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EVIDENCE OF LATE QUATERNARY SEA LEVEL STILLSTANDS ON THE UPPER BRAZILIAN CONTINENTAL MARGIN:A SYNTHESIS

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ABSTRACT

Notable regional evidence of Holocene* stillstands of sea level was gathered along the upper Brazilian continental margin, based on sedimentological, environmental and morphological data. Six persistent levels were detected approximately following the present 130, 110, 90, 75, 60 and 40 m isobaths. Radiocarbon dates and comparison with the MILLIMAN and EMERY (1968) eustatic curve assigned ages ranging from the late Wisconsin glacial maximum at 15,000 years B.P. for the deepest level to 9,000 years B.P. for the shallowest level.

INTRODUCTION

From the very initial stages of continental shelf studies in Brazil, evidence has been gathered pointing to lowered sea level conditions in the late Quaternary, as has been recognized in many other continental shelves of the world.

* Throughout this paper Holocene is meant as having started 14,000 years B.P. (right after the Wisconsin Glacial Maximum).

This early work consisted mainly of mapping bathymetry and surface sediment distribution, which indicated the presence of erosional terraces and facies incompatible with present depositional regimes and depths.

During the course of Project REMAC (Reconhecimento Global da Margem Continental Brasileira), surface sediment and bathymetric maps of the entire upper continental margin were greatly refined. In addition, subsurface evidence of lowered sea level (continental and coastal environments) was gathered by means of extensive bottom-penetrating acoustic surveys and piston coring. Radiocarbon dates of selected samples, although limited in quantity and generally lacking in diagnostic coastline material, followed a pattern resembling the MILLIMAN & EMERY (1968) eustatic curve, thus providing at least a reference for timing the main eustatic events and the resulting late Quaternary sedimentary sequence of the continental shelf (Fig. 1).

The presently available data is sufficient to reveal regional clues of sea level stillstands during the last glacial maximum and the following Holocene transgression. This evidence is of course of particular interest to IGCP-Project 61 and we shall restrict ourselves to it here.

EVIDENCE OF SEA LEVEL STILLSTANDS

SEDIMENTOLOGICAL EVIDENCE - Most well known eustatic curves, such as the ones presented by FAIRBRIDGE (1961) and CURRAY (1961), indicate that the Holocene transgression was interrupted by several short periods of sea level stillstand and regression. During these short periods, terrigenous sediments were supplied to the continental shelf. These were then reworked as coarse shore line deposits during the following transgression.

This principle was applied by VAN ANDEL *et al.* (1967) to map consecutive Holocene shoreline positions on the Sahul shelf, Timor Sea, Australia, using quartz concentration in the coarse fraction of surface sediments (>62"mμ") as the diagnostic parameter.

KOWSMANN & COSTA (1974a) applied the same method on

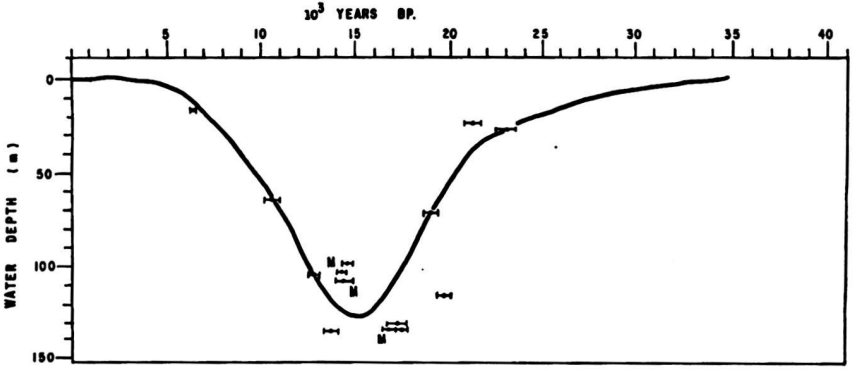


Figure 1 - Radiocarbon ages of samples from the Brazilian continental shelf plotted against the MILLIMAN & EMERY (1968) eustatic curve. Samples labeled (M), from MILLIMAN & BARRETTO (1975). All other samples from KOWSMANN *et al.* (1977).

surface samples rich in coarse material distributed throughout the northern and southern Brazil shelf using terrigenous sand percentage instead of quartz. Figure 2 summarizes the results. The curves for the northern and southern shelf are drawn as envelopes of the data points (all data points fall below the curves). They show coarse terrigenous maxima at the present 170m, 100m and inshore of the 60m isobaths, which are interpreted as former shoreline positions. An incipient 210m peak is also present.

ENVIRONMENTAL EVIDENCE - Former coastline environments indicative of sea level stillstands were detected on the Amazon--Amapá outer shelf, Abrolhos continental shelf (eastern Brazil) and outer shelf off southern Brazil.

Evidence on the Amazon-Amapá outer shelf consists mainly of oolite sediments (Fig. 3). These were described in detail and dated by MILLIMAN & BARRETO (1975) who inferred a hypersaline coastal lagoon environment of deposition based on the anomalous original magnesian calcite composition of the ooids. The oolites occur in water depths between 80 and 150 m and show ^{14}C ages ranging from 14,310 $\pm$ 250 years to 21,250 $\pm$ 400 years (Fig. 4). According to MILLIMAN *et al.* (1975),during this time interval the Amazon River was channeled directly to its shelf-edge canyon,discharging into the Amazon Cone. Thus clear waters prevailed to the north and south of the canyon head and conditions were favorable for the development of a carbonate reef facies, except during the glacial maximum when the shelf edge was subaerially exposed.

Although MILLIMAN & BARRETO (1975) and MILLIMAN *et al.* (1975) argue against a semi-arid climate prevailing in northern Brazil during the glacial Wisconsin, there is ample evidence in support of such climatic conditions, ranging from deep sea sediment mineralogy (DAMUTH & FAIRBRIDGE, 1970) to continental geomorphology (MEIS, 1971; JOURNAUX, 1975). A semi-arid climate would help explain the hypersaline conditions in the back-reef lagoon.

The oolite ages increase with water depth of sample (Fig. 4). This orderly pattern and the low energy character of the ooid internal structure led MILLIMAN & BARRETO (1975) to assume *in situ* deposition, including the continental slope

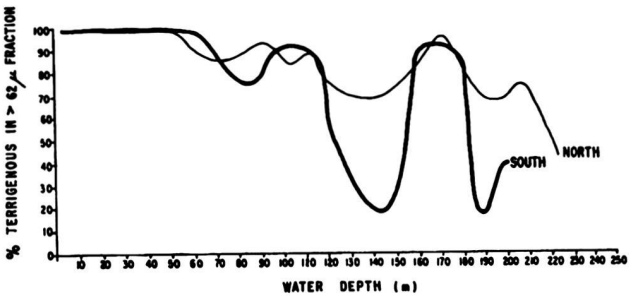


Figure 2 - Concentration of terrigenous components in the coarse fraction of sediment samples from the northern and southern Brazil shelf, plotted against water depth. Curves are envelopes around the maximum values of the data points. Peaks are believed to be produced by shoreline deposits. From KOWSMANN & COSTA (1974a).

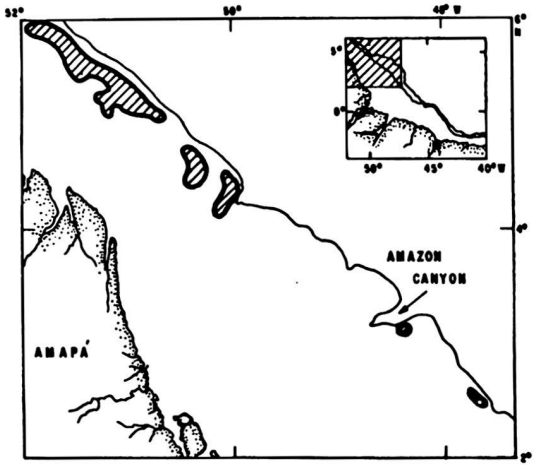


Figure 3 - Areas of ooid-rich samples on the Amazon-Amapá continental shelf. Depth contour in large chart is 200 m; in insert chart, 200 and 2000 m. From MILLIMAN & BARRETTO (1975).

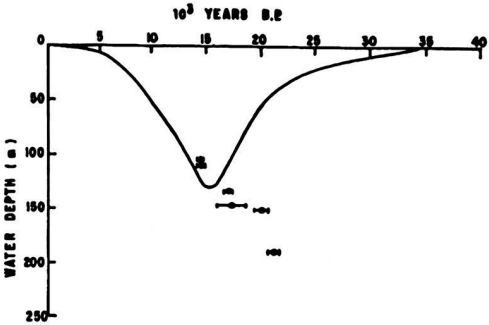


Figure 4 - Radiocarbon ages of oolitic samples from the Amazon-Amapá shelf, plotted against the MILLIMAN & EMERY (1968) eustatic curve. From MILLIMAN & BARRETTO (1975).

ooids. In order to explain their discrepant depth-age relationship with the MILLIMAN & EMERY (1968) eustatic curve, they suggested a subsidence(140m) of the outer shelf between 21,000 and 16,000 years ago. This enormously fast subsidence rate (28m/1000 years) was questioned by KUMAR *et al.* (1977) who suggested as one alternative explanation the transport of ooids from the shelf to the continental slope via mass flows and related processes.

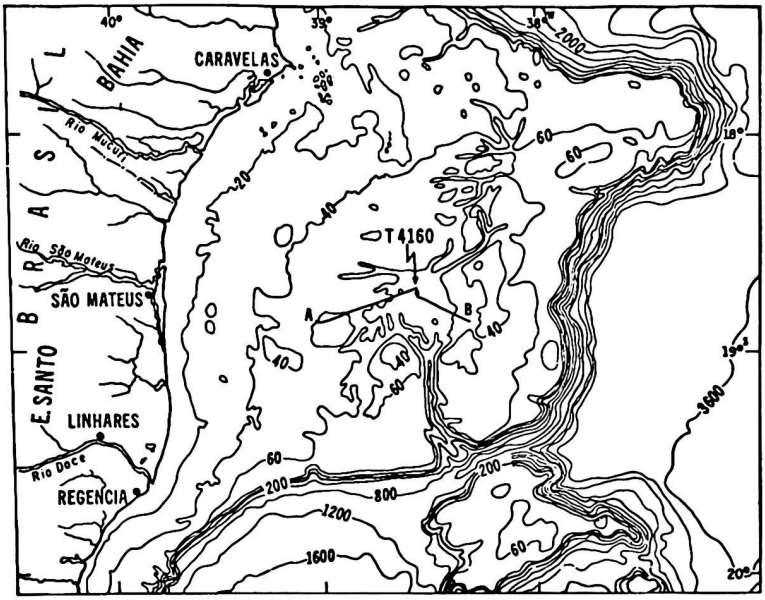
The younger ooids (= 14,000 years old), however, are in fair agreement with the eustatic curve (Fig. 4) and are most likely *in situ* and outside the age bracket of shelf subsidence proposed by MILLIMAN & BARRETO (1975). They were sampled from water depths of 100-110m and are associated with intertidal mollusks (SANTOS, 1972). Thus there is strong indication that they mark a former stillstand shoreline.

The Abrolhos continental shelf is covered by algal reefs and biodetrital carbonate (MELO *et al.*, 1975). Bathymetric maps of this area show a mid-shelf depression upon which converge a series of channels, best delineated by the 60m isobath (Fig.5).

According to MELO *et al.* (1975), these channels were carved into the carbonate substrate as the fluvial drainage extended to the continental slope due to the general subaerial exposure of the shelf during the late Wisconsin and early Holocene.

Based on the physiographic similarity between the Abrolhos Depression and the Bonaparte Depression on the Sahul shelf, MELO *et al.* (1975) suggested that during the Holocene transgression the Abrolhos Depression behaved as a lagoon just like its better known Australian counterpart.

To test this hypothesis, a piston core was taken from the thin, unconsolidated sediment cover, as revealed by a simultaneous 3.5 kHz echosounder survey (Fig. 5), that floors the Abrolhos Depression. This core, described by VICALVI *et al.* (1978), penetrated part of the section and sampled terrigenous mud overlain by carbonate mud. Microfauna confirmed the lagoonal nature of the basal mud. Dating of a mollusk shell within this unit revealed an age of 10,620 $\pm$ 300 years (VICALVI *et al.*, 1978). When this age is plotted against the water depth of the core (66m), it falls on the MILLIMAN & EMERY (1968) eustatic



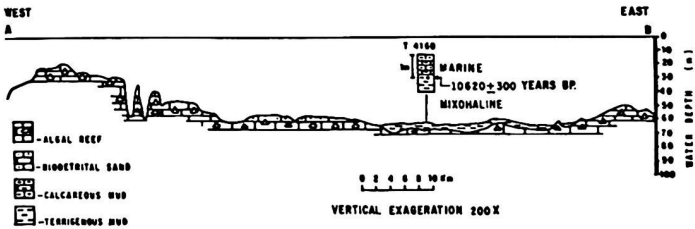


Figure 5 - Bathymetry in meters of the Abrolhos shelf, eastern Brazil (ZEMBRUSCKI & FRANÇA, 1976) and interpreted cross section of the Abrolhos Depression (VICALVI *et al.*, 1978). Piston core recovered subsurface terrigenous lagoonal sediments.

curve (Fig. 6).

The development of coastal conditions in the Abrolhos Depression approximately 11,000 years ago strongly suggests a sea level stilstand around the present 60 m isobath. The paleogeography of the area at that time is pictured in Figure 7.

Sedimentation rate calculations and the relationship between the bathymetry that surrounds the Depression and the sea level curve indicate that mixohaline conditions remained until the complete drowning of the Depresseion 8,000 years ago. At this time, terrigenous sedimentation ceased and was replaced by biogenic carbonate deposition. Microfaunal analysis suggests a progressive deepening of the water column as a result of the continuing transgression (VICALVI *et al.*, 1978).

The southern Brazil outer continental shelf is covered by mollusk shell hash (ROCHA *et al.*, 1975) (Fig. 8).The dominant fauna is characteristic of an inner shelf environment, (M.E.M. SANTOS, personal com.; KOWSMANN *et al.*, 1977). According to KOWSMANN & COSTA (1974b) and KOWSMANN *et al.* (1977), the broken nature of the shells, the character of the associated terrigenous coarse fraction and the presence of coastal benthic foraminifera indicate, however, that these sediments were concentrated as shoreline lag deposits under high energy conditions.Radiocarbon dating of a shell hash sample off Rio Grande do Sul at a water depth of 135 m revealed a late Wisconsin age of 17,420 $\pm$ 270 years. According to the MILLIMAN & EMERY (1968) curve, this depth corresponds to the shoreline position at the glacial maximum sea level stillstand 15,000 years ago. Thus it is most likely that the reworking of this Pleistocene carbonate assemblage into a lag deposit took place at this time.

MORPHOLOGICAL EVIDENCE - Detailed study of the morphology of the Brazilian inner shelf transgressive sand sheet has revealed examples of coastal retreat during the last 7,000 years when the rate of sea level rise diminished abruptly. Linear shoal retreat massifs off Rio Grande do Sul (FIGUEIREDO JR., 1975), cape shoal retreat massifs off deltaic cuspate forelands such as the ancestral Paraíba do Sul (KOWSMANN *et al.*, 1978) and Doce river mouths and estuarine retreat massifs off .Pará-Maranhão (PALMA, in press) probably evolved in a fashion

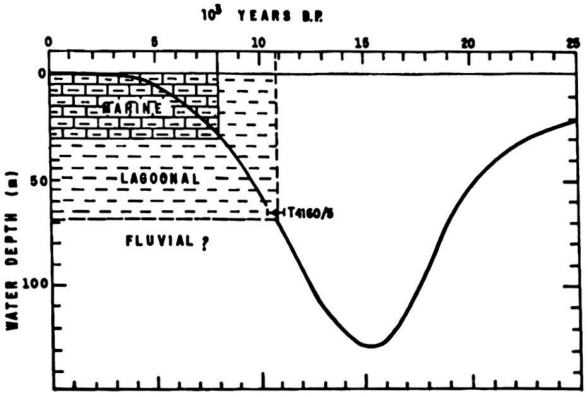


Figure 6 - Depositional environments in the Abrolhos Depression during the Holocene transgression, based on piston core data from VICALVI *et al.*(1978). Eustatic curve from MILLIMAN & EMERY (1968).

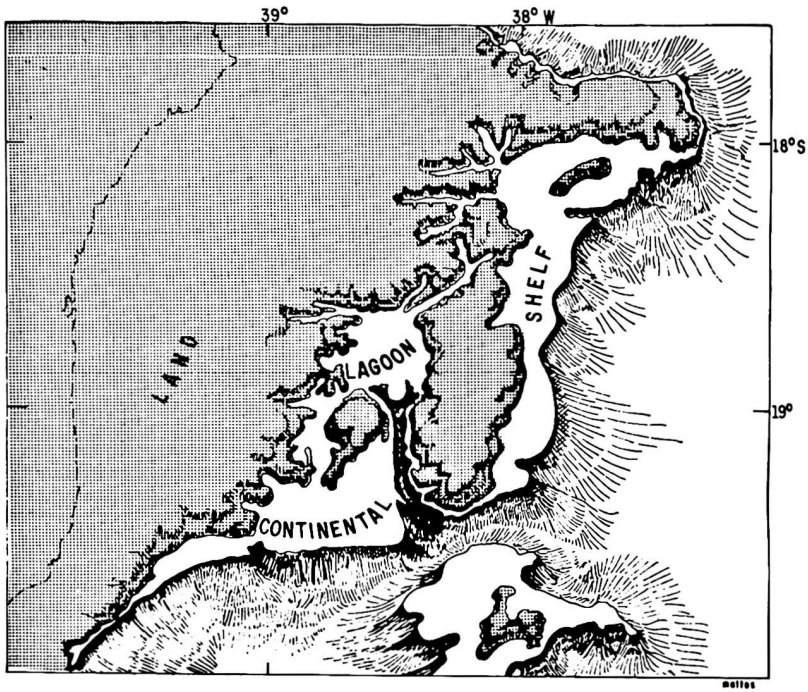


Figure 7 - Paleogeography of Abrolhos shelf during sea level stillstand 11,000 years ago. Coastline based on the 60 m isobath of figure 5. Present coastline defined by dashed line. From VICALVI *et al.* (1975).

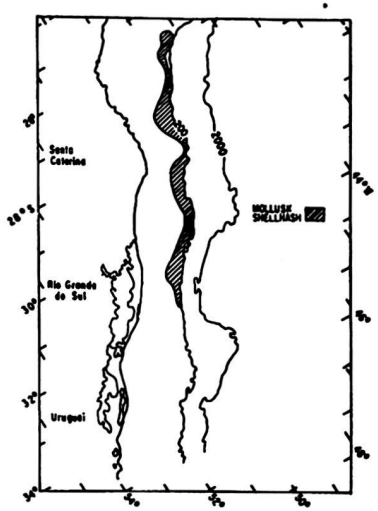


Figure 8 - Carbonate-dominated outer shelf off southern Brazil composed of mollusk shell hash. From ROCHA *et al.* (1975). These were concentrated as coastline deposits during the late Wisconsin glacial maximum.

similar to that of their eastern United States equivalents described in FIELD & DUANE (1976). However due to complications of the eustatic curve in the last 6,000 years,as pointed out by FAIRBRIDGE (1976) and SUGUIO & MARTIN (1977), the data on the Brazilian inner shelf is not yet sufficient to permit correlation with the adjoining coastal plain. Therefore we shall restrict ourselves to morphological stillstand evidence prior to 7,000 years B.P.where resolution of the eustatic curve is not much better than the existing shelf data.

Scarps in the transgressive sand sheet, of great regional extent and mostly buried under Holocene muds, were mapped off Rio Grande do Sul (KOWSMANN *et al.*, 1976) and off Cabo Frio (KOWSMANN *et al.*,1978), using a bottom-penetrating 3.5 kHz echosounder system. Off Rio Grande do Sul, they approximately follow the 110 m and 60 m isobaths (Fig. 9). Off Cabo Frio, only the -110 m scarp was successfully mapped (Fig. 10). These scarps were interpreted as remnants of former shore faces built upwards during short periods of sea level stillstand within the Holocene transgression, as in the shore face retreat model described by SWIFT *et al.*, 1973.

Another scarp of regional expression was detected by PALMA (in press), extending between the Maranhão Embayment and the mouth of the Gurupi River. Unlike the southern Brazil scarps, it has surface relief and follows the 40 m isobath. According to PALMA (in press), it probably delineates the inner limit of the former Gurupi River stillstand delta.

Erosional terraces are another kind of morphological sea level stillstand marker. They are very conspicuous along the northern, northeastern and eastern Brazil shelf edge and upper continental slope, as pointed out by BOYER (1969), DAMUTH (1973), and PALMA (in press). Terrace depths cluster around the 130, 110, 90, 75, 60 and 40 m present-day isobaths. The -75 m and the -60 m terraces are particularly conspicuous and generally delineate the shelf edge. The shallowest of the two also marks the usually flat top of seamounts of the Columbia and Abrolhos Seamount Chains on the eastern Brazil continental margin (GORINI, 1969). The -110 m level is also very common as a seamount slope inflection (BOYER, 1969).

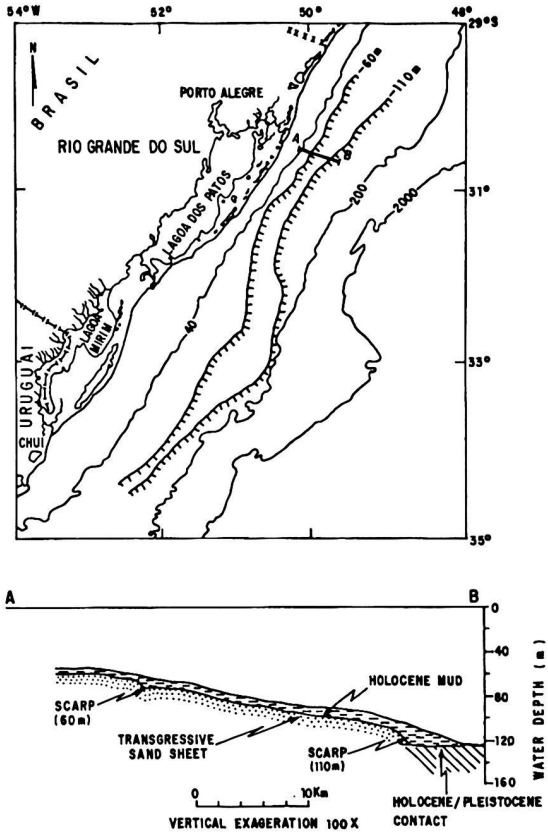


Figure 9 - Regional scarps of the transgressive sand sheet approximately following the present 110 and 60 m isobaths off Rio Grande do Sul, interpreted as remnants of stillstand shore face 13,000 and 11,000 years B.P., respectively. The scarps are generally buried by shelf muds. From KOWSMANN *et al.* (1976).

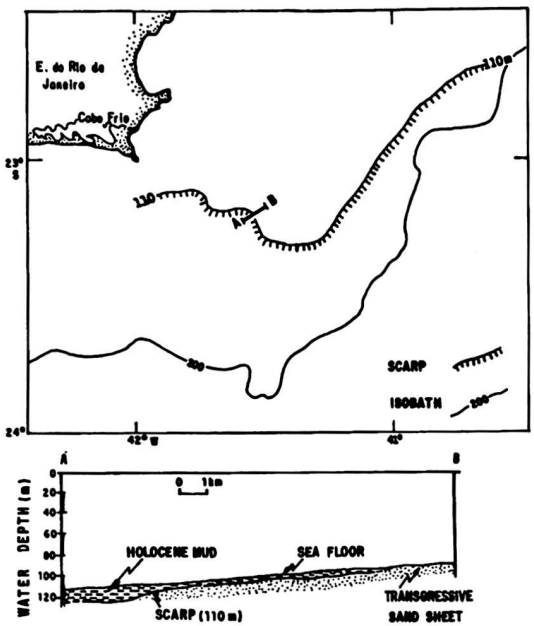


Figure 10 - Scarp off Cabo Frio approximately following the present 110 m isobath, interpreted as remnant of a former shore face developed 13,000 years ago. To the west of section AB,it is formed by buildup of the transgressive sand sheet and is buried by shelf muds. To the east, the scarp crops out as a probable erosional feature carved into carbonate sediments. After KOWSMANN *et al.* (1978).

Deeper terraces are also present, in particular along the continental slope south of Vitoria (20°S). BOYER (1969) mentions levels clustering around -140, -190 and -230 m. An additional -170 m terrace level was noticed at the sehlf edge off southern Brazil, where 3.5 kHz records show dipping strata truncated at their top (ALVES, 1972; MILLIMAN, 1978).

One last evidence, still quite speculative in nature, is presented by the pattern of the 80 m bathymetric contour on the outer shelf of the Amazon-Amapá region. This isobath delineates a series of linear crests and troughs oriented perpendicular to the shore line and shelf edge (ZEMBRUSCKI & FRANÇA, 1976) (Fig. 11). These features had always been interpreted as valleys of the Wisconsin Glacial Amazon River system, since they parallel the Amazon submarine canyon (ZEMBRUSCKI *et al.*, 1971; MILLIMAN *et al.*, 1975).Their origin has recently been reevaluated by PALMA (in press) who interpreted them as being tidal linear shoals. They have been found to continue underneath the Amazon prodelta muds. One of the hypotheses formulated by PALMA (in press) suggests that these features were built under inner shelf hydrodynamic conditions at a water depth of 20 m, just like the tidal linear shoals off the Maranhão Embayment today (Fig. 11). If this hypotheses is true, the former mid-Holocene coast line would have stood at the present isobath equivalent to 60 m minus the yet unknown thickness of late Holocene-Modern Amazon deltaic muds.

CONCLUDING REMARKS

From the data presented above, six persistent former sea level stillstand positions are inferred. They approximately follow the present day -130, -110, -90, -75, -60 and -40 m bathymetric contours. The first two levels and the -60 m level were directly or indirectly dated and are Holocene in age. The other three (-90, -75 and -40) are only evident as morphological features and were not dated. Therefore it is only assumed that they are likewise Holocene.

The -130 m level is represented by shell hash coastal lag deposits off southern Brazil and by erosional terraces on the continental slope off northern and northeastern Brazil.This

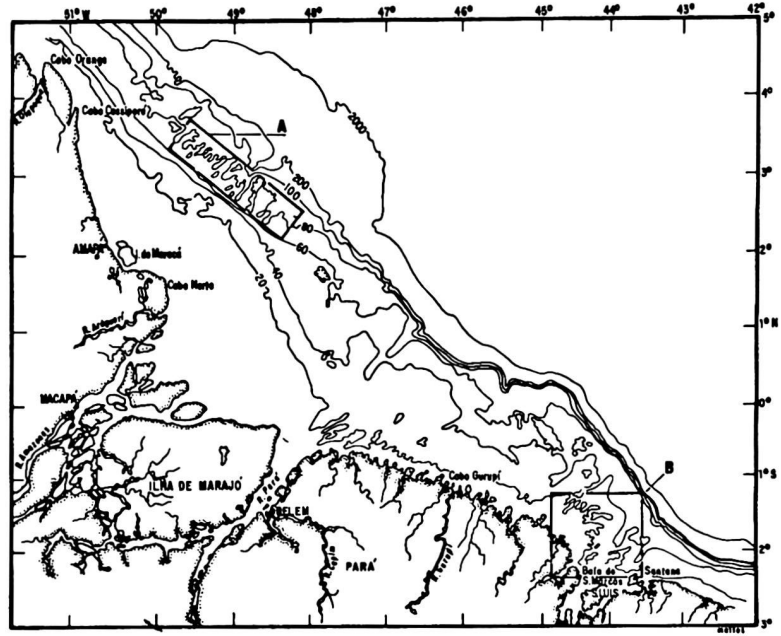


Figure 11 - Bathymetry in meters of the northern Brazil continental shelf (ZEMBRUSCKI & FRANÇA,1976), showing(A) linear tidal shoals of the Amazon-Amapá outer shelf and (B) linear tidal shoals and estuarine retreat massif off the Maranhão Embayment. (A) may be an ancestral analog of (B). Interpretation by Palma (in press).

level post-dates 18,000 years B.P. obtained by radiocarbon dating and, according to the MILLIMAN & EMERY (1968) eustatic curve, dates from the last glacial maximum,15,000 years ago.

The -110 m level is indicated by a concentration of terrigenous material in the sediment coarse fraction off northern and southern Brazil, by the presence of back-reef oolites in the Amazon-Amapá shelf, by shore face scarps in the southern shelf and by erosional terraces in the northern, northeastern and eastern continental slope. Radiocarbon age determination and the MILLIMAN & EMERY (1968) curve place this level between 14,000 and 13,000 years B.P.

The -90 and -75 m levels are conspicuous as erosional terraces distributed throughout the northern, northeastern and eastern upper continental slope of Brazil. Their respective ages as determined by the above mentioned eustatic curve are 12,000 years B.P. and a little older than 11,000 years B.P.

The -60 m level is marked by an abrupt increase in terrigenous coarse components of sediments of the northern and southern shelf, by the presence of a coastal lagoon in Abrolhos, by a shore face scarp in the southern shelf,erosional terraces in the northern, northeastern and eastern shelf edge and possibly by association with former inner shelf tidal shoals off the Amazon-Amapá area. Its age by radiocarbon dating and comparison with the eustatic curve used in this paper is 11,000 years B.P.

The -40 m level is evident as erosional terraces in the northern, northeastern and eastern continental shelf and probably as a scarp of the Gurupi stillstand delta in northern Brazil. Its age, based only on the eustatic curve, is 9,000 years B.P.

The -170 m level (indicate by the terrigenous coarse fraction in both northern and southern Brazil and by truncated shelf edge progradational beds) as well as miscellaneous deeper erosional terraces off southern Brazil are probably pre-late Wisconsin sea level stillstand positions. It is unlikely that they result from marine current erosion, such as postulated by VAN ANDEL & CALVERT (1971) for the Walvis shelf, since no powerful analog to the Benguela Current exists on this side of

the Atlantic Ocean.

The profusion of stillstand levels of which only the most apparent are listed above, if real, suggests that at least between 15,000 and 9,000 years B.P. sea level oscillated with a frequency similar to that observed for the last 6,000 years.

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