Holocene Sea-Level History Along Eastern-Southeastern Brazil

Louis Martin

Institut Français de Recherche pour le Développement, 149 Rue Oberkampf, 75011 Paris, France - louis.martin@noos.fr

Abstract

Relative sea-level curves have been delineated for several sectors of the Brazilian coast. In order to have homogeneous and consistent curves, very short segments of the coastline with the same framework are considered. To minimize systematic errors tied to the particular nature of an indicator, we use the maximum number of different indicators available from former positions of relative sea level. These sea-level curves show that, during the last 7000 years, the central Brazilian coast has been subjected to a submergence phase which lasted until 5100 ^{14}C yr BP (5600 cal yr BP), followed by a drop in sea level. This drop in sea level was not continuous but was interrupted by two high-frequency oscillations. The Salvador curve, the most detailed, can be used as a reference for the central portion of the Brazilian coastline. It is now presented with corrections for isotopic fractionation and reservoir effects as well as calibrations for astronomical ages. Additional supporting evidence for the existence of high-frequency oscillations is provided. They are of the same magnitude as is predicted for the future under greenhouse conditions. These data will help us to understand how the coastal systems will respond to these sea-level changes.
Key Words : sea-level curves, sea-level indicators, coastal evolution, Brazil.

Resumo

Curvas de variações do nível relativo do mar foram construidas para diversos setores do litoral brasileiro. A fim de obter curvas homogênas, foram utilizados dados provenientes de setores relativamente curtos do litoral com características geológicas uniformes. Para minimizar eventuais erros sistemáticos ligados à própria natureza de um indicador o máximo de indicadores diferentes de antigas posições do nível relativo do mar foi utilizado. Essas curvas mostram que, no decorrer dos últimos 7000 anos, a parte central da costa brasileira foi submetida a uma fase de submersão, até mais ou menos de 5100 ^{14}C anos AP (5600 cal anos AP), seguida por uma fase de emersão. Esseabaixamento do nível relativo do mar não foi contínuo mas caracterizado por duas oscilações de alta freqüência. A curva de variação do nível relativo do mar construída no fim dos anos 70 na região de Salvador, que serve de referência para a parte central da

costa brasileira, foi reconstruída depois de uma normalização e uma calibração das idades ^{14}C. Por outro lado, informações complementares que convergem fortemente no sentido de sustentar a existência de oscilações rápidas do nível relativo do mar são analisadas. A comprovação da existência de oscilações rápidas do nível relativo do mar (da ordem do metro por seculo) nos últimos milênios constitue um elemento importante na compreensão da evolução futura da zona costeira. Efetivamente, a anlise dos efeitos dessas oscilações sobre a morfologia da zona costeira pode fornecer exemplos do que poderá acontecer em conseqüência de uma eventual elevação do nível do mar com amplitude e velocidade equivalente.
Palavras-chave: curvas do nível do mar, indicadores do nível do mar, evolução costeira, Brasil

1 Reconstruction of Past Sea Levels

To reconstruct an ancient position of relative sea-level, it is necessary to fix a past sea-level record in space and time (Martin *et al*., 1986a). To locate this record in space it is necessary to know its present altitude in relation to its original position in relation to the sea-level at the time it was formed. To define the record in time it is necessary to date the time of formation. Once properly defined in time and space the record will provide the position of an ancient sea-level at a certain date. To minimize systematic errors tied to the particular nature of an indicator, it is advisable to confront the information provide by a given indicator with those originating from other sources. Even if an indicator provides only partial information, such as the trend of the sea-level behavior (rise or fall) and not an accurate reconstruction, this information should not be discarded. In many cases, a convergence of data using different indicators is preferable to an isolated "precise" reconstruction, although the latter may seem intrinsically better. On the other hand, one should not forget that there are numerous sources of error in the definition, in space and time, of past sea-level positions.Thus, each reconstruction should be plotted along with error bars for the estimated altitude and the measured age of the sea-level indicator used. Therefore, each reconstruction should plot not as a point but as a rectangle. This standard procedure has not always been observed (Angulo & Lessa, 1997). On the other hand, a ^{14}C age, in fact, is not an absolute age. Corrections for isotopic fractionation and reservoir effects are necessary before its significance can be adequately assessed. Furthermore, the same ^{14}C age BP may correspond to one or more calendar ages (Stuiver & Reimer, 1993). Finally, one should not forget that, despite exercising the utmost care in the sampling and analysis, some dates might exhibit totally incoherent results. It is thus necessary, in order to outline a curve of variations of relative mean sea-level, to have numerous ancient sea-level reconstructions, well distributed in time. Obviously, a reliable curve can only be derived from samples collected from small sectors of the coastal zone, in order to minimize possible effects of extraneous factors such as differential subsidence or uplift.

Several kinds of sea-level indicators have been used to reconstruct the sea-level history along the central Brazilian coast. These indicators are listed below.

Sedimentary indicators: Along almost the entire Brazilian coastline, marine, lagoon and mangrove swamp deposits situated above the present sea-level are unquestionable evidence of ancient higher sea-levels. Sands deposited in the littoral zone have many diagnostic sedimentary structures, which exhibit a close relationship with mean sea-level (Martin *et al.,* 1986a). A comparison between the altitudes in which these sedimentary structures occur in Holocene deposits and their present-day counterparts can provide acceptable reconstructions of previous sea-levels. Major uncertainties when using littoral deposits for reconstructing past sea levels are: i) reworking of shell material much older than the time of final deposition and ii) reconstructions in space will be probably biased in the sense that they will tend to provide higher levels, as a result of preferential preservation of high-energy episodic phenomena such as storm surges and abnormal wave heights.

Biological indicators: Biological indicators of former sea-levels include vermetid gastropod incrustations, oysters, corals and coralline algae. These sessile organisms have their vertical distribution intimately controlled by mean sea level and as such can be used as indicators of former levels (Laborel, 1986).

Other sea-level indicators: Under this topic we discuss other indicators of sea-level position found along the coastal zone, that although not allowing precise sea-level reconstructions can still be used as confirmating evidence of trends in past sea-level behavior (rise or fall), originally determined through the use of other indicators.

Archaeological indicators: The only archaeological indicators present along the Brazilian coastal zone (Martin et al.1986) that can be used to draw inferences about the past sea-level history are shellmounds (“sambaquis”). While it is relatively easy to establish the geographic (horizontal) relationship between the shellmounds position and a nearby ancient lagoon, estuary, or bay, it is much more difficult to establish the vertical relationship between the altitude of the shellmounds substrate and the position of the mean sea-level during its constructuion. We assume, based on the modern studies of shellmounds in southern Brazil (Gaspar, 2000), that the base of the shellmounds was originally positioned above the local high-water spring tide level (HWST). This assumption is very important for interpreting shellmounds whose substrate are now located beneath the present HWST.

Isotopic Indicators: d^{13}C (PDB)measurements of carbonate shells at coastal regions can exhibit an ample spectrum of values which are controlled by the degree of input of carbon from continental sources. The d^{13}C (PDB) value is a function of the geographic position of the organisms within the lagoon (Flexor *et al.,* 1979). Therefore, at a given geographic location, lagoonal shells living during a period of marine transgression will exhibit progressively less negative values. On the other hand, a drop in sea level or a regression will result in an increase of continental carbon influence, with the lagoonal shells exhibiting more negative d^{13}C (PDB)values. By the same token d^{13}C (PDB) values of shells collected in shellmounds whose occupation persisted for extended periods of time can be used as a yardstick to estimate variations in lagoon area and thus indirectly of sea-level fluctuations (Martin *et al*., 1986).
Conversely d^{13}C (PDB) values of shells collected in several shellmounds of different ages located around a small common lagoonal area will conceivably register variations in lagoon area as related to fluctuations in sea level. A major assumption intrinsic to the reasoning presented above is that the evolution of these coastal lagoons is controlled essentially by sea-level variations, i.e. there should be no major input of large rivers entering into it, in order to minimize effects such as reduction in lagoon size due to sediment deposition.

Although the archaeological and isotopic records do not provide precise reconstructions of past sea levels they can however provide constraints or supporting evidence for information from other sources, particularly times of maximum and minimum expansion of coastal lagoons.

2 Relative sea-Level Curves for the Last 7000 Years

Using the various types of indicators described above, it has been possible to delineate curves or sketches of curves of relative sea-level fluctuations for the last 7000 ^{14}C years for several sectors of the central part of the Brazilian coast (Dominguez *et al*,.1987, Martin *et al.*1979, 1996). In order to have relatively homogenous and consistent curves, only very short segments of the coastline (60 to 80 km), with the same geologic framework and numerous data, were considered. Although these curves are very similar to each other they show noticeable differences in vertical amplitudes.

The more detailed of these curves was produced for a sector of approximately 50 km situated to the north of Salvador city, State of Bahia (Martin et al. 1979). Sixty two determinations of former relative sea-level positions, covering the last 7000 years were used to construct this curve, which is certainly one of the most detailed produced worldwide. On Sea-level curve, reconstructions based on vermetid and littoral deposits are plotted as a rectangle, whose width and height represent respectively, the age and the altitude uncetainty associated with the reconstruction. Sea-level reconstructions based on corals and calcareous algae are plotted as a point and age error bar. The plot depicts a minimum sea-level position, the arrow pointing upward indicates that sea-level was probably higher than the position presently occupied by the indicator. Reconstructions based on dating of shells collected in shellmounds, are also plotted as a point with an age error bar, depicting a maximum position of sea level. The arrow pointing downward indicates that sea level was probably lower than the base of shellmound.

Figure 1 shows this curve plotted both as uncalibrated and calibrated ^{14}C years. We have opted for this dual display for the reasons presented below. The calculation of the radiocarbon age of a sample assumes that the specific activity of the ^{14}C in the atmospheric CO_2 has been constant. However, this is not true. The ^{14}C activity in the atmosphere and other reservoirs, and thus the initial activity of the samples dated has varied over time (Stuiver & Braziunas, 1993). A calibration dataset is necessary to convert conventional radiocarbon ages (**^{14}C yr**) into calibrated years (**cal yr**). We have used, the program CALIB 3.0, written and distributed by the Quaternary Isotope Laboratory, University of Washington (Stuiver & Reimer, 1993). It is clear that this calibration will only have real meaning if the original ^{14}C ages are first corrected for the reservoir and isotopic fractionation effects. During the seventies when most of the dates reported herein were performed (Martin *et al*., 1979), no reservoir correction was applied, although the isotopic fractionation effects were systematically corrected. Measured reservoir effect values are not available for the central part of Brazil. We could either apply a systematic – 400 years correction to all our samples of marine carbonates (coral, coralline algae, vermetid incrustations, etc) or use an indirect method to estimate this effect. Based on several assumptions an average value of 350 $\pm$ 100 years can be attributed to the coastal oceanic water of the central part of the Brazilian coast (Martin *et al.*, 2002). This value is slightly less than the 400 years usually used.

3 The calibrated curve of Salvador thus shows that (Fig.1B) :

- the present zero (mean level) was exceeded for the first time in the Holocene at about 7800 cal yr BP;

- about 5600 cal yr BP, the relative sea-level went through a first maximum of 4.7 ± 0.5m above the present level ;
- after this maximum, there was a rapid regression until 5300 cal yr BP, slowing down up to 4400 cal yr BP, and speeding up again at 4200 cal yr BP. At about this time the sea level passed through a minimum, probably below the present level ;
- after 3700 cal yr BP, a rapid transgression occurred, and at about 3500 cal yr BP, the relative sea-level passed through a second maximum of 3.5 ± 0.5 m above the present level ;
- between 3500 and 2800 yr BP, the relative sea-level fell slowly and regularly. Starting at 2800 cal yrs BP, the decline became very rapid again. At 2600 cal yr BP the marine level passed through a second minimum, probably below the present level ;
- after 2300 cal yr BP, the relative sea-level rose very rapidly, passing through a third maximum of 2.5 ± 0.5 m above the present level at about 2100 cal yr BP ;
- since 2100 cal yr BP, the relative sea-level has fallen regularly to its present position.

The Salvador curve shows the existence of two distinctive high-frequency oscillations at 4300-3500 cal yr BP and 2700-2100 cal yr BP. Also the interval between 5900 and 5300 cal yr BP was characterized by a rapid rise followed by an equally rapid fall. Recently Angulo & Lessa (1997), using sea-level reconstructions based exclusively on ^{14}C dating of vermetid incrustations, have published a new sea-level curve for Brazil in which they questioned the existence of these oscillations and the maximum of the Holocene transgression reported above. At first this might seem a controversy of local interest. However, we all have during the last decade become aware of the fundamental role exerted by sea-level changes not only in controlling evolution of coastal areas but also the deposition of entire sedimentary packages at the continental margins (the sequence stratigraphy paradigm). Additionally the high frequency sea-level oscillations delineated in the Salvador curve are of a magnitude and frequency of those predicted for the next century as a result of global warming. It is thus necessary to discuss these high-frequency oscillations a bit further (Martin *et al.*, 2002). The sea-level positions plotted in the curve for these two distinctive high-frequency oscillations are based on reconstructions using littoral sandstones. However additional evidences supportive of the existence of these high-frequency oscillations comes from the study of the evolution of the coastal plains located along the eastern and southeastern Brazil coast (Dominguez *et al.*, 1987, Martin & Suguio,1992, Martin *et al.*, 1993). These studies show that during these two periods important environmental changes affected these plains and the pre-historic peoples living there.

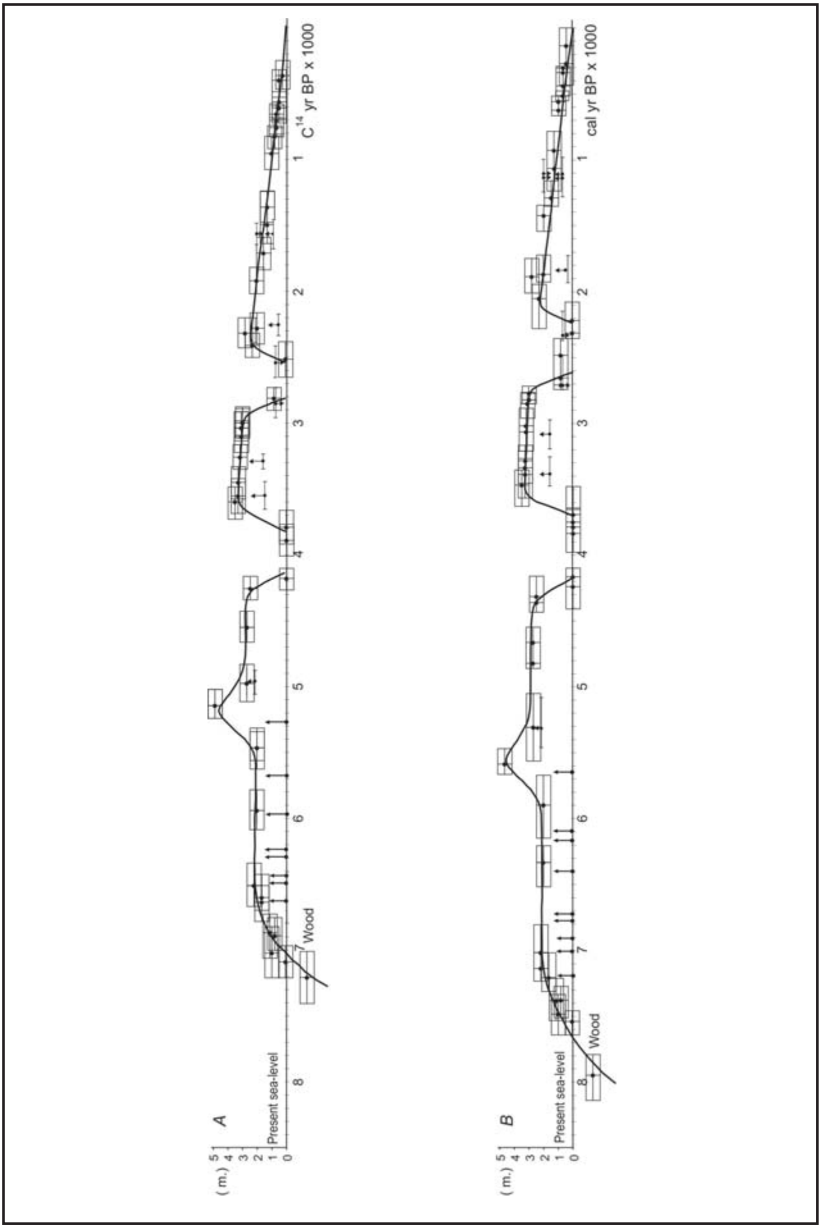

Figure 1 The Salvador relative sea-level curve plotted as 14C ages without Reservoir Correction (A) (Martin et al. 1979a) and as calibrated ages (B).

For example, detailed reconstruction of the Doce river and Jequitinhonha river strandplain evolution, supported by radiocarbon datings, has shown that shoreline progradation during the Holocene was interrupted by several erosional episodes (Dominguez *et al*., 1987, Martin & Suguio, 1992). Most of these episodes were related to changes in longshore drift direction. However there have been two episodes of severe erosion, which because of its widespread nature and association with partial inundation of the strandplains, as evidenced by the presence of lagoonal sediments, have been interpreted as a result of a rise in sea level. In the same way, the "Sambaqui" of Maratuá (Santos region – São Paulo State) provides interesting indirect information on sea-level position. The base of this shellmound is located below present sea level. Dating of two samples (Martin *et al*., 1986b) produced ages of 4080(**3850**)3650 cal yr BP (Bah.382) and 3895(**3825, 3750**)3640 cal yr BP (Io 9185). These two dates thus corroborate the existence of a lower sea level between 4300 and 3500 cal yr BP.

4 Influence of Relative Sea-Level Change on Coastal Sedimentation

Under conditions of a rising sea-level, on a gently sloping sandy coast a barrier island/lagoonal system is the dominant mode of sedimentation and beach-ridge plains are virtually absent. In contrast, a sea-level fall creates highly unfavourable conditions for the genesis and maintenance of barrier island/lagoonal systems. Lagoons and bays become emergent and beach-ridge plains rapidly prograde, resulting in regressive sand sheets (Martin & Dominguez, 1993).

5 Comparison of Brazilian and Southeastern United States Sea Level Evolution

Schematiclly, along the Brazilian coast the relative sea level rose until 5600 cal yr BP (5100 ^{14}C yr BP), when sea level was 4 to 5 m above present level. After that, relative sea level dropped more-or-less regularly until reaching its present level. The schematic average curve for the coastline of the southeastern United States shows that the Quaternary sea level has risen continuously toward its present position and has never been above its present level.

The Atlantic cosat of United States is characterized by barrier islands and lagoons that have spread over extensive pre-Holocene lowlands. On the other hand, the central Brazilian coastline is characterized by extensive Quaternary sedimentary plains partly made up of Pleistocene and Holocene marine terraces. In the swampy lowlands that comprise the contact zone between Pleistocene and Holocene terraces there are many paleolagoons field by organic-rich muddy sediments containing abundant mollusk shells. For example, the Cape Hatteras region (North Carolina) is characterized by an extensive lagoon (Palmico Sound) separated from the open sea by a series of barrier islands. By comparison, the Doce river coastal plain, comparable in size to the Cape Hatteras region, forms an extensive oceanwardly convex crescent.

The deposition of the Holocene part of the Doce river coastal plain began with the formation of a barrier island/lagoonal system. Radiocarbon dates of shells and wood fragments sampled from paleolagoonal deposits indicated that it has existed from at least approximately 7700 cal yr BP (7000 ^{14}C yr BP), when the sea level in the area was higher than today. Obviously, during that time the barrier islands must have been situated more to the exterior and they reached their final position during the transgressive maximum around 5600 cal yr BP (5100 ^{14}C yr BP). Soon after the paleolagoon formation, a hudge intralagoonal delta was being formed. However, until the transgressive maximum, the lagoon must have been dominated by the rising sea level, which could have obstructed the intralagoonal delta development to a certain extend. This explains why the molluscs obtained from paleolagoonal deposits provided ages between 7700 and 5700 cal yr BP (ocean-dominated lagoon), while ages between 5600 and 4200 cal yr BP have be obtained from wood fragments (river-dominated lagoon). Before 5600 cal yr BP, the Doce river mouth area was very similar to the present day Cape Hatteras area. From the viewpoint of relative sea level evolution, before 5600 cal yr BP, the Doce river mouth area was in submergence, just as the Cape Hatteras area is today. It is simple to imagine what will happen with a drop in relative sea level in the Cape Hatteras area. The Palmico Sound will dry up and a generation of sand ridges will be added to the outer margin of the barrier island system giving rise to a coastal plain analogous to that of the Doce river mouth. Probably the only difference would be the absence of an intralagoonal delta since there are no important rivers flowing into Palmico Sound.

It is obvious that both the present coastal morphology and depositional patterns in Brazil and southeastern United States have been influenced by distinctive relative sea level fluctuation. Prior to 5600 cal yr BP, the Brazilian coast was probably quite similar to that of the present southeastern United States. Obviously the same depositional models can not be applied to these areas for the period from 5600 cal yr BP (5100 ^{14}C yr BP) to the present.

6 Conclusions

Relative sea-level curves constructed for the last several thousand years provide an important reference against which the evolution of the coastal zone can be investigated. The relative sea-level curve for Salvador can be used for a reference to the central portion of the Brazilian coastline. Since it is very detailed it is now presented herein with corrections for isotopic fractionation and reservoir effects as well as calibrations for astronomical ages. The information from other parts of the Brazilian coastal zone provides additional evidence for the time when the maximum of the Holocene transgression was reached (around 5600 cal yr BP - 5100 ^{14}C yr BP) and for the existence of the high-frequency oscillations present in the sea level-curve. Contrary to recent work by Angulo & Lessa (1997) who constructed a sea-level curve based exclusively on data derived from just one indicator, the curve presented herein uses information from many different sea-level indicators. Even if an indicator provides only one piece of information about presense of variation but not an accurate position of the relative sea level, this information should not be discarded. In many cases, a convergent data set is preferable to isolated information, although the latter may intrinsically seem better. Data convergence in favor of the existence of at least two high-frequency oscillations after 5600 cal yr BP is too great for someone to be in doubt. As Dr N. A Mörner sagaciously stated during a scientific meeting : “There are more than mere coincidences.” (Martin *et al.*, 1998). This sea level history, which is quite different from that of several other regions in the world, played an essential role in the development of the central Brazilian coastal plains. The period of submergence, characterized by erosional phases, introduced noticeable changes in the geometry of the coastal deposits. The periods of emergence gave rise to sandy terraces covered by beach-ridges. The high-frequency oscillations are of the same magnitude as is predicted for the future under greenhouse conditions. The data provided here will help us to better understand how the coastal systems will respond to these sea-level changes.

7 References

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