

## Discussion

# Oscillations or not oscillations, that is the question — Reply

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## 1. General comments

We would like to welcome the comments made by Martin et al. on the article by Angulo and Lessa (1997) ‘The Brazilian sea-level curves: a critical review with emphasis on the curves from Paranaguá and Cananéia regions’. With this discussion we hope to have the chance to clarify several points of the original article and to strengthen our discussion on the highly unlikely existence of 3–4 m sea-level oscillations in the late Holocene.

With the article published in *Marine Geology* we have shown that, as far as the existing published data can tell, there is no indication of these oscillations in the coastal plains of the State of Paraná and south of the State of São Paulo. This was the first published review of part of a data set that has remarkably influenced the study and understanding of the coastal evolution in Brazil in the last 20 years, and it is comprehensible that it meets opposition. Paraphrasing a citation from Wilfred Trotter, in Martin et al. (1993), “the spirit has as much difficulty to accept a new idea as the human body a strange protein, to which it resists with the same energy.”

We fully agree with Martin et al. that 25 years of research, and hundreds of radiocarbon datings, along approximately 3300 km of coastline is a remarkable contribution to the understanding of the

coastal evolution and sea-level behavior during the Quaternary in Brazil. In the late 80s, when we began a more detailed investigation of the coastal plains of the State of Paraná, we started off on the knowledge gathered by several authors, but mainly by Bigarella (1946), Bigarella et al. (1978) and Martin et al. (1988). As the work went by, divergent interpretations of the contact between the Pleistocene and Holocene marine terraces and the elevation of the Holocene sea-level maximum became apparent, and were discussed in Angulo (1992) and Angulo and Suguio (1994, 1995). Also, we started to find evidence of paleosea levels above the present one between 4100–3800 years B.P. and 3000–2700 years B.P., a time when the existing sea-level curve for the area was indicating a lower-than-present sea level. This evidence encouraged the writing of the paper now under discussion.

Contrary to what is implied by Martin et al. (this volume), Angulo and Lessa (1997) have not aimed to discuss the more than 700 datings supporting the pre-established curves in other Brazilian coastal sectors, a rather difficult, if not impossible, task. The dated samples outside the Paranaguá–Cananéia region to which the article refers to are associated with shells embedded in beachrocks on the north coast of Bahia, which constitute the only absolute indication of the proposed secondary oscillations in all existing curves (with the exception of shell-middens). More specific comments on the misinterpretation of these samples, which will be addressed further, have been

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made at a recent scientific conference (Lessa and Angulo, 1997).

## 2. Discussion of Paranaguá–Cananéia data

Martin et al. have understood that we questioned the existence of the secondary oscillations based on the vermetid data only. The existing paleosea-level data for the Paranaguá–Cananéia region are plotted in Fig. 1, with the exception of those derived from shell-middens. We see that, although with a limited data set, there is an indication of a gradual sea-level fall in the last 5000 years. The figure shows more than one line of evidence suggesting the absence of the secondary oscillations in the time period between 4100 years B.P. and 3800 years B.P., such as vermetids, datings of sedimentary deposits and barrier morphology. Moreover, just the fact that we point out the weaknesses of the evidence used to propose the secondary oscillations (Angulo and Lessa, 1997) is, in itself, a strong evidence against it.

Martin et al. argue that we have “inconveniently” eliminated the analysis of some data “pleading ignorance of the way the sampling and sea-level reconstruction were made”, since “the information exists and one has only to seek it (Suguio and Martin, 1976, 1978)”. We are somewhat surprised with this statement. The radiocarbon datings of these samples (wood and wood detritus collected from sedimentary deposits) are mentioned for the first time in Suguio and Martin (1978) (Bah-445) and Martin et al. (1979b) (Bah-630), but only in tables. There are absolutely no references in these two articles, either in

the tables, figures or text, to the characteristics of the sites where the samples were taken from or how the paleosea level was estimated.

Martin et al. correctly point out that the margin of errors of the vermetid samples should have been drawn to show the variance that may exist in the trend indicated by the most possible age and elevation (we will come back to this below). In this same line, these authors understand that some of their data were misinterpreted because the margin of error in time of some samples of mollusk shells, indicating sea levels higher than present at the time of the proposed oscillations, was not considered. In accordance with these authors, if the error margins are taken into account, the samples can be displaced sideways and will fall correctly on the originally proposed trend. This is a misfortune, because this kind of argument can also be used to deny the oscillations. If we take, for instance, the margin of error of the shell-midden sample that suggests the oscillations in the Salvador curve (fig. 2 of Martin et al.), we see that they also fall outside the time frame of the proposed oscillations. Similarly, samples that indicate sea levels higher than present (up to 3 m) close to the time of these oscillations have their time domain falling inside the oscillations. Therefore, we strongly disagree with the biased interpretation of Martin et al. of samples Bah-630, Bah-1277 and Bah-1278.

We do not agree with the statement by Martin et al. that we have summarily discarded the information from shell-middens. As was said before, we have analyzed the divergences between the different indicators, and tried to explain the cause for that. We have pointed out reasons (compaction, slumping and

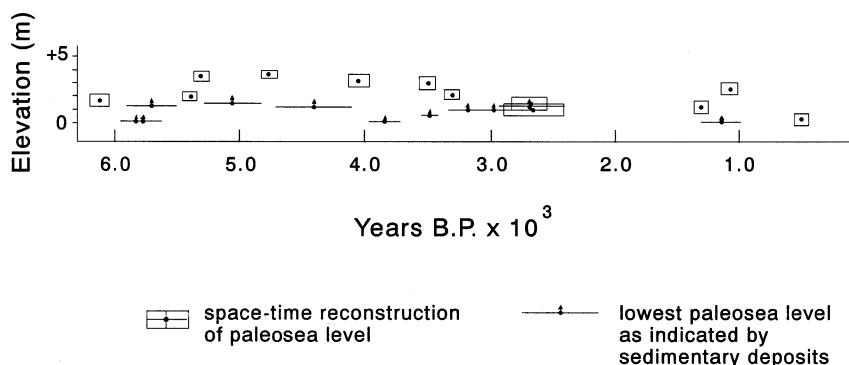


Fig. 1. Radiocarbon-dated samples from Paranaguá–Cananéia region.

whether the original construction site was below or above the water level) why shell-middens could provide contradictory information to other more reliable indicators. We could have also added the uncertainty associated with the internal stratigraphy of the middens (how the piling was performed, for instance). The variation observed in  $\delta^{13}\text{C}$  amongst different shell middens is said to be due to environmental changes in the estuaries, associated with oscillating sea levels. However, we emphasize that variations in  $\delta^{13}\text{C}$  inside an estuary can also be explained by changes in freshwater discharge, changes in the morphology of the estuary entrance and tidal prism and changes in the circulation pattern due to estuary infilling. Even admitting that fluctuations in sea level was the driving mechanism for these environmental changes, it would not be necessary to call for a 4 m oscillation. Therefore, we believe that we have more reason to doubt the paleosea levels indicated by these sources than we do in relation to other, contradictory indicators.

### 3. Discussion of critical data from other areas

By plotting all vermetid data from the Brazilian coast in one graph (fig. 3, in Martin et al.), we believed that an overall eustatic sea-level trend could be highlighted. Although the accuracy of vermetids as paleosea-level indicators has been widely accepted (van Andel and Laborel, 1964; Delibrias and Laborel, 1969; Laborel, 1979, 1986; Angulo, 1993), only with the dating of a large number of different samples from a same location one can confirm whether this degree of accuracy ( $\pm 0.5$  m in average) is real or not. As Martin et al. pointed out, there is a large degree of scattering in the elevation of samples within very narrow time frames. This indicates that the elevation precision provided by vermetids is much lower than previously anticipated.

Problems associated mainly with the uncertainty of the vertical position of the collected sample in relation to the spread of the original vermetid colony (base, middle or top), appears to be the main cause for the larger degree of inaccuracy (Angulo et al., in prep.), which is now proposed to be in the order of 1 m (as was already suggested by the paper under discussion, even though it was not drawn). However,

the existence of a large number of datings makes it possible to better define the lowest and the highest boundary within which sea level was positioned. It is possible to draw some oscillations through the cloud of points presented in fig. 3 of the discussion paper, but not with ranges over 3 m, as has been persistently suggested. The farther away from a mean trend a line is drawn, the more unlikely it becomes. On drawing a ‘4th order polynomial best fit line’ through the cluster of data (a better representation could have been an envelope around the data) we have tried to show a mean trend within those highly scattered points. We have indeed not added anything new to the figure, but we have kept away any biased perception. Had a similar attempt been done with the spread of data from Salvador (fig. 2, in Martin et al.), the singular little tip of the Brazilian sea-level curves would not exist, as it is based in only one sample.

We do not understand why Martin et al. state that they “... have not disregarded the possibility that might be a back-shore overelevation as a function of the morphology, grain size and local energy level”, and that they have not forgotten that “... there are ... sedimentary structures that permit reconstructing former sea-level positions with reasonable accuracy”. If this has ever happened, it has never been made clear in the published literature. As we have mentioned in the original article, in the Paranaguá–Cananéia region (Suguio and Martin, 1976; Martin and Suguio, 1976; Martin et al., 1979c, 1988; Suguio and Cruz, 1982; Suguio et al., 1985), as well as in the coastal sectors of Santos-Bertioga (SP) (Martin and Suguio, 1976; Martin et al., 1979c; Suguio and Cruz, 1982; Suguio et al., 1985), Ilhéus (BA) (Suguio and Cruz, 1982; Suguio et al., 1985) and Itajaí (SC) (Suguio et al., 1985; Martin et al., 1988), inferences of the sea-level maximum (or maxima) were made upon the maximum elevation of wave-built terraces. In at least three articles (Martin and Suguio, 1976; Suguio and Martin, 1976; Martin et al., 1979c) it is plainly stated that a direct relationship between the maximum elevation of wave-built terraces and the elevation of the Holocene sea-level maximum exists.

The proposal of the two secondary oscillations implied the possibility that more than one generation of barrier–lagoon systems could have developed in the late Holocene. With the simulation model we wanted to address this key assumption, as it was

also relevant for the interpretation of a key sample from Paranaguá–Cananéia region. This assumption has underlain several investigations undertaken along the barrier coast of the State of Rio de Janeiro (Maia et al., 1984; Neto, 1984; Perrin, 1984; Muehe and Ignarra, 1984; Turcq et al., 1986; Muehe and Corrêa, 1988). The paper of Maia et al. (1984), which two of the discussants co-authored, studied the geomorphology of the Jacarepaguá coastal plain. The plain shows two distinct barriers with lagoonal and paleolagoonal areas at their rear. Thirty-two shell samples, collected from surface deposits in the paleolagoons, showed ages younger than 6000 years. Both barriers were interpreted as Holocene in age, associated with the transgressive, and subsequently regressive, cycles that ended at 5100 years B.P. and 3500 years B.P. This chronology was suggested even though a shell sampled in front of the innermost barrier was dated at 5970 years B.P. In this case it was assumed that the innermost barrier rolled over the back-barrier deposit, and that the back-barrier deposit withstood the remaining transgressive episode without undergoing any kind of erosion while exposed on the shoreface (expected due to the translation of the shoreface profile). Maia et al. (1984) show two relevant points: firstly that, contrary to what is said by Martin et al., some of the presently discussing authors also have misinterpreted the chronology of the coastal plain on the basis of the pre-established curves; secondly, that their model for the behavior of the shoreface profile and barrier evolution under changing sea levels is contrary to what the stratigraphic evidence suggests (see discussion below).

Martin et al. have not understood why our statement “... *the morphological response of the shoreline would more likely be a beach terrace than another barrier/lagoon system.*” denies the oscillations. Some of the key samples favoring the oscillations in the Paranaguá–Cananéia region were open marine shells retrieved from a coring performed in the coastal plain. The shells were embedded in muddy sediments and dated at  $3830 \pm 120$  years B.P. (see Angulo and Lessa, 1997, for more details). Martin et al. (1988) interpreted the sequence as a transgressive sequence, and that a barrier/lagoon system existed when sea level was below present at around 3800 years B.P. With the simulation model, run with environmental variables characteristic of the studied area,

we tried to show that a barrier/lagoon system could not have existed, and that the stratigraphic sequence is regressive.

Martin et al. make a long remark about the “*naive and reckless*” use of this simulation model to invalidate the proposed oscillations. It is pointless to get into a philosophical discussion about simulation modeling; however it must be made clear that there are different kinds of morphodynamic models. Certainly all models are simplified representations of reality, since, most of the time, the number of variables and the nature of the interplays are beyond complete mathematical representation. In addition, the uncertainties involved in the understanding of the short-term morphodynamic processes make it impossible to directly use the deterministic principle in the explanation and prediction of large-scale coastal evolution (Cowell and Thom, 1995).

However, an alternative to a deterministic approach exists, based on methods of inverse simulation modeling (Cowell and Thom, 1995), where measurements of observable output variables (morphostratigraphy in this case) are used to infer the value of the model parameters. The model we have used to gauge the response of the shoreline to the proposed oscillations applies parametric-behavior formulations, and by using inverse simulation techniques has been able to successfully model the evolution and stratigraphic record of coastal sand bodies in transgressive and regressive scenarios (Cowell et al., 1992, 1995; Roy et al., 1995). We have certainly been neither reckless nor naive in using this tool, since the model has proven to be sound and correctly addresses a pre-established problem. Besides, the results of the simulation fully agree with the morphological or stratigraphic record of the coastal plains, as a barrier lagoon system or a ravinement surface associated with the supposed 3500 years B.P. transgression has yet to be identified. At least in this case, as implied by Martin et al., the result of the modeling has not been regarded as more important than the data.

#### 4. The beachrocks from the north coast of Bahia

The beachrocks of the northern coast of Bahia form large siliciclastic bodies in the inter- and sub-

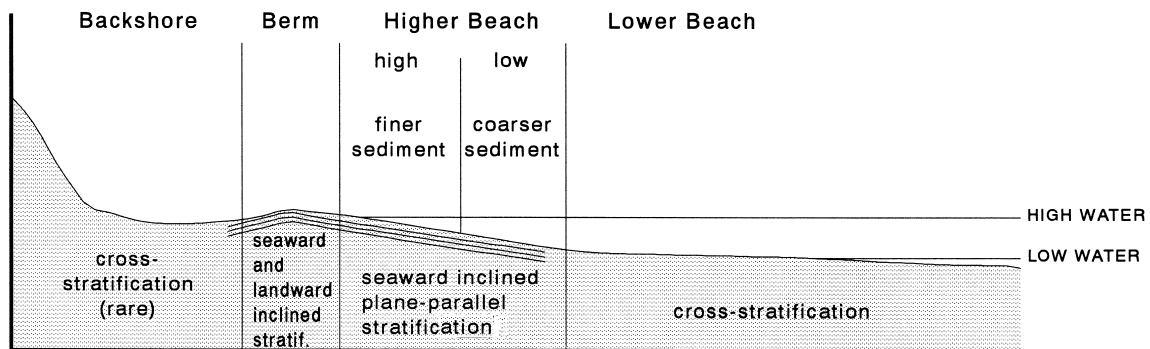


Fig. 2. Schematic representation of the sedimentary structures and grain size variation along a beach profile (after Flexor and Martin, 1979).

tidal levels. These sandstones have been used as evidence for paleosea-level variations in several articles dealing with the Holocene sea-level curves (Bittencourt et al., 1978; Flexor and Martin, 1979; Martin et al., 1979c). Mollusk shells found within the cemented deposits were dated, and the elevation of the depositional environment determined according to the type of sedimentary structure and its elevation relative to the present sea level. Five of these dated shell samples (see fig. 2 in Martin et al.) are the only absolute datings (with the exception of the shell-middens) that support the proposed late Holocene sea-level oscillations.

To interpret the sedimentary structures of those relict beach deposits, Flexor and Martin (1979) proposed a subdivision of the beach in four zones that accounted for variations in sediment texture and sedimentary structures (Fig. 2). This model shows the transition between plane-parallel and cross-stratified laminations occurring above the low water level. This is a situation difficult to envisage, since the longitudinal flows are restricted to the surf zone and the much faster flows of the wave swash tend to destroy any cross-stratified laminations produced by a short-lived (half tidal cycle), weaker longitudinal flow (see for example Reineck and Singh, 1973; Short, 1984).

Three shell samples, Bah-497, Bah-496 and Bah-508 (Martin et al., 1979c), dated at  $3880 \pm 130$  years B.P.,  $2605 \pm 135$  years B.P. and  $4175 \pm 85$  years B.P., respectively, were collected from beachrocks showing seaward-dipping plane-parallel laminations. Based on the textural characteristics of the deposit (a conglomerate, as will be shown below), Flexor and Martin (1979) and Martin et al. (1979a) sug-

gested that it was deposited in the lower part of the higher beach (Fig. 2). The authors mention that the beachrock is located approximately at the level of the change in the angle of slope on the modern beach, therefore indicating a similar environment of deposition, or a paleosea level closer to the present one. Another sample (Gif-2150), collected just south of Arembepe (Bittencourt et al., 1978), was dated at  $3780 \pm 130$  years B.P., and only because it had an age similar to Bah-497, it was assumed that it was taken from a similar deposit. Therefore, it would also indicate a paleosea level closer to the present one. The fifth and last sample Bah-617, dated at  $2815 \pm 100$  years B.P. (Martin et al., 1979c), was collected somewhere within a long (several kilometers) stretch of coastline with beachrock exposures (*its given geographical coordinates fall many kilometers offshore*).

Lessa and Angulo (1997) showed that three of these samples (Bah-497, Bah-496 and Gif-2150) were collected from a layer of beachrock situated above MSL, which is composed of tabular beds of shell-rich, poorly sorted conglomerate up to 20 cm thick, interfingering fine to medium sand layers showing a  $4\text{--}6^\circ$  dip, seaward-inclined plane-parallel laminations. A fourth sample (Bah-508) was collected from a site with similar depositional characteristics. The deposit is interpreted as a lower beach face deposit, and indicates a sea level at least 1.5 m above the present one. This first layer sits on top of a second cemented layer composed of fine and medium sand displaying trough cross-stratification suggesting a northward paleoflow. This second layer was interpreted as a nearshore deposit, and also in-

dicates a paleo-sea level at least 1.5 m above the modern one. Therefore, since these samples do not appear to indicate paleosea levels close to the present one, the secondary oscillations in the Salvador curve (fig. 2 in Martin et al.'s discussion) may cease to exist. A mistaken distribution of the depositional environments along the beach profile was probably the reason for the misinterpretation of the sea level indicated by foreshore and nearshore sedimentary structures.

### 5. The conceptual model of barrier/coastal plain evolution

An important point to be taken into account when inferring paleosea levels, or trends of the sea level, from samples within sedimentary deposits is whether the deposits are of transgressive or regressive nature. In the case of the beachrocks mentioned above, for instance, Bittencourt et al. (1978), Flexor and Martin (1979) and Martin et al. (1979a), have suggested that the preserved deposits are transgressive, and not regressive. Those authors have not taken into account that the upper part of the shoreface is prone to erosion under rising sea-level conditions, and this fact in itself could undermine their interpretation of lower sea levels in the late Holocene.

In another example, in the coastal plain of Cananéia (SP), burrows of *Callichirus* sp. outcropping in the river banks and showing an increase in elevation toward the continent, were interpreted as an evidence of rising sea level (Suguio and Martin, 1976). Since these animals live close to low tide level (Angulo, 1993), such an interpretation would mean that no reworking occurs at the lower beachface and upper shoreface during sea-level rise.

The assumption that the upper shoreface, and sometimes the lower part of the beachface, does not undergo erosion during sea-level rise is associated with the idea that, in an equilibrium profile, a very shallow lever point exists. This lever point is associated with the depth of the ravinement surface, above (below) which the shoreface will erode under a relative rise (fall) of the mean sea level. Dominguez and Wanless (1991), after studying the facies architecture of the Doce River coastal plain, suggested that this lever point is around –2 m.

Several independent studies (Thom and Roy, 1985; Kraft and Chrzastowski, 1985; Masselink and Lessa, 1995; Niederoda et al., 1995; Cowell et al., 1995) point out for a deeper lever point. Since cross-shore sediment transport on the shoreface is primarily caused by waves (Wright et al., 1991), the depth of the ravinement surface varies with the wave energy. A review of the literature shows that low energy coasts, such as the U.S. east and Gulf coasts or the northeast Australian coast, appear to have shallower ravinement surfaces, varying between 6 and 11 m (Kraft and Chrzastowski, 1985; Masselink and Lessa, 1995; Niederoda et al., 1995). Conversely, more energetic coasts, such as the southeastern Australian coast, display deeper ravinement surfaces, varying between 13 and 20 m (Thom and Roy, 1985; Cowell et al., 1995), that coincide with the toe of the shoreface. Therefore, it is possible that sedimentary sequences previously interpreted as transgressive in several studies dealing with paleosea levels, are in fact regressive. This, in some instances, may completely jeopardize previous interpretations of paleosea-level positions and trends.

### 6. Conclusion

Although the studies that lead to the proposal of the Brazilian sea-level curves started around 25 years ago (Martin et al.), the Salvador sea-level curve had already taken its form in 1979 (Martin et al., 1979a) and the other Brazilian curves were pretty well established by 1985 (Suguio et al., 1985). Since this time, little effort (Angulo, 1992; Angulo and Suguio, 1995; Angulo and Lessa, 1997) has been made to revise the interpretation of the data, even though sedimentary models have been revised, extended and updated to account for new findings.

We fully agree that “... a convergent data beam is preferable to an isolated information, ...” (discussion paper), but one must admit that the data and its interpretation have always to be reassessed in the light of the advances made in its field. Until then, any convergence can be misleading. Our position contrary to the existence of large-scale oscillations in the late Holocene, or sea level at or below the present one, remains unabated in view of the existing evidence. Morin (1996), discussing about errors in

science, says: “(Karl) Popper changed the science perspective; it was believed that science advanced by accumulating truths; he showed that progress is achieved especially by eliminating errors in the search of the truth”.

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