Anais da Academia Brasileira de Ciências (2011) 83(3): 907-920
(Annals of the Brazilian Academy of Sciences)
Printed version ISSN 0001-3765 / Online version ISSN 1678-2690
www.scielo.br/aabc

Luminescence dated Late Pleistocene wave-built terraces in northeastern Brazil

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Manuscript received on December 8, 2009; accepted for publication on December 22, 2010

ABSTRACT

This study presents field and chronological investigations along the coast of northeastern Brazil from ∼4°S to 9°S latitude, which corresponds to ∼700 km of coastline under a semi-diurnal mesotidal regime. We investigated wave-built terrace deposits and dated sediments using the optically stimulated luminescence and thermoluminescence methods on quartz grains. The wave-built terraces yielded two main age groups: 200-230 ka and 100-130 ka, which we interpreted as depositional ages. We correlated these age groups with oxygen-isotope stages 7c and 5e, respectively. These events correspond to the antepenultimate and penultimate transgressions along the Brazilian coast. The deposits occur mainly in patches on low-lying flat plateaus along the littoral zone and incision valleys that cut across coastal tablelands. The altitude of the base of the 200-230 ka terraces ranges from 10 m above mean sea level (asl) to –2m asl, whereas the base of the 100-130 ka varies from 12 m asl to –2 m asl. Both terraces were deposited in the foreshore and upper shoreface zones. We noted a coincidence between sea-level highstand chronologies in northeastern Brazil and those in the Bahamas and Bermuda.

Key words: luminescence dating, northeastern Brazil, Pleistocene, sea-level change.

INTRODUCTION

The recognition of Late Pleistocene wave-built terrace deposits along the eastern coast of South America is becoming increasingly common. These deposits represent sea levels higher than the present one. Recently, two studies have presented ages of the wave-built deposits. Barreto et al. (2002) presented thermoluminescence (TL) and optically stimulated luminescence (OSL) dates at 220-206 ka and 117-110 ka of two wave-built terrace deposits along 340 km of coast in the state of Rio Grande do Norte, northeastern Brazil. They correspond to the highstands of marine oxygen-isotope substages 7c and 5c sea levels, respectively. The former ranges between 7.5 and 1.3 m high above mean sea level asl. The latter occurs at altitudes that vary between 1 m and 20 m. A second study by Tomazelli and Dillenburg (2007) described shoreline sedimentation during the last interglacial highstand on the Rio Grande do Sul Coastal Plain, southern Brazil. They described, but did not date, a wave-built highstand associated with the last interglacial period around 125 ka. The maximum reached sea level was around 7 m above the present. Both studies presented evidence that hydrodynamics and sediment transport during these highstands were similar to present-day conditions.

Despite the progress in recent studies, Pleistocene sea-level changes along the Brazilian coast are still

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poorly understood owing to limited knowledge of wave-built terrace chronology (Barreto et al. 2002). In addition, the obtained data are frequently imprecise in both space and time, and the assumed chronology is mostly based on geomorphological attributes such as asl altitudes, the terrace reshaping degree, or tentative correlation with deep-sea, oxygen isotope stages (e.g., Suguio et al. 2001).

The objective of our present study is to describe the occurrence and luminescence chronology of wave-built terraces in northeastern Brazil along the coast of the states of Pernambuco (PE), Paraíba (PB), and Rio Grande do Norte (RN) (Fig. 1). We also compare these ages with the wave-built terrace chronology obtained by Barreto et al. (2002).

GEOLOGICAL AND GEOMORPHOLOGICAL COASTAL SETTINGS

The Brazilian coast is more than 9,200 km long and diversified geologically and geomorphologically. It extends from a latitude of 04°N to 33°S (Cruz et al. 1985). In general, there is a succession of coastal plains alternating with sea cliffs and rock coasts, following an ancient continental area composed of Precambrian polymetamorphic and igneous complexes on whose summits of sedimentary and volcanic sequences of Paleozoic, Mesozoic and Cenozoic ages were deposited.

The coastal plains, mostly composed of Quaternary deposits, were accumulated within continental, transitional and marine environments, being most conspicuously developed around major river mouths, where a terrigenous clastic sediment supply was dominant. Rocky coasts appear in several coastal sectors, where erosive processes supplant depositional processes. Sea cliffs occur where older sedimentary deposits are exposed to the open-sea hydrodynamics, and rocky coasts occur where igneous and metamorphic crystalline complexes are exposed to open-sea conditions.

According to Cruz et al. (1985), the coast of northeastern Brazil extends from São Marcos Bay in the state of Maranhão (MA) to Todos os Santos Bay, state of Bahia (BA) (Fig. 1). Coastal tablelands, composed of the Miocene Barreiras Formation and Quaternary sediments, are the most common geomorphological feature along this coast. These tablelands reach the coastline, where they form sea cliffs, partially eroded during the Pleistocene and Holocene. The Barreiras Formation overlies the Precambrian crystalline basement or the older sedimentary deposits in several sedimentary basins of the Brazilian continental margin.

Two sectors can be distinguished along this coast. The coast, which extends from São Marcos Bay to Calcanhar Cape (Fig. 1), is characterized by rivers with small sediment loads, associated with small-scale sandy-barrier/lagoon systems. Lagoons and estuaries exhibit mangrove swamps in their margins, whereas sandy barriers are frequently washed over by strong and persistent trade winds also responsible for the formation of well-developed eolian dunefields, magnificently exemplified by the Lençóis Maranhenses. The west part of this coast is characterized by a macrotidal regime, whereas the east part is characterized by a mesotidal regime.

The oriental Northeastern Coast extends from the Calcanhar Cape to the Todos os Santos Bay (Fig. 1), which shows the same geological context and is submitted to a mesotidal regime. This area is marked by sea cliffs carved in the Barreiras Formation and by beachrock reefs supporting organic reefs, mainly composed of hermatypic corals and calcareous algae favored by a small terrigenous sediment supply. Stone reefs protect the coastline against the hydrodynamics of the open sea along many stretches of this coast, giving origin to sheltered beaches with natural pools. Deltaic complexes with Pleistocene and Holocene sandy-barrier/lagoon systems occur in the vicinities of the most important river mouths (Martin et al. 1983). The lagoons and estuaries are occupied by mangrove swamps with beach ridges reworked by trade winds, originating many dune fields. In this sector, the São Francisco River is fundamental for its suspension load is being transported southward by coastal currents inhibiting organic reef buildups and maintaining the muddy waters along the coast of the state of Sergipe (SE), in contrast with the clean waters along the coast further to the north (Fig. 1).

The study area lies on these two coasts, where there is no significant climate or tidal range variation. The climate is characterized by an alternation of dry and pluvial seasons, the mean annual temperature is ca.

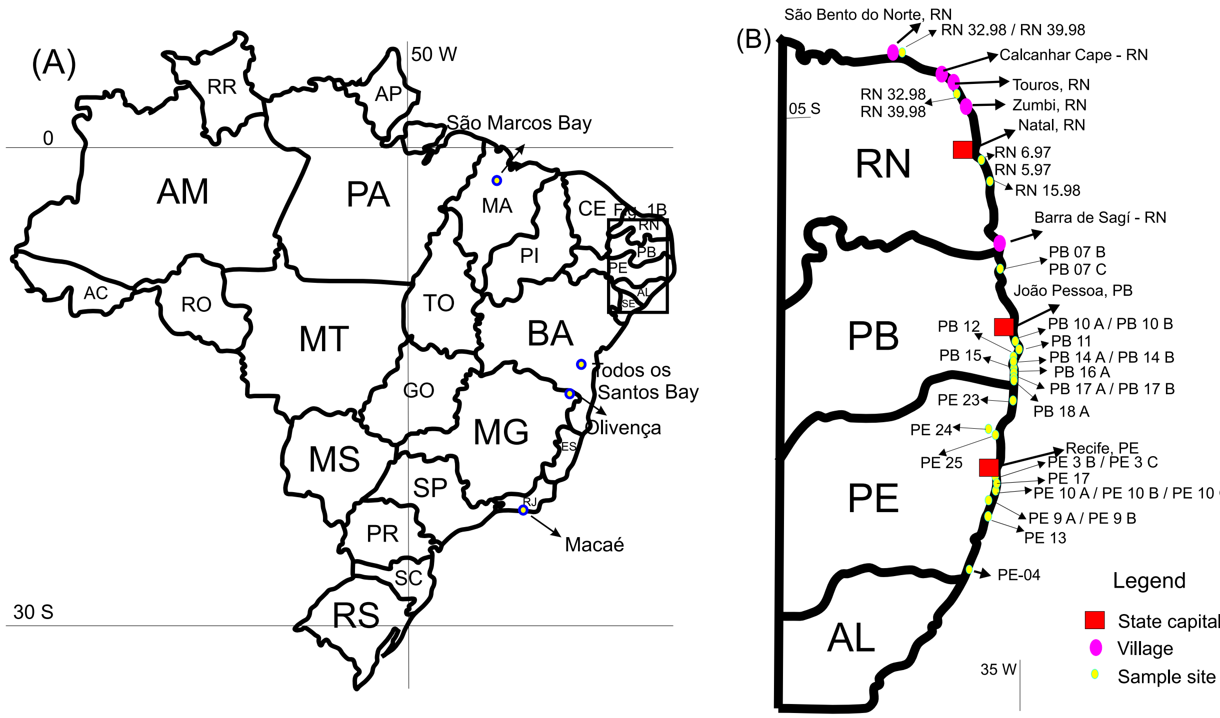

Fig. 1 – (A) Brazilian coast and main location discussed in text; (B) study area and sample locations from the 200-230 ka terraces and the 100-130 ka wave-built terraces.

30°C, and the rainfall is 600-1,000 mm/yr (Nimer 1989). The area has a mesotidal, semi-diurnal regime, where normal tides attain a maximum of 2.0 m and spring tides have a range of 3.2 m (Hayes 1979).

LATE PLEISTOCENE SEA-LEVEL HIGHSTANDS IN BRAZIL

Late Pleistocene sea-level highstand deposits in the Brazilian coast were first recognized in 1973 at Cananéia Island, state of São Paulo. The deposits were named Cananéia Formation (Suguio and Petri 1973), and the related event was named Cananéia Transgression (Suguio and Martin 1978) or Penultimate Transgression (Bittencourt et al. 1979, Martin et al. 1988). Relative sea level during this event reached $\sim 8 \pm 2$ m asl. The first age of these deposits was obtained from charcoal fragments and dated by the radiocarbon method. The age was viewed as minimum because it was beyond the limit of the radiocarbon method ($\sim$70 ka). Later, five coral sample fragments of genus Siderastrea from Olivença (state of Bahia-BA, Fig. 1), dated by the Io/U method, yielded an average age of 123.5 ± 5.7 ka (Bernat et al. 1983). The Cananéia Formation at that time was considered as existent from Rio Grande do Sul (RS) (33°S latitude) to as far as the state of Pernambuco (PE) (9°S latitude) (Fig. 1).

In a few places, however, such as the Todos os Santos Bay in the state of Bahia (Martin et al. 1984a) and the Macaé area in the state of Rio de Janeiro (Fig. 1) (Martin et al. 1984b), these Late Pleistocene wave-built deposits have probably been subsided as a consequence of recent tectonic activity.

The age of this highstand event is consistent with the North American Sangamon Interglacial Stage or European Riss-Würn interglacial stage (Bloom 1967). Details of the dates by Bernat et al. (1983) confirm this assumption. The uranium concentrations changed from about 2.6 to 3.0 μ/g, which are normal levels for coral fragments with an average age of 123.5 ± 5.7 ka. This date represents the maximum age of the deposit.

Along the states of Bahia (BA) and Sergipe (SE) (Fig. 1), high sea-level records older than 120 ka occur as ancient sea cliffs carved on the Miocene Barreiras Formation (Bittencourt et al. 1979). Older Late Pleistocene sea-level highstands were also identified in 1986 at the Rio Grande do Sul strandplain (Fig. 1).

Their absolute age, however, has not been measured. According to some studies (e.g. Tomazelli and Villwock 2000), tentative correlation with the δ^{18}O isotopic stage chrono-stratigraphic scale could indicate ages ranging from 325 ka to 400 ka.

The scheme of sea-level highstands at the Rio Grande do Sul strandplain is established. The barrier-islands/lagoon system IV, about 4 m asl, corresponds to the last transgressive event, whose culmination stage occurred at about 5.5 ka. The barrier-islands/lagoon system III ~8 ± 2 m asl corresponds to the penultimate transgressive event, whose maximum occurred at ~120 ka. The barrier-islands/lagoon system II measuring ~13-15 m asl, and the barrier-islands/lagoon system I measuring ~20-25 m asl, situated at the inner continental positions in relation to the previous ones, were formed during high sea levels older than 120 ka BP, most likely at 325 ka (δ^{18}O isotope stage 7) and 400 ka (δ^{18}O isotope stage 9) (Tomazelli and Villwock 2000, Tomazelli and Dillenburg 2007). On the other hand, along the states of Santa Catarina (SC), Paraná (PR), and Rio Grande do Sul (RS) (Fig. 1), marine terraces with a minimum height of 13 m asl were found by Martin et al. (1988). They are older than the barrier-islands/lagoon system III found in the state of Rio Grande do Sul and probably record the transgressive-regressive episode of the barrier-islands/lagoon system II. Presently, it is assumed that this ~120 ka high sea-level record extends, at least, from the state of Rio Grande do Sul (RS) to as far as Rio Grande do Norte (RN) (Fig. 1).

METHODS

Field-work

We measured wave-built terrace altitudes by leveling, and normalized them to two local standard ports according to the Admiralty Hydrograph Department (1996) using tide-table predictions from the Brazilian Navy (2009). The method is based on the assumption that the duration of the rise and fall of the tide lies within the scope of a graph (height *vs.* time diagram), which approximates to a cosine curve. We also corrected altitudes to the Brazilian Córrego Alegre National datum. In our field study, we sampled marine sediments away from sunlight by pushing or hammering plastic tubes into freshly cleaned vertical trench walls. In this study, we used the altitude of the base of deposits for correlation because the top of a few deposits show signs of erosion.

Luminescence Dating

Thermoluminescence (TL) and optically stimulated luminescence (OSL) dating was carried out at the Laboratory of Glasses and Dating of the Faculdade de Tecnologia de São Paulo (FATEC-SP). These techniques make possible the dating of the last exposure of sediment to sunlight. First, we obtained quartz grains 88-180 μm in size after chemical treatments of 20% HF for 45 min, 20% HCl for 2 h, and heavy liquid (SPT separation). These were performed to prevent problems associated with the cover of fine silt and clay particles on sand grains due to translocation. All of the irradiations were performed with a ^{60}Co source from the Instituto de Pesquisas Energéticas e Nucleares – Comissão Nacional de Energia Nuclear (IPEN/CNEN), and for bleaching experiments the samples were exposed directly to sunlight for 16 hours. Both TL glow and OSL shines down curves were recorded with Daybreak Nuclear and Medical Systems Incorporated Model 1100-series Automated TL/OSL systems. TL ages were evaluated using total bleach and additional dose methods. OSL ages were obtained using the additional dose method following the multiple aliquot protocol with natural normalization. The annual doses were calculated using ^{235}U, ^{238}U, ^{232}Th, and ^{40}K concentrations and Bell's equations. The U, Th, and K concentrations were measured by neutron activation analysis (Tables I and II). Natural radioactive isotope contents in the samples were determined with gamma spectroscopy using an Inspector portable spectroscopy workstation, lead shield model 727, and a Canberra 802 NaI (Tl) detector. Details of the methodology described above are found in Tatumi et al. (2001, 2008).

UPPER PLEISTOCENE MARINE TERRACES IN NORTHEASTERN BRAZIL

Rio Grande do Norte Coast

Marine wave-built terraces outcropping along this 280 km long coast yielded ages from 215 ± 7 ka to 109 ± 4 ka (Table I and Fig. 2). They form raised marine terraces overlying the Miocene Barreiras Formation. These sediments were grouped into two infor-

TABLE I
Rio Grande do Norte and Paraíba states coast showing locations of the 200-230 ka BP and 100-130 ka BP outcrops. Source: (1) Barreto et al. (2002), (2) this study.

Sample	Location (UTM)	TL age (Ky)	OSL age (Ky)	Base altitude (m) asl	Corrected altitude (m) asl	Source
5-97	258440; 935130	213±2	220±2	0.8	1.8±1.5	(1)
6-97	258440; 935130	215±4	207±4	0.8	1.8±1.5	(1)
15-98	266601; 933000	206±5	210±2	2.5	3.5±1.5	(1)
32-98	172340; 944250	117±10	117±4	0.8	1.8±1.5	(1)
39-98	172340; 944250	109±4	–	–	–	(1)
PB07B	283280; 926886	88.9±6	70.3±5	2.0	60±1.5	(2)
PB07C	283280; 926886	110±6.2	86±5	2.0	6.0±1.5	(2)
PB10A	301166; 920971	108±8	110±20	8.8	9.8±1.5	(2)
PB10B	301166; 920971	138±5	120±2	8.8	9.8±1.5	(2)
PB11	301718; 920496	230±6	186±14	3.7	4.7±1.5	(2)
PB12	301123; 919347	103±14	103±6	0.45	1.45±1.5	(2)
PB14A	300716; 920092	117±1	109±9	4.0	3.0±1.5	(2)
PB14B	300716; 920092	217±4.5	212±4	4.0	3.0±1.5	(2)
PB15	301498; 9185015	220±26	220±22	1.7	2.7±1.5	(2)
PB16A	300897; 9182065	117±14	116±14	0.8	1.8±1.5	(2)
PB17A	300668; 9182066	101±9	100±11	0.8	4.1±1.5	(2)
PB17B	300668; 9182066	71±7.7	46±4	2.65	4.1±1.5	(2)
PB18A	300600; 9179938	79±0.7	95±1.1	4.0	4.8±1.5	(2)

mal stratigraphic units, named 220-206 and 117-110 ka marine terraces (Barreto et al. 2002).

Lucena (1997) was the first to recognize the 220-206 ka deposits. He informally named them the Barra de Tabatinga unit. This was later formalized by Suguio et al. (2001) as the Barra de Tabatinga Formation. This unit was dated with three samples (5.97, 6.97, and 15.98 in Table I). It usually crops out in patches along the shoreline between Natal and Barra de Sagi (Fig. 1), but more conspicuously at the former site where outcrops are about 1 km long. At Natal, the top of these deposits is 7.5 m asl. Its base rises from mean beach level to 2.6 m asl (Fig. 2A).

These deposits were formed in the intertidal zone. We recognized beach structures in three main parts of the columnar section. The lower part of the deposit consists of a wave-cut surface that abruptly truncates the lower Barreiras Formation. This structure forms an unconformity that is marked by a conglomerate layer made up chiefly of highly weathered Barreiras Formation laterite pebbles. This basal part shows a lateral continuity of moderately to well sorted, clast supported seaward-dipping beds. The intermediate part of the beach deposit is characterized by through cross-bedded sandstone, consisting of coarse- to medium-grained well-rounded to subangular quartz grains. The summit of this deposit is defined by gently seaward dipping planar-bedded, well-sorted quartzose sandstone (Fig. 2A). Its grain size ranges from fine to medium sand.

We did not find macrofossils, although Lucena (1997) identified foraminifera *Globigerina* sp. and *Quinqueloculina* sp. at the base of the deposit, which could be an indication of an intertidal zone.

The marine terrace deposit about 1 km north from Formosa Bay has not been directly dated, but can be correlated with those dated at Natal and Barra de Tabatinga sites based on petrography, sedimentary structures, stratigraphic relations, and geomorphologic features. The base of the marine deposit at Formosa Bay was not observed in the outcrop, because it overlies the Barreiras Formation at the lower intertidal zone. These marine deposits, as shown by Yee et al. (2000), are overlain at many sites by the 189-186 ka eolian deposits.

The 117-110 ka marine terraces were formally named Touros Formation by Suguio et al. (2001). They are preserved for about 120 km along sea cliffs in the

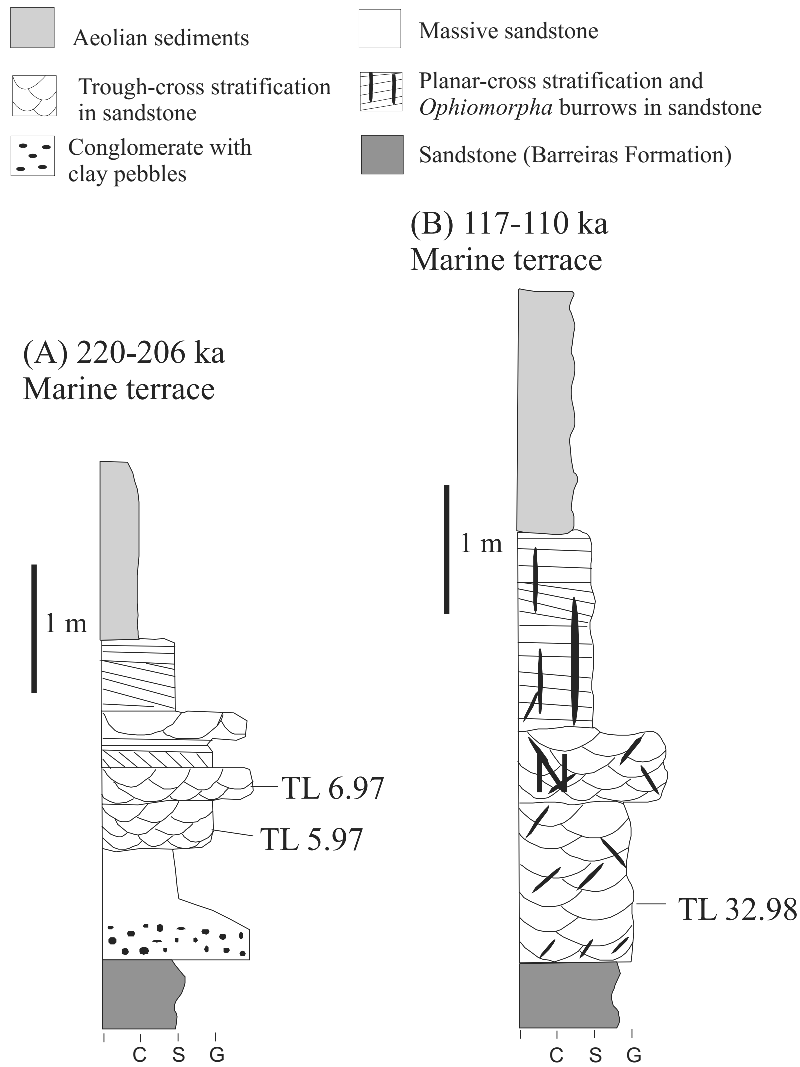

Fig. 2 – Columnar sections of Barra de Tabatinga Formation (220-206 ka wave-built terraces) and Touros Formation (117-110 ka wave-built terraces) on the coast of the state of Rio Grande do Norte (modified from Barreto et al. 2002).

current shoreline between São Bento and Zumbi (Fig. 1). This marine terrace outcrops mainly along the E-W-trending coast. The most conspicuous outcrops are more than 2 km long and are located between São Bento and Touros (Fig. 1), where they reach 1 to 10 m high and rise to a maximum of about 20 m asl 2 km to the north of Zumbi.

The São Bento and Touros outcrops typify the Touros Formation stratigraphy, whose sedimentary structures were first described by Campos-e-Silva et al. (1964). Subsequent studies were carried out by Srivastava and Corsino (1984) and Lima-Filho et al. (1995). More recently, Testa et al. (1997) and Testa and Bosence (1998) obtained ^{14}C ages at 30 ka BP and suggested that this deposit is older than the limit of conventional radiocarbon dating. They then concluded that the obtained dates were minimum ages. Bezerra et al. (2000) recognized these problems using x-ray diffraction and scanning electron microscopy, which indicated that recrystallization and overgrowth of calcite in coral and mollusk shells from this deposit were too serious or too difficult to remove or clean for reliable radiocarbon dating.

Deposits of the Touros Formation are mainly made up of medium- to coarse-grained sandstones. The most common biodetritus are coraline algae, mollusks and foraminifera. The basal portion of the deposit is composed of coarse to conglomeratic, tabular, and trough cross-bedded sandstone. Herringbone cross-bedded sandstone occurs on the top of the deposit, where *Ophiomorpha nodosa* burrows that are characteristic of beach sub-environments also occur (Barreto et al. 2001). These features, viewed collectively, indicate a high sedimentation rate in the intertidal to shoreface zone. This deposit overlies the Barreiras Formation unconformably. Inactive (fossil) and active sand dunes overlie this formation (Fig. 2B).

The Touros Formation was dated by two samples: 32-98, dated by TL additive dose, TL total bleach and OSL methods; and sample 39-98 dated by the TL additive dose method (Table I) (Barreto et al. 2002). Two TL ages and one OSL age for a quartzose sandstone layer at Touros, and one TL age for a sandstone layer about 15 km to the west of São Bento, both situated at the base of the deposits (Barreto et al. 2002), indicated an age from 117 ± 10 to 110 ± 10 ka, which corresponds to the last Pleistocene sea-level highstand along the Brazilian coast. We present the TL and OSL ages of these deposits in Figure 3.

Paraíba Coast

This coast is ~120 km long and exhibits almost continuously Miocene Barreiras Formation sea cliffs that border the ocean. We collected thirteen samples from nine outcrops of the marine terraces and dated them using the TL and OSL techniques (Table I and Fig. 3). The TL analyses yielded 7.9 to 230 ka, whereas the OSL analysis yielded 9.5 to 220 ka. Late Pleistocene wave-built terraces occupy incision valleys, which cut across the Barreiras Formation tableland, in general. The outcrops PB-11 and PB-15 represent 200-230 ka terraces, which could be correlated with the Barra de Tabatinga Formation of the coast of the state of Rio Grande do Norte. The outcrops PB-07, PB-10, PB-12, PB-16, and PB-17 yielded ages of 100-130 ka. They could be correlated with the Touros Formation of the coast of Rio Grande do Norte (Figs. 4, 5, and 6). Differing from the Rio Grande do Norte coast, the outcrops PB-07, PB-10, PB-15, PB-16, and PB-17 in the state of Paraíba exhibit sandy beds with massive structures. However, outcrops PB-11 and PB-12 exhibit sedimentary structures suggestive of intertidal to shoreface shallow marine deposits such as those described in Rio Grande do Norte coast (Barreto et al. 2002).

Pernambuco Coast

The coast of the state of Pernambuco extends for about 160 km and, similarly to the Paraíba coast, presents continuous Neogene Barreiras Formation sea cliffs being eroded on the present shoreline. We collected twelve samples from eight outcrops of the marine terraces and dated them using the TL and OSL methods (Table II). The TL analyses yielded ages from 14 to 351 ka, whereas the OSL analyses yielded ages from 96 to 346 ka (Fig. 3). Late Pleistocene wave-built terraces occur sheltered within Barreiras Formation incision valleys, which are commonly controlled by faults. The outcrops PE-09 and PE-10 represent 200-230 ka terraces (Figs. 7 and 8), corresponding to the Barra de Tabatinga Formation of Rio Grande do Norte's coast.

Differently from Rio Grande do Norte coast, and similarly to the Paraíba coast, all the outcrops of this state presented sandy beds with massive structure. Nevertheless, the sedimentary structures shown by these outcrops are also suggestive of intertidal to shoreface shallow marine deposits.

IMPLICATIONS FOR RELATIVE SEA-LEVEL CHANGES

This study presents absolute ages from wave-built terraces collected along ~700 km of coast. Most (17) TL ages are in agreement with the OSL results, considering the experimental error limits. The consistent results of the OSL and TL ages concentrated in two main periods (~100-130 ka and ~200-230 ka) indicate that two highstands occurred in the region. However, six TL ages are older than the OSL results, and one TL age is younger than one of the OSL results. The TL ages that do not match those of OSL may indicate that depositional bleaching of these samples has not been completed, and that TL results are maximum ages of the deposits. This could indicate, for example, that ages older than 100-130 ka and younger than 200-230 ka represent overestimated ages of the Penultimate Transgression (~100-130 ka). Ages younger than the Penultimate Transgression may have different explanations and should be addressed by further studies.

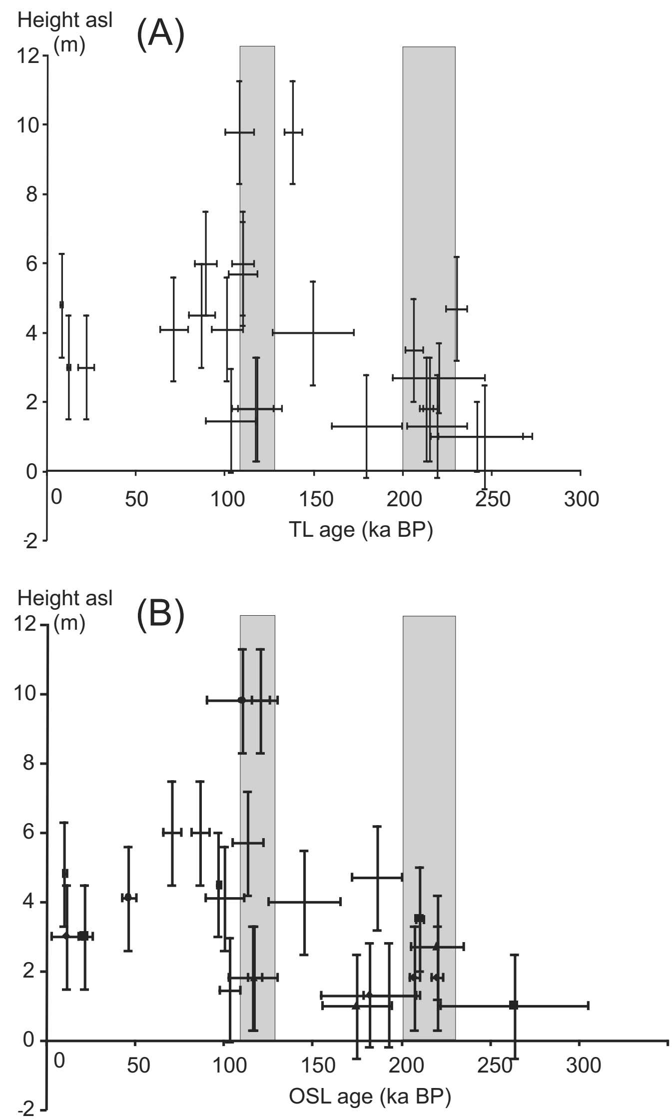

Fig. 3 – Samples from northeastern Brazil: (A) sample height *vs.* TL age; and (B) sample height *vs.* OSL age diagrams.

It is not possible to delineate any relative sea-level curve from the TL or OSL data. However, until more numerous chronological data are available, these ages can be correlated with marine oxygen-isotope stages after Raymo et al. (1990) and Haddad (1994). Dates from the ∼200-230 ka deposits indicate that they were deposited during the oxygen-isotope stage 7 sea-level highstand, mainly in substage 7c (Chappell 1983, Chappell and Shackleton 1986, Shackleton 1987, Raymo et al. 1990). This period represents the antepenultimate interglacial stage in the northern hemisphere (Fig. 9). Dates from the 100-130 ky terraces indicate that they were deposited during oxygen-isotope stage 5 sea-level highstand, mainly in substage 5e (Chappell 1983, Chappell and Shackleton 1986, Shackleton 1987, Raymo et al. 1990). This corresponds to the last Pleistocene transgression, named the Cananéia Transgression (or Penultimate Transgression), along the Brazilian coast (e.g. Suguio et al. 2001). Only one sample collected along the coast of the state of Pernambuco yielded an age of 350 ka BP, which is insufficient to be assumed as another sea-level highstand record in northeastern Brazil (Fig. 8A). Tatumi et al. (2008) described Pleistocene sediments in northern Brazil that yielded OSL

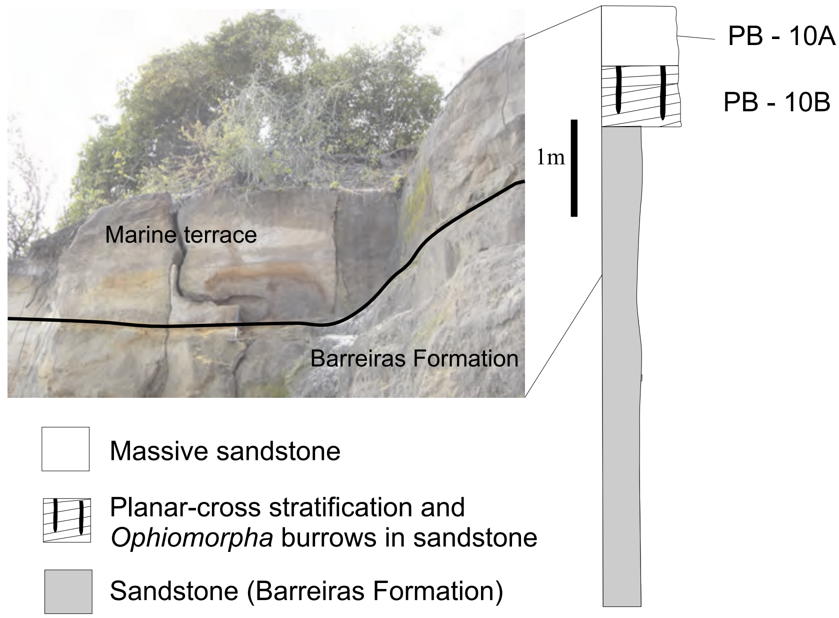

Fig. 4 – Wave-built terrace ∼10 m asl at Cabo Branco Cliff, state of Paraíba, which yielded OSL ages of 110-120 ka.

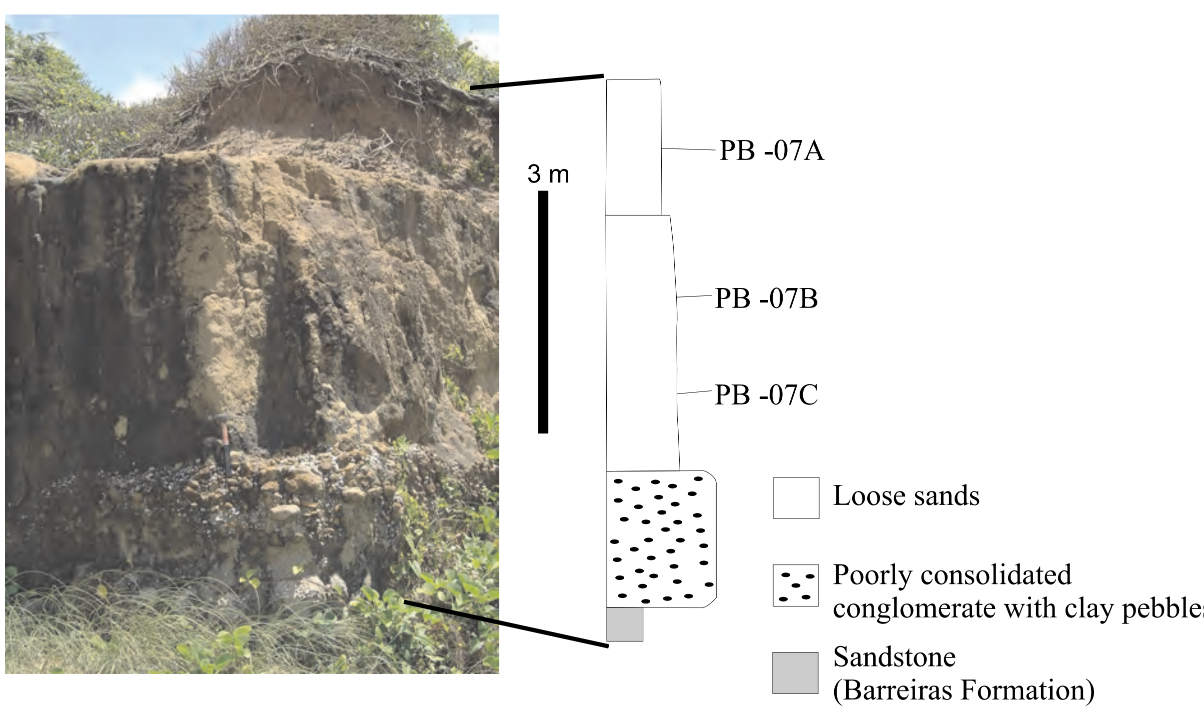

Fig. 5 – Wave-built terraces ∼6 m asl at Cordosas beach, state of Paraíba, which yielded OSL ages of 70-86 ka.

ages that may have correlations with our results: 191,000 ± 27,000 and 112, 000 ± 14,000. Possible correlations between ages in northern and northeastern Brazil, however, should be addressed in further studies.

The 100-130 ka terraces are in a few cases at altitudes higher than those of the ∼200-230 ka deposits (Fig. 8). We interpret this altitude difference as the result of Late Pleistocene faulting in the area, which may amount to as much as 14 m of vertical offset. This kind of faulting has already been observed in the region

TABLE II
Pernambuco state coast showing locations of the 200-230 ka BP and 100-130 ka BP outcrops. Source: (2) this study.

Sample	Location (UTM)	TL age (Ky)	OSL age (Ky)	Base altitude (m) asl	Corrected altitude (m) asl	Source
PE3B	284573; 909581	53±3.6	–	–	–	(2)
PE3C	284573; 909581	109±8	113±8.4	5.7±1.5	5.7±1.5	(2)
PE9A	269430; 903521	219±17	193±15	0.0	1.3±1,5	(2)
PE9B	269430; 903521	179±19.8	182±28	0.0	1.3±1,5	(2)
PE10A	276976; 904005	241±26	263±41	0.0	1.0±1.5	(2)
PE10B	276976; 904005	246±26	174±19	0.0	1.0±1.5	(2)
PE10C	276976; 904005	74±8	–	0.0	1.0±1.5	(2)
PE13	276856; 905435	87±6	97±11	3.5	4.5±1.5	(2)
PE17	282116; 906738	14	–	–	–	(2)
PE23	300393; 915770	149±22	144±20	4.7	4.0±15	(2)
PE24	290199; 915054	17	–	–	–	(2)
PE25	291451; 914979	351±31	346±31	6.0	–	(2)

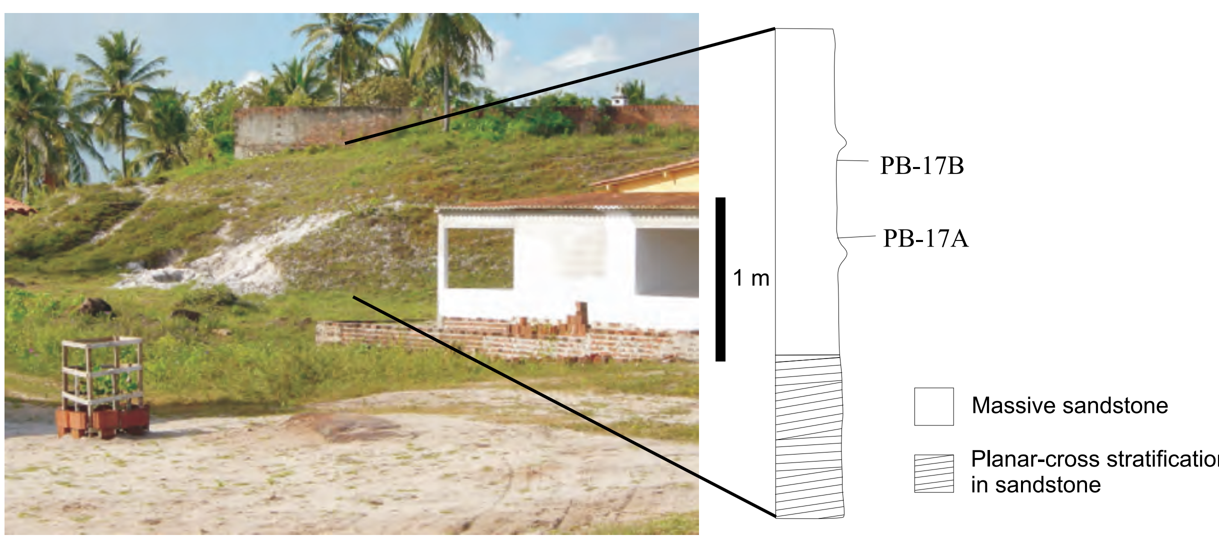

Fig. 6 – Wave-built terrace 0.8 m asl at Pitimbu beach, state of Paraíba, which yielded OSL ages of 46-100 ka.

(Bezerra and Vita-Finzi 2000, Bezerra et al. 2008) and in northern Brazil (Miranda et al. 2009, Rossetti 2010). This also needs further studies in northeastern Brazil.

We compare the Pleistocene sea-level highstands from northeastern Brazil with known patterns in the Bahamas and Bermuda, which include two highstands at about 210 ka BP and 125 ka BP (Harmon et al. 1983, Lundblerg and Ford 1994, Hearty 1998, Hearty and Kaufman 2000). In spite of the very different tectonic evolution at that time in the Bahamas, and chiefly in Bermuda, from that of the Brazilian coast, there is a remarkable coincidence between the sea-level highstand chronologies among these areas. This coincidence is more striking in the 100-130 ka wave-built terraces. It strongly suggests that these areas experienced the same sea-level highstands in the Late Pleistocene.

The sea-level highstand corresponding to the ~200-230 ka deposits was first documented by Barreto et al. (2002) on the coast of the state of Rio Grande do Norte. This paper presents evidence that these wave-built terraces continue southward as far as 9° latitude. On the other hand, the relative sea-level highstand of

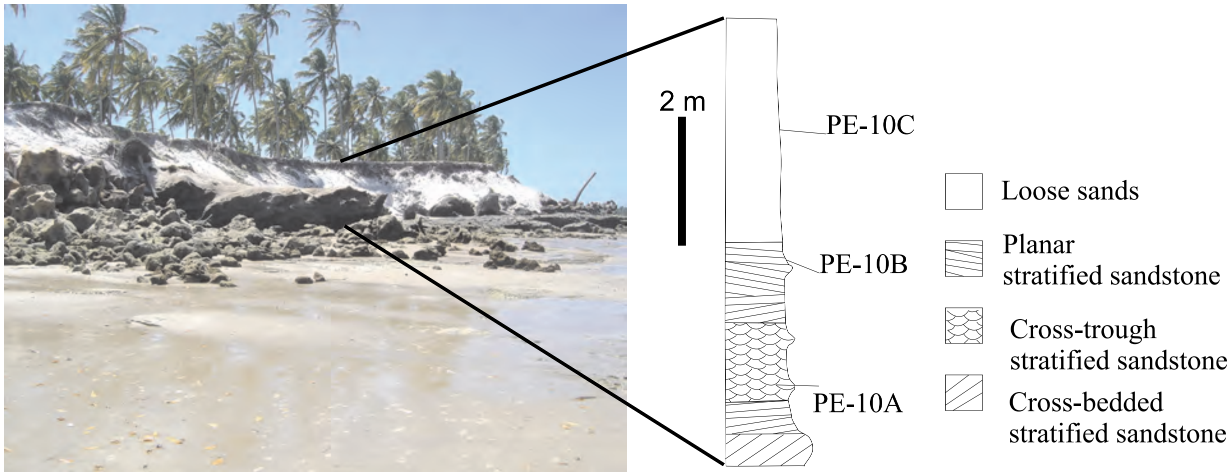

Fig. 7 – Wave-built terrace 0.0 m asl at Guadalupe beach, state of Pernambuco, which yielded OSL ages of 174-263 ka.

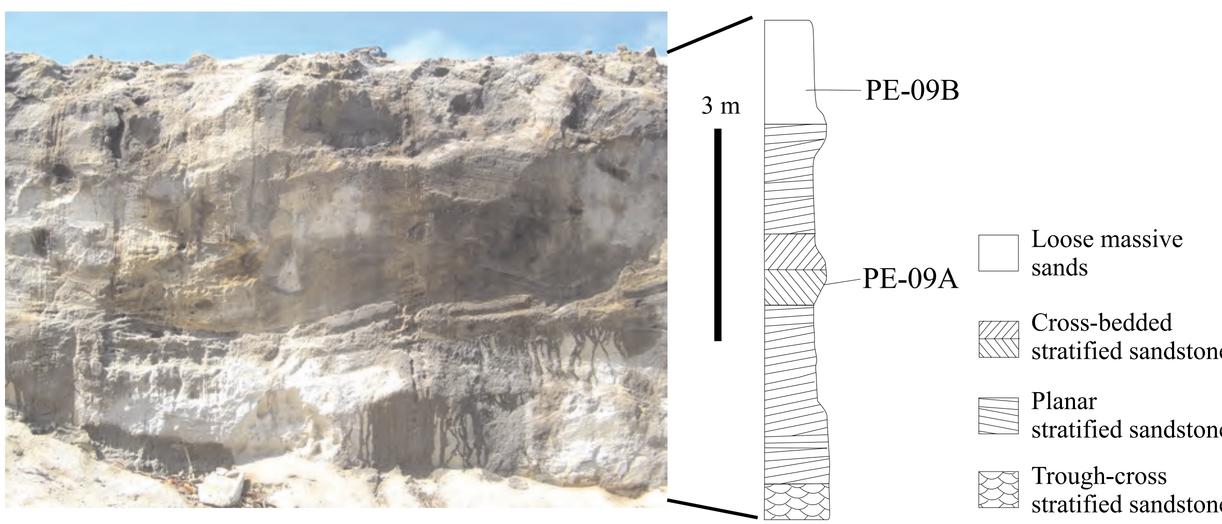

Fig. 8 – Wave-built terrace 0.0 m asl at Porto do Tijolo ranch, near Guadalupe beach, state of Pernambuco, which yielded OSL ages of 182-193 ka.

the 100-130 ka terraces was originally dated by Bernat et al. (1983), about 1,000 km southward of the study area in the state of Bahia. This marine terrace, although given different stratigraphic names, occurs at least from the coast of Rio Grande do Sul (33°S latitude) to that of Rio Grande do Norte (4°S latitude).

ACKNOWLEDGMENTS

This work was supported by Project Fundação de Amparo à Pesquisa do Estado de São Paulo (FAPESP) 2001/07468-8 coordinated by KS. We thank three anonymous reviewers for positive criticism. Sonia Tatumi deserves special thanks for numerous constructive suggestions on OSL dating, which have greatly improved this work. KS holds a senior research grant from Conselho Nacional de Desenvolvimento Científico e Tecnológico (CNPq). FHRB and AMFB thank CNPq for their PQ grants. FHRB has also been supported by an INCT/CNPq project.

RESUMO

Este estudo apresenta uma investigação de campo e geocronológica realizada ao longo da costa nordeste do Brasil entre ∼4°S e 9°S de latitude, o que corresponde a ∼700 km de costa submetida a um regime de meso-maré. Nós investigamos terraços marinhos construídos por ondas e datamos sedimentos usando luminescência oticamente estimulada e termoluminescência em grãos de quartzo. Os terraços marinhos fornece-

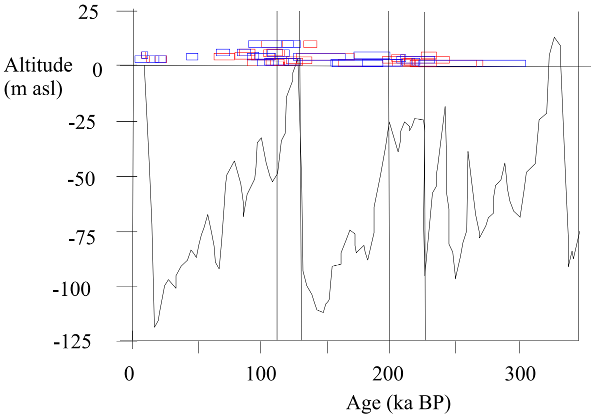

Fig. 9 – Correlation of OSL-TL ages from northeastern Brazil and sea-level changes from the sea-level curve after Haddad's conversion (1994) of the δ^{18}O record of Raymo et al. (1990) from ODP core 607 to sea level.

ram dois grupos de idades: 200-230 ka e 100-130 ka, que interpretamos como idades de deposição. Nós correlacionamos estas idades com idades do estágio isotópico do oxigênio 7c e 5e, respectivamente. Estes eventos correspondem a antepenúltima e penúltima transgressões que ocorreram ao longo da costa brasileira. Os depósitos ocorrem predominantemente em faixas sobre plateaus horizontais e de baixa altitude ao longo da zona litorânea e em vales incisos que cortam os tabuleiros costeiros. A altitude da base dos terraços de 200-230 ka varia entre 10 m e –2 m anm (acima do nível do mar), enquanto a base do terraço de 100-130 ka varia entre 12 m e –2 m anm. Ambos os terraços foram depositados na zona de frente de praia e zona de antepraia superior. Nota-se uma coincidência entre a cronologia de níveis marinhos elevados no nordeste do Brasil e aquelas das Bahamas e Bermudas.

Palavras-chave: datação por luminescência, Nordeste do Brasil, Pleistoceno, variação do nível do mar.

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