Shellfish-Eating Preceramic Indians in Coastal Brazil

Radiocarbon dating of shell middens discloses a relationship with Holocene sea level oscillations.

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Studies of the economy of the shellfish-eating Preceramic Indian residents of coastal Brazil (Fig. 1) have shed important light on several apparently unrelated disciplines. These are geodesy or, more specifically, the history of mean sea level and motions of the earth's crust, paleoclimatology, and coastal geomorphology. Results from these disciplines illuminate several archeological questions. I was introduced to these problems in the field by W. R. Hurt of the Indiana University Museum, who has excavated shell middens of coastal Brazil for several seasons, and by J. J. Bigarella of the Geological Institute of the University of Paraná in Curitiba, Brazil. In July 1975 Bigarella organized an international conference in Curitiba to consider the Quaternary history of Brazil. Numerous other archeologists and geomorphologists have contributed to the basic fund of data on which my review is based; key reviews were published by Bigarella in 1965 (*1*) and by Hurt in 1974 (*2*).

Geological Background

Brazil, in common with most of Africa, peninsular India, and the western two-thirds of Australia, is bounded by faulted coastlines that represent scars from the dismemberment of the former Gondwana continent by continental drifting (*3*) and sea floor spreading (*4*). These are "Atlantic type" continental margins and are marked by rather stable Precambrian hinterland, truncation of ancient structural grain, and an absence of the youthful folding, volcanicity, and seismicity that are associated with the "Cordilleran" (or "Pacific") type continental margins (*5*).

The structural setting of coastal Brazil is therefore ideal for studies of the interrelations between the various geological, geodetic, climatic, and oceanographic phenomena and human settlement and economy that combined to control the physical environment there during the Holocene Epoch.

The coastline of southeast Brazil is punctuated by series of rocky islets and headlands that are composed of Precambrian crystalline rocks. Some are drowned inselbergs that are partly joined to the shore by sandy beaches (tombolos) at various stages of development. The rocky headlands serve as anchor points between broad sweeping beaches. The shape of the latter develops under the influence of long ocean swells from the Antarctic, and is reinforced by the southeast trade winds. Exactly analogous beaches are described in the same latitudes along the southeastern coasts of Africa and Australia.

Behind the present beaches are series of beach ridges, in some cases more than 100 for the period since 6000 years ago, during which the coastal flats have prograded up to several kilometers. In this way thousands of square kilometers of land have been added to the Brazilian coast (*6*). The progradation has not been uninterrupted, however, and in places one packet, or sheaf, of beach ridges is cut off by a slight change in trend; some earlier ones have eroded away and the younger ones transect the truncated ridges.

The nature of beach ridges has recently been analyzed by Stapor (*7*) after detailed mapping and dating in Florida. Each ridge is the product of longshore drift and onshore accretion and accumulates by multiple small increments.

The beach ridges appear to have progressed in cycles of about 10- to 100-year periods for each new ridge, and these in turn are arranged in packets of slightly descending crescendo heights. I have mapped and reported the same system of beach ridge development, in packets that are sometimes transected by newer sheafs at the slightly lower elevations, in the Point Peron area of Western Australia (*8*), and recognized it on air photographs from many parts of the world.

In many of the air photographs, I noticed instances of parabolic dunes fingering inland over the older beach ridges and earlier coastal plain deposits of pre-Wisconsin interglacial age. For example, in Brazil at the Praia da Pinheira, south of the Rio Maciembu and Florianopolis, four distinct examples of parabolic dunes were observed. The last of these is still building from the present beach and is still unvegetated. The earlier ones are "fixed" by low vegetation. The dunes correspond to the breaks between the beach ridge packets, and are interpreted as indicative of short eustatic regressions that exposed a broad belt of beach sands and longshore bar material to wind erosion. It seems likely that the negative sea level oscillations in this latitude (about 25°S) corresponded to somewhat drier and cooler climatic conditions. All three of these factors would favor dune development.

The Brazilian coastline is also marked by many baymouth spits and bars (any sandy ridges are called restingas in Brazil), barrier beaches, and barrier islands. Closing off the interior lagoons has led to extensive sedimentation by swamp deposits, alluvium, and eolian sands.

Under the seasonally heavy tropical rainfall the calcium carbonate shells that could theoretically be used for dating the various beach ridges and barriers have been completely removed by leaching. In the lagoonal deposits, however, there are pockets of shells that can provide the critical radiocarbon dates for determining their history.

Superimposed on the littoral belt are the giant shell middens (called sambaqui in Brazil) that have also furnished dates that were valuable in helping to work out the pattern of sea level and climate change during the middle and late Holocene.

Earlier Quaternary coastal deposits of similar facies but pre-Wisconsin age are buried at shallow depth beneath these youthful deposits, and in places crop out toward their interior. They occur in terraces that reach 11 to 9 m, 7 to 5 m, and 4 to 3 m above present mean sea level (MSL) and so far have proven unfossiliferous, but by analogy with regions where there is datable material it seems probable that they represent deposits of the last interglacial (Sangamon, roughly 120,000, 105,000, and 85,000 years ago). They have sometimes been correlated with the Holocene depos-

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its, but regional study shows that they have been deeply dissected by the coastal rivers of the Wisconsin time, when MSL dropped to more than 135 m below its present level. Arkosic sands and gravels of that semiarid glacial stage partially fill the former valleys, thus establishing an unconformable relationship (*9*).

Environmental Setting

The question of why the early Indians settled along the coastal belts of the subtropics, not only in Brazil, but on every continent at about the same time, is unquestionably a problem for paleoecologists. The geological record is clear. From about 16,000 years ago, world sea level rose very rapidly. The rate often exceeded 1 to 2 m per century, which on a low relief coast would cause coastal flooding; a transgression of 5 to 10 km could occur within the short period of 500 years. There could have been no coastal lagoons at the time, and any coastal inhabitants must necessarily have been migratory. If they did settle for a while in favored estuaries, those sites would have been drowned during the transgressions and our identification of them would have been rendered extremely difficult. Exploring for them by scuba diving would be feasible but has not been attempted. Some sites might be 40 to 50 km seaward.

The rising Holocene sea level curve flattened out about 6000 years ago and since then the coastal beach ridges and lagoons have become ideal sites for colonization by man. Some environmental details for the Brazil situation may be interesting:

1) *Latitude and climate.* The south coastal belt of Brazil lies completely within the region of the southeast trade winds, with a mean annual rainfall of 100 cm and up to 300 cm. The climate has a Köppen classification of Cfa. The trade winds may be modified for periods during the southern summer (January to March) by the northeasterly winds that are appropriate to the western edge of the South Atlantic High and are accompanied by heavy rain (January precipitation: 10 to 30 cm). Most rainfall in the winter is during polar frontal conditions, but in general the winter is the relatively dry season (July precipitation: 10 cm). Winter is also quite cool for these latitudes (20° to 30°S). The coast is exposed to cold southerly winds in winter and affected all year around by the cold Falkland Current that flows north from the Antarctic; the warm Brazil Current that comes down from the equatorial belt is deflected south of Cape Frio near Rio de Janeiro in the same way that the Gulf Stream is deflected offshore near Cape Hatteras and the New England coast is chilled by a tongue of the Labrador Current.

2) *Littoral vegetation.* The mean annual ocean surface temperature ranges from 24°C near Rio de Janeiro to 18°C in Rio Grande do Sul. This permits the growth of mangrove in suitable bays and gulfs as far south as Ilha Santa Catarina (27°50′S). The mangrove is not nearly so extensive as in northern Brazil and the Guianas, but this is more a function of suitable mudflat environments than climate. There are no reefbuilders, either coral or algal.

Isolated patches of mangrove in warm, secluded bayheads may be found somewhat farther south of Ilha Santa Catarina, but in general the mangrove is replaced there by salt marsh vegetation analogous to *Spartina* in New England that leads to the accumulation of littoral peat. This type of salt marsh (banhado) grows to about mean high tide level, as elsewhere in the world, and is only flooded during exceptionally deep cyclonic low pressure conditions and at perigee high spring tides. Hurricanes do not develop along this coast.

Both geographically and geologically, southern Brazil is closely comparable to Natal (South Africa), southern Madagascar, and eastern Australia (particularly the "New England" coast of New South Wales). It is significant that they are all marked by important Holocene shell middens.

3) *Biometeorological and health factors.* From the above considerations it is evident that during the last 6000 years the entire south Brazilian coastal belt has been attractive for settlement by people with the capacity to build modest huts, make fires, and devise warm clothing for the cooler months. No month is so hot or so cool that it would lead to serious discomfort under these modest conditions of adjustment. No serious health hazards exist apart from the snakes and mosquitoes, neither of which are severe by tropical standards; sharks do not come close inshore here.

4) *Foodstuffs and fishing grounds.* According to archeological evidence the principal nutriment of the coastal Indian was a broad selection of shellfish, the consumption of which varied according to availability. The occasional addition of peccary, fish, and stranded whale to this diet is probable. Tropical fruits are fairly plentiful and taro-type tubers and lily roots are available.

Among the shellfish remains, several distinct facies may be recognized from one midden to another or from one horizon to another. Within a particular layer, representing up to several centuries, the diet was essentially monospecific. The species represented are as follows.

Mangrove oyster: The arboreal species *Ostrea arborea* requires the multiple stilt roots of the *Rhizophora*-type mangrove for its substrate. According to the midden evidence the local supplies of this species were soon depleted, so that a change to another type of shellfish was necessary. Oysters tend to reach maturity only in 4 to 6 years, so that recolonization of the swamps would require periods of abandonment or conservation. The mangrove oysters grew to 5 to 10 cm on the average.

Mud or bank oysters: Another species, *Ostrea brasiliana*, has its substrate on firm mudbanks or silt shoals and the spat (free-swimming stage) colonizes such substrates as pebbles, sticks, or most often, preexisting dead shells. Such sites are limited to open channels where strong tidal flux keeps fine mud from choking the organisms or burying the colonies. Salinity tolerances are in the range of 20 to 30 parts per thousand (open sea is 35 parts per million). The size of bank oysters is usually about 7 to 15 cm.

Rock oysters: A third species of *Ostrea* is limited to rock substrates, mostly in the intertidal belts of open sea or open gulf sites. Their size is small, 3 to 5 cm, and the difficulty of prying this species off of the hard rock substrates makes them a poor food source (although gourmets insist that the flavor is superior). The populated intertidal belt may be less than 1 m in width, so that the source area is very limited; however, it is easier of access than are the mangrove swamp sites and does not require diving as do the bank oysters. There is a fourth *Ostrea* species found off open sea beaches; it is small and apparently was never used as a foodstuff.

Anomalocardium brasiliana (Gun.): This species (berbigão in Portuguese; cockle in English) inhabits open, silty, or sandy floored lagoons of normal salinity but somewhat freshened by runoff. It is only 1 to 2 cm in length, occurs in vast numbers almost everywhere below low tide level in the appropriate substrate, and was much favored by the coastal Indians.

Mytilus perna L.: The common mussel (zururú in Brazil) is characterized by a hairy byssus with which it adheres to a rocky bottom, and may be found mainly at depths from just above low tide level down to about −5 m. The shells have to be pried off from their substrate and the prying action usually tears off fragments of loose rock with lumps of mud and sand. As a result, at *Mytilus* horizons in the midden there are usually black bands of foreign material, while other shells tend to come in cleaner form; also their larger size favors

postdepositional rainwater leaching. The *Mytilus* have thin, weak walls and are quickly crushed underfoot at campsites. Thus, a very large number of individuals may be represented by a relatively thin horizon in the midden, in comparison with the very thick horizons of bulky and almost indestructable oyster shells.

Modiolus braziliensis Cheun.: The mud mussel (bacucú in Brazil) is rather similar in form and habits to *Mytilus* but tends to occupy the floors of mud-choked tidal creeks in the mangrove swamps. The horizons of crushed *Modiolus* in the middens are marked by even larger amounts of black mud and silt than *Mytilus* layers.

Other mollusk shells: Isolated examples of *Thais* spp, a large marine snail; *Olivancilaria brasiliensis*, a variety of cockle; *Cardium muricatum* L (mija-mija in Brazil); *Lucina* spp.; and others that are observed here and there probably reflect irregular shell-gathering trips to the outer beaches and more open waterways. A large terrestrial gastropod, *Strophocheilus* spp. is also found living today and in the middens at Carniça, south of Laguna; a second, more elongate species is found at one horizon in the middens.

5) *Relief, environment and substrate factors*. An Indian campsite possessed the following essential characteristics: (i) A high and dry situation, that is, at least 1 m above normal high tide level, to ensure that the campsite was not flooded by exceptional high water stands. Once established, the Indian midden was maintained even if it meant climbing 10 to 20 m with every basketload of shells. This eminence provided access to the sea breeze, thus reducing mosquito incidence, and possibly also provided a lookout against marauders, protection against snakes, and eventually, perhaps, social prestige. (ii) A well-drained site on a rocky platform, a dune, or a high beach ridge, so that rainwater would drain off quickly. An alluvial soil that was likely to become muddy during rain was not favored. (iii) An adjacent position to fishing ground. Open waterways were originally always present at the foot of each shell midden, even though some are quite isolated now by sea level changes and sedimentation. Direct access both to the local shellfish beds and to more distant banks that were accessible by canoe seems to be the rule. However, the sharp changes in the shell components in the middens, at times corresponding to sea level changes, suggest that the midden reflects the immediately available foodstuff. Had the Indian been prepared to paddle daily a mile or two to other fishing grounds, he would have been able to remain essentially monospecific in his shellfish diet. It appears that the attraction of maintaining an established campsite exceeded any objections to occasional changes in food species. Such changes in most cases occurred at intervals of several centuries. (iv) Fishing grounds on estuarine waterways, marine gulfs, deep bays, and lagoons maintaining daily (tidal) exchange with the open ocean. No freshwater clams appear in any of the middens examined. No open-sea fishing grounds were regularly exploited.

Fig. 1. Sketch map of South America showing locality of Paranaguá and other midden sites, as well as Recife and Rio de Janeiro sites of earlier sea level analyses (*22, 23*).

Shell Middens

Several thousand shell middens have now been reported along the coast between Rio de Janeiro and the Rio Grande do Sul. This high concentration is comparable to that of the U.S. middle Atlantic coast and contrasts with a relative paucity of middens in more tropical to equatorial latitudes and cooler, poleward latitudes. In the more populated areas of the world, these shell middens are becoming more and more difficult to identify because farmers remove the shells for lime burning. Although shell middens are theoretically protected by law in both Brazil and the United States, almost nothing is done to enforce it.

Many of the Brazilian middens are of impressive dimensions. Some in São Paulo Province are reported to reach 25 m and involve 120,000 m^3 of shells (*10*). One that I examined in Santa Catarina Province contained approximately 50,000 individual shells of *Anomalocardium* per cubic meter. The midden was approximately 20 m high and 100 m in diameter and represented 2.5 billion shellfish. This could provide nearly 100 shellfish per day for a group of 100 people for 500 years.

Five distinctive types of midden sites can be recognized, each characterized by concentrations of shells that indicate that the Indians did their food gathering, whenever possible, immediately adjacent to the campsite (Fig. 2). Only occasionally is there evidence that they went farther afield.

Type A is situated on the bank of a tidal river. This is the simplest and oldest variety. Evidently the silting of the lagoons and slight drop in sea level since 6000 years ago have led to a freshening of these estuaries, so that they now no longer support the oysters that were once in profusion.

Type B is on an estuary with a mangrove swamp. Here the use of mangrove oysters is immediately apparent. A slightly larger tidal range than on a river and an open channel provide continually favorable salinity.

Type C is on a lagoon spit. Within the open lagoons, the siltation from fluvial floods and sand spit building by washovers from the ocean side provided pleasant campsites away from the noisome mangrove swamps but adjacent to shallow fishing grounds.

Type D is located on a Pleistocene platform. An older, pre-Holocene substrate provided higher and healthier campsites, but these were only available next to fishing grounds where currents maintained an adequate depth of water near the shore.

Type E is on a rock platform. In places the inselbergs of old Precambrian bedrock outcrop near the shore. Along their lee

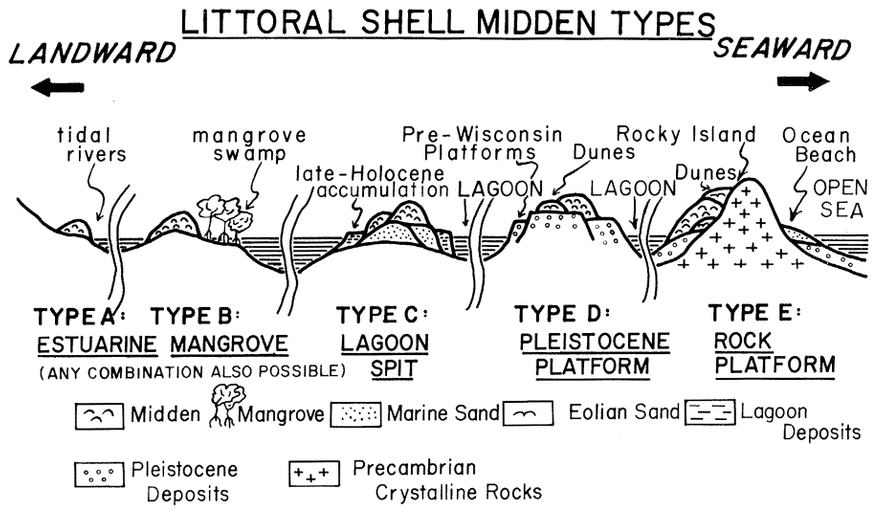

Fig. 2. Ecologic associations of various shell middens, ranging from type A on tidal rivers to type E on rocky platforms next to the open ocean.

sides they provide an excellent shelter from the wind and a safe and healthy substrate.

Each of these substrate types has been excavated by different archeological groups, so that sequential patterns of occupation and food gathering can be recognized in each type.

Radiocarbon Dating

The important information that careful excavation and systematic radiocarbon dating of these Brazilian middens have provided is that occupation of the exact sites was not extended for indefinite periods but was concentrated only in those times when radiocarbon datings along other coastlines outside of South America have shown sea level to be at or within a meter or two of the present datum.

If the Brazilian data are to be helpful in indicating a true relation to past sea levels, it is desirable that the key midden sites be tied closely to the crystalline basement. Alluvial clays and peats are liable to suffer compaction, but the sandy barrier beaches are much less affected and many of the middens have at least one foot in the Precambrian. Selected areas are briefly discussed.

1) *Baia de Paranaguá.* This is a deeply embayed drowned coast and estuary complex. Middens of types A and B mark the deeper channels on the landward side. At the Sambaqui de Gomes near the railroad station Saquarema, the foundation consists of the early Pleistocene Alexandro Formation that is transected by a wave-cut platform about 3 m above MSL. The midden is piled on this platform and consists largely of arboreal *Ostrea* and *Anomalocardium* with some bands of crushed *Modiolus*. Radiocarbon dates of 4887, 4859, 4490, and 4487 years ago were obtained by Hurt (*11*). A second site (Saquarema) furnished the dates 4243, 4218, and 4056 years ago on both shell and charcoal, according to Rauth (*12*).

The middens are now overgrown by jungle, and sedimentation with a broad belt of mangrove separates the sites from their former fishing grounds. Another site in this area, Sambaqui do Porto (Ilha das Roses), was excavated by Laming-Emperaire of the Musée de l'Homme, Paris, and is also separated from the waterways by mangrove and several hundred meters of sedimentary fill. At Porto Mauricio, a few kilometers west of Alexandro, a site excavated by Rauth rests on a platform 3.5 m above MSL and is also now isolated by a broad mangrove belt. On the Rio Guaraguaçu there is a 21-m-high, 300-m-long midden on a 4- to 5-m platform that is now separated from the water by mangrove flats up to 500 m wide; an organic sample from its base is dated 4128 years ago according to Laming-Emperaire (*13*).

Clearly, all of these middens in the over-4000-year-old range are now isolated by sedimentation and rest on preexisting platforms that would have been dry even with sea level somewhat higher than it is today. If sea level has been lower than today, the middens were isolated from the fishing grounds until it rose.

2) *Santa Catarina Island.* A site north of Lagoa on the inside of the Conceição lagoon has two occupation periods. The older one is in the over 4000 years ago period—and is marked mainly by *Anomalocardium* shells. The edge of this midden is situated on a rocky basement and it was partly truncated by a sea that reached 2.9 m above MSL, then invaded by dune sand, and then reoccupied by shell gatherers around 2200 years ago. Since then the midden has been abandoned; 100 m of sandy sediment has accumulated in front of it on the foreshore and the lagoon itself has been isolated from the ocean.

3) *Laguna region, southern Santa Catarina State.* A large lagoon complex that includes the Lagoa Santo Antonio is almost separated from the ocean by barrier islands and tied rocky islands and is being rapidly infilled by sediments brought in by the Rio Tubarão. There are also some Pleistocene terraces and coastal plains of pre-Wisconsin age.

At the Caieira site north of Laguna, the midden rises from a 3-m platform to more than 28 m and is partly draped over the side of a rocky hill. The foot of the hill was evidently the fishing ground but is today infilled by a broad sedimentary fill that is partly covered by barchan dunes. The shells are mainly *Anomalocardium*, indicative of open lagoon conditions. The earliest settlement date is unknown but the higher parts have shell and charcoal dates of 3230 and 2770 years ago. A fireplace in dune deposits on top of the shell mound is dated 710 years ago.

A second and very large complex of middens about 5 km south of Laguna, the Carniça sites, has furnished some critical data. These are middens of types C and D. Air photographs, supported by ground studies, disclose the presence of 137 beach ridges fanning out from the rocky islands, with a number of spits reaching in toward the lagoon. The shell mounds rise 20 to 25 m above the grassy meadows and from a distance look like pyramids on the coastal flats. The base of Carniça No. 1 was excavated to show that the midden rests on the sand of a marine spit that contains *Anomalocardium* with both shells in the growing position in a stratum that reaches up to 1.5 m above MSL. In front of the midden there are now up to 3 km of grassy meadows, representing sedimentation over the former shallow lagoon fishing grounds. The in situ shells that I collected were dated 3400 and 3300 years ago. Midden shell and charcoal on this and a nearby mound that are dated 3370, 3350, 3310, 3275, 3210, and 3040 years ago indicate that most of the mounds were built up within 400 years. Identical dates are indicated by shell and charcoal in juxtaposition. Another group of dates, 2550, 2460, and 2400 years ago suggests that the site was reoccupied after a period of isolation. The air photos disclose that there were four interruptions to the beach ridge growth, during which sand dunes were generated and advanced across the preexisting beach ridge plain.

Chronologic Interpretation

On the basis of archeological evidence and on the sedimentological record of sea level changes, the following periods have been identified in the coastal deposits of southeastern Brazil (*2*) and are now discussed further.

Period I lasted from about 18,000 to 5800 years ago. From a low sea level stand of about −135 m up to the present there appears to have been a highly oscillatory eustatic rise. Eustatic models that depict smooth curves, such as those by Shepard (*14*) and by Milliman and Emery (*15*) ignore the presence on the world's continental shelves of intermediate levels with terraces, platforms, beach deposits, and peat, all of which represent stillstands or negative oscillations. The oscillations that I postulated elsewhere (*16*) have received some support from subsequent studies by radiocarbon dating (*17–20*). Future exploration for submerged midden heaps should be concentrated at these places on the continental shelves; usually the middens would be broken up and effaced by wave action during the subsequent transgressions, but protected sites could probably be found. Although no adverse climatic conditions would be expected in these littoral sites in the late glacial phase, the rapid rise of sea level would have inhibited the formation of baymouth bars and prevented widespread lagoon development, the preferred environments for littoral shellfish culture. Nevertheless, short periods of negative sea level swings (for periods of the order of several centuries) could have provided the right ecologic setting for coastal shellfishery. The oldest radiocarbon-dated samples related to a midden of this period are two from Sambaqui de Maratua, Bay of Santos, that were excavated by Laming-Emperaire (*13*) and indicate 7803 ± 1300 years ago and 7327 ± 1300 years ago. At that time the sea level was appreciably lower than today, but near a deep channel shell samples could possibly have been carried up the banks. Another explanation, considering the very large range of error in the figures, is that the dates are too old due to incorporation of older (dead) carbon in the organic sample. The oldest reliable date from this period was obtained by Rauth [in Hurt (*2*)] from the Bay of Antonino in Paraná (6030 ± 130 years ago).

Period II lasted from 5800 to 4800 years ago. I have designated this time as the Older Peron (*16*) while Berglund calls it Littorina III, IV, and V (*21*) in northern Europe. It corresponds there to the Atlantic palynological climatic interval, the Climatic Optimum, when the annual mean temperature may have been 2.5°C higher than today (that is, in the middle latitudes). In Brazil it is called the *Alexandro Submergence*. At this time middens appeared extensively in Paraná and apparently farther north, but not in Santa Catarina or farther south. Radiocarbon-dated raised reef formations from Recife to Rio de Janeiro indicate a sea level that rose progressively to 3 m above present MSL (*22, 23*).

Period III lasted from 4800 to 4100 years ago and corresponds approximately to one that I designated as the Bahama stage (*16*). It also appears to correspond to a sharp cooling and a drop of sea level, possibly to 3 m below today's level (*20*). This is the Subboreal climatic interval in northern Europe. In the ocean there is evidence of an important drop in temperature (*2*, p. 17). The middens around the Bay of Antonina were isolated by the regression and abandoned. A new midden site below present sea level has been excavated at Sambaqui de Saquarema by Rauth (*12*) and dated 4370 ± 69 years ago. The latest studies from the West African coast indicate a sea level drop at 4400 to 4100 years ago to −3.5 m (*20*)—my Bahama Emergence.

The oldest dating from Santa Catarina Province (4289 years ago) comes from this period, from a collection by Piazza (*24*) at Sambaqui de Ponta das Almas. As with many shell samples from the middens, several dates appear in reverse stratigraphic order. This is not considered the result of contamination or an error in dating because numbers of side by side samples of

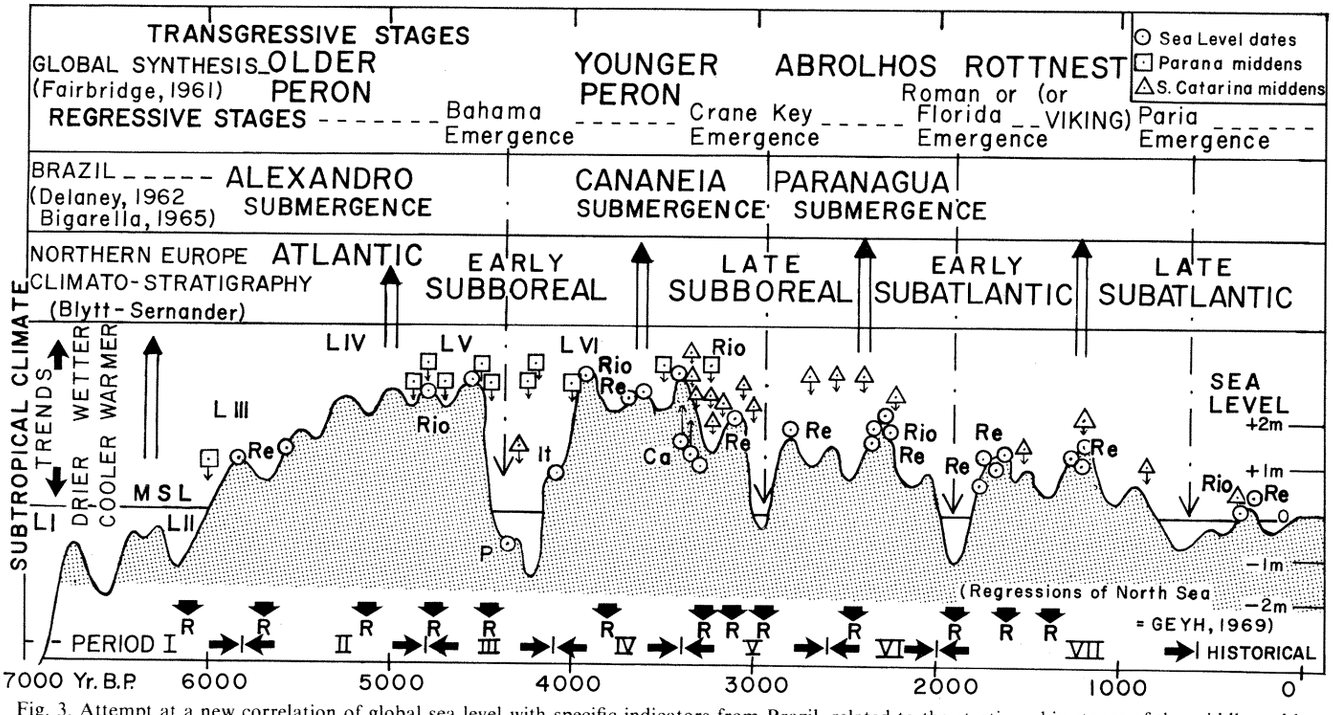

Fig. 3. Attempt at a new correlation of global sea level with specific indicators from Brazil, related to the stratigraphic stages of the middle and late Holocene. The sea level curve contains important modifications over the so-called Fairbridge Curve of 1960 to 1961, recognizing errors in the latter due to limited data, tidal effects, and crustal warping (*36*). *LI* to *LVI* are the six Littorina beach lines of the glacio-isostatically uplifted coast of southern Sweden [Berglund (*21*)]. Brazil sea level dates: *Re*, Recife region; *Rio*, Rio de Janeiro region; *It*, Itahype; *P*, Paranaguá. Midden dates are indicated with general elevation minima; heights may exceed 20 m.

shell and charcoal from these collections have been cross-checked to give identical dates. The cause is almost certainly slumping, a gravitational movement down the steep sides of the midden. One should bear in mind that a midden tends to be conical in shape and as it grew larger and higher, the families camped or built huts on the top of it, after spreading out flat sections by pushing shells out to the edge. Older layers thus became interstratified with younger ones. Samples from the central core give the best in situ dates, but are also the most difficult to reach.

Period IV lasted from 4100 to 3400 years ago. This is the second high sea level stage of the Holocene, when MSL on the average reached 3.0 m above that of today. It is the Younger Peron of Australia (*16*) or Berglund's Littorina VI in northern Europe; there are comparable data obtained in Finland by Eronen (*21*). It is still Early Subboreal according to the northern European palynology, but in tropical oceans there was a return to the warmest postglacial temperatures. A tremendous colonization by the shell gatherers occurred in southern Brazil at this time, which is called the *Cananeia Submergence* in Brazil. According to Laming-Emperaire (*13*), the oldest sample at the Sambaqui de Guaragauçu (a vast midden that is 300 m long and 21 m high) is 4128 ± 268 years old. The Ponta das Almas site provides figures of 3620 ± 100 years ago (*2*) and 3690 ± 100 years ago (*23*), which are essentially identical with a 2.6-m-high marine beach encrusted with vermetids (3660 ± 170 years ago) that was obtained by Van Andel and Laborel (*22*) from Recife in the northeast part of Brazil, and with a similar bench at 3 m (3420 ± 110 years ago) from Ilha Grande near Rio de Janeiro collected by Delibrias and Laborel (*23*).

Several excavations and dates show that MSL was higher then than today. Charcoal from the base of the Macedo midden in the Bay of Antonina that is resting on a beach terrace with its inner notch at 1.3 m above present MSL is dated 3496 ± 56 years ago. Samaquide Ponta das Almas has a similar notch at 2.6 to 2.75 m (*25, 26*). At Carniça (near Laguna) the shells I collected in the basal sands 1.5 m above sea level have both valves together (and must therefore be in their living sites) and gave a closely spaced sequence of dates: 3400 ± 150, 3350 ± 110, and 3300 ± 160 years ago (*26*).

Period V lasted from 3400 to 2600 years ago and involves another strikingly cool cycle, judging from the high latitude palynological data (Late Subboreal) when sea level may have dropped by about 3 m, possibly to a low at around present datum. However, the archeological evidence from the Laguna area suggests that the sites remained occupied for most of this period, perhaps aided by the fact that they are situated fairly close to the deeper channels which would have remained open. The clustering of huts on the big sambaquis here show that they became essentially fixed villages rather than nomadic camps. Carniça provides a date of 3040 ± 50 years ago, corresponding almost to the sea level minimum (*2*). From about 3000 to 2700 years ago, there appears to be something of a hiatus in dates that may correspond to an important rise in MSL toward the end of the period. A vermetid bench from Gaibú (near Recife) at 2.2-m elevation is dated 2790 ± 150 years ago (*23*).

Period VI, that lasted from 2600 to 2000 years ago, is roughly the time labeled the Abrolhos High mainly from Australian evidence. In northern Europe it is the Limnaea stage or early Dunkerquian (*27*), and is palynologically recognized as the first part of the Early Subatlantic. In Brazil it is the *Paranaguá Submergence*. Extensive beach ridges, in a regressive sequence that dropped to perhaps −1 m, developed coastal Brazil (*27*) to a mean height of 1 to 3 m above the present, according to Bigarella (*1*). Fossil wood in one such beach ridge in the Bay of Paranaguá at about 1 m above MSL gave a date of 2675 ± 150 years ago (*11*). The rise of sea level made it possible for some of the earlier abandoned sites to be recolonized, such as Ponta das Almas and probably also at Carniça. Vermetid levels at 2.0 to 2.2 m above MSL (2550 ± 100, 2460 ± 110, 2450 ± 95, and 2400 ± 110 years ago) were found near Recife and Rio de Janeiro (*23*).

Period VII lasted from 2000 to 400 years ago and is still mainly the Early Subatlantic stage of northern palynologists, part of the Dunkerquian of Flanders (*27*). The eustatic record suggests a low stage in the Roman (or Florida) time about 2000 to 1900 years ago, that rose to about +0.5 m in Viking time, the Rottnest sea level of the Australian region (about 1200 to 1000 years ago). A series of low sea levels coincided with the cool stages of the Medieval period (800 to 400 years ago). In coastal Brazil the appearance of ceramics made a dramatic change in the cultural debris of the middens (*2*). At Caieira dune sands temporarily engulfed the site (apparently due to the sea level drop around 2000 years ago), and charcoal from a site over the dune sand gave a date of 710 ± 95 years ago. The earliest ceramic date in a coastal area is 1140 ± 180 years ago, which might suggest that the rise of sea level would provide more open waterways favorable to trade and transport. On several of the middens there were noticeable time gaps between the preceramic cultures older than 2000 years and the reoccupations that occurred 1000 years ago. In the larger village sites that were presumably less dependent on shellfish there was no apparent gap (*2*). Radiocarbon dates of the high sea level peaks marked by vermetids in northeastern Brazil (Recife) were reported by Van Andel and Laborel (*22*) to be 1190 ± 130 years old at 1.6-m elevation and 1750 ± 170 years old for 1.4-m elevation. Comparable vermetid dates were found near Rio de Janeiro (*23*).

Discussion

The extensive excavations of shell middens and the radiocarbon dating of both shell and charcoal in coastal Brazil furnish a basis for a renewed study of the effects of Holocene sea level changes (Fig. 3). The first publication of my concepts of higher-than-present mid-Holocene sea level correlations was in 1947. The dates, at first estimated on the basis of Swedish varve chronology, received subsequent confirmation by radiocarbon techniques, and in 1960 the Fairbridge Curve was published and widely reprinted in books and journals. The detailed analyses appeared in 1961 (*6*) and have since been updated by others (*28*). It was a first approximation based on less than 100 dates, but it was based on two hard-fact and totally independent categories of data: (i) corals appearing in a position of growth, wave-cut benches, fossil cliffs, and raised beaches that mark ancient sea levels well above the present and are traceable along the subtropical coastlines of each of the continents for thousands of miles, and (ii) the palynological record of climatic changes in the high latitudes. The cool phases matched evidence of low sea level and warm phases matched the high sea levels. Precipitation changes, very apparent in fluvial and lake deposits, tend to be out of phase between high and low latitudes, but are probably not critical in the coastal Brazilian sites.

While the eustatic curve seemed a fair enough approximation at first sight, the theoretical studies of hydro-isostasy, for example, by Bloom (*29*), would suggest that water loading due to the Flandrian transgression would lead to deformation of coastlines, thus varying with the width of the continental shelf. Furthermore, neotectonic studies, geodetic releveling, global MSL analyses [as by Fairbridge and Krebs (*30*)] and other data (for example, satellite-derived gravity) suggest that there are many regional departures which must be closely studied in any estimate of a mean

global eustatic value. A worldwide study of the Holocene terraces by me and by the International Association for Quaternary Research Shorelines Commission (which has, internationally, more than 100 members, correspondents, and associates) discloses many anomalous data [see detailed bibliographies by Richards and Fairbridge (*31*)]. Nevertheless, one lasting impression is that, along the aseismic, nonorogenic coasts in the low and middle latitudes, the neotectonic motions are of brief duration, so that the Holocene shore terraces are mostly found within about 1 m of the predicted average.

There has been much controversy about the shape of the Holocene eustatic curve. A smooth, exponentially flattening curve has been offered by Shepard (*14*). I explain it as representing a simple mathematic mean that is drawn through a random collection of datum points, a large number of which came from sections of the globe that are known to be subsiding (for example, the U.S. Atlantic Coast, the Mississippi Delta, and the Netherlands). In contrast to this concept is the known fact that there have been large climatic changes during the Holocene that are recorded quite independently by palynology, glacial geology, and deep-sea sedimentology. It is physically impossible for the MSL not to oscillate. Actual tide gauge records that extend back almost three centuries show that MSL does fluctuate, with rates of 1 to 2 mm per year averaged over several decades (*30*).

Important fluctuations have been delineated on several shoreline curves published over the last few years: from West Africa [Einsele *et al.* (*20*)], from New Zealand [Schofield (*32*)], from Sweden [Mörner (*17*)], from France [Ters (*18*)], and from England [Greensmith and Tucker (*19*) and Tooley (*33*)]. Whereas Schofield's area shows shorelines at a constant height over several hundred kilometers, the Swedish record is in a glacio-isostatic uplift area, and the French and British data are within the marginal bulge downwarp of the Scandinavian ice sheet. Nonetheless, the oscillations correspond closely in time, and correlate also with climatic changes and glacier advances and retreats, as well as with many events in human history.

It should be stressed that I make no claim to present the Brazilian coastal data as a world standard of Holocene eustasy. Too many disturbing factors that inhibit any simplistic theory are now recognized; such factors involve geodesy (global spin-rate, pole shift), geomagnetic and gravitational secular trends, oceanographic processes (steric results of temperature changes, changing tilt surfaces due to current velocity, and the Coriolis effect), hydroisostatic loading, regional tectonic trends, local neotectonic accelerations, climatic anomalies (pressure and wind effects), and glacio-eustasy. Discrimination and evaluation of these disturbances should be receiving worldwide attention, and all that the Brazilian record can do is to offer certain basic generalizations.

Conclusions

Shellfish-eating Indians of coastal Brazil left large shell middens that, when excavated and radiocarbon dated, provide a nearly continuous record of environmental changes during the last 7000 years. Comparable studies could and should be undertaken in other middle to low latitude situations in the world.

The midden accumulations contain a record of occupation and abandonment that can be explained by a rise and fall of sea level as I predicted (*8, 16*), but that is denied by many authorities (*14, 15, 29*). A very similar record of rise and fall of Holocene sea level has been documented in other regions as far from Brazil as Africa, India, Australia, New Zealand, Sweden, Britain, or France, but in spite of records that are complicated by the structural motion of the earth's crust, whether positive or negative, corrections can be modeled (*17, 34*), and the key fluctuations persist.

The minor fluctuations of sea levels in the middle to late Holocene (involving amplitudes of 1 to 5 m) correspond in time with proven climatic events, known from palynology, nannoplankton records from the deep ocean, and other independent criteria (*27*). The fluctuations are therefore regarded as basically glacio-eustatic. There are, however, a large number of mechanisms that introduce regional departures, so that a world standard eustatic record cannot yet be offered.

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36. The transgressive stages in my global synthesis of 1961 correspond to warm or mild climatic periods in northern Europe (according to the pollen record) and the regressive emergent stages match cooling trends; a glacio-eustatic correlation is assumed. The most complete statistical record of (cooler) retreat phases was provided in the North Sea region by Geyh (*35*). On the Brazil coast the low beach ridges seem to have been temporarily abandoned by man during the major sea level rises, and reoccupied during the early retreat phases, to be finally abandoned in the late Holocene due to sedimentation of the lagoons. Precise indications of sea level were obtained from the Carniça (Ca) dates, and from those obtained earlier by Van Andel and Laborel (*22*) and by Delibrias and Laborel (*23*).

37. R. W. F. and J. J. Bigarella participated as consultant geologists in an excavation project in 1969 that was cosponsored by the Indiana University Museum and the Universidade do Santa Catarina with a grant from the National Science Foundation.