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Oscillations or not oscillations, that is the question: Comment on Angulo, R.J. and Lessa, G.C. "The Brazilian sea-level curves: a critical review with emphasis on the curves from the Paranaguá and Cananéia regions" [Mar. Geol. 140, 141–166]

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### Abstract

Relative sea level fluctuation curves, during the last seven thousand years, have been delineated for several sectors of the Brazilian coast. These curves have shown that the central Brazilian coast has been subject to submergence until approximately 5100 yr BP and to emergence since then. However, the emergence after 5100 yr BP was interrupted by two high-frequency oscillations with amplitude of approximately 2–3 m and duration of about 300 yr. Angulo and Lessa, [Mar. Geol. 140 (1997) 141–166] have recently questioned the existence of these oscillations. However, several different lines of evidence strongly confirm the existence of these high-frequency oscillations. © 1998 Elsevier Science B.V. All rights reserved.

**Keywords:** Holocene; sea level oscillations; Brazil

### 1. Introduction

During the last 25 years, researches developed along the Brazilian coast have allowed us to acquire a field experience that conceptual models presently in vogue cannot replace. These researches, supported by several hundreds of radiocarbon datings, have permitted the delineation of the great lines of coastal evolution to an extent of approximately 3300 km

(Fig. 1). Thanks to these datings, reconstructions in space and in time of former positions of the relative sea level during the last 7000 years were made. Based on these reconstructions, curves and curve-sketches were drawn (Martin et al., 1979, 1980), as is the case of the Salvador curve (Figs. 1 and 2). In order to minimize the possible influence of eventual local and/or regional factors, the curves were generally constructed based on information derived from limited coast sectors (some tens of km), presenting homogeneous geological characteristics.

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Fig. 1. Orientation map.

On the other hand, also to minimize eventual systematic errors tied to the particular nature of an indicator, the maximum of different indicators available from former positions of the relative sea level were used. Actually, even if an indicator provides only one piece of information about the sense of variation but not an accurate position of the relative sea level, this information should not be discarded. In many cases, a convergent data beam is preferable to an isolated information, although the latter may intrinsically seem better. One should not forget that there is a number of causes of error in the definition, in space and in time, of a past sea level position. Thus, each reconstruction of an former relative sea level position should be accompanied by the error margin over the estimated altitude ( $\pm 0.5$  m, for instance)

and the measured age ( $\pm 150$  years, for example) of the indicator considered. Thus, each reconstruction should not be represented by a point, but rather by a rectangle, the length of which may correspond to 300 years and the width to 1 meter, for example. On the other hand, a  $^{14}\text{C}$  age, in fact, is never an absolute age and will be the subject of several corrections that not always are reliable. For example, as a function of the reservoir effect, the remains of two organisms that lived in the same epoch in waters of different origins will exhibit different  $^{14}\text{C}$  ages. Furthermore, to a  $^{14}\text{C}$  age BP there may correspond one or more calendar ages (Stuiver and Reimer, 1993): thus, for example, to the  $^{14}\text{C}$  age of  $2260 \pm 50$  years BP, there corresponds two time spaces: a first one between 2335 and 2295 cal years BP and a second one between 2260 and 2160 cal years BP. Finally, one should not forget that, although exercising the utmost care in the sampling and analysis, some datings might be exhibiting totally incoherent results.

The first result of the curves we defined has been to show that, contrary to what happened in other regions of the world and, mainly, in the Atlantic coast of the US and in Europe, the relative sea level reached a level 4–5 m above the present sea level around 5000 years BP (Fig. 2). The second important result has been to show that, after 5000 years BP, there have occurred at least two important oscillations (Fig. 2). Paleogeographical reconstructions, made later in several regions of the Brazilian coast, not only on the coastal plains located at the mouth of important rivers, but also on coastal plains without connection to a river, have remarkably confirmed the existence of these oscillations (Dominguez, 1987; Dominguez et al., 1981; Martin et al., 1987a, 1993a; Martin and Suguio, 1992). Angulo and Lessa (1997), using reconstructions made solely from datings of vermetids, have questioned the existence of these oscillations. These authors, based on the fact that

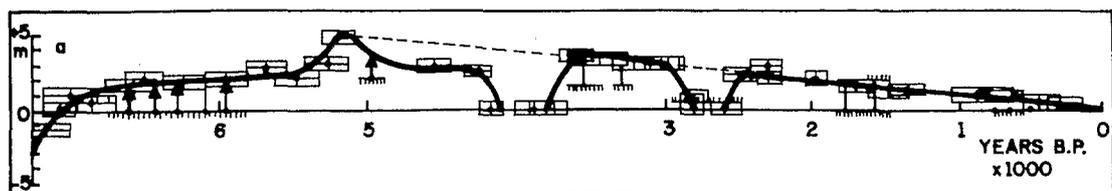


Fig. 2. Relative sea level curve variation for the last 7000 years in the Salvador region according to Martin et al. (1979).

generally "... the vermetids are widely recognized as an accurate paleosea level indicator..." consider that, when the information provided by the same contradict the information from other indicators, the latter should be discarded.

## 2. Criticisms made by Angulo and Lessa (1997) of the present curves of variation of the relative sea level on the Brazilian coast

Angulo and Lessa criticize particularly the use of information derived from shell-middens. They consider that the postulate (based not only on common sense, but also on field observations) according to which shell-middens were constructed above high-tide level, should be criticized: "Moreover, there is no supporting evidence to the fact that the shell-middens were always built above the high tide level; only the fact that it appears to be logical from our viewpoint is not enough to dispute the various possibilities that could have led an unknown culture to initiate a mound underwater. Therefore, this criteria cannot be regarded as a reliable evidence for paleo-sea levels". We will see farther why the information provided by shell-middens cannot be discarded summarily.

Also, the use of wave-built terraces for the definition, in space, of former sea level positions was criticized: "Hitherto, in the studied area as well as in any of other previously investigated sites lacking absolute datings, inference of the sea level maximum was made upon the maximum elevations of wave-built terraces". Such a statement seems flippant to us (the least someone could expect from a geologist is to know how to critically analyze each sample used). Evidently, we did not disregard the possibility that there might exist a backshore overelevation as a function of the morphology, grain-size and local energy level. Also, we did not forget that there are, in this type of terrace, sedimentary structures that permit reconstructing former sea level positions with reasonable accuracy. Finally, each altitude inferred from a construction-terrace was always accompanied of an error bar of  $\pm 0.5$  m.

In the same manner, the use of information resulting from the morphological features of strandplains was criticized: "The existence of particular topographic features at strandplains associated with large

river mouths can be explained by lateral spit growth or even the emergence of swash bars downdrift of the river outlets. Both processes can account for many isolated inland depressions characteristics of these wave dominated river mouths. In regard to the interruption of beach ridge formations, this could easily be explained by fluctuations in the sediment supply associated with the dynamics of the rivers mouths". If one could actually imagine that the variations in the amount of material transported by a river would explain some discontinuities recorded in the alignments of beach ridges, then what is the explanation when such large discontinuities occur on a large strandplain without a river, as is the case of Caravelas (Fig. 1) (Martin et al., 1987a, 1993a)? It will be shown farther why the information provided by the morphology of strandplains cannot be summarily discarded.

On the other hand, some data was eliminated by Angulo and Lessa (1997): "It is difficult to discuss samples Bah.630 and Bah.445 because there is no information about the sampling site or any indication on how the paleo-sea level was estimated. However, it is worth noting that sample Bah.630 gives a paleo-level of 2 m at the time of a proposed secondary oscillation". It appears at least inconvenient eliminating the information provided by samples Bah.630 and 445, pleading ignorance of the way the sampling and sea level reconstruction were made (the information exists, yes, one has only to seek it — Suguio et al., 1976; Suguio and Martin, 1978).

Some data was misinterpreted by Angulo and Lessa (1997): "The two datings (3160 years BP and 2970: Bah.1277 and Bah.1278) derived from samples of mollusc shells (mostly *Anomalocardia brasiliensis*, presented by Martin et al. (1988) indicate a sea level 1 m above the present (Angulo, 1993). Again, these samples indicate sea levels higher than those expected around the second oscillation (3000–2700 years BP)". It is not understood why in the curve presented by Angulo and Lessa (1997) the ages are not accompanied by error margins. With the indication of this error, sample Bah.630, which is a testimony of a paleo-sea level located at  $2.0 \pm 0.4$  m above the present level and which was dated  $3780 \pm 110$  years BP (between 3890 and 3670 years BP), is by no means in contradiction with the existence of a sea level at  $3.0 \pm 0.4$  m above the present

level around 3600 years BP (Fig. 2). In the same way, samples Bah.1277 and 1278, dated  $3160 \pm 170$  and  $2970 \pm 150$  years BP, respectively, are perfectly in accordance with a relative sea level located at least 1 m above the present level. Equally, it is not understood why Angulo and Lessa (1997) write: "Reference to Pleistocene barrier/strandplain were only made in studies of the large beach ridge plans associated with river mouths (Dominguez et al., 1981; Martin et al., 1984; Silva, 1987). Again accepting the occurrence of the secondary sea level oscillations, these investigations suggest that the 3500 years transgression would have either left a third generation of strandplains...". By no means, the description of the "Pleistocene barrier/strandplain" has remained limited only to the strandplains at the mouths of important rivers (Suguio and Martin, 1978; Martin et al., 1980). On the other hand, we have never written that the transgression of 3600 year BP has left a third generation of terraces. In reality, it has been stated that one could differentiate, particularly in the Jequitinhonha River plains (Fig. 1), three generations of Holocene terraces (Dominguez, 1983). In the same manner, it has never been written that the two secondary oscillations would generate two new barriers separated by a lagoon, as stated by Angulo and Lessa (1997): "A transgressive scenario on a barrier coast is commonly associated with lagoons stranded behind newly formed barriers. Hence, two consecutive highlands may leave behind two barriers separated by a lagoon or at least a low-lying swampy area". On the contrary, one of us (L.M.) found it most difficult to have some researchers accept ("... in the light of the recently proposed sea level curves, some Brazilian researchers interpreted the actual Pleistocene barriers/strandplains as the Holocene PMT, and the actual Holocene (PMT) barriers/strandplains as the one resulting from the proposed transgression at 3500 years BP...") that, between Niterói and Cabo Frio (Fig. 1), the "internal barrier" was of Pleistocene age and that the entire Holocene was concentrated in the "external barrier", the width of which is some tens to hundreds of meters (Martin and Suguio, 1989). Field experience has shown us that the response to an oscillation of the relative sea level may be multiple. It seems obvious that this response will not be recorded in the same manner on a Holocene strandplain of 15 to 20 km width and on

a Holocene strandplain just some tens or hundreds of meters wide.

Finally, we do not understand how the following argument may be used to deny the existence of oscillations: "The existing proposal of secondary sea level oscillations along the Brazilian coast in the late Holocene has caused problems in the interpretation of the coastal geomorphology, especially due to the premise that such oscillations would be able to develop new strandplain or barrier/lagoon systems. Given the existence of these sea level oscillations, a numerical model suggested that the morphological response of the shoreline would more likely be a beach terrace encroached against the pre-existing barrier than another barrier/lagoon system". In the cartography we made of Paraná's coastal plain (Martin et al., 1988) (Fig. 1), this type of structure does not appear and this did not generate any particular difficulty for interpretation. On the other hand, to use the response of a model to demonstrate non-existence of the oscillations seems to us somewhat naive and reckless. Actually, one should not forget that the evolution of the coastal systems is inherently nonlinear, which means that details thereof are unforeseeable and non-repetitive in time schedules from decades to millennia, since the process is non-stationary in the statistical sense (Cowell and Thom, 1994). In fact, as these authors consider "... the development of numerical models requires that each one of the processes and interactions between the processes be translated into mathematical terms, which are necessarily simplified representations of reality". On the other hand, "The basic assumptions behind the models are simplified to the point of absurdity. The physical basis of the models is nonexistent" (Pikley and Thieler, 1996). In spite of these limitations, the numerical models are being used more and more lately, even becoming, as perspicaciously observed by Smith (1994), more important than the actual data. This is what the same author designated "the model and its forecast syndrome", a behavior that reflects the unbearable Laplacian foolishness of the deterministic foreseeability.

Curiously, some important articles, pertaining to the subject and elucidating with respect to many aspects we have discussed herein, are not cited in the work of Angulo and Lessa (1997): Dominguez et al., 1981, 1992; Dominguez, 1983, 1987; Suguio et

al., 1984, 1992; Martin et al., 1987a, 1993a,b, 1996; Dominguez and Wanless, 1991; Martin and Suguio, 1992; Martin and Dominguez, 1994).

### 3. The reason why the information provided by the shell-middens should not be discarded

We are convinced that shell-middens cannot provide accurate information about the sea level position. However, they may provide very valuable indirect indications about the positioning and sense of the sea level variations (Suguio and Martin, 1978; Martin et al., 1986). The study of shell-middens of a coastal plain (Cananéia, Paranaguá or Guaratuba, for example Fig. 1) shows that they were not constructed in any way and in any position (Martin et al., 1987b). The archeological excavations at Maratuá's shell-midden (Santos coastal plain, Fig. 1), the base of which is situated lower than the present sea level, do not show that its construction could have been started in the water (Laming-Emperaire, 1968). As regards this type of indicator, a solitary datum cannot be used; rather, the use of a supplementary data set is required. For example, Angulo and Lessa (1997) use solely part of the information existing in Martin et al. (1987a): "In the Bogaçu River Martin et al. (1987a) dated mollusc shells from a shell-midden whose base is presently underwater. The shells were collected at the present MSL, and dated at 3920 years BP (Bah.1272) suggesting that the sea level was below the present elevation by that time". Elimination of a portion of the information may reinforce the assumption of a subsidence of the shell-midden. In the article of Martin et al. (1987a) it is written: "Two shell-middens from Bogaçu River (Guaratuba Bay, State of Paraná, Fig. 1), corresponding to no. 50 and no. 51 of Bigarella (1950), supplied with very interesting additional data. The shell-midden no. 51 reposes on an island formed of lagoonal deposits. At the river margin shell-midden has been eroded, showing that in this place its substrate is submerged (below present sea level). Mollusc shells collected at present sea level have been dated as 3920 ± 190 years BP (Bah.1272). The  $\delta^{13}\text{C}$  (PDB) value of these shells was -3.56‰. The shell-midden no. 50 is located about 1200 m from no. 51, and is situated on lagoonal deposits whose summit is about 1.3 m above the present level. Mollusc shells sampled from the

lower portion (not on the base) of the shell-midden were dated as 3290 ± 190 years BP (Bah.1273), and  $\delta^{13}\text{C}$  (PDB) value was -0.6‰. This value is clearly less negative than that of no. 51. Flexor et al. (1979) demonstrate that  $\delta^{13}\text{C}$  (PDB) value is a good indicator for lagoonal oscillations; thus, it is possible to conclude that about 3300 years BP the land influence was much less important than that about 3900 years BP and, consequently, the lagoon was larger and the relative sea level higher in the former case than in the latter case. So, a sea level rise was produced between 3900 and 3300 years". In order to demonstrate the existence of a low level around 3900 years BP, in addition to the fact that the shell-midden is nowadays at a level below sea level, a convergence of other data was equally used. In the same manner, on the Santos coastal plain (Fig. 1), shell samples from the central part of Maratuá's shell-midden dated by  $^{14}\text{C}$  have remarkably confirmed the existence of this same low level. Initially, in 1958 two datings were made, which gave the following ages: 7327 ± 1300 years BP (Gif.15) and 7800 ± 1300 years BP (Gif.16) (Laming-Emperaire, 1968). These results were initially accepted because the dates did coincide with a period when relative sea level was definitely lower than today. However, archeological remains within the shell-midden of Maratuá suggested much later dates. Redating of Laming-Emperaire's samples coincidentally produced ages of 3925 ± 145 years BP (Bah.382) and 3865 ± 95 years BP (Io.9185), which are more in keeping with the artifactual evidence and in accordance with a lower level around 3900 years BP (Martin et al., 1986).

In the same manner, the information originated from Pedra Oca's shell-midden, located on the shore of the Bay of Todos os Santos in Salvador (Fig. 1), has confirmed the existence of a low sea level around 2800 years BP, already evidenced by the datings of 2815 ± 100 years BP (Bah.617) and of 2805 ± 90 years BP (Bah.525) of shells collected in beach sandstones. Presently, the shell-midden base (largely destructed) is situated at 0.8 m above the high-tide level. However, traces of the destructed portion show that the latter should be situated at a level lower than high-tide. Shells from the base were dated 2830 ± 130 (Gif.878) and 2630 ± 110 (Si.470) (Martin et al., 1986). The base of the shell-midden being seated upon a former sandy beach and

sandstones from the Cretaceous, the assumption of a subsidence should be discarded. On the other hand, vermetids and shells (collected at some tens of meters from the shell-midden) indicating a paleo-sea level at  $3.0 \pm 0.5$  m above the present level, were dated  $3030 \pm 120$  years BP (Bah.542) and  $3100 \pm 120$  years BP (Bah.540), respectively, which permits us to eliminate the possibility of a tectonic sinking. We could mention a number of other examples.

#### 4. Why the information provided by the morphology of the coastal plains should not be discarded

A surface examination of the Holocene terraces of the coastal plains located at the mouths of Paraíba do Sul, Doce and Jequitinhonha rivers, but also of the Caravelas coastal plain (Fig. 1) (where there is no important river) shows the existence of important discontinuities at the beach-ridge alignments. A detailed analysis of these discontinuities (Dominguez et al., 1981; Martin and Suguio, 1992; Martin et al., 1993b) shows that some are restricted to coast sectors presenting particular features, and others are more generalized. The origin of these discontinuities was imputed to the alternation of construction and erosion phases as a consequence of periods of elevation of the relative sea level (generalized discontinuities) and inversion of the sense of shore transport of climatic origin (localized discontinuities) (Martin et al., 1993a). On the Doce River coastal plain (Fig. 1), paleogeographical reconstructions (Martin and Suguio, 1992) permitted accurately identifying, after 5000 year BP, three generations of sandy terraces and two periods of sea level elevation. During the first period, part of the former lagoon formed before 5000 years BP was reoccupied. A core of 5.5 m in length, collected in this zone, shows the overlapping of two lagoonal sequences with fluvial sediments between both. Shells of the lower lagoonal sequence were dated from  $6020 \pm 200$  years BP (Bah.950), while shells of the upper lagoonal sequence were dated  $3500 \pm 150$  years BP (Bah.1242) (Dominguez, 1987; Martin et al., 1993a; Martin and Dominguez, 1994). Shells from a shell-midden seated on the first Holocene terrace generation and situated on the border of the paleolagoon were dated  $3550 \pm 120$  years BP (Bah.951) (Martin et al., 1993a).

The paleogeographical reconstructions made on the coastal plain of the Jequitinhonha River (Fig. 1) (Dominguez, 1983; Martin et al., 1987a, 1993a) showed the existence of two paleomouths and of three distinct generations of Holocene sandy terraces. The second mouth presents clear-cut flooding features. It appears very clearly that the two changes of position of the river mouth have occurred at the time of the two periods of sea level elevation and that the three generations of sandy terraces were built during the periods of sea level lowering. Fifteen datings, made on material from the third generation, gave ages always less than 2500 years BP.

North of the Paraíba do Sul river mouth (Fig. 1), the second and third generations of Holocene sandy terraces are separated by an anciently lagoonal low zone. Shells from this lagoonal material were dated  $2530 \pm 170$  years BP (Bah.1098) and  $2490 \pm 170$  years BP (Bah.1261) (Martin et al., 1993a).

#### 5. What the curve built solely from vermetids shows

In reviewing this curve (Fig. 3), it is immediately noticed that the points are quite scattered and that reconstructions of former sea level positions are not very coherent. For example, two samples collected by Angulo at Ponta da Galheta (SC) (Fig. 1) and indicating ancient sea levels at  $+2.00 (\pm 0.50)$  m and  $+0.75 (\pm 0.50)$  m were dated, respectively,  $2910 \pm 70$  (CENA-180) and  $2820 \pm 70$  (CENA-178) years BP (Angulo and Lessa, 1997). In the same manner, around 2800–2700 years BP there are several points indicating quite different sea level positions. Two interpretations may be given: (a) vermetids are less accurate indicators than intended for; (b) overlapping reconstructions between 2.00 m, 0.75 m and 2.20 m may perfectly indicate a sea level oscillation between 2900–2700 years BP. Finally, the line figuring the “new trend” for the sea level variations in Brazil is quite similar to the average curve that we have used many times to scheme the difference between the sea level variations in Brazil and in the United States (Suguio et al., 1984; Martin et al., 1987a). That this line be “the 4th order polynomial best fit...” (Angulo and Lessa, 1997) does not add anything and it is not for this reason that this curve is more reliable than any other that one can draw manually. With the

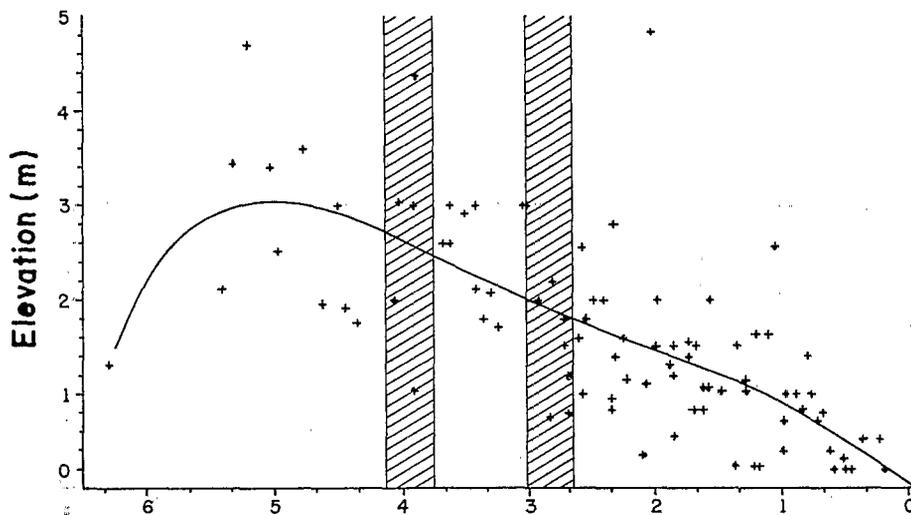


Fig. 3. Vermetid sea level curve for the Brazilian coast according to Angulo and Lessa (1997).

points existing in this curve, one even may perfectly draw another with two or more oscillations. Finally, to validate this curve one may not use the fact that: "The new trend suggested by the vermetid sea level curve is more similar to the trends detected in other coastal regions of the southern hemisphere, where a smooth decline of sea level is observed after the Holocene post-glacial sea level maximum" (Angulo and Lessa, 1997). On the one hand, because one cannot compare the relative sea level variations in the last 7000 years along Brazil's coast with the same variations in an island in the middle of the Pacific, for example. On the other hand, because the curves under consideration are too schematic not to exhibit false similitudes imbedded in its design. For example, the Surinam curve for the last 6000 years (Angulo and Lessa, 1997) was established from six reconstructions. Under these conditions, it would be very difficult evidencing fluctuations of the relative sea level. By comparison, Salvador's curve (Martin et al., 1979) (Fig. 2) was established from 63 reconstructions.

## 6. Conclusion

The fact of choosing a single sea level indicator (although it might hitherto be acknowledged as the best) in detriment to others seems dangerous to us. It is very likely that reconstructions of former sea level

positions made solely from vermetids should not go beyond average curves. It happens that this type of curve does not permit evidencing the secondary variations that constitute a fundamental feature of natural phenomena. The sea level variations present a nonlinear character (Turcotte, 1990; Petit-Maire, 1994). Therefore the adjustment made in a cloud of points, indicative of former sea-levels, to give an elegantly Euclidean curve, constitutes an abstraction of reality: it avoids the nature of the phenomenon. The stochastic behavior (with fluctuations) of the curves of sea level variations is fundamentally an attribute of nonlinear systems.

Unlike Hamlet whose problem was "to be or not to be", for us, between oscillations and non-oscillations there is no hesitation. Data convergence in favor of the existence of at least two oscillations after 5000 years BP is too great for someone to be in doubt. As Dr. N.A. Morner sagaciously stated during a scientific congress: "There are more than mere coincidences".

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