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Shell middens as a source for additional information in Holocene shoreline and sea-level reconstruction: examples from the coast of Brazil

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ABSTRACT

Artificial accumulations of brackish-water shells and marine organisms constructed by ancient inhabitants of coastal regions may, under some conditions, be used as indicators of past sea levels. They are particularly useful in coastal areas that have experienced submergence and emergence once or several times. Assuming that the ancient inhabitants established their campsite near a suitable locality to furnish sufficient shell food and above the local high water spring tide level, it is possible to establish a horizontal relationship between shell-midden sites and former lagoonal, estuarine or marine environments. Although shell middens do not provide direct evidence of former sea-level positions, study of their stratigraphical position, internal stratigraphy, height, radiocarbon and archaeological age, fauna composition and $^{13}C/^{12}C$ isotope ratio of mollusc shells can supply valuable additional information within a more encompassing shoreline/sea-level investigation. This paper discusses several examples of the use of shell middens in the study of relative sea-level movements along the coast of Brazil.

INTRODUCTION

Artificial accumulations made up of shells of brackish-water and marine organisms are very commonly found in coastal regions around the world, as in Natal (South Africa), southern Madagascar, eastern Australia (particularly the 'New England' coast of New South Wales), Senegal, middle Atlantic coast of the United States.

In coastal Brazil, between Rio de Janeiro and Rio Grande do Sul, several hundreds of giant shell middens (known in that country as 'sambaquis' (Indian terminology) have been built up by ancient inhabitants of these areas, whose basic food was shellfish, as shown by archaeological investigations (Laming-Empéraire, 1968; Hurt, 1974; and Fairbridge, 1976). These ancient inhabitants have been named 'shellfish-eating preceramic Indians' (Fairbridge, *op.cit.*). The middens exhibit a variety of shapes and sizes, ranging from huge elongated (300 x 60 x 6m) or ellipsoidal (86 x 40 x 25 m) to small circular (10 x 1 ∿ 1.5 m) accumulations. Some of them occur as far as 40 km inland from the present coastline.

It may be assumed that site selection was decided primarily by near occurrence of shellfish in sufficient quantity to provide nourishment over a long period of time. One shell midden examined by Fairbridge (*op.cit.*) in the State of Santa Catarina was approximately 20 m high and 100 m in diameter, representing about 2.5 billion shellfish, that is almost 100 shellfish per day for a group of 100 people for 500 years. Obviously, shallow and quiet-water bay bottoms, lagoonal and estuarine zones, with muddy surface areas exposed during low tides, would have been more favourable from this standpoint than sandy areas at the open ocean margin. In the former case, biological productivity is much higher. Presently, large numbers of people pick up considerable quantities of molluscs from areas exposed during low tides as, for instance, in certain parts of the Todos os Santos Bay (State of Bahia, Brazil), without exhausting the stock. It is probable that paleo-inhabitants chose campsites above high-tide level, immediately adjacent to favourable collecting grounds, where the best conditions of comfort and safety were found. Only occasionally is there evidence that they went farther afield, in which case one may assume an important relationship between the shell midden's position and the presence of shallow-marine, lagoonal or estuarine zone in the vicinity. Ecological investigations of the dominant mollusc species found in the shell midden will indicate the paleo-environmental conditions of the surrounding area.

While it is relatively easy to establish the geographic relationship between the shell midden and a nearby ancient lagoon, estuary or bay, it is much more difficult to establish the vertical relationship between the altitude of the base of the shell midden and the position of sea level (SL) during its construction. We can only assume that initially it was above local high-water spring tide (HWST) level, a very important assumption for interpreting shell middens whose substrates are located beneath present high-tide level. A detailed investigation of the shell midden's substrate and composition may provide some criteria to eliminate the possibility of the shell middens having been built up below high-tide level. Probably, this is the case with shell middens that originated as wastedumps (mixture of shells and man-made artifacts) below houses which were built on poles, standing in shallow water during high tides. Furthermore, when the shell midden is situated near a

lowland (ancient lagoonal area) we must assume, as a postulate, that its construction occurred near the mollusc collecting area. From these two assumptions, proximity of the collecting zone and construction above local HWST level, it is possible to establish a rather close relationship between geographic position of shell middens and ancient SLs.

The main purpose of this paper is to evaluate the usefulness of shell middens for SL-height/shoreline reconstruction. The method used for this evaluation is to show how information obtained from the study of shell middens correlates with SL data derived from geo(morpho)-logical and biological indicators and how that information has been used in the construction of SL curves for several sectors of the States of São Paulo and Bahia

RELATIVE SEA-LEVEL CHANGE DURING THE LAST 7000 YEARS ALONG THE BRAZILIAN COAST

Papers by Martin & Suguio, (1975, 1976a, 1978); Martin *et al.*, (1979a, 1979b, 1980); Suguio & Martin, (1976, 1978); Suguio *et al.*, (1980); and Bittencourt *et al.*, (1979), on the coastal plains of the States of São Paulo and Bahia provide very good knowledge of both the SL fluctuations during the Quaternary and the ages of associated sandy deposits. An evolutionary history of these regions during the Quaternary has been reconstructed from this information. About 120 000 years ago the relative SL (RSL) stood about 8 ± 2 m above the present level. Between the end of this transgression (Cananéia transgression) and the beginning of the following regression a first generation of sandy beach ridges was deposited. During the last glacial when SL was low, these deposits were carved by rivers and a system of valleys, some very large and deep, developed. The original wave-built terrace surfaces, frequently marked by beach-ridge alignments, have been preserved only in interfluvial zones. When, during the Holocene, SL reached its present position (about 7000 to 6500 ^{14}C years ago; Santos transgression), the low-lying parts of the ancient terraces were invaded by the sea, forming extensive lagoonal systems. About 5000 BP SL attained a maximum height, which was coincident with the maximum extension of the lagoonal areas. From that time on, RSL fell more or less regularly with two important negative fluctuations between 4100 and 3600 BP and 3000 and 2500 BP.

INFORMATION TO BE DERIVED FROM SHELL MIDDENS

1. Different types of shell-midden sites

Four distinctive types of midden sites can be recognized (modified from Fairbridge, 1976).

Type I is located on Cananéia transgression terraces, always at the margins of zones formerly, or up to the present time, occupied by lagoons. Among these we must look for the shell middens constructed during the period of greatest lagoonal extent. In general, the more inland shell middens are smaller than those situated near the present strandline. Here, at the coast, favourable living conditions for molluscs continue to exist today.

Type II shell middens are situated on Santos transgression terraces. These terraces have been deposited as beach ridges during the regressive phases that followed the SL maxima, in particular the 5100 BP maximum. Type II shell middens have necessarily been constructed after the maximum Holocene SL stands, and in some cases their position on the terraces can provide additional data on SLs.

Type III shell middens are situated on ancient lagoonal deposits in front of sandy terraces. Hence, they must have been constructed after a period of high SL, probably during the ensuing lowering of SL. One must be cautious with type III middens, because the substrate of lagoonal organic clays is liable to have been subjected to compaction, thus diminishing the height of the midden's base.

Type IV shell middens are located on rocky hills at the margins or centres of ancient lagoons or bays. Their age varies widely. Clearly, those situated more inland may have been constructed when the lagoon reached its greatest extent.

2. Faunal composition of shell middens

About fifty different species of molluscs have been identified within the shell middens but the most dominant species are very few; according to Bigarella (1949) these are:

Anomalocardia brasiliana Gmelin
Ostrea brasiliana sp.
Ostrea arborea Chemnitz
Lucina jamaicensis Chemnitz
Modiolus brasiliensis Chemnitz

Except for *Ostrea arborea*, which lives fixed on aerial roots of mangrove trees, these bivalves live within sandy or clayey-sandy sediments deposited in shallow-water lagoons and bays. Shell remains of other organisms are generally negligible. Some middens are composed practically of one mollusc species, others show a mixed composition. *Ostrea* sp. and *Modiolus brasiliensis* are dominant species within more inland shell middens, and in this case *Anomalocardia* is very scarce or completely absent. On the other hand, shell middens situated nearer to the open sea are formed almost entirely of *Anomalocardia*

3. $^{12}C/^{13}C$ ratios of carbonate shells from shell middens

$\delta^{13}C$ (PDB) measurements for carbonates show a spectrum of values varying as a function of the influence of continental environmental conditions during the carbonate formation. Shells from lagoonal organisms show $\delta^{13}C$ (PDB) values between those for fresh-water organisms ($\cong$ 13 ‰) and those for marine organisms ($\cong$ 0 ‰). At the same time, the $\delta^{13}C$ (PDB) values for carbonate shells from a lagoon

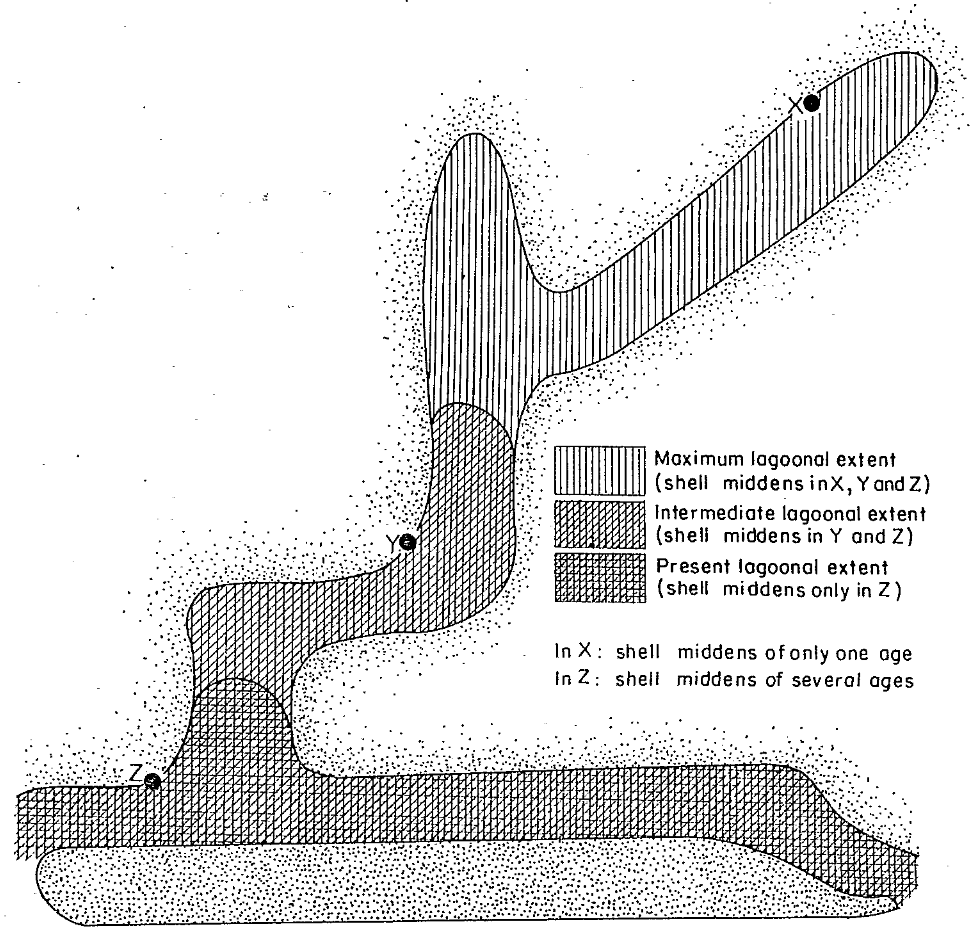

Figure 1. Age variations of the shell middens as a function of lagoonal extent.

change as a function of their geographic position within it (Flexor *et.al.*, 1979). Shells from outer zones (nearer the open sea) of a lagoon show only slightly negative $\delta^{13}C$ (PDB) values, while those from inner zones are clearly characterized by more negative values (Table 1). In the latter case, carbon, derived from decomposition of land plants, has been incorporated by the molluscs within their carbonate shells. Deeper and inner portions of the lagoons are characterized by a poor water circulation propitiating an accumulation of large quantities of plant-derived organic matter. This is independent of water salinity and explains why the carbonate shells of lagoonal organisms present $\delta^{13}C$ (PDB) values characterized by a strong land influence.

Conversely, at the same locality, but at different moments, the $\delta^{13}C$ (PDB) values change according to the increase or decrease of the lagoonal area. In this case, this parameter will be a good indicator of the lagoonal oscillations and thus indirectly of SL fluctuations (Table 2).

Taking into consideration the example in Figure 1, it is quite possible to find at 'X', 'Y' and 'Z' shell middens of similar age but with quite different $\delta^{13}C$ (PDB) values for carbonate shells: very negative in 'X' and slightly negative in 'Z'. Where, in 'Y' and 'Z' shell middens exhibit different ages, the least negative $\delta^{13}C$ (PDB) values correspond to periods of greatest lagoonal extent and vice-versa.

Generally, we do not know the paleo-RSL position with respect to the present level. However, we know if it was lower or higher and so we can deduce whether SL was (or had been) rising or falling and approximate the time that a maximum or minimum was reached.

COMPARISON OF SEA-LEVEL DATA WITH SHELL-MIDDEN DATA

1. Cananéia-Iguape region

The Cananéia-Iguape sedimentary plain has the shape of a large crescent and covers an area of about 2500 km². Its outer portion is presently drained by a lagoonal system and water courses subjected to tidal influence. A large part of the plain is occupied by remnants of more or less dissected Pleistocene terraces and by presently dried-out ancient lagoonal areas, at the far inland margins of which several shell middens have been found.

a) Information furnished by dating geological samples

Shell debris and wood fragments from littoral marine or lagoonal deposits have been dated, and this information, when associated with the nature of the sediments, indicates that (Fig. 2A):

a) about 6600 to 6500 BP, RSL reached approximately its present level and it was rising;

b) about 5400 BP, RSL was about 1.5 m above present level:

c) about 4400 BP, RSL was about 2 m higher than present level but it was falling. Hence, between 5400 and 4400 BP, RSL passed through a maximum height which, according to morphological data, must have been 3.5 to 4 m above the present one;

d) between 3800 and 3700 BP, RSL rose very rapidly reaching a second maximum of about 3 m above present level; between 4400 and 3700 BP it passed through a minimum;

e) after the second maximum, RSL returned more or less regularly to its present level. Unfortunately we have insufficient data for detailing this return.

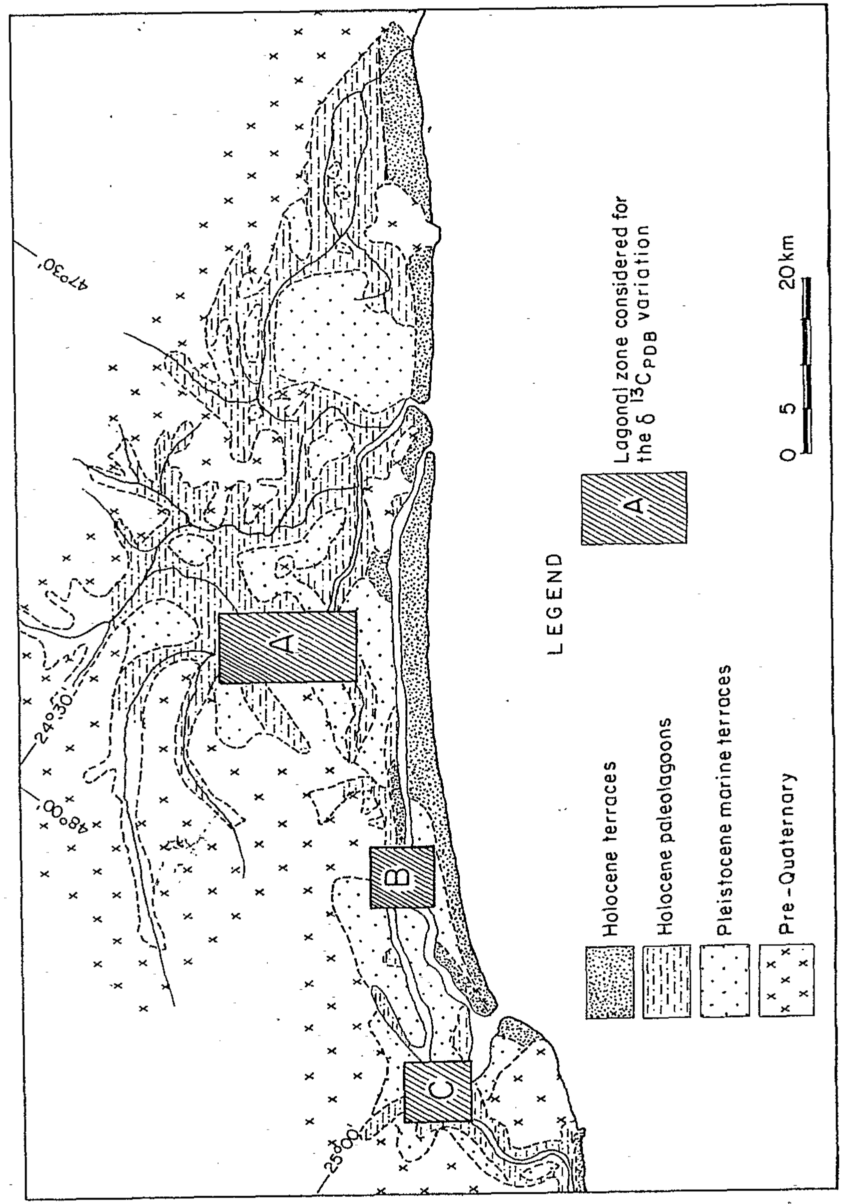

Figure 2. Reconstruction of relative sea-level fluctuation curve for the past 7000 years in the Cananéia-Iguape region (State of São Paulo, Brazil).

b) Information furnished by dating shell middens

As indicated above, between 5400 and 4400 BP RSL was always higher than at present, attaining a maximum of 3.5 to 4 m above present level. One may expect that this high SL occurred contemporaneously with the maximum lagoonal extent and that the shell middens situated more inland should date this phase (Tables 3 and 4). Analysis of the majority of these shell middens shows that only a SL higher than the present one can explain their positions (Fig. 2B). Moreover, the ages of the shell middens situated far from the present strandline lie between 5200 and 4800 BP.

Thus, we believe that the maximum lagoonal extent occurred during this period, probably at about 5000 BP. Moreover by 4100 BP RSL was probably no more than 0.5 m above the present level, and around 3800 BP it may even have been lower. This confirms the conclusion reached above on the basis of geological evidence that SL reached a minimum between 4100 and 3800 BP.

Table 5 shows that the oldest shell midden (Estaleiro = 3690 ± 80 BP) is situated on the Pleistocene terrace which may be an indication of a high lagoonal level. This hypothesis seems to be confirmed by the $\delta^{13}C$ (PDB) value of its shell carbonate. In fact, this value is much less negative than for shells of Sambaquinho, which was constructed in the same area when SL can have been at most 0.5 m above present level. Evidently, around 3700 BP RSL was well above the present level. It was stated above that since 3700 BP RSL reached a second maximum situated 3 m above the present one. The age of the Boguacu-I shell midden (3080 ± 55 BP), which was constructed when SL cannot have been more than 2.5 m above present level, shows that at about 3100 BP, the maximum of 3 m was already passed. The information from the Guarapari and Sambaquinho shell middens indicate that RSL at about 2300 and 1500 BP has not been more than 1 m and 0.5 m respectively above present level.

c) Information furnished $\delta^{13}C$ (PDB) values

As discussed above, $\delta^{13}C$ (PDB) values can be used as an index to marine versus continental influences, and as indirect evidence of SL change (Fig. 2C). Below, we discuss $\delta^{13}C$ (PDB) values obtained for shell samples from three groups of middens in the Cananéia-Iguape coastal plain (A, B and C in Fig. 3). The first two groups (A and B) concern shell middens constructed in the period 5200-4200 BP and 5200-4800 BP respectively; the middens of group C were built between 3800 and 1500 BP.

Group A We take the example of seven shell middens of region A of the Cananéia coastal plain (Fig. 3). The first six have ages ranging from 5200 to 4200 BP (Table 2). It would be interesting to have information on a shell midden constructed about 4100 BP, when SL cannot have been higher than 0.5 m above the present level. We could then compare $\delta^{13}C$ (PDB) values of carbonate shells formed in the same

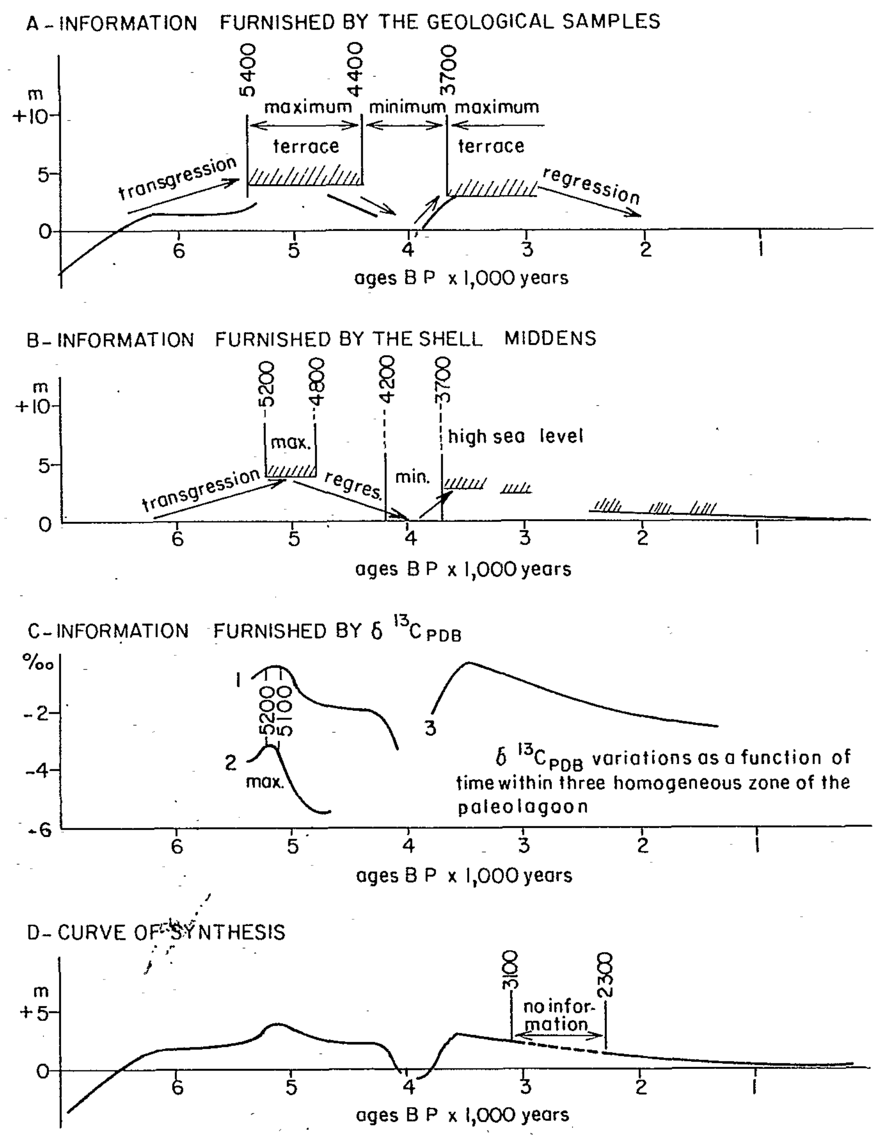

Figure 3. Cananéia-Iguape Quaternary coastal plain (State of São Paulo, Brazil).

geographic position between 5200 and 4100 BP, encompassing the first Holocene regressive phase. For want of a shell midden dated 4100 BP we have considered another about 1000 years old, when SL was quite similar to that at 4100 BP. It is assumed that $\delta^{13}C$ (PDB) values of shell carbonate from shell middens of both ages are comparable.

When plotted as a function of time (curve 1 in Fig.2C), the $\delta^{13}C$ (PDB) values show a maximum between 5200 and 5100 BP and decrease rapidly until about 4800 BP, then slowly until 4200 BP, whereafter another rapid decrease is noticed. These $\delta^{13}C$ (PDB) differences can be interpreted both in terms of changing lagoonal extent and, assuming constant (local) tide range, in terms of changing RSL as follows;

a) the maximum lagoonal extent, and thus the SL maximum probably occurred between 5200 and 5100 BP;

b) the maximum was followed by a rapid decrease in lagoonal extent, which is indicative of a quick SL lowering between 5100 and 4800 BP;

c) lagoonal extent and hence RSL were stationary between 4800 and 4200 BP; and

d) lagoonal extent reduced rapidly after 4200 BP suggesting an equally rapid SL lowering.

Group B Here we have considered three shell middens from the same area of the inland portion of the Iguape coastal plain (area B in Fig. 3). From these data (Table 6) one may derive a curve of variation of $\delta^{13}C$ (PDB) which shows that the maximum was well established between 5200 and 5100 BP and that the fluctuation was very rapid between 5100 and 4800 BP (curve 2 in Fig. 2 C).

Group C We have considered four shell middens in the same area (area C in Fig. 3) of the Cananéia coastal plain, whose ages range from 3800 to 1500 BP (Table 7). The corresponding $\delta^{13}C$ (PDB)-variation curve is given in Figure 2 C (curve 3). Between 3800 and 3500 BP, values increase very rapidly and then decrease. Put in terms of RSL it might be that there was a rapid rise between 3800 and 3500 BP followed by a drop.

In summary, radiocarbon dating of shell debris and fossil wood fragments from both sedimentary deposits and shell middens, as well as information on $\delta^{13}C$ (PDB) of carbonate shells from shell middens has allowed us to establish with sufficient accuracy a fluctuating RSL curve for the Cananéia-Iguape region (Fig. 2 D).

2. Santos-Itanhaém region

The Santos-Itanhaém coastal plain has the same characteristics as the Cananeia-Iguape area. A lagoonal system originated during each high SL period and shell middens, some of them dated by radiocarbon method, were established at the margins of paleo-lagoons.

a) Information from geological and biological sources

A large number of radiocarbon dates of shell debris and fossil wood fragments contained in lagoonal and shallow-marine deposits, as well as of vermetid incrustations, allowed us to delineate a rather accurate curve of RSL fluctuations (Fig. 4 A). This curve is very similar to that for Cananéia-Iguape, though some differences in amplitude are apparent.

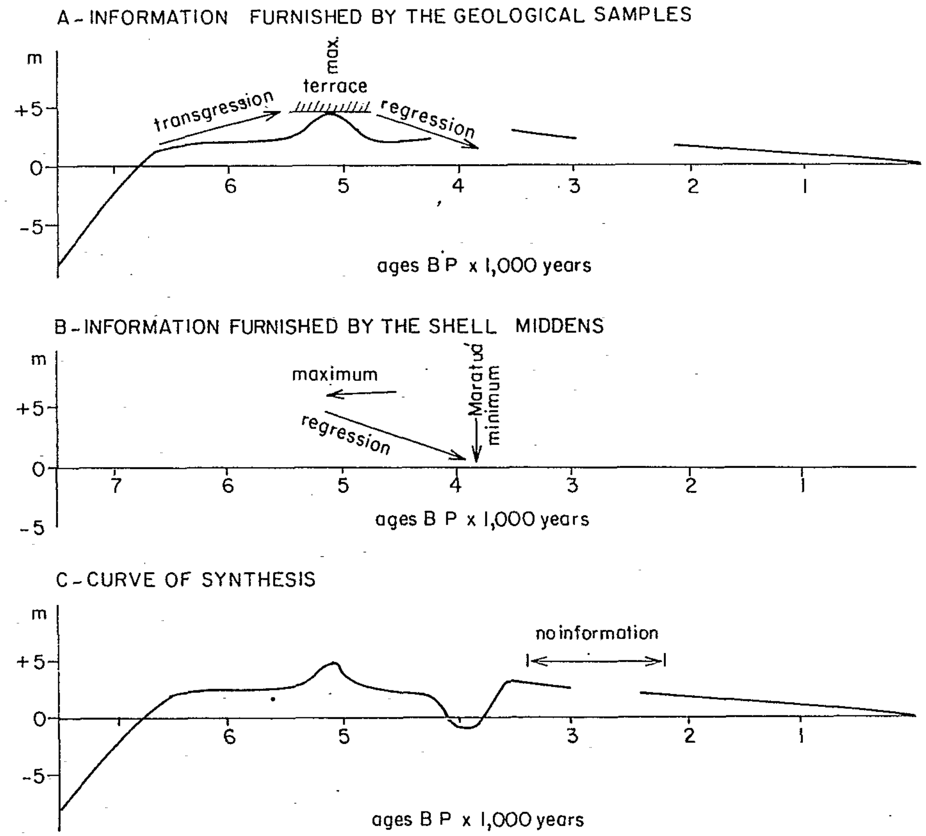

Figure 4. Reconstruction of relative sea-level fluctuation curve for the past 7000 years in the Itanhaém-Santos region (State of São Paulo, Brazil).

b) Information furnished by dating shell middens

Dated shell middens are much less numerous than in the Cananéia-Iguape area, but they are important for corroborating the information dated from geological samples (Fig. 4B; Table 8).

The Rio Preto, Ararañ, and Mundo Novo shell middens are situated in an inner portion of the Itanhaém paleo-lagoon. Possibly, therefore, they were constructed during maximum lagoonal extent. However, if this hypothesis is correct, this maximum lagoonal extent could be different from that previously defined. The $\delta^{13}C$ (PDB) values of the shells from these middens are much more negative than those of the samples dating the high SL period of Cananéia-Iguape. In fact, the $\delta^{13}C$ (PDB) values of the Itanhaém shell middens are quite similar to that of the Momuna shell midden

(Table 3), which has about the same age. Thus, possibly about 4600 BP the continental influence in the inner portion of the Itanhaém paleo-lagoon was very strong, perhaps because the maximum had passed and the paleo-lagoon was beginning to dry out.

The shell middens A229 and Mar Casado (Table 8), located on a Holocene terrace, obviously were constructed after the transgression maximum, when SL was probably less than 3.5 m and 3 m respectively, above the present level.

The Maratuá shell midden, which has been completely destroyed, has furnished the most interesting information (Fig. 4B). The base of this midden was located below present SL. This fact cannot be attributed to substrate subsidence due to the shell midden's weight, because in that case the central portion would have sunk more than its margins, thereby deforming the shell midden's layers. No deformation whatever was noticed. Two samples from this shell midden dated at the beginning of radiocarbon investigations indicated ages of 7330 ± 1300 BP (Gif-15) and 7800 ± 1300 BP (Gif-16) (Laming - Empéraire, 1968). These values, now known to be in error, coincided with a period when RSL was definitely lower than today, so that initially these two ages were thought to be consistent with known SL curves. However, archaeological remains within the Maratuá shell midden suggested that its construction must have occurred more recently. Two radiocarbon ages were obtained for the same samples and indicated ages of 3925 ± 145 BP (Bah-382) and 3865 ± 95 BP (Gif-9185), which are more in keeping with modern data. It is now possible to infer that RSL about 3800 BP was lower than today, as we have also observed in the Cananéia-Iguape region.

3. Salvador region

On a sector of the coast with homogeneous conditions in the northern part of Salvador (State of Bahia), 66 reconstructions of former RSL positions were made. From these data we have delineated a very accurate curve of RSL change (Fig. 5), which shows that:

a) the present level was crossed about 7000 BP;

b) about 5100 BP, RSL was at a maximum, some 4.7 ± 0.5 m above the present level;

c) about 3900 BP, RSL reached a minimum, lower than at present;

d) about 3600 BP, RSL attained a second maximum, located more than 3 m above the present level;

e) about 2700 BP, RSL had fallen to a second minimum, near present level;

f) about 2500 BP, RSL reached a third maximum situated about 2.5 m above the present; and

g) since this time, RSL has returned progressively toward the present level.

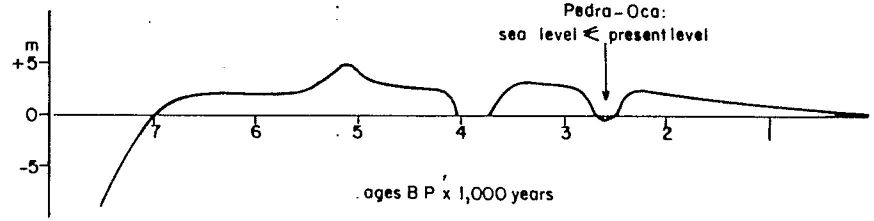

Figure 5. Relative sea-level fluctuation curve for the Salvador region (State of Bahia) with indication of the Pedra Oca shell midden

This curve presents characteristics quite similar to that of the Santos region (Fig. 4) with some small variations in amplitude.

In the Salvador region SL was low about 2700 BP, which was not evidenced in the Santos region. Perhaps, the absence of data for this period in the Santos region is indirect evidence of a lower SL. In fact, if SL has been lower, the evidence must presently be submerged.

At one time there were numerous shell middens around Todos os Santos bay, but unfortunately the great majority of them have been destroyed. It has been possible to obtain information about the Pedra Oca shell midden (Calderon, 1964) located in the sector studied by Martin *et al.* (1979a, 1980). Presently, the lower part of the non-eroded portion of this shell midden is situated 0.8 m above high-tide level (Martin *et al.*, 1979a). Two ages obtained from basal shells indicated ages of 2830 ± 130 BP (Gif-878) and 2630 ± 110 BP (Si-470). These data confirm the occurrence of a low SL position at about 2700 BP, which is also evident from other data.

FINAL CONSIDERATIONS

It is clear that shell middens are not the best tool for reconstructing, in space and time, the positions of former SLs. In fact, in practice it is not possible to establish directly the vertical relationship between the base of a shell midden and SL. The only thing of which we are more or less certain is that the base of the shell midden was above local HWST level at the beginning of its construction. If we postulate that the paleo-inhabitants established their campsites near the mollusc harvesting place, it is easy to establish the geographical relationship between the shell middens and an ancient lagoonal, estuarine or shallow-marine zone. Shell middens located further inland were probably associated with a period of maximum lagoonal extent, obviously when a SL maximum occurred. Nevertheless, it is necessary to ascertain that coastal progradation was unrelated to intense continental sedimentation, but rather to a RSL change. Plainly, only one dating is insufficient, and one must have a statistically significant series of dates in order to interpret correctly the period of maximum lagoonal extent. On the other hand, the shell middens whose substrates are located beneath present high-tide level suggest, if compaction can be ruled out, a period of lower SL. Values of $\delta^{13}C$ (PDB) for carbonate shells give us additional information about the high or low SL positions, as well as about the trend of SL change.

ACKNOWLEDGEMENT

The authors wish to express their thanks to Dr. Thomas R. Fairchild for revision of the English text.

Table 1. Variation of $\delta^{13}C$ (PDB) as a function of position of the samples within a paleo-lagoon, coastal plain of the State of São Paulo, Brazil (Flexor *et al.*, 1979).

Sample	Radiocarbon age (BP)	$\delta^{13}C_{PDB}$ ‰	Distance from the open sea (km)
Itapoã III	5245 ± 125	- 0.63	5
Jataituba	5240 + 150	- 3.26	20
Vapumauva II	5080 + 60	- 0.06	1
Pariquera Acu	5035 + 140	- 3.88	24
Vapumauva I	4680 + 115	- 0.12	2
A195	4636 + 100	- 6.17	18
Ubatuba	3870 + 100	- 0.02	?
A123	3775 + 130	- 5.69	33

Table 2. Variation of $\delta^{13}C$ (PDB) as a function of age within the same portion of a paleo-lagoon, coastal plain of the State of São Paulo, Brazil (Flexor *et al.*, 1979).

Sample	Radiocarbon age (BP)	$\delta^{13}C_{PDB}$ ‰
Itapoã III	5245 ± 125	- 0.63
Guaxixi	5110 ± 70	- 0.48
Juruvaúva I	5010 ± 115	- 0.76
Juruvaúva III	4970 ± 150	- 1.34
Juruvaúva II	4305 ± 140	- 2.07
Itapoã II	4215 ± 140	- 2.27
Vamiranga	1015 ± 70	- 3.81

Table 3. General characteristics of shell middens constructed between 5400 and 4400 BP

Shell midden	Radiocarbon age (BP)	Laboratory number	Nature of substrate	Position in the paleo-lagoon	$\delta^{13}C_{PDB}$ ‰
Itapoã III	5245 ± 125	Bah-365	P.T.	Outer	- 0.63
Jataituba	5240 ± 150	Bah-346	P.T.	Inner	- 3.26
Guaxixi	5110 ± 70	Bah-370	P.T.	Outer	- 0.48
Vapumaúva	5080 ± 60	Bah-365	P.T.	Outer	- 0.06
Pariquera Açu	5035 ± 140	Bah-295	P.T.	Inner	- 3.88
Juruvaúva I	5010 ± 115	Bah-359	P.T.	Outer	- 0.76
Juruvaúva III	4970 ± 110	Bah-361	P.T.	Outer	- 1.34
Batatal	4920 ± 100	I.9186	P.T.	Outer	----
R.das Pedras I	4860 ± 100	Bah-343	C.B.	Inner	- 3.17
Momuna	4790 ± 100	Bah-308	P.T.	Inner	- 5.39
R.das Pedras III	4750 ± 110	Gif-3641	P.T.	Inner	- 4.67
	4710 ± 145	Bah-300			
Rio Comprido	4560 ± 110	Gif-3646	C.B.	Outer	----
Cananéia	4340 ± 110	Gif-3435	P.T.	Outer	- 1.28
	4300 ± 140	Bah-302			

(P.T.= Pleistocene Terrace; C.B. = Crystalline Basement; Bah = Laboratorio de Física Nuclear Aplicada, Universidade Federal da Bahia, Brazil; Gif = Laboratoire des Faibles Radioactivités, Gif-sur-Yvette, France and I = Isotopes, USA)

Table 4. Shell middens constructed between 5000 and 3700 BP on Holocene terraces and lagoonal deposits

Shell midden	Radiocarbon age (BP)	Laboratory number	Position of sea level	$\delta^{13}C_{PDB}$ ‰
Vapumaúva II	4680 ± 110	Bah-362	< + 3.5m	- 0.72
Nóbrega	4380 ± 160	SPC-21	< + 3.5m	----
Boguaçu II	4160 ± 100	Bah-303	< + 1.5m	- 1.39
	4120 ± 100	Gif-3436		
Ararapira II	4175 ± 100	Bah-290	< + 0.5m	- 1.67
Ubatuba	3870 ± 100	Bah-294	< + 2.0m	- 0.02
Ararapira I	3790 ± 110	Gif-3437	< 0m	----

(SPC = Centro de Pesquisa Geocronológicas do Instituto de Geociências, Universidade de São Paulo, Brazil)

Table 5. Shell-middens constructed since 3700 BP.

Shell midden	Radiocarbon age (BP)	Laboratory number	Nature of substrate	Position of sea level	$\delta^{13}C_{PDB}$ ‰
Estaleiro	3690 ± 80	Bah-367	P.T.	> 0m	- 0.65
Fosfasa I	3350 ± 135	Bah-340	P.T.	> 0m	- 1.80
Pereirinha	3330 ± 125	Bah-286	H.T.	> 0m	- 0.09
Boguaçu I	3080 ± 55	Bah-285	H.T.	< + 2.5m	- 3.57
Boguaçu III	3220 ± 90	Bah-307	H.T.	< + 3.0m	- 3.25
	3090 ± 110	Gif-3645			
Pindu	3090 ± 120	Bah-348	C.B.	> 0m	- 4.31
Guarapari	2285 ± 45	Bah-368	L.	< + 1m	- 2.24
R. das Minas	1850 ± 100	Gif-3643	H.T.	< + 0.5m	----
Sambaquinho	1500 ± 120	Bah-292	L.	< + 0.5m	- 2.61
Itapitangui	1490 ± 120	Bah-293	H.T.	< + 1.5m	- 4.45
Vamiranga	1015 ± 70	Bah-369	P.T.	indefinite	- 3.81

(H.T. = Holocene Terrace and L. = Lagoonal).

Table 6. $\delta^{13}C_{PDB}$ values of carbonate shells from three shell middens constructed in the same inner zone of the Iguape coastal plain

Shell midden	Radiocarbon age (BP)	$\delta^{13}C_{PDB}$ ‰
Jataituba	5250 ± 150	- 3.26
Pariquera Açu	5040 ± 140	- 3.88
Momuna	4790 ± 115	- 5.81

Table 7. $\delta^{13}C_{PDB}$ values of carbonate shells from four shell middens of the Cananéia coastal plain

Shell midden	Radiocarbon age (BP)	$\delta^{13}C_{PDB}$ ‰
Fosfasa II	3790 ± 110	- 2.63
Estaleiro	3490 ± 60	- 0.67
Guarapari	2285 ± 45	- 2.24
Sambaquinho	1500 ± 120	- 2.61

Table 8. General characteristics of the dated shell middens of the Santos-Itanhaém coastal plain

Shell midden	Radiocarbon age (BP)	Laboratory number	Nature of substrate	Position of sea level	$\delta^{13}C_{PDB}$ ‰
Piaçagüera	4930 ± 100	I-4491	C.B.	> 0m	----
Rio Preto	4635 ± 100	Bah-331	P.T.	> 0m	- 6.07
Araraú	4630 ± 130	Bah-296	C.B.	> 0m	- 5.29
Mundo Novo	4575 ± 110	Bah-446	C.B.	> 0m	- 8.91
A229	4520 ± 130	Bah-328	P.T.	< + 3.5m	- 2.98
Mar Casado	4400 ± 130	Gif-1194	H.T.	< + 3.5m	----
Maratuá	3925 ± 145	Bah-382	L.	< 0m	----
	3865 ± 95	I-9185			

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