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GEOID CHANGE INDICATIONS ALONG THE BRAZILIAN COAST DURING THE LAST 7,000 YEARS

INDICES DE DEFORMATION DE LA SURFACE DU GEOIDE, LE LONG DU LITTORAL BRESILIEN, AU COURS DES 7 000 DERNIERES ANNEES

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ABSTRACT

Many radiocarbon ages have allowed us to reconstruct sea-level changes during the past 7000 years along 2000 km of the Brazilian coastline. From these data, it has been possible to define sea-level fluctuation curves for different sectors. Despite these curves being very similar in shape, it is possible to observe some differences in amplitude which cannot be fortuitous.

The geoid map of Brazil shows that the coastline of the State of Bahia, approximately in the N-S direction, is parallel to the isobases of the geoidal height. In this case, shifts between different sea-level curves are not observed: for instance the 5100 years B.P. maximum is everywhere situated 5.0m above the present level. Otherwise, the coastline of the States of Sao Paulo and Parana, in the NE-SW direction, intercepts the isobases of the geoidal height. In this case, the sea-level curves are clearly shifted: for instance the 5100 years B.P. maximum varies between 4.5 and 2.5m above the present level.

The possibility of neotectonic movements being eliminated, it can be deduced that these shifts could have been caused by a deformation of the present geoid surface.

RESUME

De nombreuses reconstructions d'anciennes positions du niveau moyen de la mer, au cours des 7000 dernières années ont pu être effectuées sur plus de 2000 km du littoral brésilien. A partir de ces données, plusieurs courbes de variation du niveau relatif de la mer ont pu être construites. Celles-ci présentent des formes très semblables mais il est toutefois possible de noter des différences d'amplitude qui ne semblent pas être fortuites.

Un examen de la carte géoïdale du Brésil montre que le littoral de l'Etat de Bahia, de direction approximativement N-S, est parallèle aux lignes d'égale élévation géoïdale. Dans ce cas, on ne note pas de décalage entre les courbes : par exemple, le maximum de 5100 ans B.P. se situe partout approximativement à 5,0 m au-dessus du niveau actuel. Par contre, le littoral des Etats de Sao Paulo et du Paranà, de direction NE-SW, recoupe les lignes d'égale élévation géoïdale. Dans ce cas, les courbes présentent des décalages nets : par exemple le maximum de 5100 ans B.P. se situe selon les endroits entre 4,5 et 2,5 m au-dessus du niveau actuel.

L'éventualité de mouvements tectoniques différentiels étant écartée, on en déduit que ces décalages auraient pu être provoqués par une déformation du relief géoïdal actuel.

INTRODUCTION

The relative sea level fluctuations during the Quaternary, along more than 2,000 km of the Brazilian coast, are rather well known (Martin et al., 1980). Several records indicating two periods of sea level higher than today have been observed. The oldest records are constituted by extensive sandy terraces frequently with superimposed traces of ancient beach ridges. During its maximum transgression, dated at about 120,000 years B.P., according to coral remains sampled along the coast of the State of Bahia (Martin et al., 1982), sea level was situated about 8±2m above the present level. Unfortunately, there are no samples to date this event in other sectors of the littoral, hence a precise reconstruction, in space and time, of old sea levels is not possible. On the other hand, numerous radiocarbon ages have allowed us to reconstruct the positions of ancient sea levels during the past 7,000 years. For this period, it has been possible to obtain partially or fully delineated curves for differents sectors of the coast (Fig.1).

Relative sea level fluctuations are related to true variations of sea level (eustasy) as well as to modification of the earth's crust (tectonism and isostasy). The ocean-water-volume changes (glacial-eustasy) and the ocean-basin-volume changes (tectono-eustasy) are worldwide phenomena. Changes of the surface of the geoid (geoidal-eustasy) and crustal movements have only regional or local influence. Thus, shifts in positions of contemporaneous ancient relative sea levels can be interpreted as a consequence of geoid change or vertical displacements of the earth's crust. If tectonism can be eliminated as a major cause of these shifts they must be produced by geoid change (Morner, 1976).

Mean sea level correspond to the gravity equipotential surface or geoid. Very important irregularities on this surface have been found since the application of satellites in geodetic measurements. The difference between the true geoid surface and that of a regular ellipsoid, corresponding to homogeneous earth, can be as great as 80m. Obviously, geoid surface changes could be produced as a consequence of modifications in mass distribution in the earth's interior, variations in the earth's orbit, etc... Around the continents, this phenomenon will produce transgressions and regressions.

RELATIVE SEA LEVEL FLUCTUATIONS DURING THE LAST 7,000 YEARS FOR SEVERAL SECTORS OF THE BRAZILIAN COAST

A valid relative sea level fluctuation curve can be obtained only by using the information which come from a homogeneous sector where the local phenomena are essentially uniform and equal. Very frequently, we are faced following dilema: (a) to construct a curve based on a great number of data, in which case, however, we need to use information from a relatively long portion of coast where the local factors could not be the same in all the sector; (b) to consider a very short portion of coast, although in this case the amount of information is frequently insufficient for compiling very accurate and complete curves.

In this paper, we consider short sectors of the coast with homogeneous characteristics. Thus, it has been possible to obtain partially or fully delineated curves (Fig.2).

(a) Sector N of Salvador (Bahia).

In this 50 km-long sector, it was possible to obtain about 60 positions of ancient relative sea levels distributed more-or-less regularly during the past 7,000 years. An accurate curve was delineated.

(b) Sector Itacaré-Ilhéus (Bahia).

In this 60 km-long sector, positions of ancient sea levels have been insufficient to delineate a whole curve. The portion outlined however, bears a strong resemblance with the Salvador curve.

(c) Sector Caravelas-Nova Viçosa (Bahia).

In this 30 km-long sector, it was possible to measure 11 ancient sea level positions, However, 7 of them are situated between 7,000 and 5,700 years B.P., allowing us to delineate a good curve for this period. All data agree with the Salvador curve.

(d) Sector of Angra dos Reis (Rio de Janeiro).

This sector is 70 km-long. It was possible to measure 17 ancient sea level positions, which were insufficient to delineated a complete curve. However, the portion of the curve between 2,500 years B.P. and today was well characterized. The existence of two maxima has been recognized: one slightly above 3.0m between 3,600 and 3,450 years B.P. and one another near 4.8m about 5,200 years B.P.

(e) Sector of Santos (São Paulo).

This sector is approximately 60 km long and 30 ancient sea level positions have allowed us to delineated a complete curve.

(f) Sector Iguape-Cananéia (São Paulo).

This sector is about 100 km-long and is especially characterized by numerous ages from shell-middens, which furnished additional informations about the evolution of ancient shorelines and relative sea levels (Martin et al., 1985). We also have data on the $\delta^{13}C$(PDB) variations in calcium carbonate shells as a function of time and which are indicative of change in lagoonal extension related to relative sea level. We measured 11 ancient sea level positions with accuracy, 7 of them are situated between 6,650 and 5,300 years B.P., thus allowing us to delineate this part of curve very well.

(g) Sector of Paranaguá (Paraná).

This sector is about 50km-long, and few ancient sea level positions have been measured. However, these data were sufficient to elucidate the general trend of variations in relative sea level. In the Paranaguá Bay, the top of the external portion of the Pleistocene marine terrace is situated 2.5m above the present high -tide level. It has not been submerged during the Holocene, since the surface of this terrace is still covered by traces of Pleistocene beach ridges. Consequently, the height of the ancient relative sea level during the 5,150 years B.P. maximum could not have been greater than 2.5m above present sea level. Here also, as in the Cana-

neia region, ages of shell-middens furnished information .

(h) Sector Itajaí-Laguna (Santa Catarina).

Although numerous samples are presently being dated, we have a small amount of information regarding relative sea level fluctuations along the coast of the State of Santa Catarina. However, preliminary information allows us to establish a general outline of relative sea level fluctuations during the last 7,000 years. Therefore, we know that about 5,600 years B.P., in the Itajaí region, relative sea level was rising and situated about 1.0 m above present level. As in the other sectors, relative sea level reached its maximum about 5,150 years B.P. In fact, the Gaspar shell-midden, situated in the Itajaí-River valley, has been dated as 5,230 ± 350 years B.P. (Piazza, 1966). Its geographic situation, in the hinterland can only be explained by a period of high sea level. Another ancient sea level position, reconstructed for Santa Catarina Island, indicate that about 3,600 years B.P., relative sea level was about 2.6m above present level. Similarly in the Laguna region, about 3,400 years B.P. relative sea level was about 2.5m above the present level and was dropping. An interruption in the construction of Carniça shell-midden seems to confirm the existence of a fluctuation between 3,000 and 2,500 years B.P.

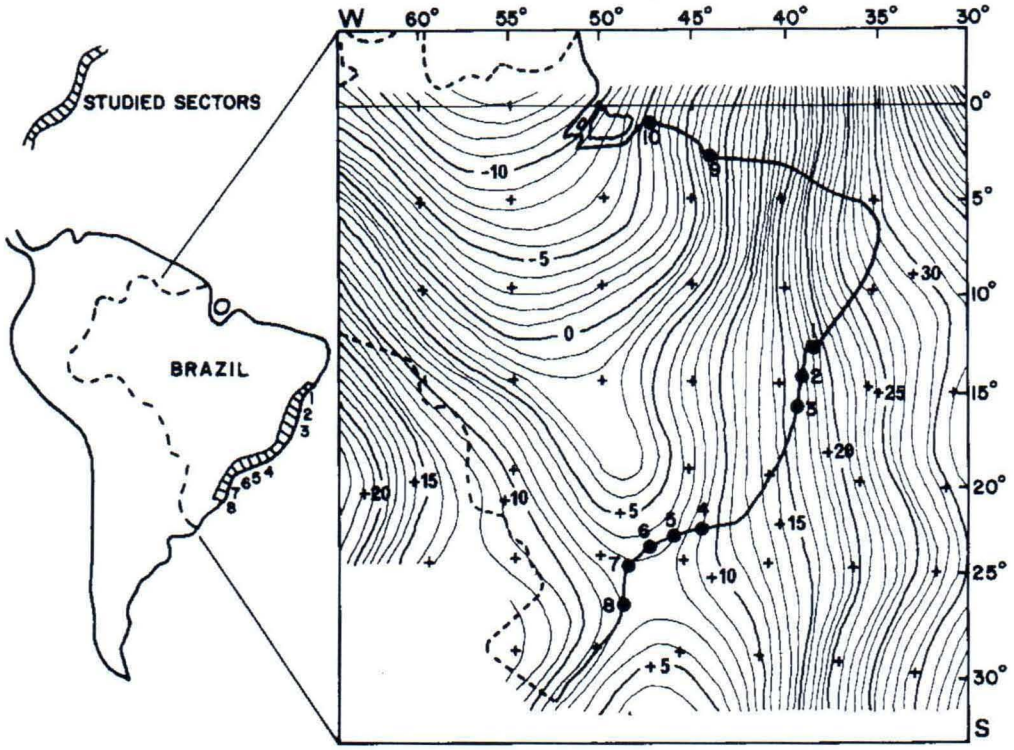

FIGURE 1 - Index map of the studies sectors of the Brazilian coast. Geoid chart of Brasil. (1) Salvador; (2) Ilhéus; (3) Caravelas; (4) Angra dos Reis; (5) Santos; (6) Cananéia; (7) Paranagua; (8) Itajaí; (9) São Luis; (10) Belém.

GENERAL CONSIDERATION ON THE CURVES

One glance is enough to verify that, everywhere, the relative sea level has clearly been above the present level, with a maximum elevation having occurred about 5,150 years B.P. This is not, however, a world wide trend and thus can not be explained by glacial eustasy and, in this case, hardly by crustal movements.

On the other hand, the curves have many points of likeness with the exception of the vertical amplitudes. Moreover, two quick fluctuations of relative sea level occurred after 5,150 years B.P. These fluctuations are too important to be related to glacial eustasy and they cannot be of crustal origin. According to Morner (1981), while sea level drops in Brazil, it rises in Scandinavia and vice-versa. It would appear, then, that these quick fluctuations are related to geoidal changes.

In the Salvador curve, which was outlined with the maximum of precision, 17 ancient sea level positions used for reconstruction of the last 2,500 years are situated on a straight line. Moreover, 8 positions between 3,000 and 3,600 years B.P. are situated on the extension of this line. The number of observations indicating this trend is too large to be considered fortuitous. By extending this line until 5.150 years B.P., corresponding to one of sea level maxima, we obtain a relative sea level about 5m above the present level. From field measurements we found 4.8±0.5m at about 5,150±110 years B.P. It seems then, that several ancient relative sea level positions are situated on the same straight line. When the altitude of the 5,150 years B.P. ma-

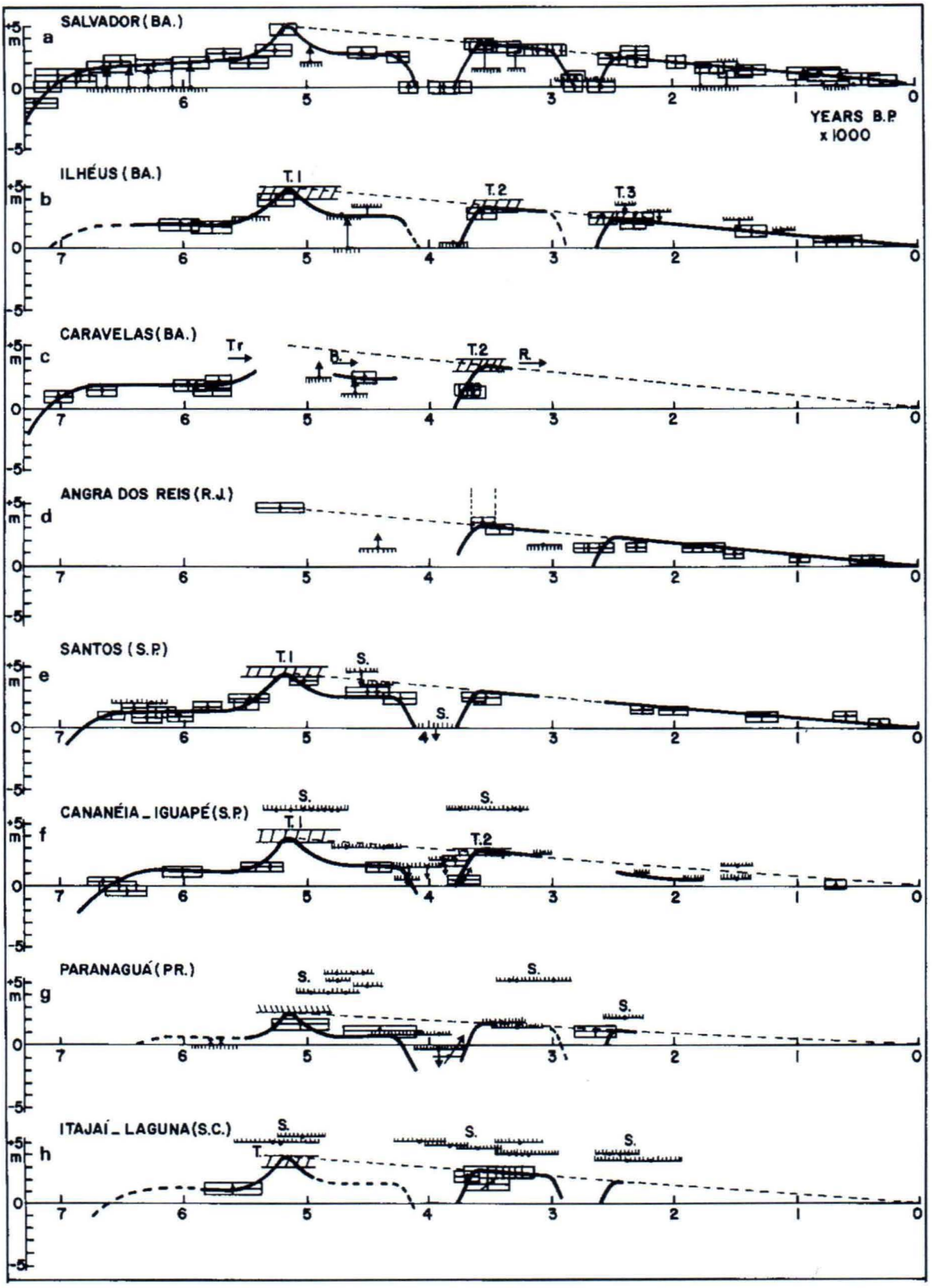

FIGURE 2 - Relative sea level fluctuation curves during the last 7,000 years for several sectors of Brazilian coast.

ximum is known,but the curve has been partially reconstructed,the altitude may be found by extrapolating this line to 5,150 years B.P.

All this evidence points to a single mechanism for the regular drop of relative sea level and another superimposed mechanism for the very rapid fluctuations of this level.

To determine the vertical variations between the curves, it is interesting to compare critical points for each curve,such as the moment when present sea level was crossed for the first time in the Holocene,the altitude of the maxima at 5,150, 3,600 and 2,500 years B.P.It is easy to see in table I that the characteristics of the Salvador, Ilhéus and Caravelas curves are identical. On the other hand,the characteristics of the Angra dos Reis,Santos,Cananéia,Paranaguá and Itajaí curves are different.

Sectors of the Brazilian Coast		Time when the present sea level has been crossed (years B.P.)	Altitude of maximum sea level about 5,150 years B.P. (in meters)	Altitude of maximum sea level about 3,600 years B.P. (in meters)	Altitude of maximum sea level about 2,500 years B.P. (in meters)	Altitude of stillstand phase of about 6,000 years B.P. (in meters)	Altitude of stillstand phase of about 4,500 years B.P. (in meters)
Salvador	(a)	7,100	5.0	3.5	2.5	2.0	2.8
Ilhéus	(b)	-----	5.0	3.5	2.5	2.0	2.8
Caravelas	(c)	7,100	---	3.0 to 4.0	---	2.0	2.0 to 3.0
Angra dos Reis	(d)	-----	4.8	3.3	2.3	---	---
Santos	(e)	6,800	4.5	3.0	---	1.5	2.5
Cananéia	(f)	6,600	3.5 to 4.0	2.8	---	1.0	1.5
Paranaguá	(g)	-----	2.3	1.6	---	---	1.0
Itajaí	(h)	-----	3.5	2.7	---	1.3	---

TABLE I - Principal characteristics of relative sea level fluctuation curves during the last 7,000 years for several sectors of the Brazilian coast.

NATURE OF THE PHENOMENA

In some restricted sectors of the Brazilian coast,it has been possible to demonstrate the role played by the vertical tectonic movements: within Todos os Santos Bay (Bahia),located in the Recôncavo graben,vertical displacements of faulted blocks produced shifted holocene shoreline(Martin et al., 1984).The situation is similar for the Guanabara graben(Martin et al.,1980)and the southern end of the Campos coastal plain(Martin et al.,1984), both in the State of Rio de Janeiro.

Within all sectors chosen for construction of curves, with the exception of the Angra dos Reis sector,there are Pleistocene marine terraces.If the 2,5m vertical difference between the Salvador and Paranaguá sectors for maximum level at 5,150 years B.P.is of tectonic origin,then,we should expect to find an even greater variation in height for the records of the 120,000 years B.P.sea level maximum perhaps as much as 60m,if one assumes the same rate of displacement as that acting over the past 5,150 years. Such a situation is not observed. Moreover, the differences can be attributed to geoid surface changes.

A geoid map of Brazil is shown in Fig. 1. This map was prepared using the model GEM 10-B of the complete gravity potential until the 36th order. The term zero order has been obtained comparing the spheroidal heights of 120 Doppler points. The heights are referred to the Brazilian geodetic system whose ellipsoid is that of the reference system of 1967,and the parameters are: a= 6,378, 160m and f=1/298.25 and the origin is the geodetic point "CHUA" with the following coordinates: 19°45'.6525"S and 48°06'04.0639"W. The transformation of the geocentric values in the local system has been done using the following translation parameters: Tx=85.5m, Ty=25.4m and Tz=16.1m.

This map shows that the eastern part of Brazil is situated on a height of the geoid where the equal elevation lines are approximately N - S. The western part of Brazil is situated on another height whose focus is located in Bolivia. Between these two heights, there is a depression intercepting the southeastern and northern coastal areas of Brazil. The N-S trending coastal area of the State of Bahia, where sectors a, b and c are situated, is more-or-less parallel to equal elevation lines of the geoid. On the other hand, the portion of coast containing sectors d, e, f and g (Southern Rio de Janeiro, and States of São Paulo and Paraná), trending NE-SW,obliquely cuts the equal elevation lines of the geoid.

No significant shifting will be produced between the curves a, b and c by horizontal displacements of geoidal relief following N-S or E-W directions,but this could happen with the curves d,e,f and g as well as their relation with curves a, b and c.

If we assume that the regional scale geoidal relief modification are, at least in part, responsible for Holocene high sea levels found in greatest part of the Brazilian coast, the verified shifts could be explained by their differential displacements.For example the submergence period which has influenced the greatest part of the Brazilian coast until 5,150 years B.P.would be due to rising of this relief and the subsequent emergence would be due to subsidence of this relief. Apparently, shifts between the curves are particularly importants within the portion of coast occupied by the central depression (between Angra dos Reis and Paranaguá). The subsidence of the geoidal relief has been less important within the depression, particularly toward its axis, than on the height.

A slight displacement of the central depression axis eastward during the subsidence of geoidal relief can explain shifts observed between Angra dos Reis and Paranaguá (Fig. 3).

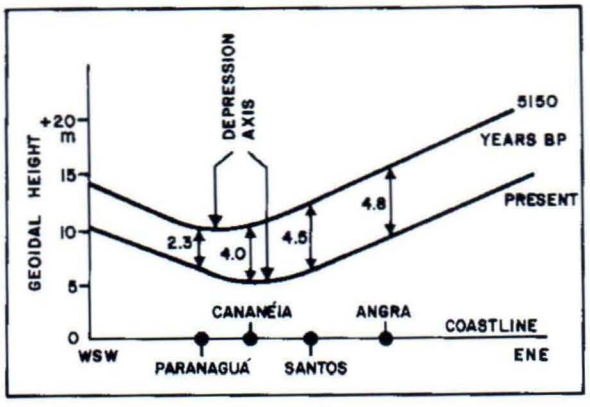

FIGURE 3 - Present day and 5,150 years B.P. geoidal surfaces. The vertical shifts can be explained by a subsidence of the geoidal relief and a slight displacement of the central depression to the east direction.

If this hypothesis is correct, sea levels of northern Brazil must be equally shifted in comparison with the Salvador region. Unfortunately, we have no information from northern Brazil. However, it is perhaps significant, in this respect, that the coast between São Luis and Belém shows many characteristics of submergent coasts: ragged and indented coastline, active erosional escarpments in Pliocene continental deposits, absence of Holocene marine terraces and downstream portions of rivers transformed in rias.

CONCLUSIONS

Relative sea level fluctuation curves delineated for several sectors of the Brazilian coast reveal many interesting aspects. Everywhere, the relative sea level has been heigher than present mean level with a maximum elevation at about 5,150 years B.P.. All these curves are very similar in shape but they are shifted vertically.

Occurence of high sea levels during the Holocene is not a worldwide phenomenon, and obviously the fluctuations observed in Brazil cannot be due to the glacial eustasy. On the other hand, as they are hardly explained by vertical crustal movements, they probably can be attributed, at least partially, to geoid surface changes.

Where the coastline is more-or-less parallel to the isobases of geoidal height, the sea level curves are not shifted. It is possible that high sea levels found in Brazil, as well as the shifts observed between some relative sea level fluctuations curves during the last 7,000 years could be explained by a regional rise of the geoidal surface until about 5100 years B.P., followed by subsidence and slight eastward displacement on a time scale of thousands of years. Similarly, the quick oscillations since about 5,150 years B.P. may be explained by regional subsidence of geoidal relief followed by rising on a time scale of hundred years.

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