Sea Level Fluctuations During the Past 6000 Years Along the Coast of the State of São Paulo, Brazil[1]

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Abstract

Uncontestable geological records indicative of Holocene sea levels higher than present are observed along the State of São Paulo's coastal plain. During the past 6000 years the relative sea level was subjected to two maxima about 5000 and 3300 years BP and to a minimum about 3800 years BP. The comparison of sea level change curves established for several parts along this coastal plain showed that the maxima have different amplitudes. At present stage of our knowledge about this problem, the mechanism of the vertical deformation of the geoid surface furnishes the best explanation to the amplitude differences.

Morphology of the Studied Region

The portion of the Brazilian coastline studied here is elongated in a NE–SW direction and is located between 44° and 48° W longitude. It covers the entire extent of the State of São Paulo's coastline as well as the southern half of the coast of the State of Rio de Janeiro.

This region is characterized by a submergent morphology in the north and an emergent morphology in the south (Martin and Suguio, 1975, 1976c). In fact, in the north, the crystalline basement reaches the sea almost continuously, except along small plains made up inland by continental deposits and seaward by marine sediments. In the south, very extensive sedimentary plains, mostly formed by Quaternary marine and lagoonal deposits, isolated from each other by points of crystal-

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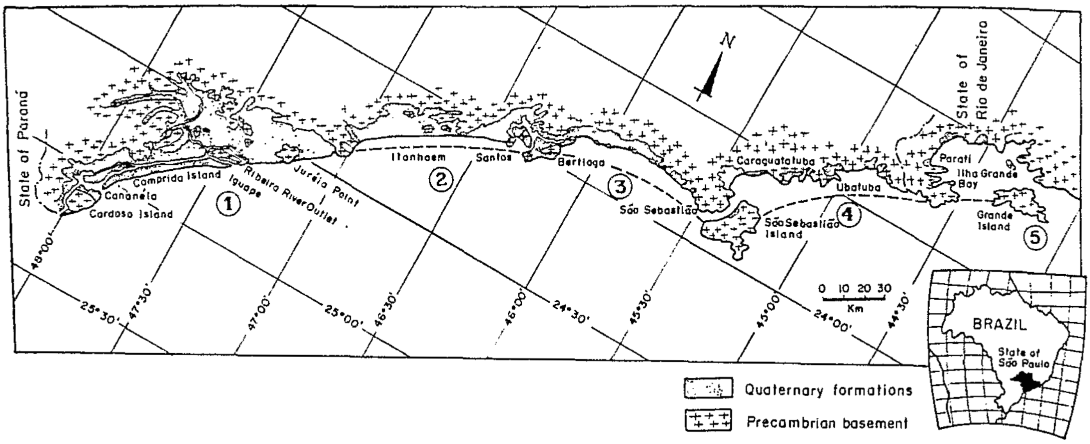

Fig. 1. Quaternary deposits in the coastal plain of States of São Paulo/southern Rio de Janeiro

line Precambrian rocks are found. Taking into consideration the limits of the Precambrian basement, five morphological units may be recognized, which are from south to north (Fig. 1): (1) Cananéia–Iguape unit; (2) Itanhaem–Santos unit; (3) Bertioga unit; (4) Caraguatatuba–Ubatuba unit; and (5) Ilha Grande bay unit.

The first of these is completely filled by Quaternary deposits, and the strandline is practically straight. Northward these plains are less and less filled, until finally, in the Ilha Grande bay area, only a few Quaternary marine deposits occur. In the Parati region there are true 'rias'.

This morphological differentiation could be explained by differences in the dynamics of sedimentation or by tectonic influences. Given the pattern of the regional hydrographic net (the majority of the rivers begins in the 'Serra do Mar'—Coastal Ranges—and flows into the interior of the continent), the former hypothesis would not be expected. Thus, by assuming that the latter hypothesis is true, the coastline would have a tendency for submergence in the north and for emergence in the south. It is interesting to note that there is not an abrupt transition between the emergent and the submergent zone but rather a gradual transition. This would seem to eliminate the possibility of morphological differentiation by the tectonic interaction between blocks that are separated by discontinuities normal to the coastline, which has been observed in the State of Bahia (Suguio and Martin, 1975a; Martin and Suguio, 1976a).

Structural Scheme of the Continental Margin

Along this part of the Brazilian coastline, the continental margin is characterized by:

1. The presence of the Santos submarine sedimentary basin (Fig. 2), which is a Mesozoic–Cenozoic tectonic depression filled by basaltic flows and sedimentary deposits. This basin is limited landward by the Santos fault zone the displacement of which is more than 3000 m in the north but which passes gradually to a great faulted inflections to SW with a much smaller displacement.

2. The occurrence of the southeastern Brazilian Atlantic Plateau (Planalto Atlântico), which ends in an escarpment 900 to 2000 m high and continues over 1200 km forming the 'Serra do Mar' (Coastal Ranges) according to Almeida (1975).

The South Atlantic Brazilian continental margin was subjected to reactivation after separation from Africa. This reactivation was reflected on the continent by several events, such as the uplift of the Coastal Ranges and the formation of the Paraíba and Guanabara grabens; meanwhile, the Santos basin was continuously subsiding. It appears that these

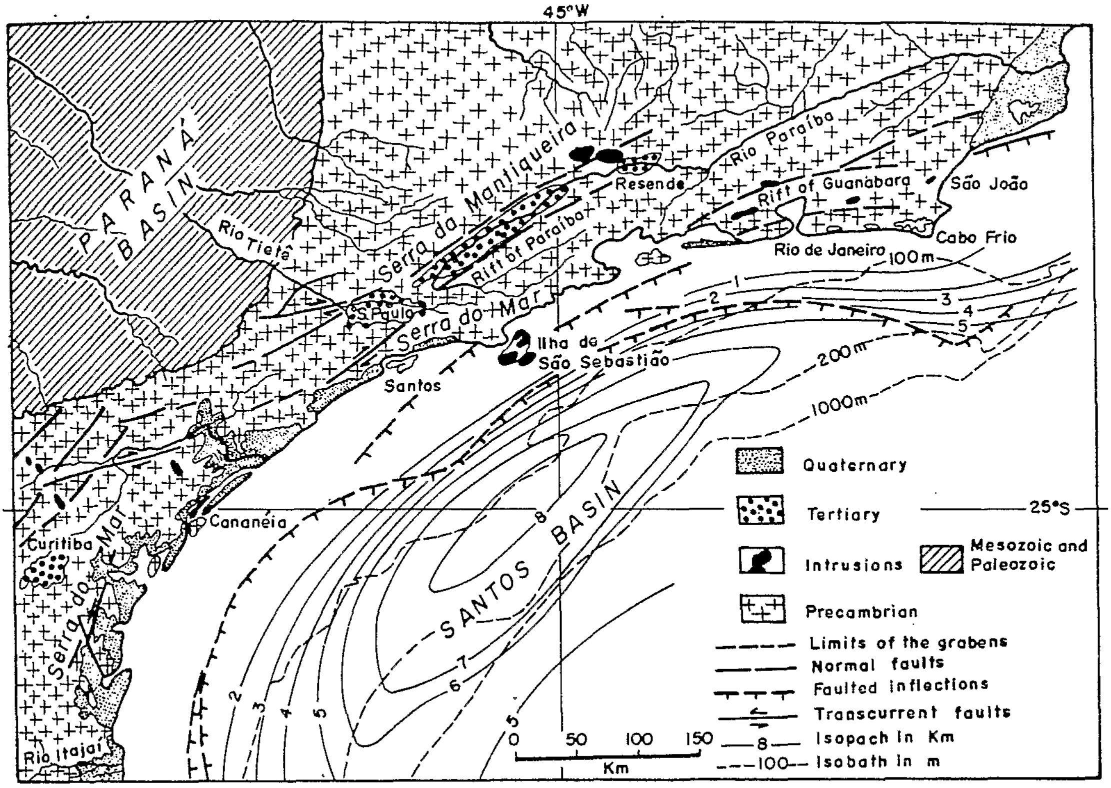

Fig. 2. Structural framework of the continental margin at southeastern part of Brazil (from Almeida, 1975)

mechanisms have continued into the Quaternary, as recent sediments of the Paraíba graben are cut by marginal faults (Suguio, 1969).

During the Cenozoic, a positive zone on the continent and a negative area seaward remained active. Consequently, a hypothetical line of inflection is traceable between the two areas. It is possible to visualize a continental inflection mechanism (Bourcart, 1949), which would have been different in the north in relation to the south, as having caused the morphological characteristics mentioned above (Suguio and Martin, 1976b). Schematically, the following cases can be considered (Fig. 3):

1. *First case* The strandline is situated left of the inflection line, that is, in the zone of uplift. The strandline will exhibit an emergent morphology.

2. *Second case* The strandline is right of the inflection line, that is in the subsiding zone. The strandline will be characterized by a submergent morphology.

3. *Third case* The strandline is on the same side of the inflection line in both the north and the south, but at relatively different distances from it. In this case, the strandline will present differential emersion or submergence characteristics.

These three cases can be completed by two other situations when we consider the distance between the maximum uplift and the inflection line.

4. *Fourth case* The maximum uplift zone is far from the inflection line.

5. *Fifth case* The maximum uplift zone is near the inflection line.

When we assume an uplift height h, equal in both cases, the surface affected by the phenomenon will be more extensive in the fourth case than in the last case. Thus, if we consider two points A and B, separated by a distance d from the inflection line, the uplift

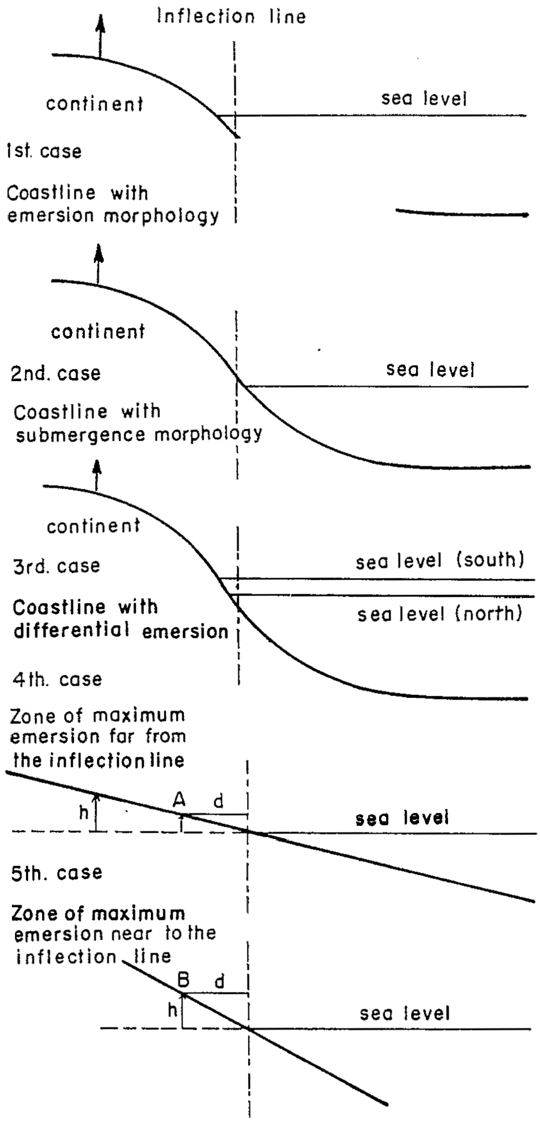

Fig. 3. Scheme of differentiation into emergent and submergent coast by continental inflection mechanism

height will be greater in the fifth case than in the fourth.

In reality, the maximum uplift zone is observed nearer the strandline in the north than in the south. This may explain why more extensive zones are subjected to uplift in the south and why possibly higher ancient sea levels may be recorded in the north.

Evidence of Ancient Strandlines

Several important transgressive and regressive phases have occurred along the coast of the State of São Paulo during the Quaternary. In certain parts of the coastal plain, these different episodes left records that can be dated and whose heights relative to present mean sea level can be measured.

Detailed mapping and radiocarbon dating have permitted us to identify uncontestable evidence left by two great transgressive episodes in the southern half State of São Paulo's coastal plain (Units 1, 2 and 3; Fig. 1).

A sandy marine sediment, the 'Cananéia' Formation (Suguio and Petri, 1973; Petri and Suguio, 1973), which was deposited in the intertidal zone (with occurrences of fossil *Callianassa* burrows: Suguio and Martin, 1976a), covers a majority of the Unit 1 surface. Radiocarbon dating of fossil wood (charcoal) from this formation indicated an age of more than or equal to 30,000 years BP (Ba. 227). Another sample of fossil wood from Unit 2 showed an age equal or superior to 35,000 years BP (Gif. 3844). It is possible that these shalow marine deposits have been formed during the transgressive episode of 120,000 years ago. Their altitude changes between 5 to 6 m in the external zone (near the sea) to 9 to 10 m in the internal zone (near the crystalline basement). Significant differences in altitude of the 'Cananéia' Formation's top have not been observed between Units 1 and 2. Nevertheless, the importance of this Pleistocene formation diminishes from the south northward, and it disappears completely in the northern half of the coastal plain of São Paulo.

Holocene shallow marine sands, which formed during the transgressive episodes, are found stratigraphically above but topographically below the 'Cananéia' Formation. Apparently, this formation is not higher than 3.5 m in Unit 1, although it reaches 4.5 m above present level in Unit 2. The lowlands of the 'Cananéia' Formation, originated during the great regression following its deposition, were filled by clayey–sandy sediments of fluviatile–lagoonal origin.

Several 'sambaquis' (kökkenmödings) occur in the great sedimentary coastal plain in the southern half of the State of São Paulo (Units 1 and 2; Fig. 1). Obviously the mollusc shells from the 'sambaquis' are not the best materials for dating ancient strandlines. In fact, the relationship between the 'sambaqui' substrate and the mean sea level in the beginning of its construction is frequently unknown. However, the fact that high tide level was not above the 'sambaqui' substrate during its construction is obvious. The value of one isolated dating without any other information is very restricted. Nevertheless, a series of datings of 'sambaquis' from any given area, when interpreted on the basis of such criteria as molluscan ecology of the dominant shells, geographical position, substrate altitude, regional geomorphology, etc. may be a valuable tool (Suguio and Martin, 1975b; Martin and Suguio, 1976b). We must also assume, as a postulate, that the molluscs whose shells make up the 'sambaquis' were not transported from very great distances by the Indians. From this hypothesis, it follows that the 'sambaquis' situated on the Pleistocene formation at distances as far as 40 km from the present strandline can only be explained by a having had sea level higher than present. Furthermore, the 'sambaquis' whose bases are near or even below the present high tide level must be correlated to episodes when the sea level was near or even below the present relative mean sea level.

Sea Level Change Curve of the Cananéia–Iguape Region

Several samples of fossil woods and shell debris from marine lagoonal deposits were subjected to radiocarbon dating. Moreover, studies of the sedimentological nature and geological situation of the sampled deposits permitted the recognition of the position and the trend of variance of mean sea level at the time of their sedimentation (Table 1).

The position of samples A93, A55 and A89

Table 1. Ages of geological samples from the Cananéia–Iguape area

Sample	Nature	Position of the ancient sea level	Age BP	Lab. refer.	Coordinates
A93	Fossil Wood	− 1.1(± 0.3m)	6500 ± 170	Ba.230	24°.59.7'S 47°.53.7'W
A55	Fossil Wood	+ 1.0(± 0.4m)	6100 ± 130	Ba.226	25°.12.7'S 48°.01.7'W
A89	Shell	+ 1.4(± 0.4m)	5410 ± 120	Gif.3444	25°.00.0'S 47°.53.8'W
A60	Shell	+ 1.5(± 0.3m)	5370 ± 100	Ba.341	25°.09.2'S 47°.02.1'W
A28	Fossil Wood	+ 1.5(± 0.3m)	4400 ± 110	Gif.3439	25°.09.2'S 47°.02.1'W
A131	Plant debris	+ 0.6(± 0.3m)	3500 ± 100	Ba.445	24°.51.3'S 47°.28.5'W
A37	Plant debris	+ 0.6(± 0.3m)	3430 ± 100	Gif.3430	24°.51.3'S 47°.28.5'W
A23	Fossil Wood	+ 0.0(± 0.3m)	680 ± 90	Gif.3438	25°.01.9'S 47°.55.0'W

Ba = Laboratorio de Fisica Nuclear Aplicada Universidade Federal da Bahia, Salvador, Bahia.
Gif = Laboratoire du Radiocarbone, Gif-sur-Yvette (France).

Table 2. Ages of the 'sambaquis' from the Cananéia–Iguape area

Sample	Position of the ancient sea level	Age BP	Lab. refer.	Coordinates
A137	Near to a maximum	5100 ± 100	Ba.348	24°.38.0′S 47°.42.8′W
IPH.7	Near to a maximum	5070 ± 110	Ba.363	24°.53.0′S 47°.53.0′W
A140	Near to a maximum	5040 ± 100	Ba.295	24°.37.6′S 47°.45.5′W
A30	Above present level	4920 ± 100	I. 9186	25°.02.7′S 47°.58.2′W
IPH. 1	Above present level	4920 ± 100	Ba.370	24°.55.0′S 47°.52.0′W
A123	Near to a maximum	4860 ± 100	Ba.343	24°.28.1′S 47°.23.1′W
A121	Near to a maximum	4750 ± 100	Gif.3641	24°.30.0′S 47°.28.0′W
A175	Above present level	4560 ± 110	Gif.3646	24°.27.8′S 47°.13.4′W
IPH.4	Below + 3m	4440 ± 80	Ba.366	24°.52.9′S 47°.53.8′W
E91	Below + 3m	4380 ± 160	SPC.21	25°.00.0′S 47°.55.5′W
IPH.9	Below + 3m	4380 ± 100	Ba.359	24°.56.0′S 47°.50.0′W
IPH.10	Below + 3m	4350 ± 110	Ba.361	24°.56.0′S 47°.50.0′W
A3	Above present level	4340 ± 110 4250 ± 90	Gif.3435 Ba.302	25°.01.5′S 48°.03.5′W
P.A.	Above present level	4288 ± 90	Tk.90	24°.36.8′S 47°.46.7′W
IPH. 11	Below + 3m	4130 ± 100	Ba.360	24°.56.0′S 47°.50.0′W
A50	Below + 3m	4120 ± 100	Ba.289	25°.01.5′S 48°.03.5′W
A16	Below + 2m	4130 ± 110 4120 ± 90	Gif.3436 Ba.303	24°.59.0′S 47°.53.0′W
IPH.8	Below + 2m	4070 ± 100	Ba.362	24°.53.0′S 47°.53.6′W
A58	Below + 1.5m	3960 ± 90	Ba.291	25°.12.0′S 47°.59.0′W
IPH.5	Slightly above	3900 ± 100	Ba.365	24°.12.0′S 47°.59.0′W
A115	Below + 2m	3800 ± 90	Ba.294	24°.51.5′S 47°.45.3′W
A29	Equal or below	3790 ± 110	Gif.3437	25°.08.2′S 48°.02.1′W

Sample	Position of the ancient sea level	Age BP	Lab. refer.	Coordinates
IPH.6	Slightly above	3635 ± 90	Ba.364	24°.52.0'S 47°.53.0'W
IPH.3	Indifferent	3490 ± 80	Ba.367	25°.03.0'S 48°.03.0'W
A25	Above present level	3250 ± 90	Ba.286	25°.05.0'S 48°.01.0'W
A47	Above present level	3160 ± 95	Ba.340	25°.01.5'S 48°.03.5'W
A11	Below + 2.5m	3100 ± 80	Ba.285	24°.58.6'S 47°.53.4'W
A149	After a maximum	3090 ± 110	Gif.3645	24°.58.4'S 47°.51.7'W
A154	Above present level	2390 ± 90	Ba.348	24°.39.0'S 47°.29.0'W
A81	Below + 0.5m	1850 ± 100	Gif.3643	25°.01.5'S 48°.02.2'W
IPH.2	Below + 0.5m	1740 ± 70	Ba.368	25°.03.0'S 48°.01.0'W
A144	Indifferent	1650 ± 80	Ba.347	24°.47.0'S 47°.40.0'W
A69	Below + 1.6m	1460 ± 90	Ba.293	25°.00.7'S 48°.00.0'W
A65	Below + 0.5m	1440 ± 90	Ba.291	25°.04.0'S 48°.02.0'W

Ba = Laboratório de Física Nuclear Aplicada, Universidade Federal da Bahia. Salvador, Bahia.
Gif = Laboratoire du Radiocarbone, Gif-sur-Yvette (France).
I = Isotopes (United States).
SPC = Laboratório de Radiocarbono. Centro de Pesquisas Geocronológicas. Instituto de Geociências, Universidade de São Paulo.
TK = Radiocarbon Laboratory. Department of Anthropology, Faculty of Sciences, University of Tokyo (Japan).
IPH = 'Sambaqui' samples collected by GARCIA and UCHOA of the Instituto de Pré-História, Universidade de São Paulo.

indicates that these materials were deposited during a transgressive period, but the deposit represented by sample A28 was followed by a regressive episode. Finally, the deposit containing samples A131 and A37 was followed by a transgressive period (Suguio, Martin and Flexor, 1976).

The data suggest that:

1. About 6500 years BP the relative sea level was slightly lower than at present.
2. Between 5400 and 4400 years BP the relative sea level reached a maximum.
3. Between 4400 and 3500 years BP the relative sea level reached a minimum.
4. A second maximum was attained after 3000 years BP.

As the wave-built terrace from which samples A131 and A37 were collected has a maximum altitude of 3 m, indicating an ancient sea level, we believe that during the second Holocene maximum the relative sea level was 3 m higher than at present.

Detailed study of the 'Cananéia' region indicates that the 'Cananéia' Formation was erased when the relative sea level was 3.5 m above the present. A sample from a 'sambaqui' (E91), built after erosion on this part of the island, yielded an age of 4380 ± 160 years BP (SPC. 21), suggesting that this maximum was produced before this time. Thus, it must be related to the first maximum, which occurred between 5400 and 4400 years BP.

In order to better define the positions of these two maxima and the minimum separating them, ages of materials from 'sambaquis' abundantly distributed throughout the area were used (Table 2).

If we consider the geographical location of the dated 'sambaquis', we can see that samples A137, A140, A123 and A121 were collected closer inland, and this situation can only be explained by assuming an ancient sea level higher than present. As the ages of these 'sambaquis' range between 5100 and 4700 years BP, we believe that the maximum level has been attained about 5000 years ago. The above mentioned 'sambaqui' represented by the sample E91 was accumulated after this maximum and, therefore, after the lowering of the relative sea level. However, the dating of the 'sambaqui' P.A. (4288 ± 90 years BP) located in the interior of continent near the town of Pariquera-Acu, revealed that about 4300 years ago the relative sea level was certainly higher than present. It is possible that, after the maximum level was reached about 5000 years BP, the relative sea level was subjected to a slight lowering, followed by a still-stand period, and finally by a rapid regression 4100 years BP. The occurrence of the 'sambaqui' represented by sample A29, which has its base at the present high-tide level, suggests this minimum. Evidently, when the 'sambaqui' was built up, the relative sea level would not have been higher than at present. The 'sambaquis' of samples A16, A58, IPH.5, A115 and A50, whose substrate altitudes are less than + 2 m confirm a regressive episode; therefore the maximum level would have occurred about 3800 years BP. At this time the relative sea level would have been lower than present.

As mentioned above, the second maximum occurred 3500 years BP. The location and composition of the 'sambaqui' represented by sample A149, with an age of 3090 years BP, indicate that it was accumulated some time after a maximum (Suguio, Martin and Flexor, 1976). Moreover, the 'sambaqui' represented by sample A11 (3100 years BP) has its substrate 2.5 m above present high-tide level. Thus at this time the maximum level has been transected. It is possible that this occurred about 3300 years BP.

Finally, the 'sambaquis' of samples A81, dated as 1860 years old, and A65, dated as 1440 years old, have their substrates 0.5 m above present high-tide level, suggesting that since 1850 years ago the relative sea level could never have been higher than 0.3 m above the present level, otherwise they would have been extensively eroded.

From these data, we can deduce that the relative mean sea level changes were as follow (Fig. 4a):

1. About 6300 years BP the relative sea level may have been near the present level.
2. About 5000 years BP the relative sea level would have been the first maximum when the sea level was 3.5 m above present.
3. 3800 years ago the relative mean sea level may have been equal to or slightly lower than present sea level.
4. About 3300 years BP the mean sea level reached the second maximum 3 metres above present level.
5. Since 1850 years ago the mean sea level has always been lower than 0.3 m above present level.

Sea Level Change Curve of the Santos–Itanhaem Region

An ancient mangrove deposit, represented by a charcoal sample from a drill-hole, gave an age of 7700 years BP, when the relative sea

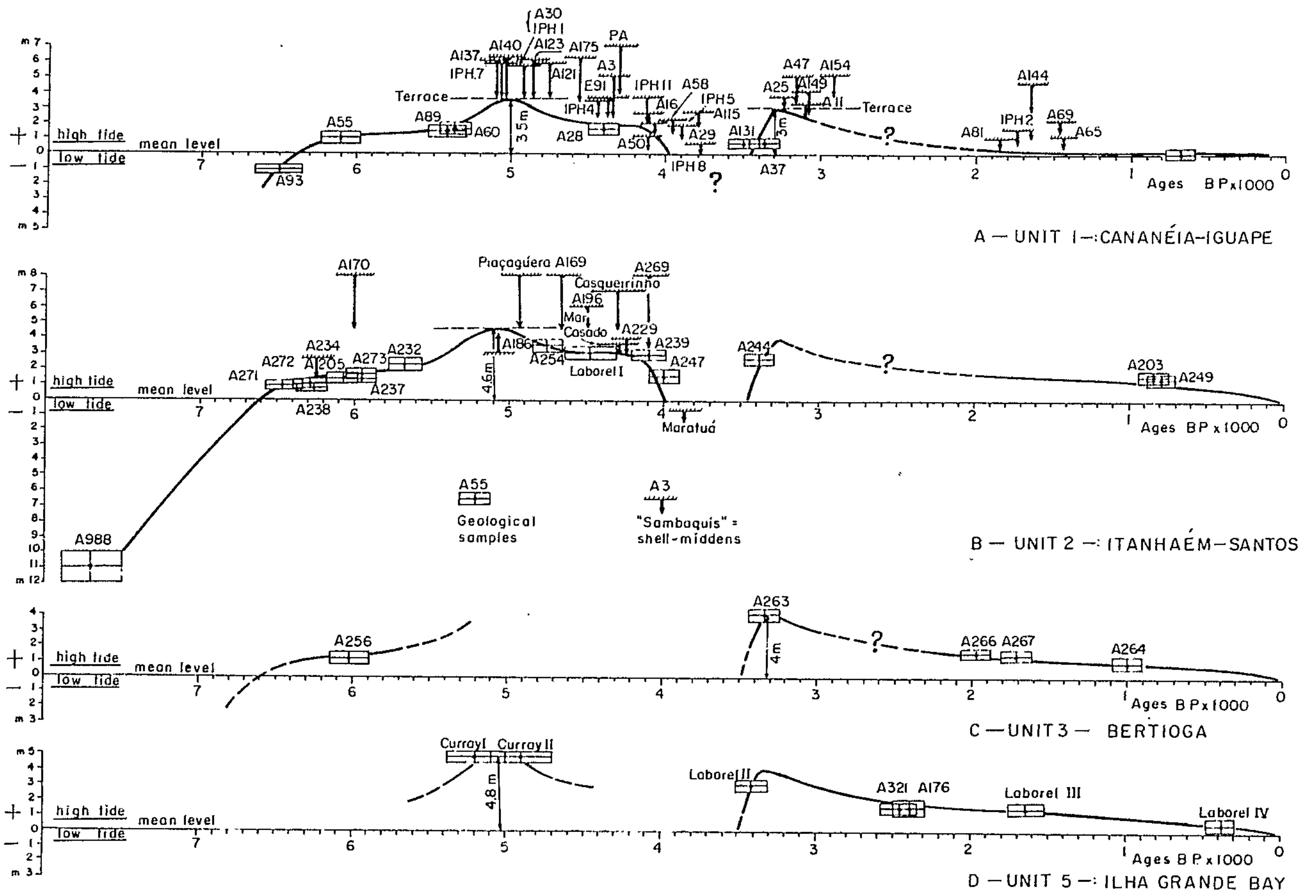

Fig. 4. Relative sea level change curves for the past 6000 years in different units

Table 3. Ages of geological samples from the Santos–Itanhaem area

Sample	Nature	Position of the ancient sea level	Age BP	Lab. refer.	Coordinates
A988	Fossil Wood	− 11(± 1.0m)	7700 ± 190	Ba.233	23°.52.7′S 46°.26.1′W
A271	Fossil Wood	+ 0.9(± 0.3m)	6465 ± 120	Ba.448	24°.00.8′S 46°.23.3′W
A272	Fossil Wood	+ 1.0(± 0.3m)	6290 ± 110	Ba.449	24°.00.8′S 46°.23.3′W
A238	Fossil Wood	+ 0.8(± 0.3m)	6280 ± 130	Gif.3846	23°.57.2′S 46°.26.4′W
A234	Fossil Wood	Below + 1.5m	6250 ± 130 6240 ± 100	Gif.3845 Ba.234	24°.00.8′S 46°.23.3′W
A205	Vermetidae	+ 1.3(± 0.4m)	6090 ± 120	Ba.350	24°.12.0′S 46°.48.6′W
A273	Fossil Wood	+ 1.7(± 0.3m)	5960 ± 130	Ba.450	24°.00.8′S 46°.23.3′W
A237	Oyster (in situ)	+ 1.3(± 0.4m)	5960 ± 110	Ba.329	24°.00.8′S 46°.23.3′W
A232	Fossil Wood	+ 2.3(± 0.4m)	5680 ± 110	Ba.326	24°.00.1′S 46°.26.2′W
A186	Fossil Wood	Above + 3.0m	5070 ± 100	Ba.331	24°.12.5′S 46°.50.8′W
A254	Vermetidae	+ 3.4(± 0.4m)	4760 ± 110	Ba.354	23°.52.3′S 46°.08.0′W
Laborel I	Vermetidae	+ 3.0(± 0.4m)	4480 ± 180	Gif.2147	23°.55.0′S 46°.14.0′W
A239	Fossil Wood	+ 2.9(± 0.3m)	4100 ± 110	Gif.3847	23°.57.2′S 46°.26.4′W
A247	Shell	Between + 2 and + 1m	4010 ± 100	Ba.353	23°.57.8′S 46°.12.3′W
A244	Vermetidae	+ 2.6(± 0.4m)	3380 ± 100	Ba.252	24°.00.9′S 46°.17.7′W
A203	Vermetidae	+ 1.5(± 0.4m)	850 ± 80	Ba.325	24°.12.0′S 46°.48.6′W
A249	Vermetidae	+ 1.4(± 0.4m)	790 ± 90	Gif.3848	23°.58.4′S 46°.11.3′W

level may have been 11 ± 1 m below present level. Samples A271, A272, A273 and A237 collected from a similar profile as well as samples A238 and A232 from other profiles in its proximities furnished indications of ancient sea levels very coherent with their positions (Table 3 and Fig. 4b). Apparently, the relative sea level may have been at its present zero level about 6600 years BP. Since this time the rate of transgression has diminished. In fact, the ancient mangrove deposit lies between marine sands and formed during this sea level stillstand.

About 6000 years BP the relative sea level was clearly above the present level. This fact is corroborated by the presence of a 'sambaqui'

Table 4. Ages of the 'sambaquis' from the Santos–Itanhaem region

Sample	Position of the ancient sea level	Age BP	Lab. refer.	Coordinates
A170	Above present level	6000 ± 110	Ba.292	24°.04.3'S 46°.48.0'W
Piaçaguera	Above present level	4930 ± 110	I.4481	23°.51.8'S 46°.22.1'W
A169	Above present level	4660 ± 100	Ba.297	24°.08.3'S 46°.55.8'W
A196	Above present level	4500 ± 100	Ba.231	24°08.9'S 46°.54.0'W
Mar Casado	Below + 3m	4400 ± 130	Gif.1194	23°.57.9'S 46°.11.5'W
A229	Below + 3.5m	4340 ± 100	Ba.328	24°.00.1'S 46°.26.2'W
Casqueirinho	Indifferent	4300 ± 180	SPC.15	23°.53.0'S 46°.23.0'W
A269	Above present level	4100 ± 90	Ba.446	24°.08.9'S 46°.57.1'W
Maratuá	Below present level	3865 ± 95	I.9185	23°.57.0'S 46°.15.0'W

(sample A170) dated as 6000 ± 110 years BP whose geographical location can be explained only by a sea level above the present one. On the other hand, carbonate tube crusts of *Vermetidae* (Laborel, 1967) sampled near Itanhaem (sample A205), indicated 6090 ± 120 years BP, when the sea level was + 1.3 m (± 0.4 m). In the Santos area digging exposed tree trunks (sample A234) in growth positions covered by shallow marine sands. This fossil wood was dated as 6250 ± 100 years BP. The top of the sandy marine formation is related to an ancient sea level at least 4.6 m above the the present level. Fossil wood (sample A186), from a transgressive clayey deposit related to the maximum lagoonal extension within the Pleistocene formation, suggests that this maximum was reached about 5100 years BP. The sample A254, Laborel I (Delibrias and Laborel, 1969), and A239 indicate that the relative sea level was subjected to a slight lowering, however stillstanding above the present level. This situation is confirmed by dating of the 'Mar Casado sambaqui' (4400 ± 130 years BP) sample A229 (4340 ± 100 years BP), which are indicative of a relative sea level probably 3 m above the present level about 4400 years BP. However, the 'sambaquis' represented by samples A169, A196, and A269 were collected more inland, on the Itanhaem Quaternary plain, and their locations can be explained only by a sea level above the present one, thus corroborating the idea of a sea level higher than present and the occurrence of a stillstand period (Table 4).

About 4100 years BP the relative sea level rapidly lowered to reach to a situation below the present level. This is confirmed by a new dating of the 'Maratuá sambaqui' (3865 ± 95 years BP; Prof: Caio Del Rio Garcia, personal communication), whose substrate is located at minimum lowtide level (Emperaire and Laming, 1956). This fact indicated that the sea level was at least 1.5 m below present level. Nevertheless, the hypothesis of the 'sambaqui' substrate sinking can not be discarded. However, though this has been active mechanism, a negative sea level fluctuation is still evidenced by the present position of the 'Maratuá sambaqui' base.

A *Vermetidae* sample (A244) dated as 3380 ± 100 years BP and indicative of an ancient sea level of + 2.6 m (± 0.4 m) suggests a new relative sea level rising toward a second maximum. Unfortunately, we have no data about the altitude attained by this transgression.

Finally, two *Vermetidae* samples (A203 and A249), located at + 1.5 m (± 0.4 m) and + 1.4 m (± 0.4 m), have been dated as 850 ± 90 years BP and 790 ± 90 years BP, respectively. These ages seem to be abnormal at first glance, but new evidence has been found that possibly confirms them.

The sea level change curve outlined from these data (Fig. 4b) exhibits sea level oscillations similar to that of Unit 1. But, a remarkable fact is that the oscillation amplitudes are different.

Data from the Bertioga Region

Only a few data are available at the moment for this region, although some other datings are in progress (Table 5).

Sample A256, dated as 6020 ± 130 years BP is proof that the relative sea level was higher than present. Sample A263, collected near the top of a beach-rock outcrop, has been dated as 3350 ± 90 years BP. Apparently this assures that the second maximum occurred about 3300 years BP. At this time, the relative sea level in that area was 4 m higher than present. Finally, three *Vermetidae* samples (A266, A267 and A264), attesting to ancient sea levels of + 1.6 m (± 0.4 m), + 1.4 m (± 0.4 m), were dated as 1990 ± 90 years, 1720 ± 90 years and 1000 ± 90 years BP, respectively.

Comparison of the partially outlined curve (Fig. 4c) with the corresponding part of the Unit 1 curve (Fig. 4a), reveals a positive amplitude displacement with respect to the first curve.

Data from the Caraguatatuba–Ubatuba Region

Only now have we obtained data from the Caraguatatuba Quaternary coastal plain (Table 6). Geomorphological aspects seem to indicate the occurrence of two generations of beach-ridges which can be correlated to the two sea level maxima (Suguio and Martin, 1976b).

A charcoal sample obtained by drilling through an ancient mangrove sediment has been dated as 7950 ± 220 years BP. This attests to an ancient sea level of about − 12.5 m (± 1 m), which agrees with the results for Unit 2.

A series of drillings made by the Instituto de Pesquisas Tecnológicas S/A (Fulfaro and colleagues, 1976) revealed that the thickness of this organic-rich clay formation ranges from 15 to 20 m. Two sample of shells collected between 1 to 2 m beneath the surface were

Table 5. Ages of Geological Samples from the Bertioga Region

Sample	Nature	Position of the ancient sea level	Age BP	Lab. refer.	Coordinates
A256	Fossil Wood	+ 0.8(± 0.4m)	6020 ± 130	Gif.3850	23°.50.5′S 46°.08.6′W
A263	Beach rock	+ 4.0(± 0.4m)	3350 ± 90	Ba.355	23°.49.1′S 46°.02.2′W
A266	Vermetidae	+ 1.6(± 0.4m)	1990 ± 90	Ba.357	23°.47.8′S 45°.59.7′W
A267	Vermetidae	+ 1.4(± 0.4m)	1720 ± 90	Ba.358	23°.45.9′S 45°.48.1′W
A264	Vermetidae	+ 1.0(± 0.4m)	1000 ± 90	Ba.356	23°.49.2′S 46°.02.2′W

Table 6. Ages of Geological Samples from the Caraguatatuba Area

Sample	Nature	Position of the ancient sea level	Age BP	Lab. refer.	Coordinates
SP.5	Fossil wood	− 12.5(± 1m)	7950 ± 220	Gif.3433	23°.39.3′S 45°.29.0′W
A300	Shell (in situ)	Below present level	6745 ± 170	Ba.445	23°.40.6′S 45°.28.6′W
A302	Shell (in situ)	Below present level	6725 ± 170	Ba.456	23°.41.3′S 45°.28.8′W
A290	Shell (in situ)	Above present level (after 2nd.maximum)	2565 ± 90	Ba.452	23°.38.5′S 45°.26.1′W
A291	Oyster (in situ)	Above present level	640 ± 80	Ba.453	23°.38.5′S 45°.26.1′W

dated as 6745 and 6725 years BP. As the shells were collected from materials excavated from a trench opened during the construction of the highway BR–101 (Santos–Rio de Janeiro), their altitudes are not precisely known. Nevertheless, as the shells have been collected from the top of the excavated material, we believe that they are from the deepest part of the trench and possibly their altitudes could be slightly negative.

The sea invaded lower zones of the Caraguatatuba plain during the last great transgression when clays rich in charcoal and shells were deposited there. A lagoon developed when part of bay was confined by a beach-ridge shortly after the first maximum. This lagoon, partially filled by organic-rich clays, dried up with sea level lowering after the first maximum. Thus, the upper part of the organic clay must have an age similar to that of the first maximum (Suguio and Martin, 1976b).

A shell sample (A290) from the second generation of beach-ridges was dated as 2565 ± 90 years BP, which is consistent with its provenance (second generation beach-ridges). Finally, oyster shells obtained from a clayey formation near the margin of the 'Ribeirão da Lagoa' were dated as 640 ± 80 years BP. These data demonstrate a sea level higher than present at that time, since mangrove deposits were developed under the influence of tides acting on the creek's margin.

Data from the Ilha Grande Bay Region

Similarly to the last two described regions, we have only a few data from this unit (Table 7).

Oyster shell crusts fixed to rock were dated by J. Curray (personal communication, 1975) as 5200 and 4800 years BP. They are evidence of a sea level 4.8 m higher than present. These occurrences are located near the Precambrian basement, about 600 m from the present strandline, which suggests that first maximum occurred about 5000 years BP, and that time the relative sea level could have been 4.8 m higher than present.

A *Vermetidae* sample (Laborel II; Delibrias and Laborel, 1969), dated as 3,420 ± 110 years BP testifies to an ancient sea level of + 3.0 m (± 0.4 m). This evidence could be correlated to the second maximum positive phase which apparently occurred at 3300 years BP. Shells (A178) collected from a clayey formation on a small sedimentary plain were dated as 2390 years BP. This formation records an ancient sea level located + 2.0 m (± 0.5 m) above the present. The sample A231 dated as 2450 ± 130 years BP indicated sea level of + 1.5 m (± 0.4 m). The sample Laborel III, dated as 1670 ± 100 years BP, is related to an ancient sea level at + 1.5 m (± 0.4 m). Finally, the last sample (Laborel IV), dated as 380 ± 90 years BP, is indicative of a sea level at 0.5 m (± 0.5 m).

Table 7. Ages of geological samples from the Ilha Grande bay region

Sample	Nature	Position of the ancient sea level	Age BP	Lab. refer.	Coordinates
Curray I	Oyster *'in situ'*	+ 4.8(± 0.4m)	5200 ± 200	LJ.1364	22°.57.0'S 44°.25.6'W
Curray II	Oyster *'in situ'*	+ 4.8(± 0.4m)	4800 ± 200	LJ.970	22°.57.0'S 44°.25.6'W
Laborel II	Vermetidae	+ 3.0(± 0.4m)	3420 ± 110	Gif.1059	23°.00.0'S 45°.00.0'W
A321	Vermetidae	+ 1.5(± 0.4m)	2450 ± 130	Ba.465	22°.58.7'S 44°.26.3'W
A178	Shell *'in situ'*	+ 1.5(± 0.5m)	2390 ± 100	Gif.3647	23°.08.2'S 44°.42.3'W
Laborel III	Vermetidae	+ 1.5(± 0.5m)	1670 ± 100	Gif.1060	23°.00.0'S 45°.00.0'W
Laborel IV	Vermetidae	+ 0.5(± 0.4m)	380 ± 90	Gif.1061	23°.00.0'S 45°.00.0'W

L J = C-14 Dating Laboratory, Univ. of California, La Jolla, Ca., USA.

These data agree very well with that observed in Unit 3. It appears that in relatively recent times the sea level has been higher than present. This was related to a very interesting historical event. Once, during the especially higher tides (syzigial tides) the sea invaded some streets of the colonial village of Parati (State of Rio de Janeiro). Presently this ingression of the sea is not observed, and we believe that a little lowering of sea level has occurred since the arrival of Portuguese colonists.

Comparison of Sea Level Change Curves

When we compare the curves of the Units 1 and 2 with the partially delineated curves of other units, we see an almost constant dislocation in their amplitudes. Thus, the maximum of 5000 years BP left records that are situated at + 3.5 m within Unit 1, at + 4.6 m within Unit 2 and at + 4.8 m within Unit 5. The second maximum of 3300 years BP left evidence at about + 3.0 m within Unit 1 and + 4.0 m within Unit 3.

The present zero level was transected at about 6300 years BP in Unit 1 and at about 6600 years BP in Unit 2. Between 2000 and 1000 years BP the relative sea level could not have been higher than 0.3 m within Unit 1, while in other units it was between + 1.5 m (± 0.4 m) and + 1.0 m (± 0.4 m).

These differences appear to be greater than the errors of measurement and are too constant to be fortuitous. It is obvious now, that local components played different roles in relative sea level fluctuations.

Nature of the Phenomena Causing Amplitude Dislocations in Sea Level Curves

Differential Continental Inflection

This mechanism could explain very easily the altitude differences in records of the maximum sea level of 5000 years BP within Units 1 and 2. Similarly, the apparent contradiction of records of highest altitudes being located in the north could also be explained by the differential continental inflection mechanism (Fig. 3: fourth and fifth cases). On the other hand, the dislocation from 2000 years BP to today is hardly explainable by the continental inflection phenomenon. Moreover, if this was the cause of the dislocation, the records representing the second from the last great transgressive episode (120,000 years BP) must show proportional dislocations. So, if the dislocation of 1.0 m, observed between Units 1 and 2 in records left by the maximum of 5000 years BP, has been produced by a continental inflection mechanism, then this should have originated a dislocation of 20 to 25 m in the records left by the second from the last great transgressive episode ('Cananéia' Formation). In reality, however, great differences in the altitude of the 'Cananéia' Formation's top between Units 1 and 2 are not observed.

Thus, it is necessary to look for another mechanism to explain the observed dislocation. But, it is also necessary to emphasize that on a very great time scale (120,000 years) the continental inflection phenomena seems to play a not unimportant role. In fact, the importance of the 'Cananéia' Formation diminishes from south to north and disappears within Units 4 and 5. So, it is possible that the continental inflection phenomena is playing a role as a local component (also on the Holocene time scale), but in this case its influence is masked by a much more important mechanism.

Variation of the Geoid Surface

Geodetical measurements of the real ocean surface (equipotential surface of geoid) using satellites in the last few years, have revealed several irregularities. Thus, the map of the the geoid (Smithsonian Standard Earth III, Guposchkin, 1973) indicates very important variations. For example, between the New Guinea 'hump' and Maldive islands depression there is a difference of 180 m in the sea level surface.

Certainly, the geoid surface has not remained the same throughout geological history. Some horizontally oriented changes (relief dislocation) and/or vertical changes (increasing or diminishing hump and depression amplitudes) have occurred through time. According to Mörner (1976) this kind of movement has occurred during the Holocene causing transgressions and regressions by relative dislocations of sea level.

So, we believe that, in the present stage of our knowledge, vertical movement of the geoid surface is the best explanation for the vertical dislocation verified for the records of the last transgressive phase in several parts of the Brazilian littoral zone here studied.

Conclusions

The last transgressive phase left uncontestable geological records indicating Holocene sea levels higher than present along the coast of the State of São Paulo. During the past 6000 years the relative sea level has been subjected to oscillations, with maxima at 5000 years and 3330 years BP, separated by a minimum at 3800 years BP.

The comparison of different curves or partially delineated curves for several parts of this coast showed a constant amplitude dislocation. The observed differences appear to be greater than errors of measurement and are too constant to be considered fortuitous. So, it is obvious that a local component played a role in different parts of the coast causing relative sea level changes.

A continental inflection mechanism conveniently explains the diminishing importance of the records left by the second from the last great transgressive episode ('Cananéia' Formation), but it can not explain the dislocation of records left by more recent transgressions. In our present stage of knowledge we believe that the mechanism of vertical deformation of the geoid surface can properly explain these differences of altitude.

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