast will exhibit emersion morphology.

b) If shoreline is situated at right side of flexure line, that is within subsidence zone, the coast will be characterized by submersion morphology.

c) If shoreline is situated at same side of flexure line both at north and south, but at different distances from it, the coast will show differential emersion features.

These three possibilities could be complemented by two situations taking into account the distance between the maximum uplift and the flexure line:

d) The maximum uplifting zone is far from the flexure line.

e) The maximum uplifting zone is near the flexure line.

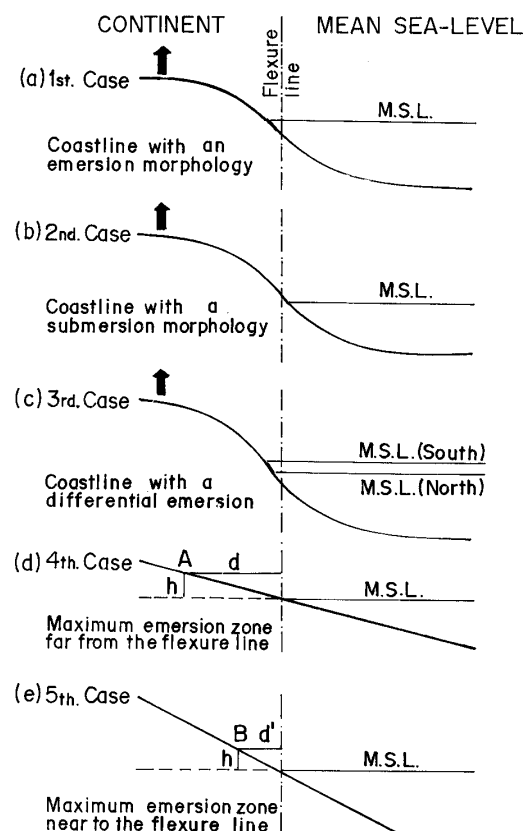


Figure 6: Schemes of differentiation of the state of São Paulo coast in areas with emersion (southern half) and submersion (northern half) characteristics by continental flexure mechanism (Suguio & Martin, 1978).

Considering an uplifting height h for (d) and (e), the area affected by this phenomenon will be more extensive in (d) than in (e), that is the maximum uplifting zone is found nearer to the shoreline at north than at south. This could explain why uplifted areas are more extensive at south, and why Holocene paleosea-levels, near the present shorelines, are higher at north than at south.

MICROSCALE NEOTECTONICS

In some very restricted sectors of the Brazilian coast, it has been possible to demonstrate Holocene shoreline shifts, as a consequence of neotectonics. For instance, in the Todos os Santos bay (state of Bahia), lying upon the Recôncavo marginal basin, vertical movements of fault blocks produced shifts of Holocene shorelines (Martin *et al.* 1984a, 1986). The same could be true for portions of state of Rio de Janeiro coast, lying upon the Guanabara graben (Martin *et al.* 1980), for the south of São Tomé cape (Martin *et al.* 1984b), for differences in thicknesses of marine deposits between two wells drilled by IGG (Instituto Geográfico e Geológico) in the Cananéia- Iguape coastal plain (Suguio & Petri 1973; Souza 1995), etc.

Among the mentioned examples, the portion of the Brazilian coast situated between 120 30' and 130 51' southern latitude, dominated by the Recôncavo marginal basin (state of Bahia), was probably the most studied. There is a reasonable knowledge on Quaternary marine sediments overlaying Cretaceous deposits (Bittencourt *et al.* 1979). This area is located on the Bahia state Oriental Shield, confined within São Francisco craton (Fig. 7), which was subjected to the Transamazonian Regional Deformation during the Proterozoic (1.9 to 2.1 by ago), however record of any geological event was still characterized yet from that time to Jurassic. At the end of this period, huge Afro-Brazilian Depression was formed, which was subsequently filled by Jurassic, Cretaceous and Tertiary sediments (Fig. 3 and 4). This basin was strongly affected by synsedimentary and post-sedimentary movements, represented by gravity faults and faintly sloping anticlines, delimited system of marginal faults, like the Salvador fault at the east with a total displacement of about 4,000m, and the Maragogipe fault at the west with 300m (Fig. 7).

In different sectors around the Todos os Santos bay, there are geomorphological evidences of Quaternary tectonic activities. Entirely contained within Recôncavo marginal basin and surrounded by Precambrian crystalline rocks, the situation of this bay could be suggestive of an origin related to a differential erosion mechanism. Nevertheless, a momentary view of the associated hydrographic net shows that the drainage

towards the bay is embryonary which, according to Tricart & Cardoso da Silva (1968), is an evidence of negligible differential erosion, being necessary to assume an age geologically recent for the origin of Todos os Santos bay. This idea was also vindicated by King (1956) and Howard (1962). In fact, very indented and small drowned valleys occurring around the bay are hinting at differential behavior between fault blocks, and Salvador and Maragogipe faults, previously mentioned, exhibit many indications of neotectonic activities, mostly represented by waterfalls associated to scarps.

Along the coast of state of Bahia there are two generations of sandy marine terraces related to two transgressive-regressive episodes (Bittencourt *et al.* 1979), overlying older rocks. Excepting some coral samples, which supplied with $^{10}\text{Be}/^{10}\text{B}$ dates (Martin *et al.* 1982), there are no other absolute ages to allow reconstruction of relative sea-level curve for the penultimate transgressive episode. The most detailed Brazilian relative sea-level curve, for the last 7,000 years of the Holocene, has been delineated for the Salvador area using 66 radiocarbon ages, obtained from samples collected in a geologically homogeneous sector of the coast.

The Recôncavo marginal basin in the Todos os Santos bay area, based on geomorphological characteristics and on distribution of Quaternary marine terraces, could be divided into many compartments. They can be grouped in two sectors, separated by an almost E-W oriented line going from Salvador to Nazaré, the sector A (southern) characterized by conspicuous presence of Pleistocene marine terraces, and the sector B (northern) corresponding to the Todos os Santos bay, where only Holocene marine terraces are represented (Fig. 7).

The deep geological structures of the Recôncavo marginal basin, as an oil-producing area, are very well known. An E-W cross-section through this basin shows that actually it is formed by a series of compartments limited by more-or-less parallel fault blocks (Fig. 7). On the other hand, these fault blocks are clearly unlevelled themselves, being enough easy to re-find the compartments delineated by morphological characteristics and differences in heights of ancient strandlines. So, in the fault block 2, where a clear Quaternary subsidence is suggested, a lowering of ancient shoreline is evident and analogously the fault block 3 is characterized by a less intensive subsidence. The fault block 4, situated on a structural high, probably remained stable during the Quaternary. The informations from deep geological structures support the idea of subdivision in northern and southern sectors limited by the Barra fault, as well as the Quaternary shorelines unlevelings, which show that the fault blocks have been active until the Holocene.

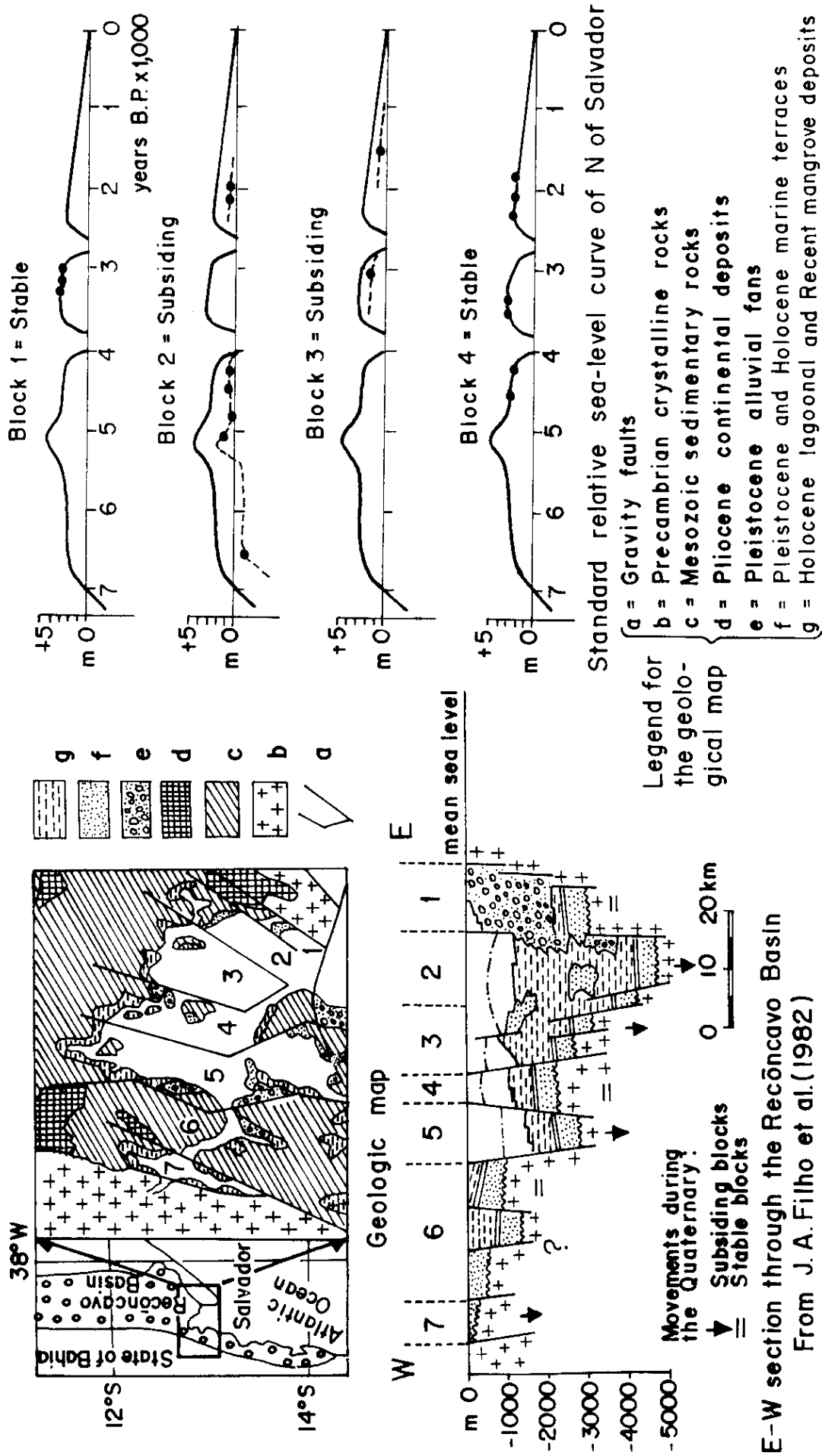


Figure 7 - Vertical movements of fault blocks of the Recôncavo marginal basin, within the Todos os Santos bay (state of Bahia), during the past 7,000 years (Martin et al. 1984a, 1986).

FINAL CONSIDERATIONS AND RECOMMENDATIONS

Considering numerous evidences here presented, undoubtedly the important role of neotectonics in the evolution of the Brazilian coast is almost unquestionable. Nevertheless, if there are much speculations, it lacks more scientific works based on actual field and laboratory data, which are necessary to get a more reliable picture of this subject.

Even the most detailedly studied marginal basins, major part of their knowledge is restricted to Cretaceous and Paleogene, and very rarely they have been studied from neotectonic viewpoint.

Then, a lot of work embracing several time and space scales studies are needful and recommendable until to have a better idea about the true role played by neotectonics in the evolution of the Brazilian coast.

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