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Influence of the “Hypsithermal Age” and “Neoglaciation” climatic conditions on the brazilian coast

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Abstract - Meanwhile the highest relative sea-level is the present one in southeastern United States (Gulf of Mexico) or in Netherlands coast, most of the Brazilian coast exhibited Holocene sea-levels higher than the present in the past. The Brazilian curves, representing the relative sea-level changes during last 7,000 years, are outlined using sedimentological, biological and prehistorical past sea-level records. This paper shows that these relative sea-level records, during the Holocene, can be suitably used to demonstrate the influence of the worldwide known paleoclimatic events, like the “Hypsithermal Age” and “Neoglaciation” on the Brazilian coast.

Keywords - “Hypsithermal Age”, “Neoglaciation”, Holocene paleoclimate.

INTRODUCTION

It is possible to assume that the end of the Northern hemisphere last glacial stade occurred about 10,000 years B.P. In reality, this is an arbitrary age because the glacial – interglacial transition was gradual and, moreover, it differs according to the latitudes.

Until the end of XIX century, before the discovery of the Holocene paleoclimate fluctuations, there was a speculative idea that the glacial stade climate became gradually warmer until the present conditions. However, this simple hypothesis was wrong, a mistake revealed through Scandinavian fossilized plant debris studies. Plant leaves and stems, collected from lacustrine and swampy post-glacial deposits, were identified, followed by fossil palynomorphs analyses. In reality, palynomorphs have been much more useful than leaves and stems, because they are by far numerous and very resistant against chemical weathering, excepting oxidation. They have been identified, counted, statistically treated, and finally grouped. Thus, they supplied a scenary characterized by past peculiar vegetal assemblages, which flourished at the neighborhood of those lakes and swamps, when sedimentary layers with those plant remains deposited. The reconstituted floristic assemblages have been compared with similar ones living in proximities, or frequently, further north or south. Past temperatures and pluviosities have been estimated, and the organic remains dated by radiocarbon method. The substrates of most studied sites were composed of till or meltwater fluvio-glacial

sediments. Therefore, studies of crowded sediment samples, collected from bottom to top, allowed reconstitution of past climatic history from the end of the last glaciation until today (Fig.1).

At the post-glacial phase, from *Preboreal* to *Boreal*, following the *Betula* genus, the *Corylus* became more abundant, and in *Atlantic* the paleoclimate changed into more temperate and wet propitiating the development of genus *Tilia*, *Quercus*, *Alnus* and *Pinus*. From about 9,000 to 2,500 years B.P. (Deevey & Flint, 1957), the paleotemperatures of northern Europe were perceptibly warmer than today, being this time interval commonly referred as “*Hypsithermal Age*” (or “*Climatic Optimum*”). According to Andersen & Borns Jr. (1994), this name could be applied to any late cenozoic interglacial stade however, preferably, refers to the Holocene warmest time interval (Fig.2). Probably, according to above mentioned authors, the average temperature during winter in the present Oslo (Norway) area was about 3.3°C higher than today. After about 5,000 years B.P. began the *Subboreal* phase with decreasing *Ulmus* and *Tilia* pollen frequencies, and in the *Subatlantic* occurred an increase in genus *Fagus* pollen.

According to Bradley (1989) the middle Holocene “*Hypsithermal Age*” could be assumed, throughout the Earth, as 1 to 2°C warmer than present average temperature (about 15°C). However, this kind of average global temperature extrapolation is very complicated even presently, when instrumental records are relatively abundant, mostly in Northern hemisphere countries.

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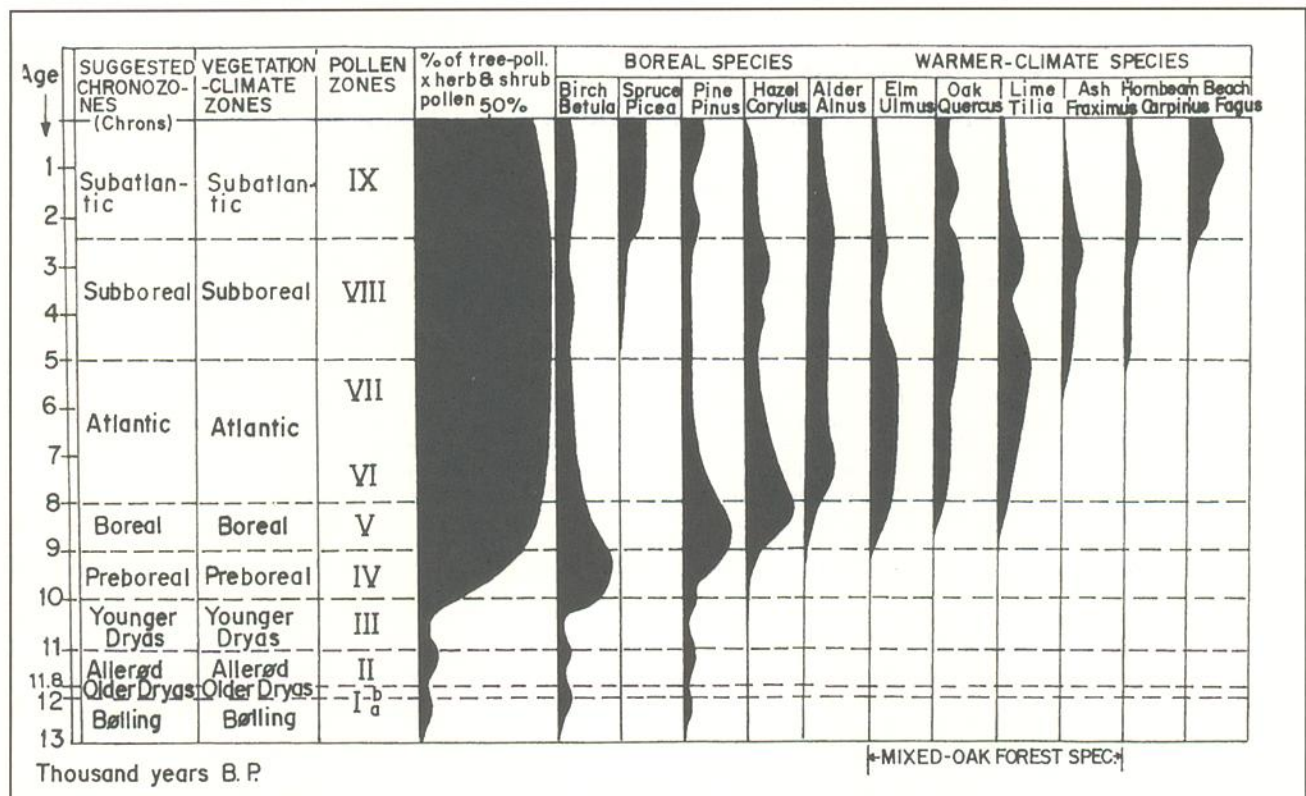


Figura 1 - Generalized pollen diagram from southern Scandinavia combined with traditional chronostratigraphic, climatic-vegetational, and palynologic zones (modified by Andersen & Borns Jr., 1994, according to several authors proposals). Black corresponds to arboreal plant pollen frequencies, whose lower values could not be necessarily indicative of low frequency of occurrence in the studied area, so they could suggest a distant source area and/or reworking from older sediments.

Many Alpine-type small glaciers, almost totally melted during the “Hypsithermal Age”, enlarged after about 2,500 years B.P. This fact is recorded by end moraines, some containing wood fragments related to thrown down tree trunks due to glacier readvance, which have been sampled and radiocarbon dated. This most recent event, of worldwide climatic deterioration is commonly known as “Neoglaciation”. In effect it was not an unique colder event, which continues until presently, but exhibits slight oscillations (Fig.2), as the “Little Ice Age” (1,450 to 1,890 years A.D.).

Fortunately, “Neoglaciation” paleoclimatic records, mostly that related to the “Little Ice Age”, as a latest glacial event, exhibit seasonal to even annual precision supplying with very detailed data. The “Little Ice Age” is very clearly recorded, as for example, in ice cores from tropical regions (Thompson *et al.*, 1986), as well as in other global scale paleoclimatic proxy records (Grove, 1988), as in coral reefs.

However, there is still a lack of data on global scale relationships and final originating causes of these paleoclimatic secular events. Still insufficient knowledge on these secular to millennial paleoclimate

constitutes a serious hindrance for a more precise global climate forecast. Additionally, the “greenhouse gases” induced artificial global warming effect superimposes high amplitude natural secular changes. Therefore, past secular and millennial events, as “Hypsithermal Age” and “Neoglaciation”, must be more hardly studied to reach a better understanding about how the atmosphere, the cryosphere, and the biosphere could react against man-induced bigger climatic changes in very near-future.

These informations are very scarce in Southern hemisphere, particularly in Brazil, where even the well-established concepts on “Hypsithermal Age” or “Neoglaciation” are simply ignored by most of few paleoclimatologists. However, several informations gathered by Holocene paleoenvironmental researches along the Brazilian coastal lowlands (Fig.3), mostly during the last 20 years, could be influenced by global paleoclimatic changes.

Among the pioneer works on Holocene paleoclimates, trying a worldwide correlation, there is a paper by Bombin (1976). In this work the author used unsuitably the Scandinavian Holocene paleoclimate

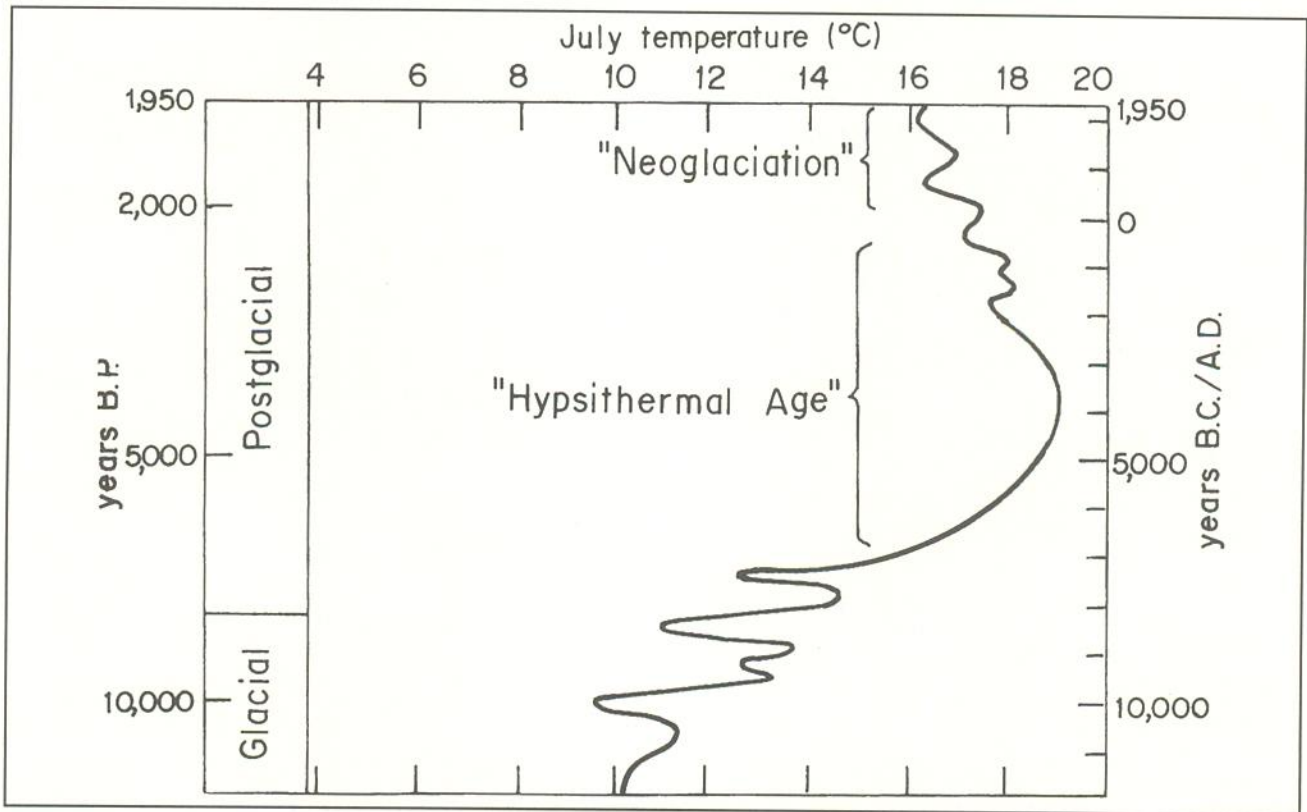


Figura 2 - Average temperature changes in Denmark during the last 12,000 years, based on glacial deposits, fossil palynomorphs, and alternating peat levels representative of warmer and drier episodes intercalated by cooler and wetter (with *Sphagnum*) conditions. Modified by Flint & Skinner (1974) from Iversen (1973).

subdivision (Fig.1), invalid for a research done in Rio Grande do Sul State, Brazil.

According to Markgraf & Bradbury (1982), the Holocene paleoclimate history in South America is characterized by warmer paleoclimates which were changeable through the continent. Paleotemperatures higher than presently would have been frequent in early Holocene records, relatively dry in the northern and southern Andes, but wetter in the tropical lowlands. Cooler paleoenvironments would be recorded in middle Holocene, with an effective growth of humidity on higher elevations and an increasing evaporation in the tropical lowlands. The late Holocene paleoclimates could have been more changeable, thus frustrating a simplified chronostratigraphic correlation of these past events.

In Behling's (1995) summary, the Holocene warm and drier paleoclimate (10,000 to 3,000 years B.P.), in the Santa Catarina State coast, changed to a cold and wetter regime (3,000 to 1,000 years B.P.), and finally to a cold and very humid period (after 1,000 years B.P.).

Analogous preoccupation with the Holocene paleoclimate has been demonstrated recently by Angulo

et al. (1999) who, based on vermetid tube $^{18}\text{O}/^{16}\text{O}$ ratios, assumed a gradual paleotemperature decreasing in southern Santa Catarina State coast during the last 5,000 years. They hypothesized that vermetid eradication southward of Cabo Frio (Rio de Janeiro State) could be attributed to a gradual cooling of ocean waters during the Holocene.

HOLOCENE RELATIVE SEA-LEVEL CHANGES

The last Brazilian coast high sea-level episode, known as Santista transgression in São Paulo State (Suguio & Martin, 1978), is represented in Rio Grande do Sul State coast by barrier-island/lagoonal system IV (Villwock *et al.*, 1986). The last 7,000 years of this transgression are well known thanks to sedimentological, biological and prehistorical higher sea-level episodes, field evidences and dated by radiocarbon method (Suguio *et al.*, 1985; Martin *et al.*, 1996). From the outlined relative sea-level change curves, the Salvador (Bahia State) curve is considered as the most representative, where disregarding some



Figura 3 - Brazilian coast, with indication of studied area and names mentioned within the text.

second order variations, all the studied sectors exhibit relative sea-level dominantly higher than presently (Fig.4):

a) The present average sea-level was intersected, for the first time, between 7,000 and 6,500 years B.P.;

b) At about 5,100 years B.P., corresponding to Holocene culmination stage, the relative sea-level was between 3 to 5 m above the present level;

c) Somewhere near 3,900 years B.P., the relative sea-level dropped until slightly lower than the present one;

d) At about 3,600 years B.P., the relative sea-level rose until 2 to 3,5 m above the present level;

e) At approximately 2,800 years B.P., occurred a renewed lowering until a level lower than presently, and finally;

f) At the beginning of the last 2,500 years occurred the last culmination stage, when the relative

sea-level rose until 1,5 to 2,5m above the present one. After that occurred a gradual dropping until presently.

Comparing the above mentioned curve with the durations of the "Hypsithermal Age" (9,000 to 2,500 years B.P.) and of the "Neoglaciacion" (last 2,500 years) it is possible to assume that:

g) The relative sea-level above the present level between 6,500 to 7,000 years B.P. until 2,500 years B.P. could be due to the "Hypsithermal Age" global warming, which would propitiate glacier melting, causing a glacioeustatic sea-level rise. This phenomenon does not originate relative sea-levels higher than the present one in rapidly subsiding areas, as the United States southeastern coast or Netherlands, where records of Holocene sea-levels above the present are unknown.

h) The gradual dropping of relative sea-level during the last 2,500 years could be related to "Neoglaciacion", accompanied by climatic deterioration and glacier expansion, causing a glacioeustatic

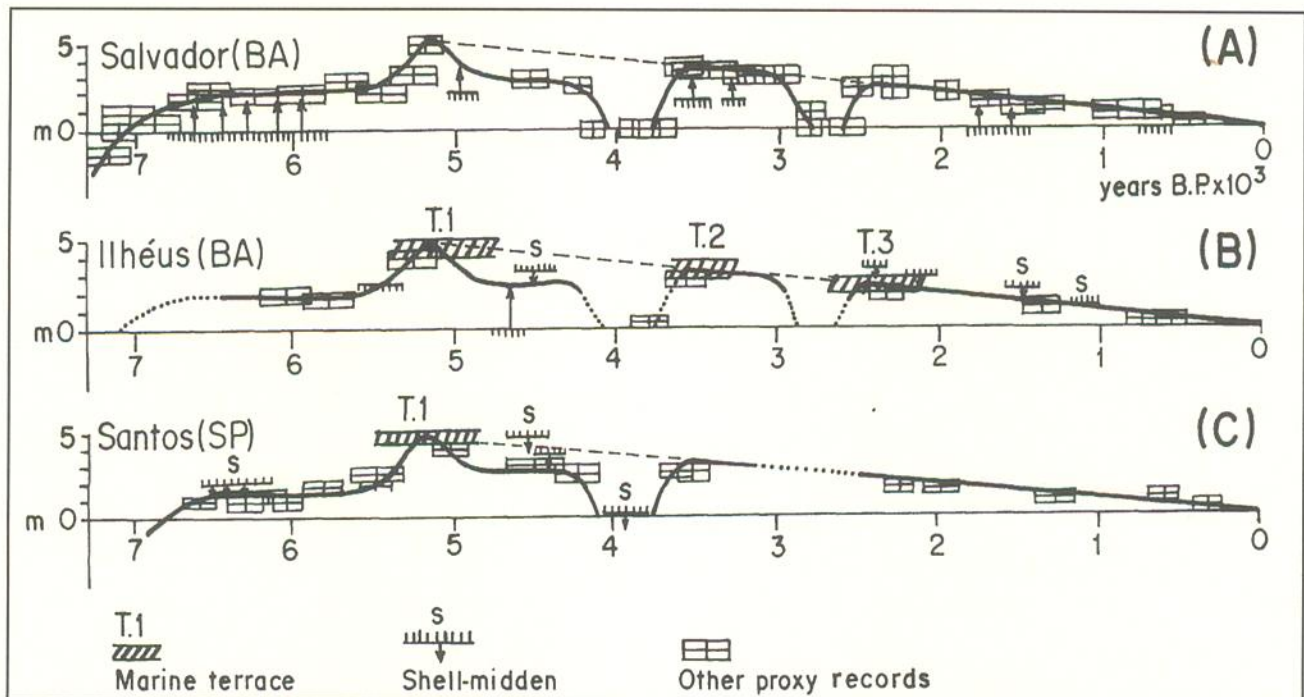


Figura 4 - Some examples of relative sea-level change curves for the last 7,000 years along the Brazilian coast (Suguio *et al.*, 1985). Observe the great similarity of the curves. The Salvador (Bahia State) curve (A) is the most representative, because it was based on most numerous proxy records.

sea-level drop. Along the Brazilian coast this period is clearly evidenced by coastal progradation, mostly at proximities of Paraíba do Sul (Rio de Janeiro State) and Doce (Espírito Santo State) rivers mouths (Martin *et al.*, 1997).

BEACH ROCKS

They are inorganic sedimentary rocks, mostly sandstones and conglomerates, forming stone reefs, in contrast to organic reefs, dominantly composed by living organisms (corals, calcareous algae and bryozoans). The beach rocks are dominantly constituted by quartzose and rocky fragments cemented by calcite, frequently with fragmented or entirely preserved mollusk shells and other biodetrital particles. They represent a stage of coastal geologic evolution when, after their formation within an active beach, would have been submitted to a coastline retreat.

In general, beach rocks are formed within intertidal zones of tropical and equatorial regions, where originate several parallel narrow stripes every one representing an ancient strandline dipping less than 15° oceanward. Along the Brazilian coast Holocene beach rocks are relatively common from northern Rio de Janeiro (Paraíba do Sul river delta), dominantly occurring along the northeastern states coast. They

have been studied by Branner (1904), Mabesoone (1964), Bigarella (1975), Flexor & Martin (1979), etc.

Nevertheless any detailed work has been done, some submerged beach rock occurrences in Rio de Janeiro and São Paulo states have been mentioned. The author of this paper observed the occurrence of beach rock in southern part of Mar del Plata (Argentina), in a locality named Pehuen-Co, which must be older than Holocene in age. Practically nothing is known about these southernmost occurrences, almost limited to some radiocarbon ages obtained by Suguio & Martin (1978) on emerged beach rock outcropping at the São Lourenço hill, northward of Bertioiga (São Paulo State). However, if they have been of Holocene age, as in the last site, could represent the "Hypsithermal Age", when probably the Brazilian oceanic current could reach southward than today. Presently, the ocean water temperatures could be assumed as exceedingly low to propitiate beach rock formation.

Amongst the Brazilian beach rock occurrences, mostly between Bahia and Rio Grande do Norte states, there are about 52 ages (Fig. 5A). As shown in this figure, the obtained ages are extremely changeable, from more than 7,000 to less than 500 years B.P. In general, there is no correlation between the three most important sea-level culmination stages and the histogram's modes. Nevertheless, there is probably a gradual decrease of

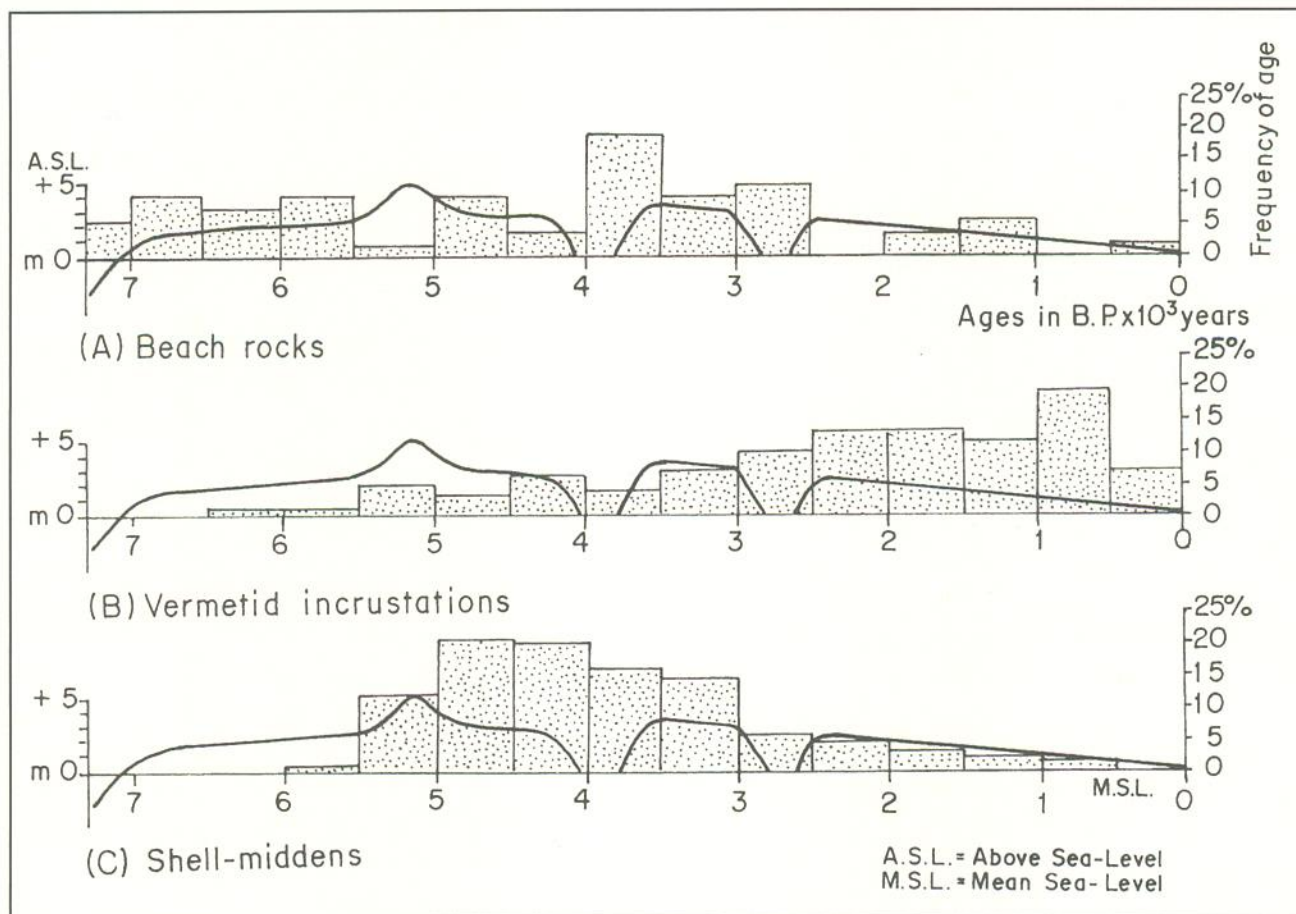


Figura 5 - Salvador (Bahia State) relative sea-level change curve for the last 7,000 years superimposed by histograms of most frequent ages of beach rocks, vermetid incrustations and shell-middens.

frequencies in ages lower than about 4,000 years B.P., mostly within the last 2,500 years. These trends could represent an influence of “*Neoglaciation*”, which diminished the intensity of beach rock formation.

BIOLOGICAL EVIDENCE

Marine sessile organism remains, ichnofossils and mollusk shell deposits, in life position or transported, have been used by Suguio *et al.* (1985) and Martin *et al.* (1996), as evidence for Holocene sea-levels above the present one. On the other hand, the majority of these indicators can be used as evidence of “*Hypsithermal Age*” influence.

Mollusk shell deposits

In Brazil there are important shell deposits of marine mollusks which are submerged, as for example, in Todos os Santos bay (Bahia State), in a area of Rio

de Janeiro State informally known as “*região dos lagos*” mostly within Araruama lagoon, and in a region adjacent to Laguna city (Santa Catarina State). Considering first two occurrences, only the Todos os Santos bay deposits are relatively well known (Leão, 1971). Perhaps, because they are dominantly emerged, Laguna area deposits are the best studied (Mendes, 1993; Pitoni, 1993; Caruso Jr. *et al.*, 2000).

In the areas neighbouring Laguna city, mollusk shell deposits occur as several types of natural accumulations, as well as artificial accumulations (shell-middens). Within the natural deposits the shells are associated with estuarine muddy sediments or beach and shallow marine sands. They have been subjected after death to hydrodynamic reworking in littoral zone, giving rise to lagoonal and shallow marine facies of tidal channel, flood tidal delta and transgressive lag deposits. All these deposits, commercially exploited until now, are allochthonous and have been concentrated under high energy conditions. The high

frequency of broken shells, the mixture of mollusk shells from open-sea, lagoon and estuary, and the presence of conspicuous megascale crossbeddings are indicative of this origin (Caruso Jr. *et al.*, op. cit.).

At the northern extremity of this lagoonal complex, in the Nova Brasília area, there is a 4,000m long, 420m wide and 0,60 to 6m thick shell deposit. According to Forti-Esteves (1986), Mendes (op. cit.) and Pitoni (op. cit.), the most frequent mollusk species are: *Heleobia australis* (d'Orbigny, 1835), *Cerithiopsis greeni* (Adams, 1839), *Crepidula plana* (Say, 1822), *Nassarius viabex* (Say 1822), *Tellina (Eurytellina) lineata* (Turon, 1819) and *Tagelus plebeius* (Lightfoot, 1786). The first two are estuarine species and the rest are species from shallow marine environment. Other less frequent species are: *Neritina virginea* (Linnaeus, 1758), *Cerithium stratum* (Born, 1778), *Bulla striata* (Bruguère, 1792), *Ostrea equestris* (Say, 1834), *Codakia costata* (d'Orbigny, 1842) and *Anomalocardia brasiliiana* (Gmelin, 1791). Therefore, the species of mollusks from these shell deposits are relatively well known. However, their paleoecological characteristics as, for, example, the best paleotemperatures for their life are insufficiently known. Finally, there are not comparative studies with mollusk assemblages presently living in the area. On the other hand, the allochthonous nature of these shell deposits practically invalidate more detailed bio and or chronostratigraphic studies. Nevertheless, according to Martin & Suguio (1986) the average radiocarbon age of mollusk shells of this area is about $4,490 \pm 200$ years B.P. Even if this age could not be associated directly with depositional phase due to its allochthonous nature, still is interesting because it belongs to the time interval assumed for the "Hypsithermal Age" Probably, the dominant radiocarbon ages of Todos os Santos bay (Bahia State) and Araruama lagoon (Rio de Janeiro State) are also indicative of this global warming time interval. If this statement is true it could suggest that middle Holocene warmer paleotemperature favoured an anomalous proliferation of mollusks in these areas.

Therefore, it could be extremely interesting that in all these areas could be done researches as from Matsushima (1979) in southern Kanto area (Japan). This author recognized there a typical warm water malacofaunal association composed of 13 species, which exhibited an extraordinary development only during the "Hypsithermal Age", mostly during 9,000 and 4,000 years B.P.

Vermetid incrustations

The tubular aragonitic incrustations due to vermetid (Gastropoda, Mollusk) of the species *Petalocochus (Macrophragma) varians* (d'Orbigny) are, according to Laborel (1986), one of the most reliable biological indicator of past sea-level.

These incrustations are better preserved only in special sites, sheltered against waves, rain and run-off waters, frequently situated below huge boulders or within rock fractures, near present strandline. At Brazilian northeastern coast, like of Rio Grande do Norte and Pernambuco states, the vermetids are incrustated on Barreiras Formation laterites or above older beach rocks. From Salvador (Bahia State) toward south, these incrustations occur, besides Barreiras Formation laterites and beach rocks, on precambrian crystalline basement outcrops, at least until the Santa Marta cape (Santa Catarina State) area.

According to studies done by Laborel (1969, 1979), the vermetids developed intensively and extensively along the Brazilian coast during the last millennia, represented by the dominant species *Petalocochus (Macrophragma) varians*. However, from Cabo Frio (Rio de Janeiro State) southward it has been almost extirpated, being represented in this sector by fossilized incrustations. The vermetid of this species lives in the lower fourth of the intertidal zone, between neap and spring-tide levels. At southeastern and southern Brazilian coasts, where living specimen is missing, as in the Angulo *et al.* (1999) work, the used reference was the upper limit of *Phragmatopoma lapidosa* colonies, a polychaete worm living in a level equivalent to the living vermetid.

During several surveys along the Brazilian coast (Martin *et al.*, 1996; 1997; Angulo *et al.*, op. cit.) about 131 ages of fossilized vermetid samples, indicative of past relative sea-levels, have been measured. Geographically they are distributed from Rio Grande do Norte to Santa Catarina states. When their age interval frequencies were plotted on a histogram (Fig. 5B), it was shown that their ages are erratic, and are variable from more than 6,000 to less than 500 years B.P. However, about 64.4% of the dated samples were younger than 2,500 years B.P., approximately coincident with "Neoglaciation" which is suggestive of its eradication through accentuated slaughter, which was closely related to this paleoclimatic event.

Ichnofossil of *Ophiomorpha nodosa*

Along the Brazilian coast, studied until now, there are *Ophiomorpha nodosa* (Suguio & Martin, 1976; Suguio *et al.*, 1984; Barreto *et al.*, 2000b) ichnofossils, which are associated both to Pleistocene and Holocene shallow marine deposits. However, as they are most conspicuous, have been better studied in Pleistocene sediments.

They correspond to simple or ramified burrows, which originate vertical, horizontal or oblique tubular nets, whose outer surface is adorned by crenulations. From ethological viewpoint they could be classified as dwelling (domichnia) and nourishment (fodinichnia) ichnofossils. The probable generator of these ichnofossils could be Callianassid crustacean, which build their burrows within intertidal or upper supratidal environments. According to Rodrigues (1966) there are, along the São Paulo State coast, at least five species, whose ecological knowledge is still insufficient (Rodrigues *et al.*, 1984).

Apparently, the *Ophiomorpha* burrows found in Osório (Rio Grande do Sul State), within upper Pleistocene deposits correlative to the Cananéia Formation (Suguio & Petri, 1973), could be attributed to the species *Callichirus mirim*, and that occurring along São Paulo State coast could be ascribed to the species *Callichirus major*. On the other hand, the ichnofossils recently described by Barreto *et al.* (2000b) are different from previous ones by their huge sizes. At the same place with beach rock outcrops in Pehuen-Co (Argentina), this author found *Ophiomorpha* burrows, perhaps attributable to the species *Callichirus mirim*, however their ages could be older than Holocene.

Thus, not only because they have been studied almost only in Pleistocene deposits, but also due to precariousness of their ecological and paleoecological informations, a Holocene paleoclimatic interpretation based on this ichnofossils is still very dubious.

PREHISTORICAL EVIDENCE

In Brazil, the unique prehistorical evidence of Holocene sea-levels higher than the present is represented by coastal shell-middens, which are artificial mounds built by ancient Indians (Fairbridge, 1976). According to Bigarella (1949), the Brazilian shell-midden's malacofauna in the Paraná and Santa Catarina states consists of about 50 different species, but with dominance of the following: *Anomalocardia*

brasiliensis, *Ostrea arborea*, *Lucina jamaicensis* and *Modiolus brasiliensis*. Excepting *Ostrea arborea*, which lives fixed on subaerial mangrove tree roots, other mollusks live within sandy and muddy bay-bottom and lagoonal-bottom deposits submerged by quiet saline and brackish coastal shallow waters.

Some kind of relationship between coastal shell-midden's locations and past sea-levels was assumed a long time ago. However, this assumption was better explained by Martin *et al.* (1986) and Suguio *et al.* (1992). These studies have shown that there is also a correlation between three culmination stages of Holocene relative sea-levels and the most frequent ages of shell-middens.

The Fig. 5C shows that the ages of about 91 coastal shell-middens, situated between Bahia and Santa Catarina states, present ages variable from more than 5,500 years to less than 1,000 years B.P. The most frequent ages are situated within the interval between 5,500 and 3,000 years B.P., which is embraced within "Hypsithermal Age" extent. Therefore, probably this higher temperature event favoured malacofauna proliferation as, for example, in the Laguna (Santa Catarina State) area, and consequently propitiated more numerous shell-midden's construction.

An unexpected fact is an accentuated scarcity of shell-middens in Salvador (Bahia State) area, which is represented only by one probable shell-midden, despite the Todos os Santos bay. This bay could represent a very favourable area for malacofauna development, as revealed by shell deposits studied by Leão (1971). It is probable that many shell-middens existed in the area, which could have been destroyed during Portugal colonial times to make lime for civil constructions and other purposes.

FINAL CONSIDERATIONS

The usefulness of high relative sea-level proxy records, for the last millennia, to demonstrate the influence of some worldwide Holocene paleoclimatic events on Brazilian coast was shown in this paper. However many aspects of this problem are still insufficiently known, as for example, the time correlation shifting between these proxy records and worldwide Holocene paleoclimatic events.

Past coastal water masses circulation could have been strongly affected during transition of these paleoclimatic events. For example, according to Labrel (1969), Cabo Frio in Rio de Janeiro State is

the most important place to understand coastal hydrodynamics, because today it is the meeting point of warmer Brazilian and cooler Malvinas oceanic currents. But during warmer global paleoclimatic events of Holocene this point was much more shifted southward and, consequently, longshore currents would have different orientations.

In fact, according to Fasano *et al.* (1983) and Codignotto (1983), longshore currents along Caleta Valdés, Chubut (Argentina) coast was submitted to an inversion, and the southward pattern in Holocene changed to northward nowadays, which was evidenced by northward quickly prograding sandy spit. This fact has been recently confirmed by Monti (1997) and Kokot (1999).

Arz *et al.* (1999a, b), studying western Equatorial and Tropical Atlantic sedimentary records off northeastern Brazilian coast, identified two most important paleoclimatic changes, which were correlated by them with the LGM (“*Last Glacial Maximum*”) and “*Younger Dryas*” (11,000 - 10,000 years BP). Additionally, as shown in this paper, the influence of younger paleoclimatic events, as “*Hypsithermal Age*” and “*Neoglaciation*” can be apparently recognized on Holocene high sea-level proxy records found on Brazilian coastal lowlands.

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