Neotectonic Movements on a Passive Continental Margin: Salvador Region, Brazil

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In some restricted sectors of the Brazilian coast, it has been possible to demonstrate the role played by the vertical tectonic movements in shifting Quaternary shorelines. Within Todos os Santos Bay, State of Bahia, located in the Reconcavo graben, vertical movements of faulted blocks produced shifted Holocene shorelines. This neotectonism is related to the reactivation, during the Quaternary, of faults bounding the several crustal blocks which form the sedimentary basin. These deformations are not uniform throughout the basin.

INTRODUCTION

The interest of Brazilian specialists in seismological and neotectonic research in coastal areas was inhibited for a long-time, because the continental margins of Atlantic type were generally assumed to be very stable regions. Nevertheless, from the sixteenth century until the present days, earthquakes have been recorded in different parts of Brazil.

Up until now, structural features indicating neotectonic activities along the Brazilian continental margin and adjacent emerged portions have scarcely and only locally been recognized. Ponte (1969), in the Alagoas-Sergipe basin, and Almeida (1969), Bjornberg et al. (1972), Fulfaro and Ponçano (1974), Hasui et al. (1978), and Asmus and Ferrari (1978), in a narrow emerged portion of southeastern Brazil, presented the most convincing evidence of neotectonic activities.

In the State of Bahia, Sampaio (1916, 1919, and 1920) and Branner (1920) reported some earthquakes during the first two decades of this century in the Reconcavo basin, graben generated during the separation of the African and South American continents (Fig. 1). According to these authors, some witnesses revealed that these seismic events can be considered to have been "very strong." Branner (1920) even presents an isoseismic contour map based on these data.

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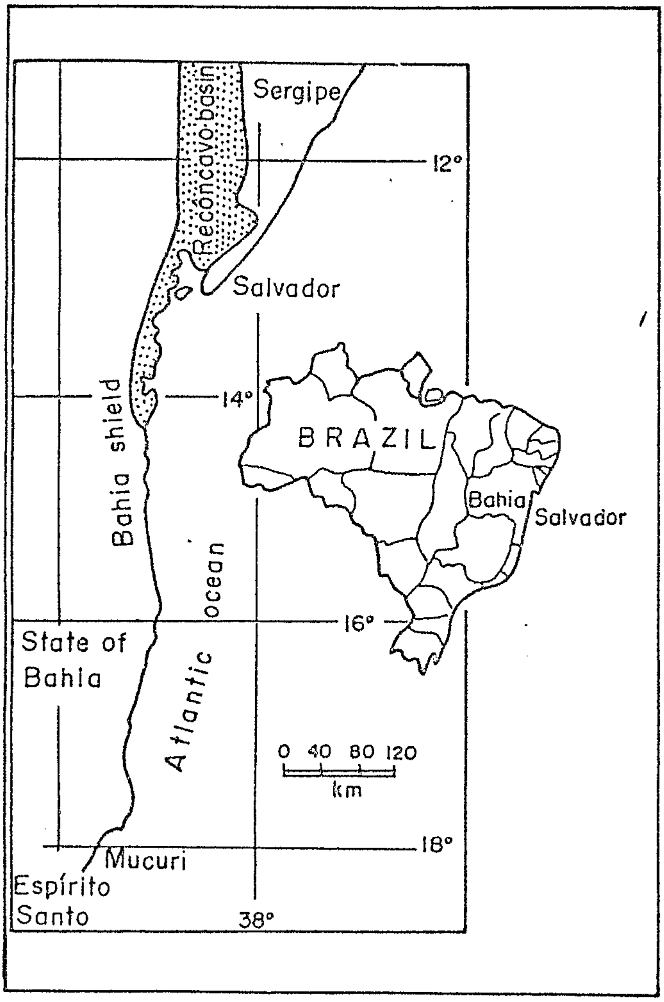

Figure 1. Location map of the study area.

Other authors, considering different kinds of evidence, believe in neotectonic activities in this area (King, 1956; Putzer, 1959; Grabert, 1960; Tricart and Cardoso da Silva, 1968; Suguio and Martin, 1976; Pedreira, 1976; Inda and Barbosa, 1978; Bittencourt et al., 1979; Haberhlenger, 1979; Martin et al., 1980; Fernandes Filho et al., 1982).

The main objective of this paper will be to recognize and try to interpret some geomorphologic and geologic evidence indicative of neotectonic activities in the part of the State of Bahia located between 12°30′ and 13°51′ S that contains the southern extremity of the Reconcavo basin (Fig. 1). This area has been selected because of the above-mentioned reports of seismic activity and because we have reasonable litho- and chronostratigraphic knowledge of the Quaternary marine sediments overlying the Reconcavo basin Cretaceous deposits (Bittencourt et al., 1979, and Martin et al., 1980).

HISTORICAL GEOLOGY OUTLINE

The studies area belongs to the Eastern Bahia shield, part of the São Francisco craton. The Eastern Bahia shield is a crustal zone deformed during the geodynamic event that occurred toward the end of the Lower Proterozoic, between 1.9 and 2.1 b.y.a. (Transamazonic Regional Deformation) (Inda and Barbosa, 1978).

No record of geological events has remained from the Precambrian to the beginning of the Jurassic. A huge depression, known today as the "Afro-Brazilian depression," formed at the end of the Jurassic, in the present coastal area, and then began to be filled in by essentially continental deposits. This Jurassic basin was affected by deformational movements, as is evident from gravity faults and gently dipping anticlinal folds. When, at the onset of the Early Cretaceous, these movements started to exceed plasticity limits, the structural highs began to evolve into a system of marginal faults marking the borders of the Reconcavo basin. To the east, the system includes the Salvador fault, with a total slip of 4000 m, and to the west the Maragogipe fault, with a total slip of 300 m (Fig. 1) (Asmus and Ponte, 1973; Asmus and Porto, 1980; Fernandes Filho et al., 1982).

In the meantime, during the Early Cretaceous, the basin substrate began to subside, forming a rift valley. Invasion by the sea resulted in sedimentation of deep water deposits and marginal deltas. After a period of inactivity, another sequence of tectonic movements began, this time more vigorous and extensive. The end of the Cretaceous was characterized by progressively diminishing tectonic activity, by loss of its identity and integration into the shield. Some restricted records from northeast Salvador indicate that a brief marine incursion took place in the Reconcavo basin during the Miocene (Ghignone, 1978). The Pliocene is represented by alluvial fan-type continental deposits consisting of sandy and clayey sediments with variegated color. In the State of Bahia they are known as the Barreiras Formation. Two generations of sandy marine terraces related to two distinct transgressive episodes (Bittencourt et al., 1979) have been recognized along the Bahia coastline during the Quaternary. Coral samples from the basal portion of the older terrace have been dated to ca. 120,000 years B.P. (Bernat et al., 1982, and Martin et al., 1982), suggesting that it is of Pleistocene age. At that time sea level was about 8 ± 2 m above the present level (Martin et al., 1980). The more recent terraces are Holocene in age and related to the end of the last great transgression, which crossed the present sea level at about 7000 years B.P. (Martin et al., 1979). During the maximum, about 5100 years B.P., relative sea level was about 4.8 ± 0.5 m above the present level.

The evidence discussed herein shows that some sectors of the Mesozoic graben exhibited differential structural evolution during the Quaternary.

EVIDENCE OF QUATERNARY TECTONISM

Geomorphologic Evidence

Geomorphologic evidence confirms Quaternary tectonism in different parts of the studied region. One of the most remarkable physiographic features within the region is the Todos os Santos bay (Fig. 2). As the bay is situated entirely on the Mesozoic sedimentary rocks of the Reconcavo basin, enclosed by crystalline rocks, its orgin could be explained by differential erosion. Moreover, a detailed study of the hydrographic net shows that its drainage toward the bay is embryonal. In fact, the water separation line is situated 1 to 2 km from the margins. This situation, according to Tricart and Cardoso da Silva (1968), indicates that differential erosion is negligible and of very recent origin. This idea was also held by King (1956), Howard (1962), and Bittencourt et al. (1976). As it is, the bay shows some geomorphologic characteristics of a submerged area, in that it has many islands, indented margins, and several estuaries. The Todos os Santos bay was probably formed by differential subsidence of a series of faulted blocks.

Two other equally remarkable geomorphologic indicators are the Salvador and Maragogipe faults (Fig. 2). The Salvador fault exhibits features of recent movements within the sector between Porto da Barra and Lobato (Fig. 2). In this region the Precambrian crystalline rocks form cliffs at the coast whereas the northeastern portion of the fault is covered by Pliocene sediments of the Barreiras Formation and seems to have been inactive during the Quaternary. On the other hand, the greater part of the Maragogipe in the study area shows indications of recent reactivation. In the portions from the northern extremity of the Iguape bay to Jequiriça river, and from Valença to Igrapiuna, the Precambrian highlands form an extensive, more than 100 m-high, fault scarp. Some rivers did not have enough time to carve down their valleys and flow into Todos os Santos bay as water falls. Elsewhere, the portion of the sedimentary basin at the foot of the fault scarp is depressed and occupied by small bays or tidal creeks, as for example in the Iguape bay area and between Valença and Itubera. Taken together, this evidence suggests that Maragogipe fault is still active and causing subsidence of the areas mentioned.

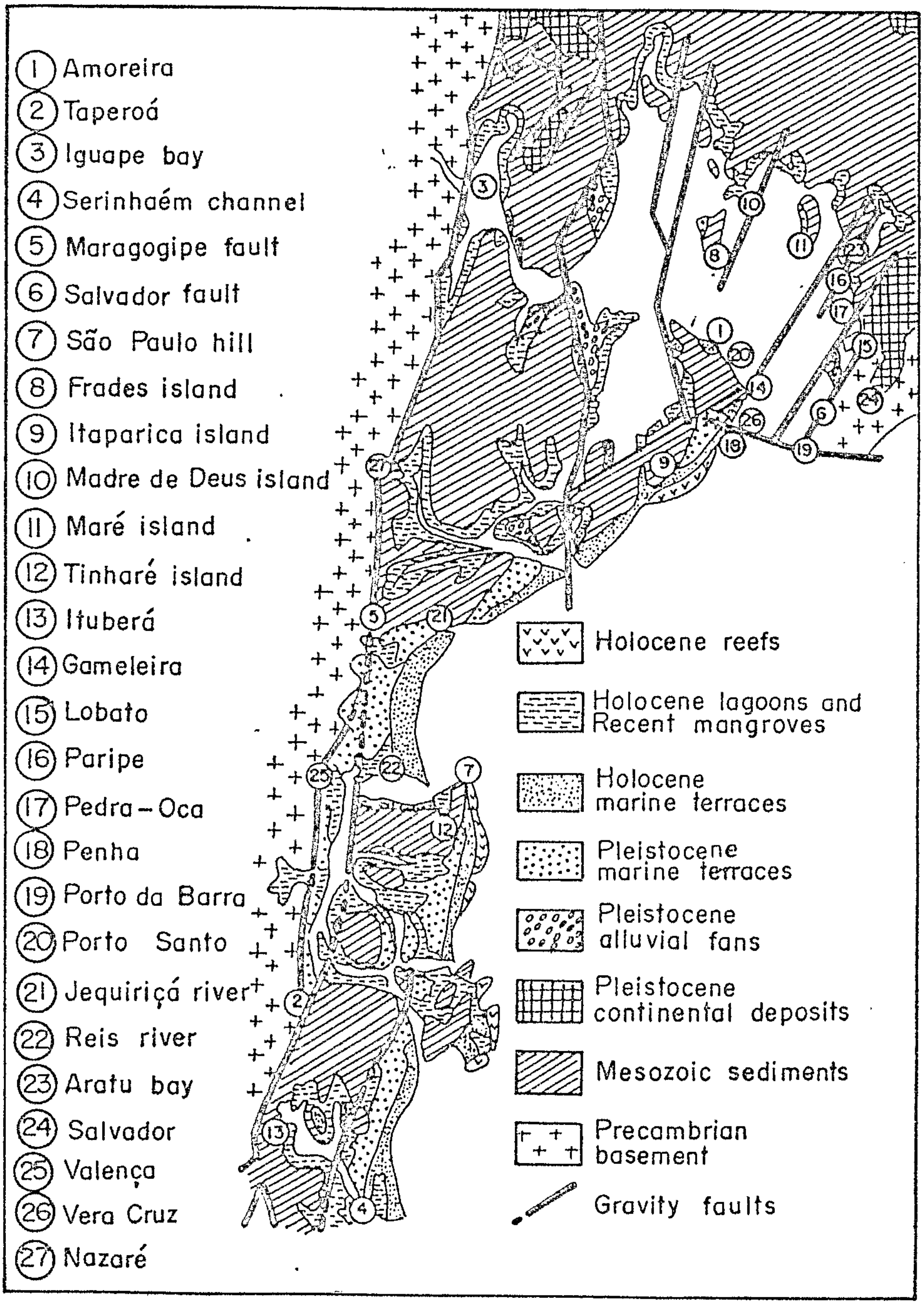

Figure 2. Geological map of southern part of the Reconcavo basin (Martin et al., 1980).

Evidence Related to the Geographic Distribution and Characteristics of the Pleistocene Marine Terraces

As absolute age determinations are lacking, it is not possible to reconstruct relative sea level heights during the penultimate marine transgression (ca. 120,000 years B.P.). However, it is possible to verify if the geographic distribution of the deposits provide some data about possible tectonic activity during the Quaternary. Two distinctive areas, separated by a straight line trending E–W, from Vera Cruz (Itaparica Island) to Nazare, have been identified. At the northern part (Todos os Santos bay) there are no Pleistocene terraces, with the exception of three occurrences situated at the north of Itaparica island and in the Frades and Fontes islands. It is interesting to note that these occurrences are situated within a central band parallel to the margins of the graben. At the southern end of the Vera Cruz–Nazare line, the Pleistocene marine sandy terraces are very well developed. Therefore, it is possible that this line represents an important structural boundary.

Moreover, drainage on Tinhare island is toward the continent, suggesting that the surface of the terrace dips landward, contrary to the original situation, when it was gently sloping toward the ocean. To the north and south of Tinhare island, drainage of Pleistocene terraces is toward the ocean, following the original slope.

Evidence Related to Difference in Level of Holocene Shorelines

To reconstruct the position of an ancient sea level it is necessary to define an indicator in time and space. The position (present height) of the indicators measured in the field is a function of sea level fluctuations (eustasy) and of vertical changes in the earth's crust (tectonism and isostasy). Therefore, it is possible to measure the relative position only. Sea level fluctuations are related to changes in the volume of the ocean water (glacio-eustasy) and in the volume of the oceanic basins themselves (tectono-eustasy), and to deformations of the surface of the geoid (geoidal-eustasy). The first two factors are of regional influence. Two indicators of the same level, when separated by a short distance, must be situated at the same height. Difference in elevation between closely spaced levels can be caused only by crustal deformation.

In a homogeneous sector of the Salvador region, situated to the north of the sedimentary basin, it was possible to construct a relative sea level fluctuation curve for the past 7000 years, based on 66 positions of ancient relative sea levels (Fig. 3). Another sea level fluctuation curve constructed with data from the Precambrian coast to the south of the sedimentary basin, exhibits the same characteristics as the Salvador curve. Both curves seem to indicate that the Eastern Bahia shield has been subjected to the same evolution for the past 7000 years. Therefore,

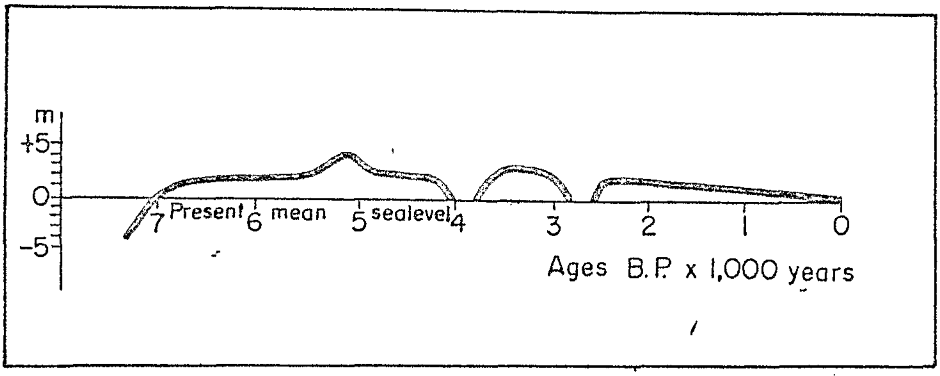

Figure 3. Curve showing the relative sea level fluctuation during the last 7000 years in the Salvador area (Martin et al., 1979).

reconstruction of ancient sea levels in different sectors of the sedimentary basin can be conceived by taking the Salvador curve as reference standard. This will allow us to verify if these sectors have evolved in the same way as the Eastern Bahia shield and to compare sectors among themselves. Table I reveals that some sectors of the sedimentary basin show elevations that are different from those of the Salvador curve. Moreover, it is remarkable that these differences in elevation are not homogenous.

COMPARTMENTATION OF THE RECONCAVO BASIN AS A FUNCTION OF THE DATA SUPPLIED BY THE MORPHOLOGY AND DIFFERENCE IN ELEVATION OF HOLOCENE SHORELINE

The data furnished by the morphology, by the distribution of Pleistocene terraces, and by differences in elevation of Holocene shorelines with respect to the Salvador curve, allow us to subdivide the Reconcavo basin into several compartments (Fig. 3). Firstly, we may distinguish two major units separated by a line trending E–W from Salvador to Nazare and crossing the Itaparica island. The northern unit corresponds to the Todos os Santos bay. In both units a number of compartments maybe recognized (Fig. 4).

Northern Unit

Compartment No. 1

This compartment lies in a narrow zone parallel to the easternmost boundary of the graben. At Pedra Oca, the ancient sea level does not show any difference in elevation with respect to the Salvador curve (Table I and Fig. 5). The Barreiras Formation, which covers the Salvador

TABLE I. Positions of ancient sea levels in several sectors of Todos os Santos Bay compared with positions of the same age on the Salvador curve.

Compartments (See Fig. 4)	Location (See Fig. 2)	Sample No.	Radiocarbon age (y.B.P.)	Position of sea level (m)	Corresponding position in the Salvador curve (m)
1	Pedra Oca	B 50	3260 ± 100	+3,0 (±0,5)	+3,2 (±0,5)
		B 51	3110 ± 105	+3,0 (±0,5)	+3,1 (±0,5)
		B 53	3100 ± 120	+3,0 (±0,5)	+3,1 (±0,5)
		B 52	3030 ± 120	+3,0 (±0,5)	+3,0 (±0,5)
2	Paripe	B 29	6600 ± 180	≃ −1,0	+2,0 (±0,5)
		B 31	5120 ± 120	≃ +1,5	+4,7 (±0,5)
		B 30	4840 ± 120	≃ 0,0	+3,0 (±0,5)
		B 28	4245 ± 100	≃ +0,5	+2,5 (±0,5)
		B 10	2105 ± 70	≃ +0,5	+2,0 (±0,5)
		B 7	2060 ± 100	≃ +0,5	+2,0 (±0,5)
	Aratu bay	B 15	4405 ± 110	≃ 0,0	+2,5 (±0,5)
3	Frequesia	B 174	1685 ± 85	+0,8 (±0,5)	+1,6 (±0,5)
	Maré island	B 176	3110 ± 105	+2,3 (±0,5)	+3,0 (±0,5)
4	Frades island	B 178	3595 ± 120	+3,5 (±0,5)	+3,4 (±0,5)
		B 49	4245 ± 95	+2,5 (±0,5)	+2,5 (±0,5)
		MD1	3550 ± 130	+3,3 (±0,5)	+3,4 (±0,5)
		MD2	3450 ± 120	+3,3 (±0,5)	+3,3 (±0,5)
		Bah.244	1470 ± 100	+1,3 (±0,5)	+1,4 (±0,5)
	Porto Santo	B 43	4525 ± 120	+2,8 (±0,5)	+2,7 (±0,5)
	Penha		2450 ± 95	+2,3 (±0,5)	+2,4 (±0,5)
	Amoreira	B 281	2280 ± 120	+2,0 (±0,5)	+2,2 (±0,5)
	Gameleira	B 283	1915 ± 100	+2,0 (±0,5)	+1,9 (±0,5)
8	Jequiriçá	B 36	5745 ± 140	+2,3 (±0,5)	+2,3 (±0,5)
	Reis river	B 32	4700 ± 160	+2,7 (±0,5)	+2,8 (±0,5)
11	Serinhaém	B 87	2405 ± 100	+2,3 (±0,5)	+2,3 (±0,5)

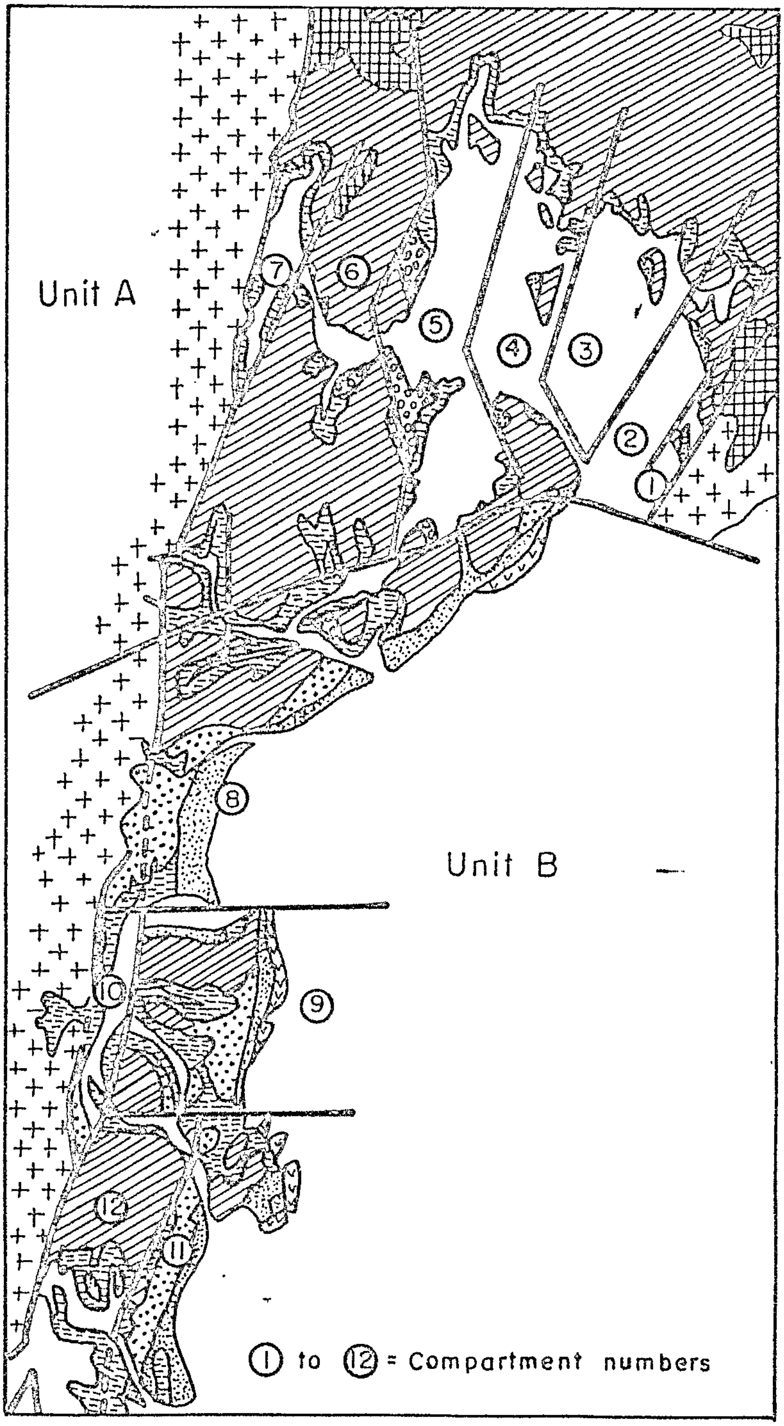

Figure 4. Compartmentation established as a function of Quaternary geological information.

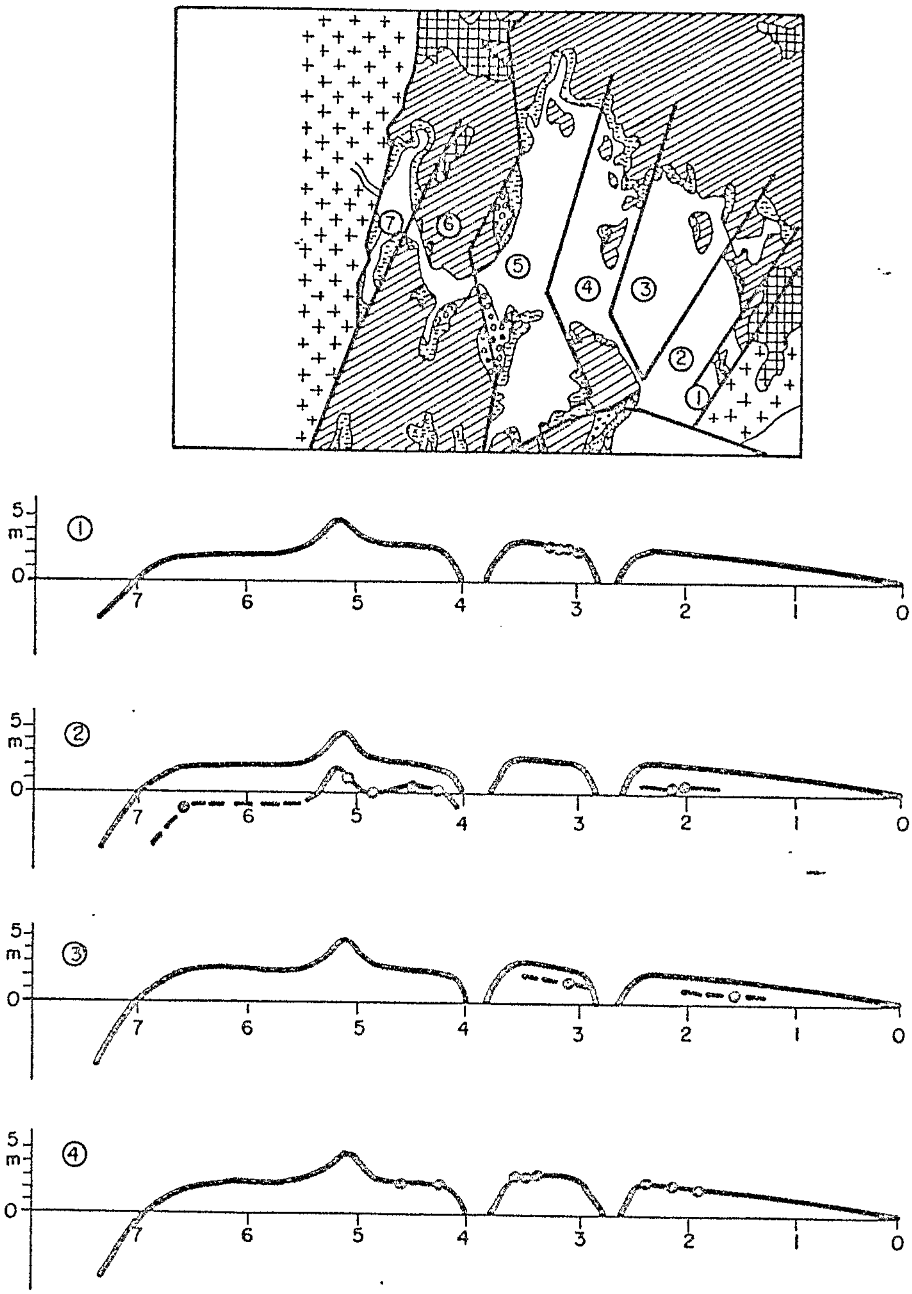

Figure 5. Positions of ancient relative sea levels (dots) in several compartments (1 to 4) compared with the Salvador curve.

fault to the north, was not affected by reactivation. To the south it seems that the fault line was reactivated during the Quaternary, being subjected very recently to subsidence.

Compartment No. 2

This compartment, parallel to the previous one, is separated at the western side by a line running from the Aratu bay entrance to the northern extremity of Itaparica island. Ancient relative sea levels reconstructed for the Paripe and Aratu bay region (Table I and Fig. 1) differ from those of the Salvador curve. The compartment appears to have been in relative subsidence during the Quaternary.

Compartment No. 3

This compartment also lies parallel to the previous ones, bounded at the south by the northern portion of Itaparica island. Evidence of ancient sea levels on the island is in concordance with the Salvador curve. The western boundary of the compartment is probably situated near the rectilinear eastern coast of Frades island. Contrary to the western coast, the eastern cost of this island has no marine terraces. Two ancient relative sea level points lie outside the Salvador curve. The amplitude seems to be less important than in Compartment No. 2.

Compartment No. 4

This compartment, very irregular, embraces the northern part of the Itaparica island and Frades, Madre de Deus, das Vacas, das Bimbarras, and das Flores islands. Only in this area of Todos os Santos bay have Pleistocene marine terraces been found. Ancient relative sea level reconstructions do not show discrepancies with respect to the Salvador curve (Table I and Fig. 5). The western boundary of the compartment corresponds to the western coast of northern Itaparica island and the western coast of das Fontes island. This compartment shows the same tectonic behavior as the Precambrian basement.

Compartment No. 5

The western boundary of this compartment is characterized by important scarps delineating the eastern margin of the Todos os Santos bay. The compartment seems to have been subjected to relative subsidence during the Late Quaternary, since there is no evidence of relative sea levels higher than the present one.

Compartment No. 6

This compartment is situated between Todos os Santos bay and Iguape bay. As this area is situated almost entirely on the continent, no ancient relative sea levels could be reconstructed. Probably, however, it remained stable throughout the Late Quaternary.

Compartment No. 7

This compartment lies at the foot of the cliff of the Maragogipe fault, which forms the western boundary of the graben. It comprises the Iguape bay, which shows clear evidence of subsidence. The compartment probably subsided during the Late Quaternary.

Southern Unit

Compartment No. 8

The northern boundary of this compartment is formed by the Salvador-Nazare line while the southern limit is constituted by the line running E–W from Valença to São-Paulo hill. Two reconstructed ancient relative sea levels obtained in the area agreed with the Salvador curve (Table I), suggesting that during the Late Quaternary its evolution was the same as that of the Precambrian basement.

Compartment No. 9

The southern limit of this compartment is parallel to the E–W line from Valença to São-Paulo hill. To the west it is bounded by the Valença-Taperoa lowlands. As mentioned previously, the rivers on the Pleistocene marine terraces of this area flow landward, indicating that the area tilted toward the continent after the transgressive episode of ca. 120,000 years B.P.

Compartment No. 10

This compartment forms a narrow band at the foot of the Precambrian cliff. It shares its western border with Compartment No. 9. The area is presently occupied by a lagoon. There is no evidence of Holocene sea levels higher than at present. This compartment probably has been subjected to subsidence during the late Quaternary.

Compartment Nos. 11 and 12

Scarce information is available for the area south of Compartment No. 9, but it is possible to delineate two other compartments. The first one, lying seaward, contains Pleistocene marine terraces with a drainage system oriented toward the sea. The second one, lying landward, shows features of subsidence. An ancient relative sea level reconstructed in the first compartment (No. 11), was in agreement with the Salvador curve.

COMPARTMENTATION BASED ON QUATERNARY GEOLOGY AND STRUCTURAL FRAMEWORK OF THE RECONCAVO BASIN

The structural framework of the Reconcavo basin is very well established because it has many producing oil fields. The basin is made up of a series of fault blocks associated with more or less parallel gravity faults. In general, these fault blocks show tilt and differential vertical displace-

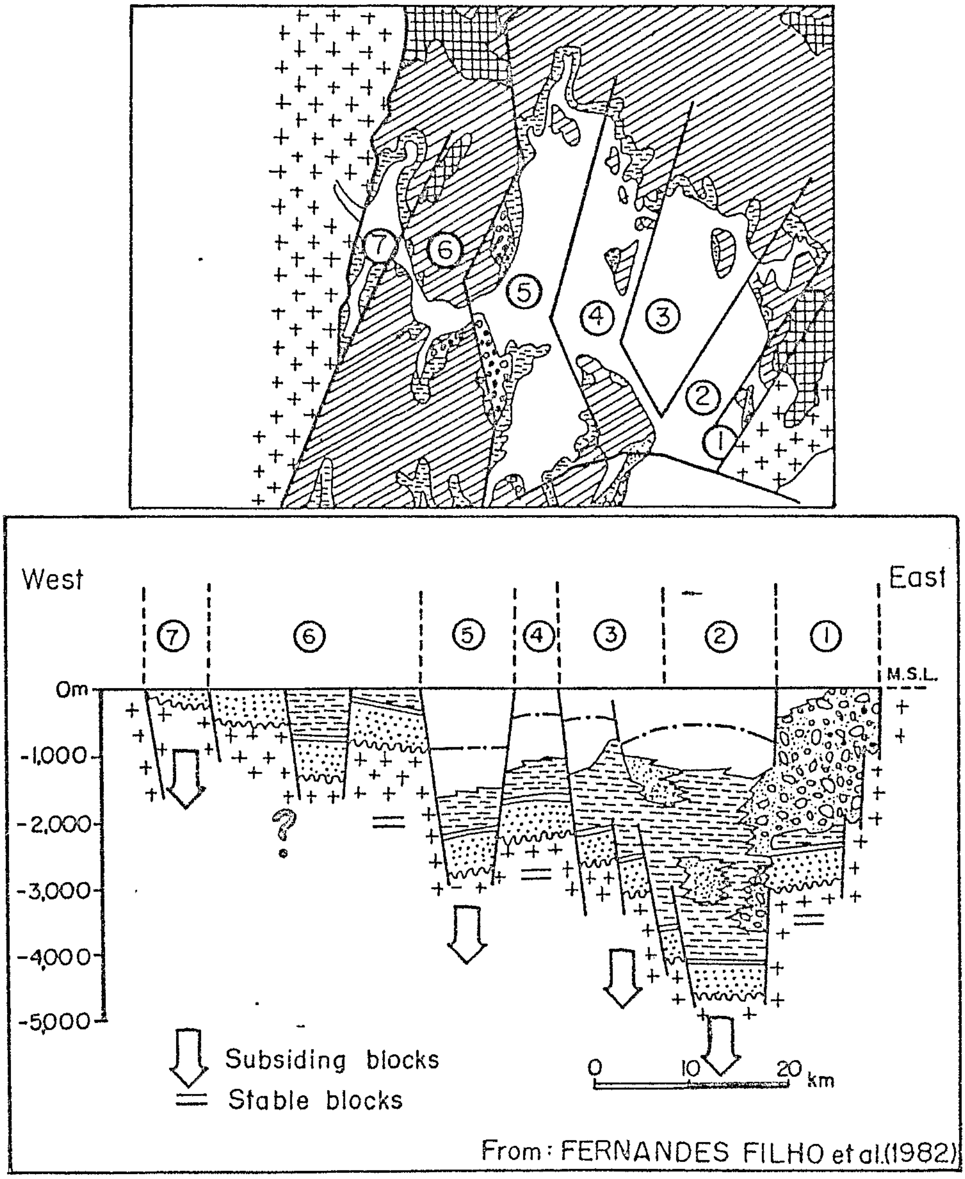

Figure 6. Comparison among compartmentation based on Quaternary geology and the structural framework of the Reconcavo basin.

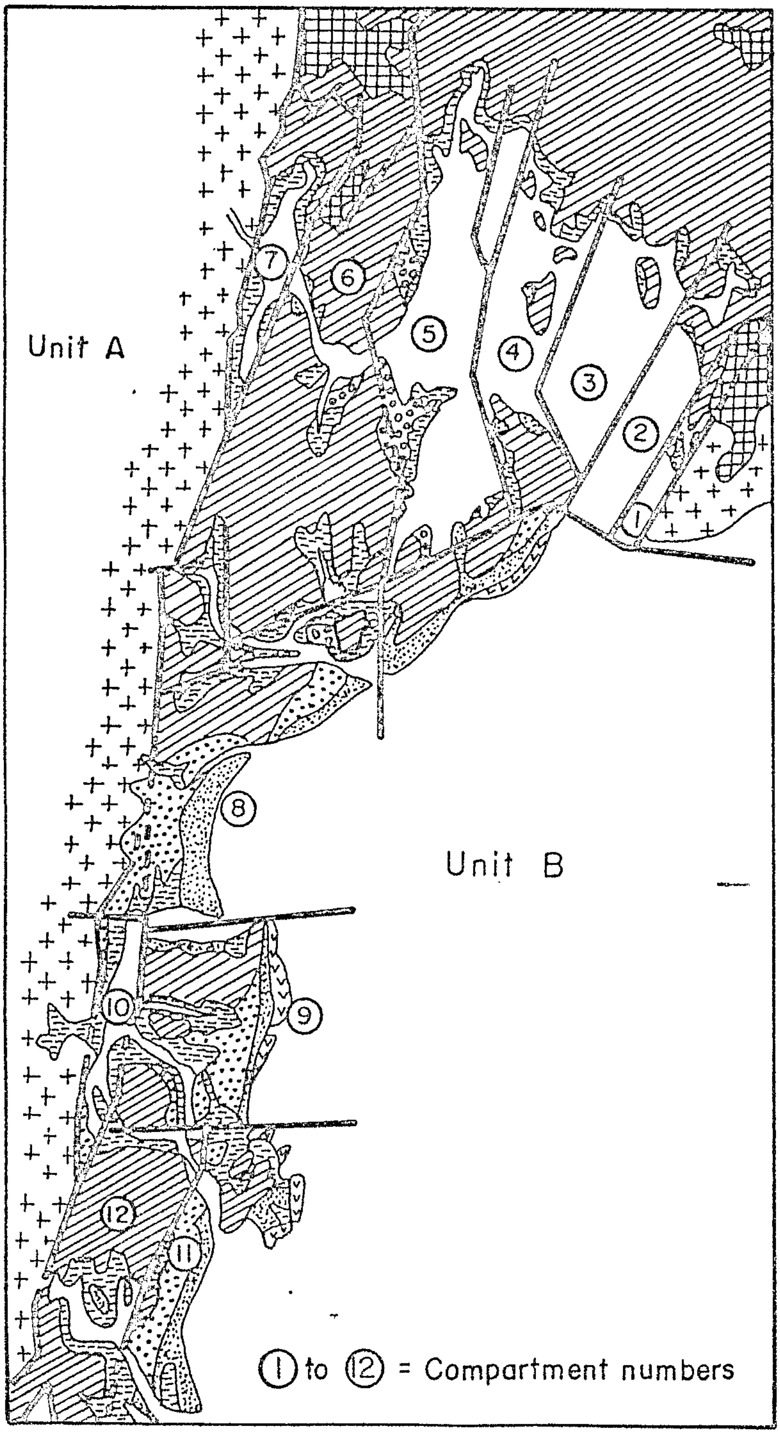

Figure 7. Synthesis map of the compartmentation (structural and Quaternary geology data).

ment. The fault blocks correspond perfectly to the compartment distinguished above on the basis of Quaternary geology. For example, fault block no. 2, characterized by maximum subsidence during the Mesozoic, showed clear evidence of subsidence during the Quaternary, too. Similarly, fault block no. 3 was much less active during both Mesozoic and Quaternary times. Compartment no. 4, which was stable during the Quaternary, is situated on a structural high.

The subsidence which occurred along the western boundary of the basin during the Quaternary only appears south of Iguape bay. Therefore, it does not appear in the cross-section of Figure 6. Information from "deep geology" (oil prospecting) confirms the existence of a northern and a southern unit in the Reconcavo basin (Fernandes Filho et al., 1982). The boundary between these two units corresponds to the Barra fault, which runs through the south of Salvador and through Itaparica island, converging with the Maragogipe fault south of Nazare.

So, we have been able to notice striking agreement between the Quaternary geology and structural framework of the Reconcavo basin (Fig. 7). Moreover, information from the present morphology and from the position of ancient Quaternary shorelines allowed us to infer that some faults were reactivated during the Quaternary.

CONCLUSIONS

Continental margins of Atlantic type are normally considered to be stable areas, but in some parts of Brazil, namely in the Reconcavo basin, noticeable vertical movements have been recorded during the Quaternary. Information from present morphology and ancient Holocene shorelines have been used to demonstrate these tectonic activities. Data from deep geology show that the Reconcavo basin is made up of fault blocks with differential evolution through time. Some of the fault lines bounding the blocks were active, while others remained completely inactive during the late Quaternary.

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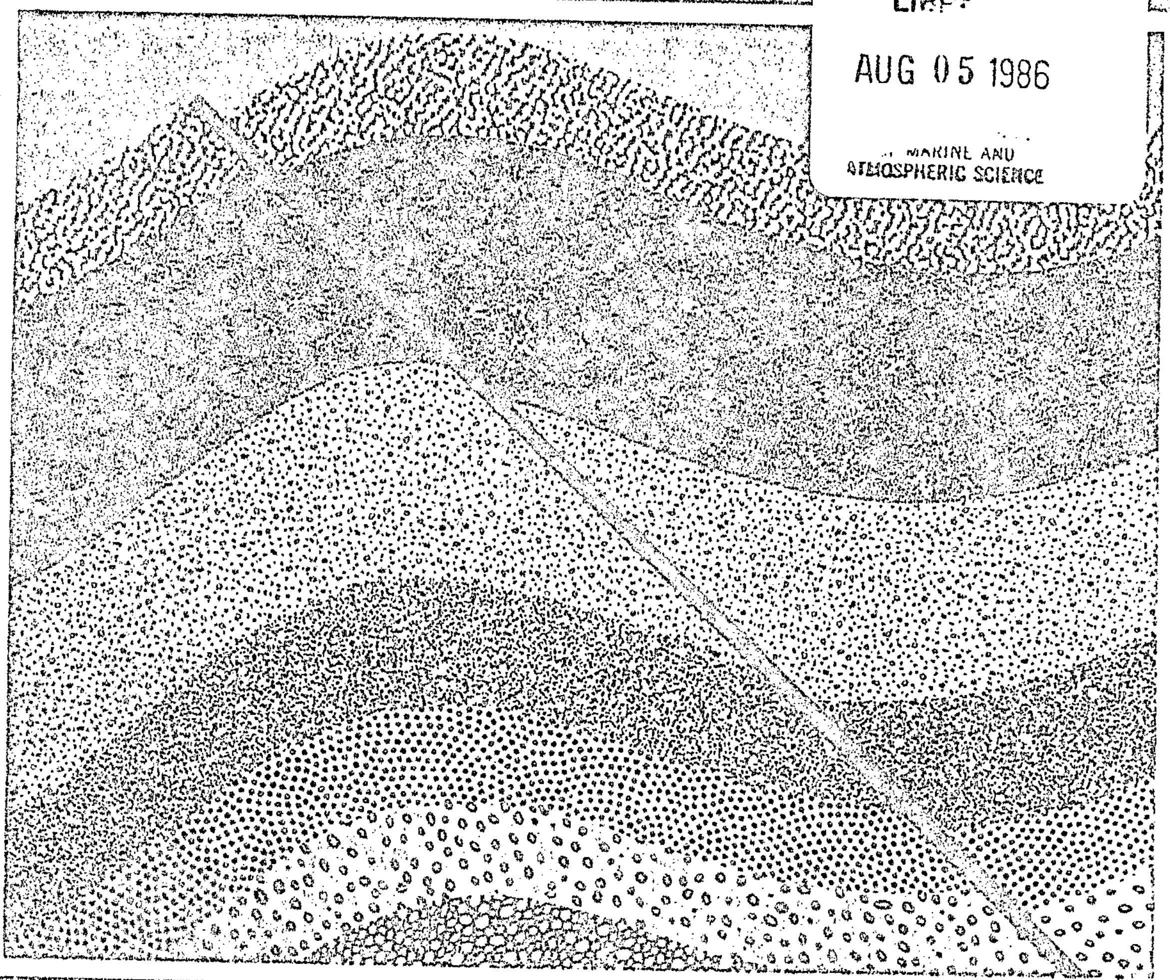

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