Anais da Academia Brasileira de Ciências (2003) 75(3): 357-382
(Annals of the Brazilian Academy of Sciences)
ISSN 0001-3765
www.scielo.br/aabc

Quaternary evolution of the Caravelas strandplain – Southern Bahia State – Brazil

ANA C.S. ANDRADE[1,2], **JOSÉ M.L. DOMINGUEZ**[2], **LOUIS MARTIN**[3] **and ABÍLIO C.S.P. BITTENCOURT**[2]

[1]Departamento de Ciências Agrárias e Ambientais
Laboratório de Oceanografia Geológica, Universidade Estadual de Santa Cruz
45650-000 Ilhéus, BA, Brasil
[2]Laboratório de Estudos Costeiros, Centro de Pesquisa em Geofísica e Geologia, UFBA
40210-340 Salvador, BA, Brasil
[3]IRD/CNPq, Laboratório de Estudos Costeiros, Centro de Pesquisa em Geofísica e Geologia, UFBA
40210-340 Salvador, BA, Brasil

Manuscript received on September 12, 2002; accepted for publication on April 9, 2003;
contributed by Louis Martin*

ABSTRACT

An evolutionary model is proposed for the Caravelas strandplain. The model encompasses integration of: (i) mapping of Quaternary deposits, (ii) cartography of beach-ridge alignments and their truncations, (iii) relative sea-level history, (iv) development history of the Abrolhos coral reefs, (v) vibra-coring and (vi) C^{14} dating of Quaternary deposits. Seven major evolutionary stages were identified. These stages show that the strandplain has had its Quaternary evolution strongly controlled by relative sea-level changes. In addition, the development of the Abrolhos coral reefs has also played an important role in dispersion and accumulation of sediments along the coastline, causing localized inversion in longshore sediment transport.

Key words: coastal evolution, sea-level fluctuations, sedimentary facies, coastal geomorphology.

I INTRODUCTION

The Caravelas strandplain is located in the southern Bahia State (Fig. 1). It has an area of approximately 800 km^2 and is bordered by the Tablelands of the Barreiras Formation (Upper Tertiary).

This strandplain has had its Quaternary evolution strongly controlled by relative sea-level changes. Contrary to other strandplains present along the east coast of Brasil such as the Jequitinhonha-BA and the Doce-ES, situated respectively north and south of Caravelas, the latter has no association with a major river (Dominguez 1983, 1987, Martin et al. 1984a, b).

The Caravelas strandplain fronts a wide continental shelf, extending up to 246 km offshore. The Abrolhos reefs present on this shelf comprise the largest and richest reef complex of the South Atlantic Ocean (Fig. 2). During the Quaternary evolution of the Caravelas strandplain, the development of these coral reefs in association with changes in relative sea-level have played an important role in dispersion and accumulation of sediments along the coastline. In this aspect, the evolution of the Caravelas strandplain presents peculiarities that distinguish it from other Brazilian strandplains.

*Foreign member of Academia Brasileira de Ciências
Correspondence to: Ana Cláudia da Silva Andrade
E-mail: acsaa@hotmail.com

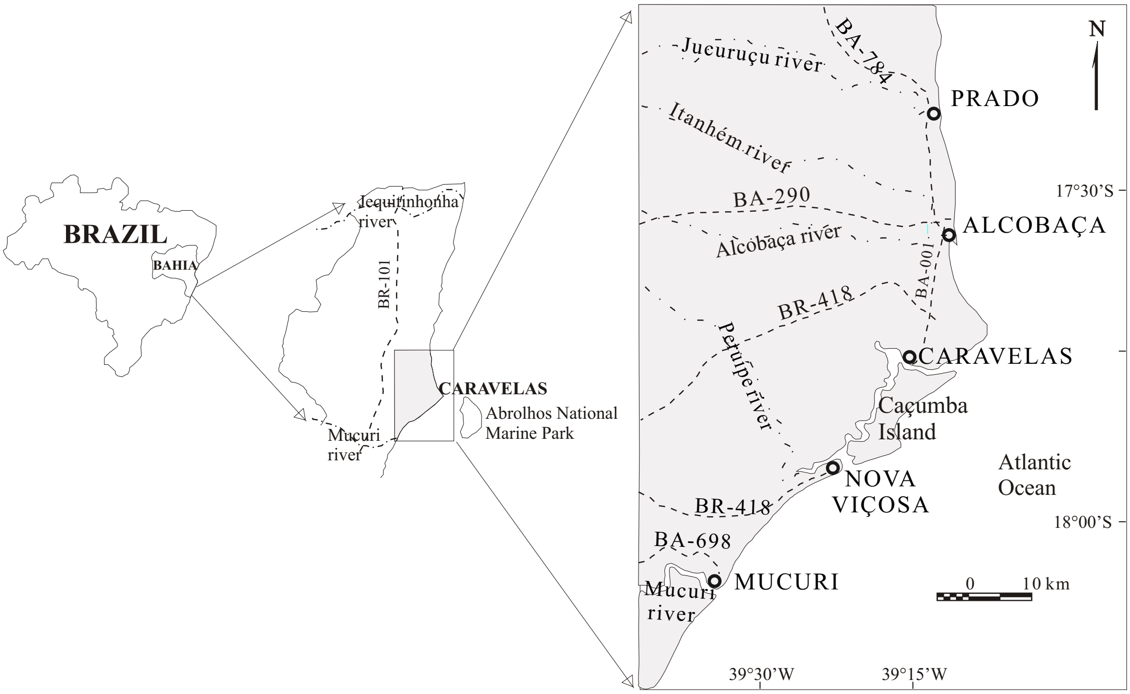

Fig. 1 – Location of the study area.

The aim of this paper is to present a geologic-geomorphologic evolutionary model for this strand-plain. This evolutionary model provides us a better understanding of the structure and functioning of the Caravelas coastal systems, as well as helps us in predicting future coastal behavior.

The general approach used in this paper was to combine data from several sources of information: (i) mapping of Quaternary deposits; (ii) cartography of beach-ridge alignments and truncations; (iii) cartography of *chênier*-type sand bodies; (iv) relative sea-level history (Martin et al. 1980, 1999); (v) development history of the Abrolhos coral reefs (Leão et al. 2000, Leão and Kikuchi 1999, 2000); (vi) vibra-coring and (vii) C^{14} dating of Quaternary deposits.

II RELATIVE SEA-LEVEL HISTORY FOR THE EAST BRAZILIAN COAST

During the Late Quaternary, the east coast of Brazil was affected by two important relative sea-level fluctuations. At least two phases of higher stand than present sea-level have been identified for the last 123,000 years B.P. (Suguio et al. 1985, Dominguez et al. 1987, Martin et al. 1987). The Penultimate Transgression (Bittencourt et al. 1979) reached a maximum around 123,000 years B.P., when sea-level was positioned 8 ± 2 meters above the present level (Martin et al. 1980). The subsequent regressive event extended up to 18,000 years B.P., when sea-level reached a minimum of 100-120 meters below the present level. The most recent transgressive episode, which initiated around 18,000 years B.P., is known as the Last Transgression (Bittencourt et al. 1979) and reached a maximum approximately 5,600 cal. years B.P. (5,200 years C^{14} B.P.). This last event left several records that were dated by the C^{14} method, allowing the construction of relative sea-level curves for the last 7,700 cal. years B.P. (7,000 years C^{14} B.P.) (Suguio et al. 1985, Martin et al. 1987, 1999, 2002) (Fig. 3).

The relative sea-level curve built for the Salvador region (Fig. 3A) is by far the most detailed of the entire eastern-northeastern coast of Brazil

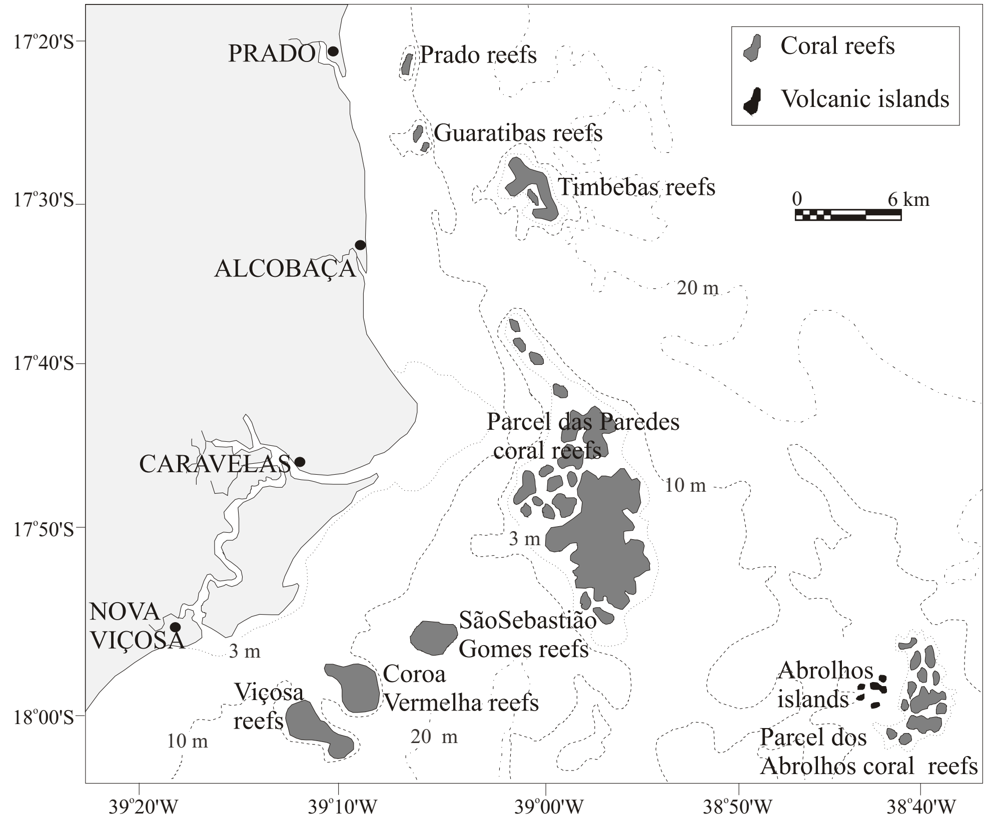

Fig. 2 – Morphology of the continental shelf adjacent to the Caravelas strandplain (modified from Dominguez et al. 1998).

(Suguio et al. 1985, Martin et al. 1987, 1988, Suguio et al. 1988, Martin et al. 2002). Martin et al. (2002) have recently presented a new version of this curve incorporating corrections for the reservoir effect and, calibrations for calendar ages (Fig. 3B). The number of relative sea-level reconstructions for the Caravelas region was insufficient for the construction of a complete curve (Fig. 3C). Nevertheless, the reconstructions obtained for the Caravelas region are in agreement with the Salvador curve (Suguio et al. 1985, Martin et al. 1987). The Salvador curve exhibits an important highstand ($4, 8 \pm 0, 5$ meters) around 5,600 cal. years B.P. (5,200 years C^{14} B.P.), followed by a drop since that time. This drop was not continuous, but interrupted by two high-frequency oscillations. After 5,600 cal. years B.P. (5,200 years C^{14} B.P.), a rapid regression occurred and the sea-level went down reaching a level a little lower than the present one. Between 3,800 and 3,500 years cal B.P. (3,900 and 3,600 years C^{14} B.P.), a rapid transgression occurred. Around 3,500 cal. years B.P. (3,600 years C^{14} B.P.), the relative sea-level reached a second maximum placing it over $3, 5 \pm 0, 5$ meters above the present level. Between 3,500 and 2,800 years cal B.P. (3,600 and 2,800 years C^{14} B.P.) another regression occurred and the relative sea-level went down once again slightly below the present level. Around 2,100 cal. years B.P. (2,400 years C^{14} B.P.) the relative sea-level reached a third maximum placing it $2, 5 \pm 0, 5$ meters above the present one. Since that time, the relative sea-level has dropped reaching its present position.

Angulo and Lessa (1997) questioned the exis-

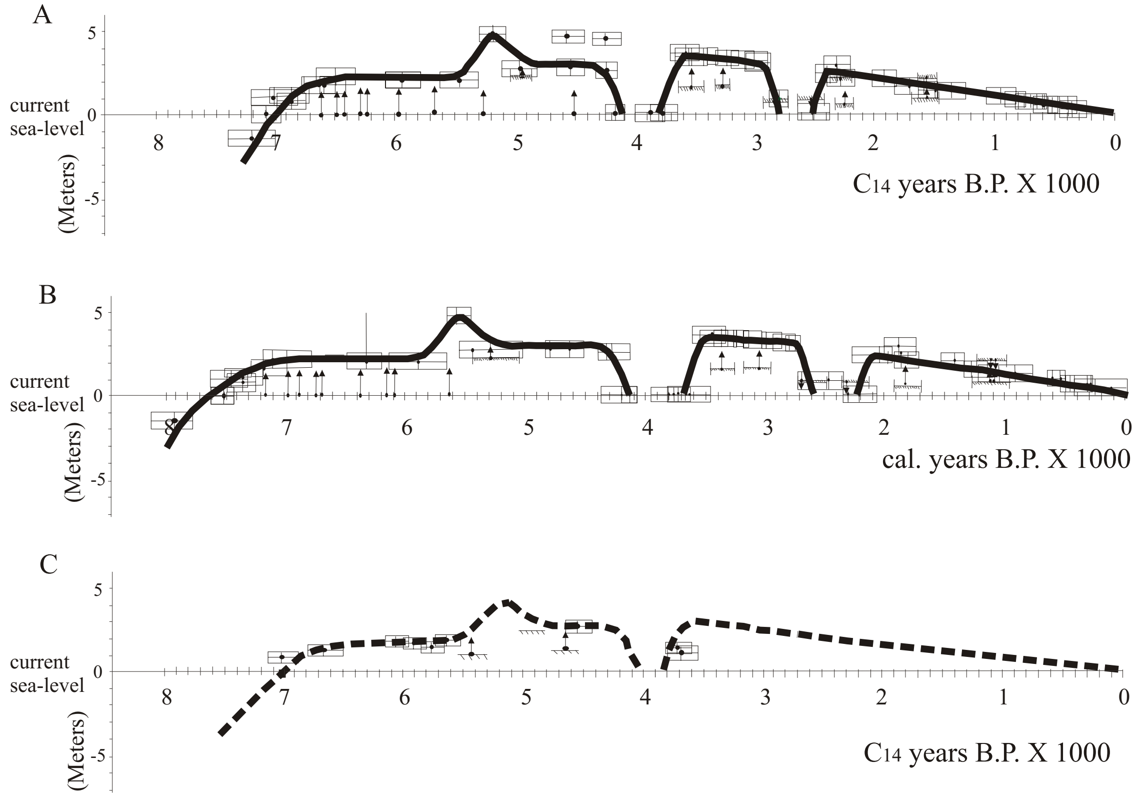

Fig. 3 – Relative sea-level curves: A – Salvador sea-level curve (radiocarbon years) (Martin et al. 1980), B – Salvador sea-level curve (calendar years) (Martin et al. 2002), C – sea-level reconstructions for the Caravelas strandplain plotted on the Salvador curve (radiocarbon years) (Martin et al. 1980).

tence of the two high-frequency sea-level oscillations. According to these authors, most of the indicators used in the determination of the two high-frequency oscillations comes from mollusks and not from vermetid incrustations which they consider to be the best and more precise indicators. Martin et al. (1998, 2002) however pointed out that Angulo and Lessa (1997) did not consider that the data from vermetid incrustations should be analyzed together with other biological, sedimentological, archaeological and morphological indicators, and not isolated as those authors did.

III RELATIVE SEA-LEVEL HISTORY AND THE DEVELOPMENT OF THE ABROLHOS REEFS

Data obtained from a core taken in the Coroa Vermelha reef (Fig. 2) allowed the calculation of the Abrolhos reefs growth rate. The island surface is about 1,5 meters above the mean sea-level (Leão 1982). The Coroa Vermelha core reached a total depth of 15,2 meters. The top of the pre-holocenic sequence was found at 11,2 meters below the present mean sea-level. Datings of corals collected in different depths in relation to the present mean sea-level provided ages of 7,371(**7,219**)7,096 cal. years B.P. (-11 meters), 5,728(**5,605**)5,485 cal. years B.P. ($-8,5$ meters) and 4,527(**4,415**)4,287 cal. years B.P. ($-2,4$ meters). A sample dated from the reef border provided an age over 1,683(**1,538**)1,504 cal. years B.P. (Leão and Kikuchi 1999).

The comparison between the Salvador curve and the Coroa Vermelha reef growth rates evidenced four major stages in reef development (Leão and Kikuchi 1999, 2000, Leão et al. 2000) (Fig. 4):

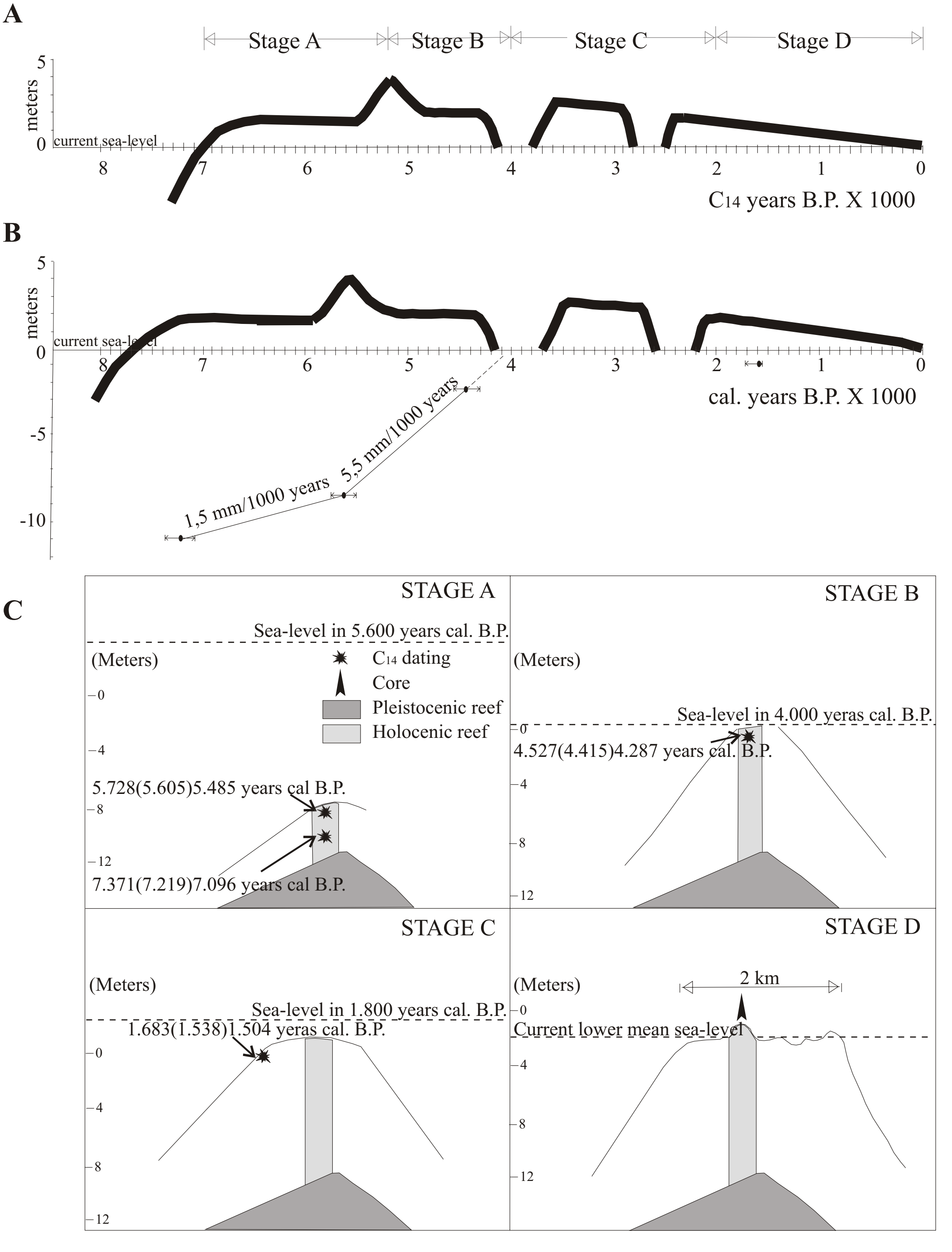

Fig. 4 – Coral reef evolutionary model based on radiocarbon ages and accumulation rates determined for the Coroa Vermelha reef: A – Coral reef development stages plotted on the Salvador sea-level curve (radiocarbon years) and B – Coral reef development stages plotted on the Salvador sea-level curve (calendar years). In the curve B are also plotted the growth rates of the Coroa Vermelha reefs (Leão and Kikuchi 1999). C – Coral reef development stages: Stage A – initial reef establishment stage, Stage B – rapid vertical accretion, Stage C – rapid lateral growth and Stage D – reef degradation (modified from Leão et al. 2000).

Stage A (initial reef establishment stage) – the oldest age from the Coroa Vermelha core indicates that the corals started its growth a little before 7,700 cal. years B.P., during a sea-level rise period (Last Transgression). The reef growth rate in this stage was small, around 1,5 mm/year.

Stage B (rapid vertical accretion of the reefs) – this stage is associated with the regression that occurred after the maximum of the Last Transgression and it is characterized by a rapid reef growth, with rates in the order of 5,5 mm/year. The corals dated from the top of the Coroa Vermelha core (4,527(**4,415**)4,287 cal. years B.P.) indicate that by this time these reefs reached the present mean sea-level.

Stage C (lateral growth of the reefs) – the vertical accretion of the reefs stopped when they reached sea-level. Since that time, the reefs have had their tops truncated and started growing sideways. The age of 1,683(**1,538**)1,504 years cal B.P., obtained from the border of the reef, which is younger than the one from the top corroborates the statement above.

Stage D (reef degradation) – this stage is marked by a decline of the reef growth which persists to the present day.

IV CLIMATIC AND OCEANOGRAPHIC PARAMETERS

Wind and Wave Patterns

The Trade Wind Belt of the South Atlantic (NE-E-SE) and the periodic advanced of the Atlantic Polar Front (SSE) are important elements of the atmospheric circulation on the coastal zone of the State of Bahia. The area is reached by winds arising from NE and E during the spring-summer and from SE and E during the autumn-winter. These winds and the morphology of the inner continental shelf are responsible for the generation of the wave-patterns that reach the coastline: (i) wave-fronts coming from NE and E, with height of 1,0 meter and period of 5 seconds and (ii) wave-fronts coming from SE and SSE, with height of 1,5 meter and period of 6,5 seconds (Dominguez et al. 1992, Bittencourt et al. 2000).

Tides

Tidal regime at the Caravelas strandplain is semi-diurnal and located at the upper microtidal range which is close to 2 meters. Spring tidal range at the Ilhéus port located 300 km north of the city of Caravelas is 2,5 meters (DHN 1998).

V GEOLOGY-GEOMORPHOLOGY OF THE CARAVELAS STRANDPLAIN

Five major geologic-geomorphological units were mapped in the Caravelas strandplain (Fig. 5): pleistocene beach-ridge terraces, lagoonal deposits, holocene beach-ridge terraces, freshwater marshes and tidal flats/mangroves.

The Caravelas strandplain is bordered landward by unconsolidated Tertiary alluvial fan deposits of the Barreiras Group. These deposits are made up of poorly sorted sand-clay sediments, slightly cemented by iron oxide. Altitudes vary from 10 to 100 meters. A line of inactive sea cliffs marks the limit between these Tablelands and the strandplain. North and south of this strandplain the Tablelands of the Barreiras Group reach the shoreline forming active sea cliffs such as in Mucuri and Prado (Fig. 1).

Pleistocene Beach-Ridge Terraces

These terraces occur in the internal portion of the strandplain, with altitudes varying from 6 to 10 meters. They present on its surface remnants of beach-ridge. Truncation lines separate different sets of beach-ridges. These terraces are made up of white to brown, medium to coarse-grained, well sorted sands. Soil processes gave origin to a horizon cemented by humic acids located 3 to 4 meters below the surface. Martin et al. (1982), based on Io/U dating from coral fragments collected from the base of terraces with these characteristics in the region of Olivença, Ilhéus (BA), attributed an age of over 123,000 years B.P. to these terraces. The only available dating for this unit at the Caravelas strandplain is from shells collected in a mud layer located at the base of the Pleistocene Beach-Ridge Terraces,

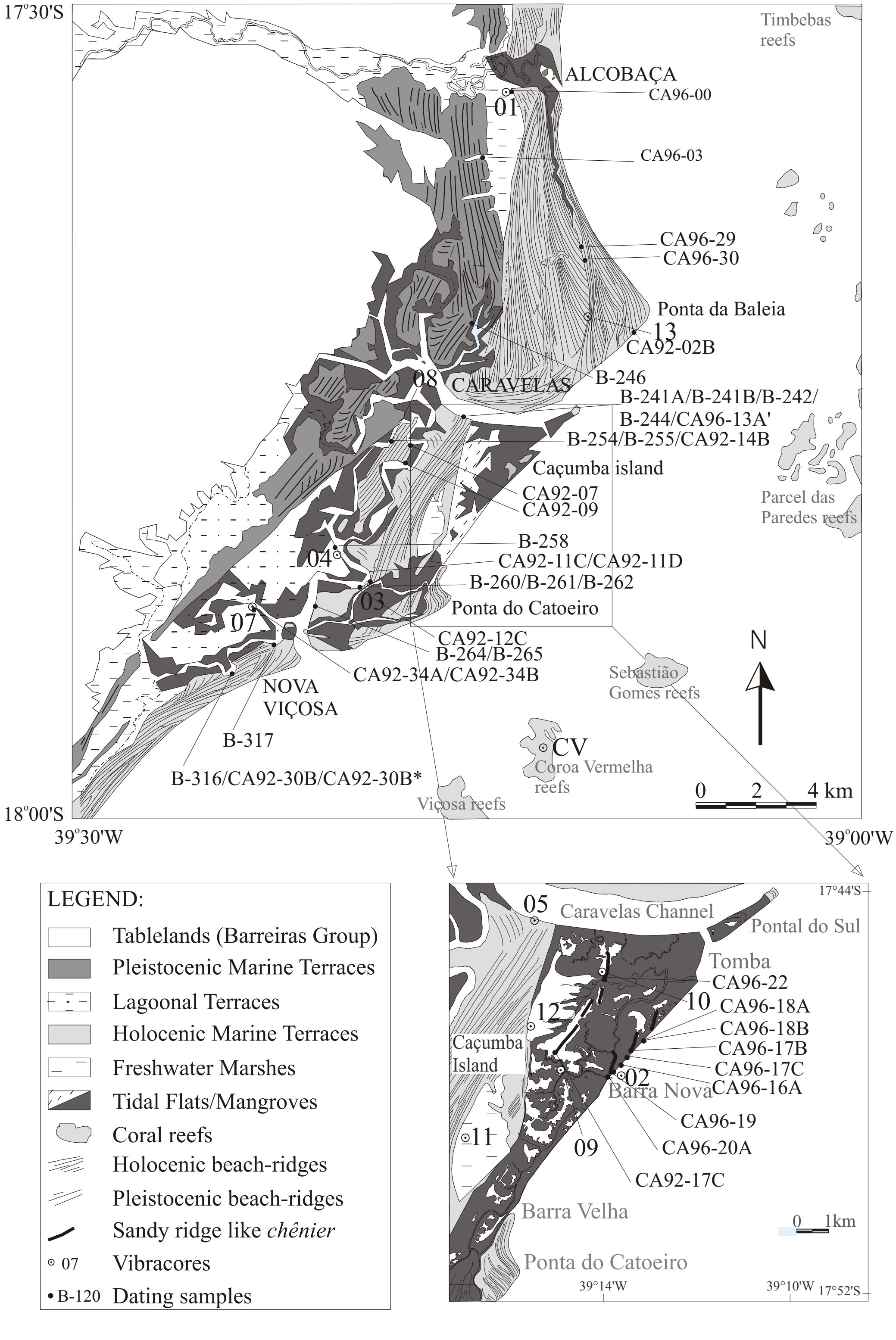

Fig. 5 – Location of vibracores and samples collected in outcrops for radiocarbon dating.

which provided an age of over 32,000 years B.P. (B-246) (Fig. 5, Table I).

Lagoonal Terraces

Ancient lagoonal deposits occur mainly in the southwestern portion of the Caçumba Island forming a terrace approximately 1,0 meter above the maximum of the high spring tide level. This unit is made up of gray to brown muddy sediments, moderately consolidated, exhibiting mollusk shells (mostly oysters) in life position. C^{14} dating of these shells provided ages around 7,000-5,000 cal. years B.P. (CA92/34B, CA92/34A, B-258, CA96/00 and CA96/03) (Fig. 5, Table I).

Holocene Beach-Ridge Terraces

These terraces occupy a large extension of the Caravelas strandplain exhibiting altitudes varying from some decimeters to up to 6 meters. Contrary to their Pleistocene counterparts, in the Holocene Terraces the beach-ridges are narrow and very well delineated, and separated by low zones, many times occupied by freshwater wetlands. Truncation lines separate the different sets of beach-ridges. These terraces are made up of fine to medium yellowish sands. Plane-parallel lamination dipping gently seaward is the dominant sedimentary structure. At the Caçumba Island, 3 meters thick beach sands rest directly on the top of plastic gray mud of shoreface origin evidenced by the presence of hummocky cross beddings. ^{14}C dating of mollusks shells present in these terraces provided ages around 5,000-3,000 cal. years B.P. (B-260, B-316, B-317, CA92/11D). Two radiocarbon datings of bivalve mollusks shell fragments, collected in the low-lying zones coincident with an important beach-ridge truncation, presented ages of 4,799(**4,531**)4,445 cal. years B.P. (CA96/29) and 2,353(**2,344**)2,331 cal. years B.P. (CA96/30). Other datings from shells collected in the shoreface gray muds referred above provided ages varying from 8,000 to 4,000 cal. years B.P. (B-255, B-261, B-262, CA92/30B, B-242, CA96/13A', CA92/14B, CA92/11C and B-264). Dated wood fragments provided ages varying from 6,500 to 4,000 cal. years B.P. (B-265, CA92/30B*, B-241A and B-241B) (Fig. 5, Table I).

Tidal Flats / Mangroves

The southern portion of the Caravelas strandplain is characterized by the presence of large tidal flats cut by numerous tidal creeks. Mangrove swamps comprised of Rhizophora, Laguncularia, Avicennia and Terminalia has colonized the upper intertidal areas. ^{14}C datings of wood and oysters shells collected along the Caçumba island shoreline where these tidal flat deposits presently outcrop provided ages around 700-500 cal. years B.P. (CA96/16A, CA96 / 18A, CA96 / 17C, CA96 / 18B and CA96 / 20A). In these tidal flats isolated shell-rich sandy *chêniers* are common. Datings of shells from reworked bivalve mollusks, collected on the surface of these *chêniers*, provided ages varying from 800 to 300 cal. years B.P. (CA92/17C, CA96/17B, CA96/19 and CA96/22) (Fig. 5, Table I).

Freshwater Marshes

The freshwater marshes and associated deposits occupy mainly the low-lying areas that separate the Pleistocene from the Holocene Beach-Ridge Terraces, the swales between individual beach-ridges and valleys and riverine areas of the Tablelands. Plastic muddy sediments, rich in organic matter, in most cases constitute these deposits. Exception is made for the beach-ridge swales, where the substratum is sandy. A peat layer with variable thickness is sometimes present on the top of this unit. Typical freshwater wetland vegetation grows in these areas.

VI FACIES ASSOCIATIONS

Twelve vibracores were retrieved from the Caravelas strandplain. Nine sedimentary facies were identified from the integration of vibracore and outcrop information based on sediment texture, mollusks species and sedimentary structures (Figs. 5, 6, 7 and 8). These facies were grouped into two major facies associations (Andrade 2000): (i) littoral zone (A1, A2,

TABLE I

C^{14} datings in field samples.

Field Sample No.	Laboratory Sample No.	Material	Facies	Ages corrected for isotopic fractionation (C^{14} years B.P.)	Ages corrected for reservoir effect (C^{14} years B.P.)	Calendar ages (cal years B.P.)
B-241A	Bah 760	Wood	A2	5, 300 ± 100	5, 300 ± 100	6,260 **(6,165-6,035)**5,935
B-241B	Bah 761	Wood	A2	5, 400 ± 120	5, 400 ± 120	6,301**(6,259-6,198)**5,996
B-242	Bah 762	mollusk	A2	5, 710 ± 100	5, 360 ± 100	6,284**(6,177)**5,990
B-244	–	mollusk	A1	6, 050 ± 120	5, 700 ± 120	6,662**(6,479)**6,319
B-246	Bah 765	mollusk	A3	^{3}32, 000		
B-254	Bah 767	mollusk	A1	6, 650 ± 120	6, 300 ± 120	7,282**(7,205)**7,027
B-255	Bah 768	mollusk	A2	7, 010 ± 120	6, 660 ± 120	7,571**(7,522-7,476)**7,391
B-258	Bah 769	mollusk	B5	5, 700 ± 100	5, 350 ± 100	6,281**(6,175-6,115)**5,956
B- 260	Bah 770	mollusk	A1	4, 520 ± 110	4, 170 ± 110	4,840**(4,814-4,649)**4,527
B-261	Bah771	mollusk	A2	4, 910 ± 110	4, 560 ± 110	5,446**(5,292)**4,997
B-262	Bah 772	mollusk	A2	5, 760 ± 160	5, 410 ± 160	6,394**(6,264-6,203)**5,956
B-264	–	mollusk	A2	4, 100 ± 150	3, 750 ± 150	4,400**(4,089)**3,885
B-265	Bah 775	Wood	A2	3, 640 ± 110	3, 640 ± 110	4,087**(3,960-3,926)**3,831
B-316	Bah 808	mollusk	A1	3, 675 ± 100	3, 325 ± 100	3,685**(3,558-3,497)**3,417
B-317	Bah 809	mollusk	A1	3, 310 ± 100	2, 960 ± 100	3,320**(3,107-3,083)**2,954
CA92/02-B	Bah1809	Wood	B3	410 ± 140		543**(488)**299
CA92/07	Bah1810	mollusk	A1/A2	6, 920 ± 270	6, 570 ± 270	7,630**(7,395)**7,206
CA92/09	Bah1811	mollusk	A1 or A2	6, 620 ± 270	6, 270 ± 270	7,392**(7,178)**6,814
CA92/11-C	Bah1812	mollusk	A2	4, 760 ± 200	4, 410 ± 200	5,314**(4,982)**4,659
CA92/11-D	Bah1813	mollusk	A1	4, 410 ± 210	4, 060 ± 210	4,838**(4,526)**4,239
CA92/12-C	Ba 1814	mollusk	A1/A2	6, 040 ± 250	5, 690 ± 250	6,758**(6,467)**6,217
CA92/14-B	Ba 1815	mollusk	A2	7, 130 ± 280	6, 780 ± 280	7,894**(7,570)**7,385
CA92/17-C	OBDY -	mollusk	*Chênier*	1, 220 ± 40	870 ± 40	788**(755)**724
CA92/30-B	Bah1817	mollusk	A2	4, 420 ± 190	4, 070 ± 190	4,836**(4,531)**4,288
CA92/30-B*	Bah1818	Wood	A2	4, 100 ± 210	4, 100 ± 210	4,861**(4,564)**4,298
CA92/34-A	Ba 1819	Oysters	B5	6, 080 ± 260	5, 730 ± 260	6,852**(6,494)**6,287
CA92/34-B	Bah1820	mollusk	B5	6, 310 ± 270	5, 960 ± 270	7,166**(6,840-6,786)**6,468
CA96/00	Ly. 7960	Oysters	B3	6, 075 ± 50	5, 725 ± 50	6,623**(6,492)**6,448
CA 96/03	Ly. 7961	Oysters	B3	4, 855 ± 50	4, 505 ± 50	5,290**(5,249-5,058)**4,997
CA 96/13A'	Ly. 7897	mollusk	A2	6, 480 ± 60	6, 130 + 60	7,152**(7,004)**6,896
CA 96/16A	Ly. 7893	Wood	B3	685 ± 45	685 ± 45	665**(654)**571
CA 96/17B	β100121	mollusk	*Chênier*	1, 160 ± 60	810 ± 60	759**(705)**668
CA 96/17C	Ly. 7896	Oysters	B3	885 ± 45	535 ± 45	550**(537)**516
CA 96/18A	Ly. 8463	Wood	B3	480 ± 45	480 ± 45	533**(514)**502
CA 96/18B	Ly. 7895	Oysters	B3	915 ± 45	565 ± 45	629**(546)**529
CA 96/19	β100119	mollusk	*Chênier*	620 ± 80	270 ± 80	434**(299)**0*
CA 96/20A	Ly. 7894	Oysters	B3	955 ± 45	605 ± 45	645**(625-556)**545
CA 96/22	Ly. 7962	mollusk	*Chênier*	1, 000 ± 45	650 ± 45	656**(645-577)**556
CA 96/29	Ly. 7898	mollusk	T. zone	4, 420 ± 50	4, 070 ± 50	4,799**(4,531)**4,445
CA 96/30			T. zone	2, 690 ± 45	2, 340 ± 45	2,353**(2,344)**2,331

A3 and A4) and (ii) lagoon/freshwater wetlands zone (B1, B2, B3, B4 and B5). The different facies and the interpretation of their depositional environment are described below.

VI.1 Littoral Zone Facies Association

VI.1.1 *Facies A1*

This facies was identified only in outcrops. It rests on top of the facies A2 in vibracores 3 and 5 and exhibit thickness varying from 2,8 to 4,0 meters. This facies is characterized by fine to medium yellowish quartz sand, including localized concentration of heavy minerals and shells. The dominant sedimentary structure is plane-parallel bedding dipping gently towards the sea (Figs. 6 and 7). ^{14}C datings of mollusks shells collected from an outcrop near vibracore 3 provided ages of 4,800-4,200 cal. years B.P. (CA92/11-D and B-260) (Figs. 5 and 6, Table I). This facies was interpreted as a result of deposition in a beach-face environment based on the sedimentary structures observed and on the presence of beach-ridges capping the studied outcrops.

VI.1.2 *Facies A2*

This facies occurs in vibracores 1, 2, 3, 5, 8, 12 and 13. It is comprised by gray to orange medium sands, with interbedded fine to coarse sands and mud. Layers of detritus organic matter were observed in vibracores 1, 5 and 8. The dominant sedimentary structures are tabular and trough cross bedding and plane-parallel bedding. Bioturbation is rare, except in vibracores 1, 3 and 5, where vertical tubes filled with clay and sands are present. The following bivalves were identified: *Anomalocardia brasiliana*, *Mulinia cleryana*, *Glycimeris longior*, *Chione subrostrata*, *Lunarca ovalis* (Figs. 6, 7 and 8). According to Rios (1985) these shells are indicative of sandy shallow water environments. C^{14} datings of shells and wood debris provided ages varying from 4,100 to 7,900 years cal B.P. (CA92/11-C, B-261, B-262, B-241A, B-241B, B-242, CA96/13A', B-254, CA92/14B, B-255, CA96-13/150-152 cm) (Figs. 5, 6, 7 and 8, Tables I and II). This facies is interpreted as a result of deposition in a sandy shoreface environment (surf zone and shallower portions of the shoreface), due to the following evidences: i) sediment texture, ii) cross bedding (the result of longshore and rip currents typical of the surf zone, and iii) stratigraphy (position of this facies, situated immediately below the facies A1 – beach-face).

VI.1.3 *Facies A3*

This facies is present in vibracores 1, 2, 3, 11 and 12 and is made up of interbedded layers of light to dark gray muds (thickness from 5 to 8 cm) and fine gray sands (thickness varying from a few millimeters to over 4 cm) forming various arrangements of wavy and linsen bedding. The mud layers are locally enriched with mica minerals. Low-angle cross bedding and parallel lamination are also present. Bioturbation occurs mainly in vibracores 3, 11 and 12. Mollusk shells are rare in this facies, except in vibracores 11 and 12, where a shell bed is observed. Species of mollusks shells present include: *Mulinia cleryana*, *Chione subrostrata* and *Mactra iheringi* (Figs. 6 and 8). Radiocarbon dating of shells provided ages around 6,300-5,300 years cal B.P. (CA96-11/469cm and CA96-12/408-413cm) (Figs. 5, 6 and 8, Table II). This facies is the result of deposition in a muddy shoreface environment based on the following evidences: i) sediment texture, ii) stratigraphic position, immediately below facies A2 (sandy shoreface) and iii) dominance of wavy and linsen beddings.

VI.1.4 *Facies A4*

This facies occurs in vibracore 2 and is characterized by medium to coarse sands. The sedimentary structures are represented by trough cross bedding intercalated with plane-parallel bedding (Fig. 6). This facies is interpreted as having been deposited in an ebb-tidal delta environment as evidenced by: i) sediment texture, ii) dominance of trough cross bedding, iii) geographical position where the vibracore was collected; in the present day shoreface, near to a tidal creek mouth.

VI.2 Lagoon and Freshwater Wetland Facies Association

VI.2.1 *Facies B1*

This facies is present in vibracores 1, 11 and 13 and it is characterized by gray-yellowish to dark gray muds. The top of this facies is characterized by the presence of whitish roots in vertical position. A peat layer, with thickness varying from a few centimeters to half meter, caps this facies (Figs. 6 and 8). In vibracore 13, radiocarbon dating from the base of the peat layer supplied an age around 1,175(**1,067**)977 cal. years B.P. (CA96-13/69-72 cm) (Figs. 5 and 8, Table II). This facies is interpreted as the result of deposition in a freshwater wetland environment due to the similarity between the remnant vegetable matter present in the vibracore and those found in the present day freshwater wetlands, where the vibracores were taken.

VI.2.2 *Facies B2*

This facies is characterized by yellowish-brownish to dark gray muds that occur in the top of vibracores 4, 7, 9 and 10. Sedimentary structures are not visible (Figs. 6, 7 and 8). This facies is interpreted as having being deposited in a supratidal environment, where these vibracores were taken.

VI.2.3 *Facies B3*

Plastic muds of yellowish-brown and gray color characterize this facies, present in vibracores 1, 3, 7, 8, 9, 10, 11 and 12. The presence of intraclasts is observed in vibracore 7. Sedimentary structures of physical origin were not observed. Cylindrical tubes present in this facies are filled with sand or mud. Remnants of plant matter characterized by brownish fibrous roots both in vertical and horizontal position occur throughout this facies, and are very similar to the present day mangroves rootlets. Mollusks shells are virtually absent and restricted to: *Anomalocardia brasiliana*, *Corbula cubaniana* and *Chione subrostrata* (Figs. 6, 7 and 8). According to Rios (1985) all of these shells can inhabit muddy environments. Radiocarbon dating of mollusks shells collected in this facies provided ages varying from 6,400 to 7,900 years cal B.P. (CA96/00, CA96-3/676-678cm, CA92/34-A and CA92/34-B) (Fig. 5, 6, 7 and 8, Tables I and II). Mollusks shells from vibracore 11 however presented an age of 1,310(**1,290**)1,273 cal. years B.P. (CA96-11/ 70 cm).

This facies is interpreted as having been deposited in an intertidal environment, colonized by mangroves. This interpretation was based on the presence of: (i) fibrous roots similar to the ones associated with present day mangroves; (ii) absence of sedimentary structures of physical origin; (iii) mollusks species and (iv) sediment texture.

VI.2.4 *Facies B4*

This facies was found in vibracores 4, 10 and 11 and it has been subdivided into two sub-facies (Figs. 6 and 8):

Sub-Facies B4a: corresponds to the lower portion of the facies B4. It is made up of cross bedding sands locally exhibiting flaser bedding. Bioturbation is present as vertical tubes filled with sand. Intraclasts were also observed. The mollusks shells although rare are represented by the *Corbula cubaniana* and *Diplodonta punctada*.

Sub-Facies B4b: It corresponds to the upper portion of facies B4. This sub-facies was differentiated from the sub-facies B4a because it is predominantly muddy, exhibiting a typical linsen bedding. The bioturbation increases towards the top, where the sand and clay are quite mixed, which causes difficulty in the individualization of the sand and mud lenses. The mollusks shells are also rare, and represented by: *Diplodonta punctada*, *Mulinia cleryana* and *Corbula cubaniana*.

The facies B4 was interpreted as the result of infilling of a tidal creek. This interpretation was based on the following criteria: i) presence of flaser and linsen bedding, ii) fining upwards of sediment grain size, iii) dominance of cross bedding in the lower portion of the lithofacies and iv) presence of intraclasts.

TABLE II

C^{14} datings in vibracore samples.

Core Sample Number	Laboratory Sample Number	Material	Facies	Ages corrected for isotopic fractionation (C^{14} years B.P.)	Ages corrected for reservoir effect (C^{14} years B.P.)	Calendar ages (cal years B.P.)
CA96-3A (676-678cm)	β104777	mollusk	B3	$7,420 \pm 50$	$7,070 \pm 50$	7,913(**7,896-7,838**)7,802
CA96-10 (295-305cm)	Pa. 1561	mollusk	B4a	$4,965 \pm 40$	$4,615 \pm 40$	5,442(**5,311**)5,296
CA96-11 (70cm)	β104778	mollusk	B3	$1,730 \pm 50$	$1,380 \pm 50$	1,310(**1,290**)1,273
CA96-11 (469-471cm)	Pa. 1563	mollusk	A3	$5,805 \pm 40$	$5,455 \pm 40$	6,294(**6,281**)6,204
CA96-12 (408-413cm)	Pa. 1562	mollusk	A3	$5,095 \pm 40$	$4,745 \pm 40$	5,576(**5,564-5,471**)5,332
CA96-13 (69-72cm)	Pa. 1556	peat	peat	$1,180 \pm 80$	$1,180 \pm 80$	1,175(**1,067**)977
CA96-13 (134-136cm)	β104779	org. sed.	B5	$2,260 \pm 50$	$2,260 \pm 50$	2,338(**2,317**)2,153
CA96-13 (150-152cm)	β104780	mollusk	A2	$4,060 \pm 50$	$3,710 \pm 50$	4,129(**4,077-3,994**)3,933
Cvborder	UM1583	coral		$2,015 \pm 70$	$1,660 \pm 70$	1,683(**1,538**)1,504
CV14.1 (–12,5 m)	UM1581	coral		$6,660 \pm 110$	$6,340 \pm 110$	7,371(**7,219**)7,096
CV8.1 (–10 m)	UM1582	coral		$5,230 \pm 110$	$4,880 \pm 110$	5,728(**5,605**)5,485
CV1.3 (–3,9 m)	UM1584	coral		$4,320 \pm 90$	$3,970 \pm 90$	4,527(**4,415**)4,287

VI.2.5 *Facies B5*

This facies occurs in vibracores 9 and 13. In vibracore 9, it has more than 3 meters of thickness and it is made up of a massive gray clay (Figs. 7 and 8). Organic sediments dated from this facies in vibracore 13 provided an age of 2,338(**2,317**)2,153 years B.P. (CA96-13/134-136cm) (Figs. 5 and 8, Table II). This facies was interpreted as a result of clay deposition, in a subtidal environment with calm waters, probably inside a lagoon.

VII QUATERNARY COASTAL EVOLUTION

The evolutionary model proposed for the Caravelas strandplain (Andrade 2000) is described below:

Stage I: Construction of the Pleistocene Strandplain – after 120,000 years B.P. (Fig. 9)

This stage corresponds to the regressive event that followed the maximum of the Penultimate Transgression (123,000 years B.P.) (Martin et al. 1980). During this period, the sediments reworked from the inner continental shelf, as a result of a relative sea-level drop, in association with those brought into the area by longshore currents favored progradation of the coastline through the successive accretion of beach-ridges, giving origin to the Pleistocene Beach-Ridge Terraces. The paleogeographic reconstruction depicted in Fig. 9 shows that the coastline exhibited a great lateral continuity and was made up of sandy beaches. The general configuration of the Pleistocene coastline was very similar to the present day coastline orientation, reflecting the presence of offshore obstacles such as the Parcel das Paredes coral reefs. Analysis of beach-ridge alignments show progradational phases intercalated with erosional episodes as evidenced by the pres-

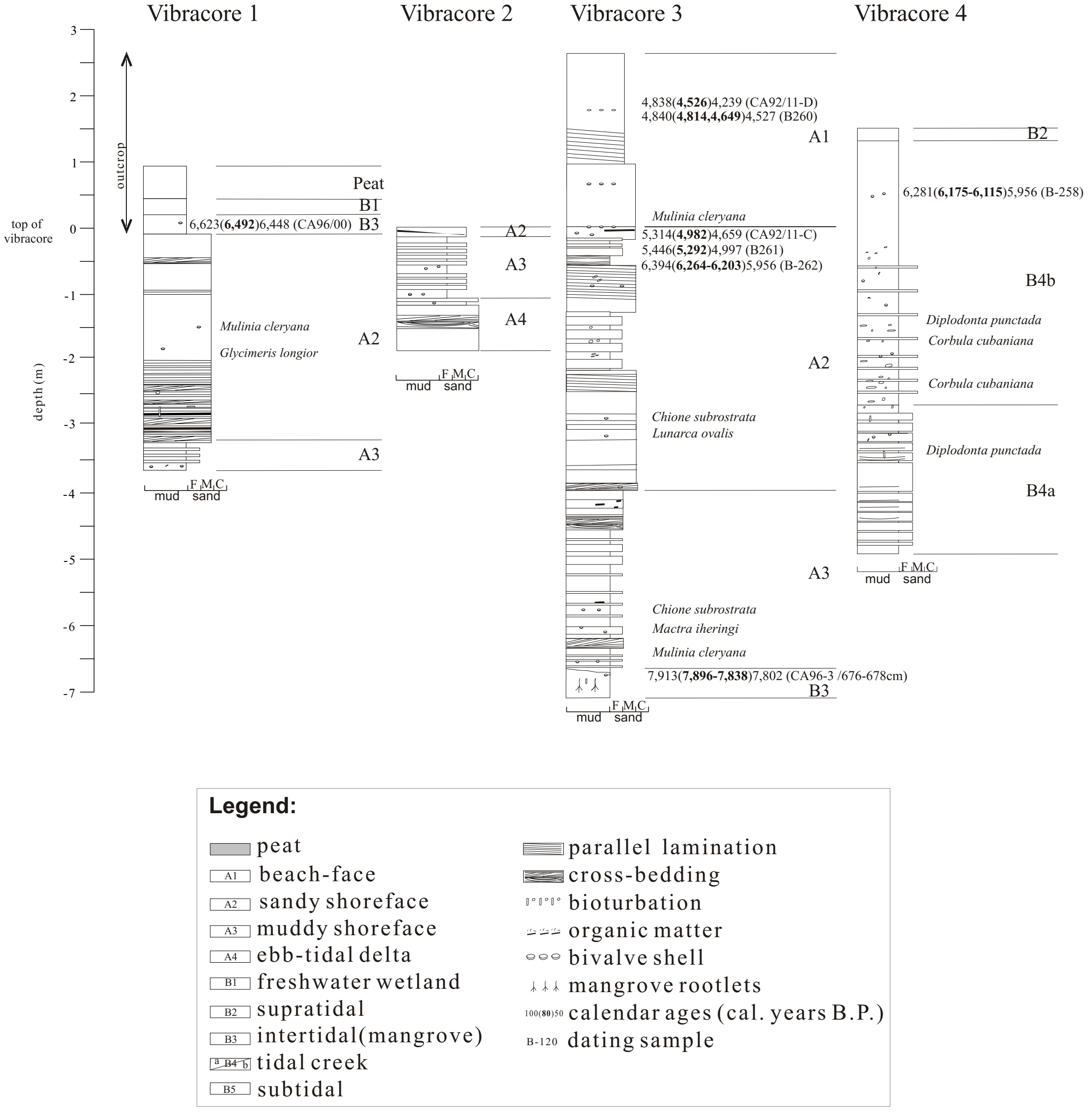

Fig. 6 – Sedimentary facies of vibracores 1, 2, 3 and 4.

ence of beach-ridge truncations. Inversions in the longshore transport direction, as indicated by sandy spit growth, are also observed.

Stage II: Drowning of the Pleistocene Strandplain during the Last Transgression (5,600 cal. years B.P./5,200 years C^{14} B.P.) (Fig. 10)

The sea-level rise that occurred after the last glacial period reached its maximum around 5,600 cal. years B.P. (5,200 years C^{14} B.P.), favoring the drowning of the pleistocene strandplain, with partial erosion and reworking of the Pleistocene Beach-Ridge Terraces. As a result a barrier island/lagoon system was formed. The paleo-geographical reconstruction of the strandplain by that time shows the existence of two lagoonal systems: one located in the southern sector (Lagoonal System I) and the other in the northern sector of the Caravelas strand-

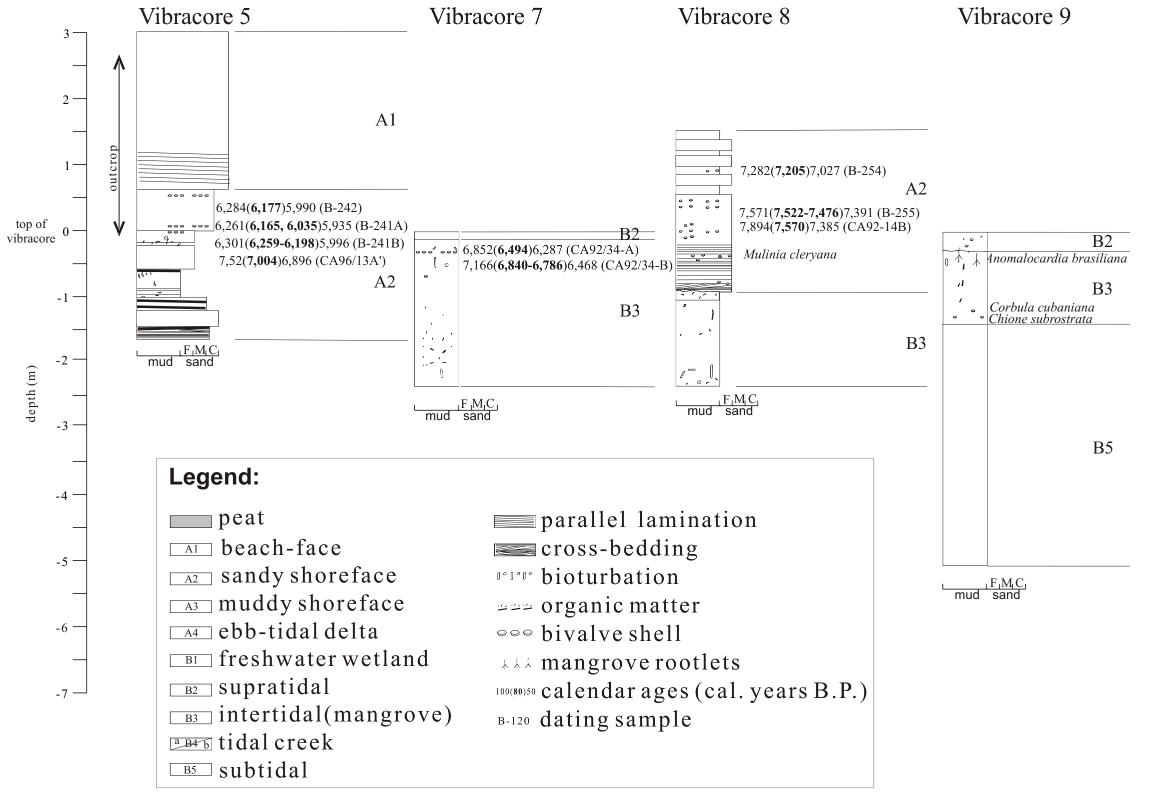

Fig. 7 – Sedimentary facies of vibracores 5, 7, 8 and 9.

plain (Lagoonal System II). Radiocarbon datings of these lagoonal sediments show that the barrier island/lagoon system was already present before the maximum of the Last Transgression (5,600 cal. years B.P. or 5,200 years C^{14} B.P.). Strong evidence to the presence of a lagoon around 7,700 cal. years B.P. (7,000 years C^{14} B.P.) was found in vibracore 3, retrieved from the southern sector of the strandplain. Shells collected in the mangroves facies (B3) near to the contact with the superimposed foreshore facies (A3) provided an age of 7,913(**7,896,7,838**)7,802 cal. years B.P. (CA96-3A/676-678 cm). The sea-level by that time can be reconstructed, based on information from that vibracore, as being positioned 6,7 meters below the present sea-level, since the mangrove facies (B3) which accumulated in an intertidal zone is now located about 6,7 meters below its modern equivalent.

Another important aspect to be pointed out is the presence by that time, of a Paleo-Ponta do Catoeiro in the barrier island chain that protected the lagoonal system I. This cape-like form of the coastline is probably the result of the influence of the Coroa Vermelha, Viçosa and Sebastião Gomes reefs on the wave refraction-diffraction patterns in shaping the barrier island chain. At the lagoonal system II, the southern tip of the barrier island was anchored in the paleo-Ponta da Baleia cape and extended northwards as a result of the dominant longshore drift. A general north-directed longshore drift affected almost the entire coastline of the barrier island system by that time.

Finally at the northern portion of the Caravelas strandplain a strong inflection of the paleo-coastline towards the continent is observed on both sides of the paleo-mouth of the Itanhém River. This probably reflects a larger importance of the tidal currents in modeling this coastline, due to the existence of a

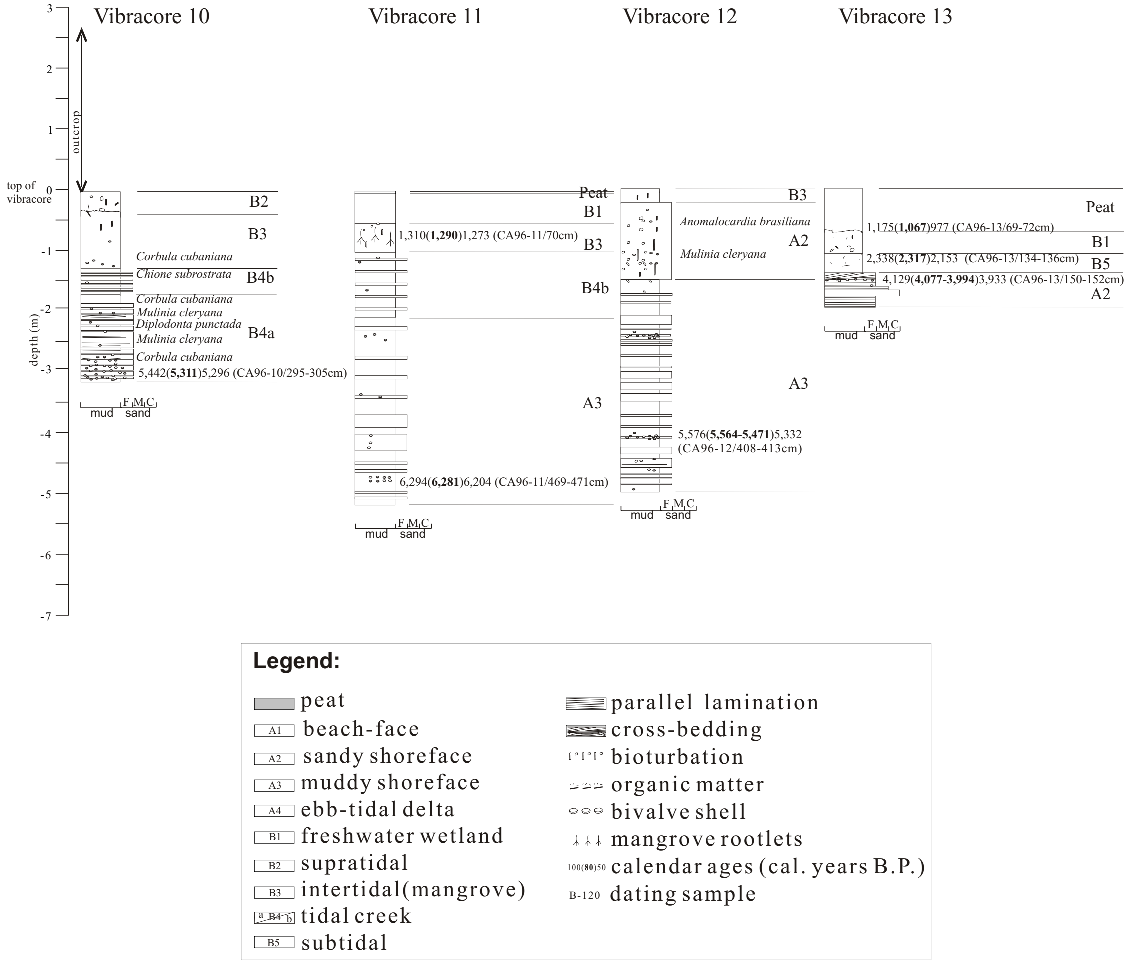

Fig. 8 – Sedimentary facies of vibracores 10, 11, 12 and 13.

more important tidal prism during the maximum of the Last Transgression.

Stage III: Coastline Progradation in the Embayment Situated Between the Paleo-Ponta da Baleia and the Ponta do Catoeiro (5,600 cal. years B.P. or 5,200 years C^{14} B.P.) (Fig. 11)

The sea-level drop after the maximum of the Last Transgression (5,600 cal. years B.P. or 5,200 years C^{14} B.P.) favored coastline progradation. Apparently, this progradation happened first in the embayment situated between the Ponta da Baleia and the Ponta do Catoeiro. This progradation took place following two phases:

(i) infilling of the concave sector (embayment). The orientation and parallelism of the beach-ridges in this sector suggest that the progradation of the coastline has had essentially a traverse component.

(ii) Afterwards, the progradation acquired a character essentially longitudinal, with the growth of a sandy spit indicating a longshore sediment transport directed towards the northeast. As a result of the infilling of the embayment, the coastline became more rectilinear in the southern portion of the strandplain.

In other sectors of the strandplain, the coastline did not progradated at first in a significant way. With

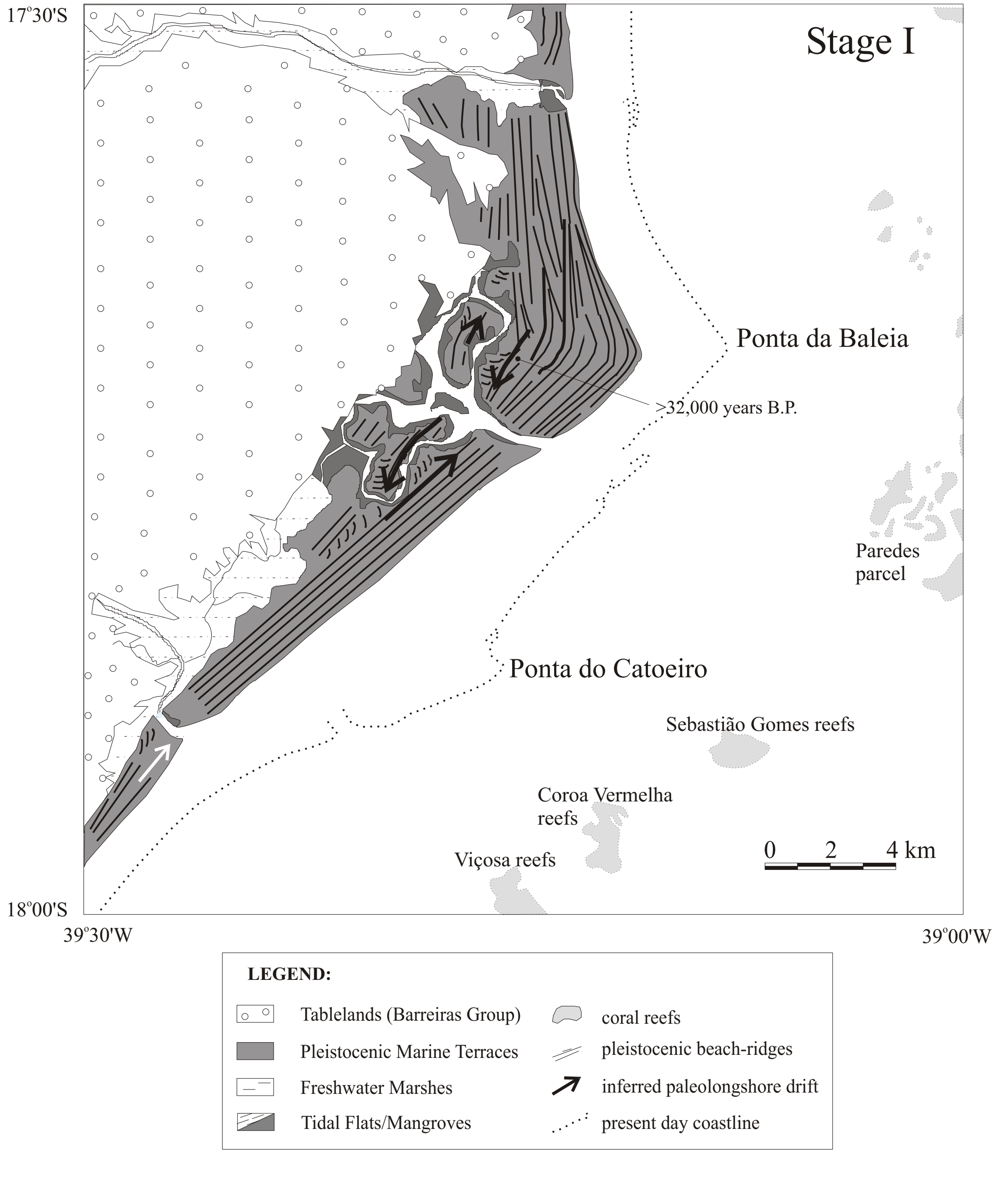

Fig. 9 – Quaternary evolution of the Caravelas strandplain: Stage I – Construction of the Pleistocene strandplain – after 120,000 years B.P.

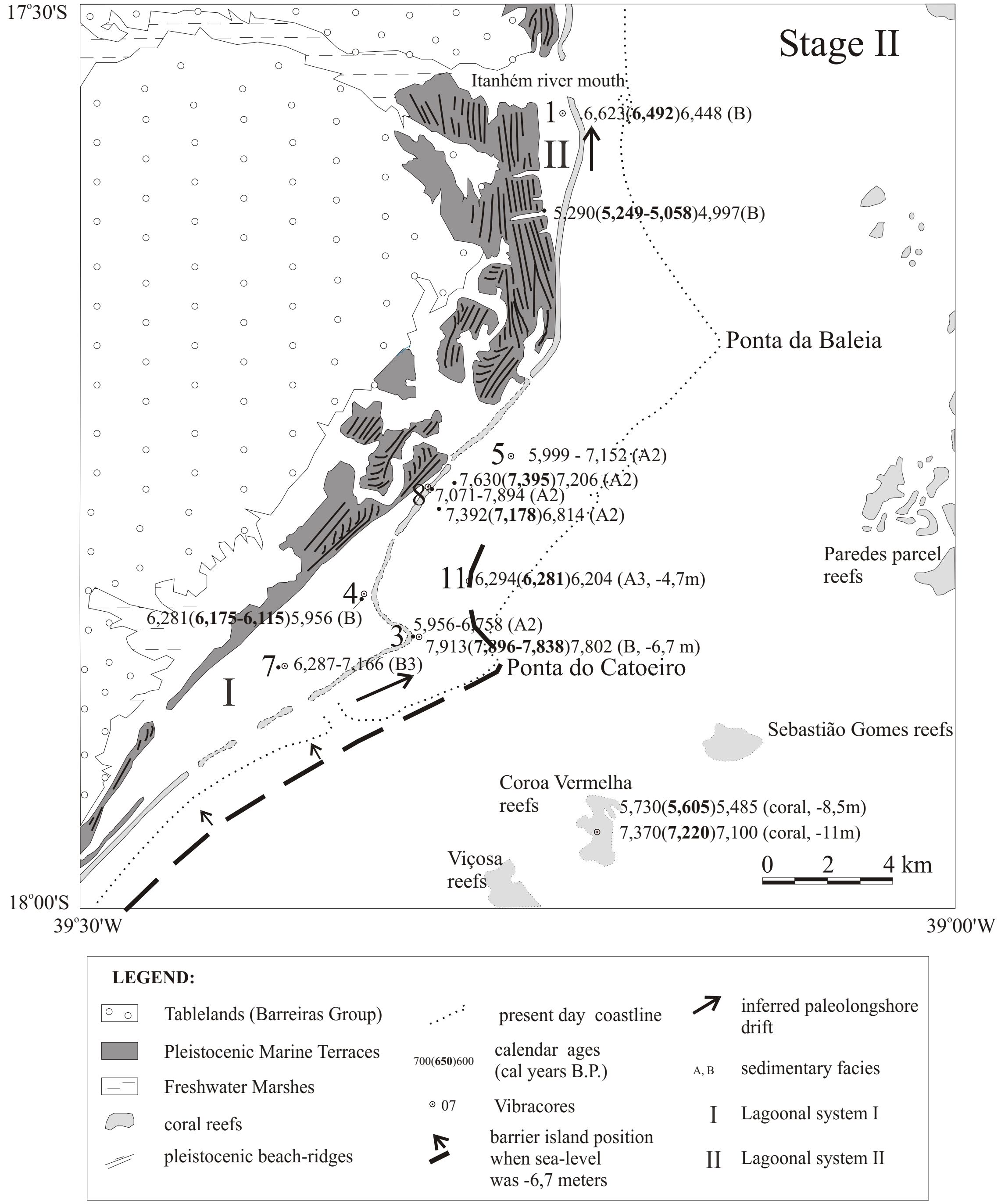

Fig. 10 – Quaternary evolution of the Caravelas strandplain: Stage II – Drowning of the Pleistocene strandplain during the Last Transgression (5,600 cal. years B.P./5,200 years C^{14} B.P.).

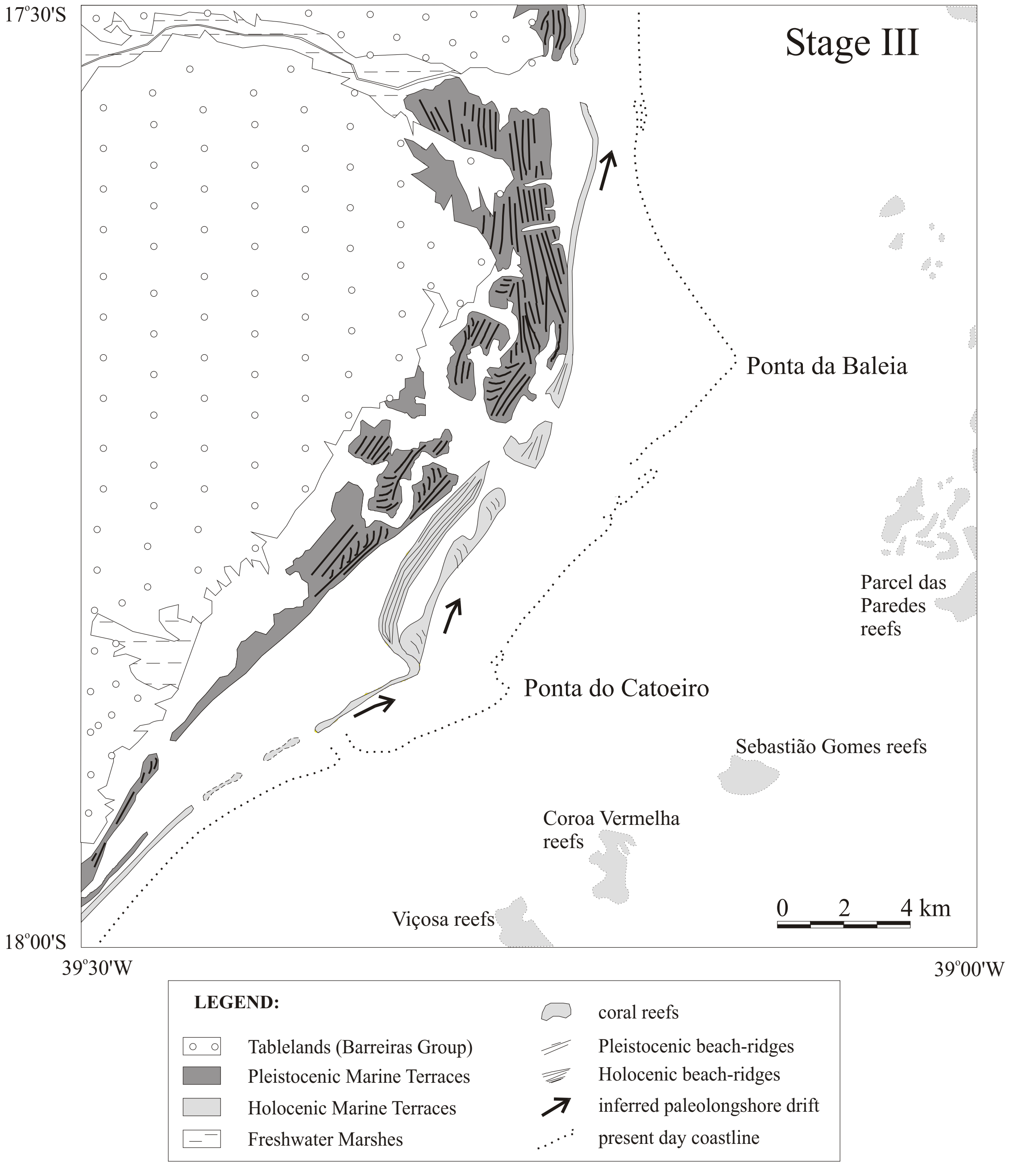

Fig. 11 – Quaternary evolution of the Caravelas strandplain: Stage III – Coastline progradation in the embayment situated between the paleo-Ponta da Baleia and the paleo-Ponta do Catoeiro (5,600 cal. years B.P. or 5,200 years C^{14} B.P.).

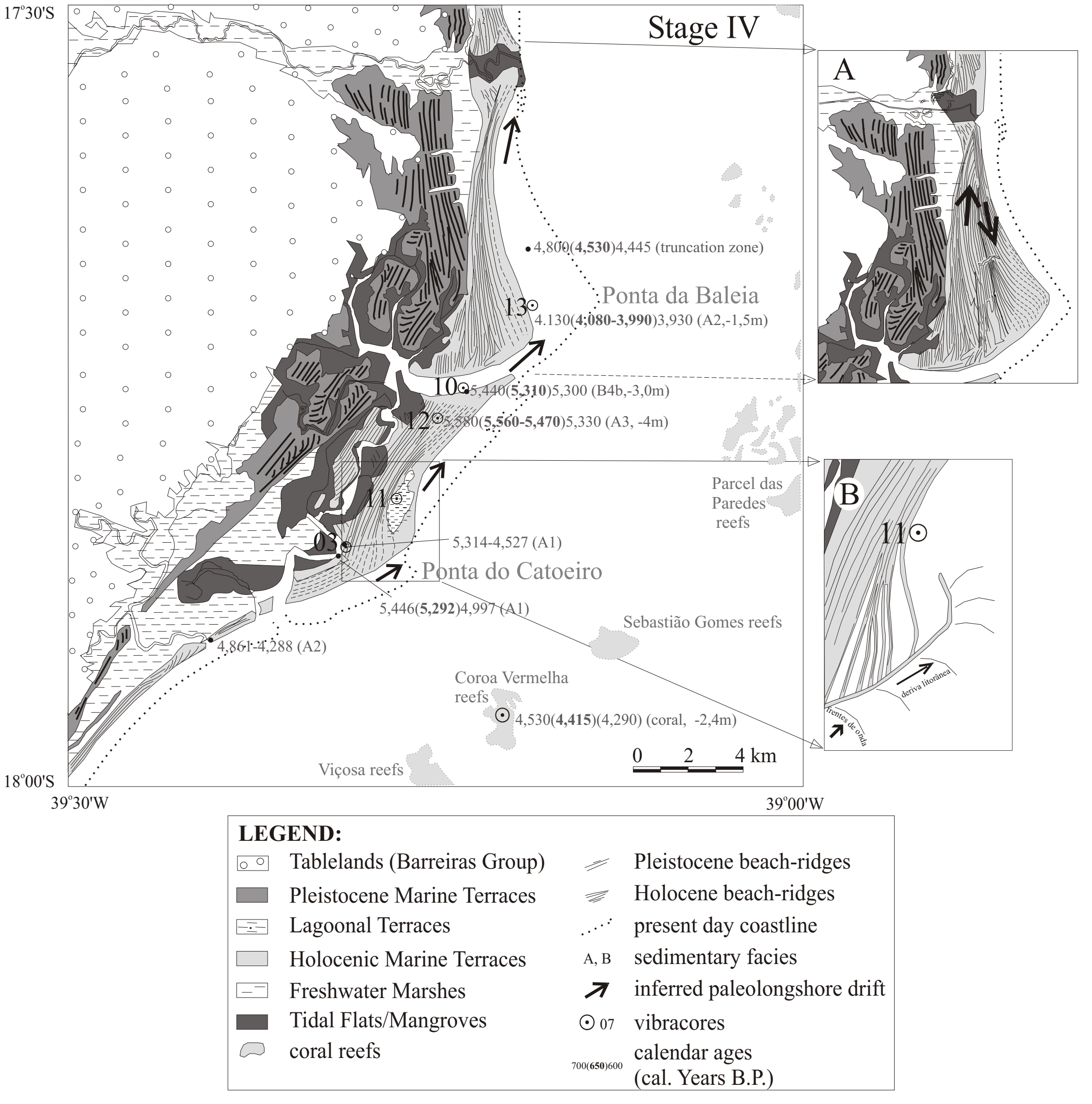

Fig. 12 – Quaternary evolution of the Caravelas strandplain: Stage IV – Beginning of the sedimentation in the northearn sector of the Caravelas strandplain.

the progressive drop of sea-level, the lagoonal systems (I and II) have lost contact with the sea, being replaced by fresh-water wetlands.

Stage IV: Beginning of the Sedimentation in the Northern Sector of the Caravelas Strandplain (Fig. 12)

This stage is marked by the beginning of the sedimentation in the northern sector of the Caravelas strandplain. This stage marks a major change in the dominant longshore drift direction in the northern sector of the strandplain. Firstly, this dominant direction was northeastwards and later changed to southwards. A possible reason for this inversion could be the emersion of the internal arch of coral reefs as a result of sea-level drop. This emersion has blocked in a significant way the propagation of the southeast waves into the northern sector. As this happened the northeastern waves became more effective in determining the dominant longshore drift direction, therefore originating an inversion in the net longshore transport direction in this sector.

In the southern sector of the strandplain, shoreface sediments (facies A2) with ages varying from 7,900 to 5,900 cal. years B.P. are recovered by beach-face sediments (facies A1, 4,500-5,500 cal. years B.P.). The littoral sands in this sector probably comprise a composite sequence in which the basal portion has accumulated during the Last Transgression, but before its maximum (Stage II); while the upper portion has accumulated in the subsequent regressive phase.

By that time the paleo-coastline presented a general southwest-northeast orientation, south of the Ponta da Baleia, and southeast-northwest, north of that feature. Two major capes, represented by the paleo-Ponta da Baleia and the paleo-Ponta do Catoeiro were present. This general shoreline orientation is in conformity with the present coastal processes.

The coastline contour was strongly influenced by offshore obstacles such as the Coroa Vermelha reefs, the Sebastião Gomes reefs, the Viçosa reefs and the Parcel das Paredes coral reefs. After a period of slow growth during 7,700-5,600 cal years B.P./7,000-5,200 years C^{14} B.P, the reef community then presented a rapid vertical accretion, with accumulation rates over 5,5 meters/1000 years (Leão et al. 2000). The rapid vertical growth of the reefs, concomitant to the progressive sea-level drop, allowed probably, the subaerial exposition of the reefs since around 4,000 cal. years B.P. and the truncation of their tops by wave action. As a result the reefs started to grow sideways (Leão 1982, Leão et al. 2000). From that time on, the reefs of the internal arch started to play a more important role in the coastal dynamics, resulting in an inversion in the dominant longshore drift as discussed above.

The study of beach-ridge orientation in the northern sector of the strandplain indicates that during the Holocene, important shifts in longshore drift direction have occurred, generating truncations in beach-ridge alignment (Fig. 12-A). These truncations might have resulted from changes in waves climate.

On the other hand, the sedimentation style at the strandplain in the neighborhood of the present Ponta do Catoeiro cape can be described in the following way (Fig. 12-B): at the cape position the paleo-coastline bent abruptly continentwards, creating an embayment. The tendency of the coastline is to maintain its lateral continuity (Swift 1975, Dominguez 1987). In this way, the beach fed by the longshore drift from southwest, trying to maintain its lateral continuity, would extend into the embayment. As a result of this process, sandy spits were formed and they were elongated more and more towards the northeast. While the spits extended into the open ocean, the refraction of the southeast waves pushed the spit towards the embayment, until its northern extremity was welded to the mainland coastline in the concave sector. This process created narrow elongated lagoons, separated from the ocean by spits. These elongated lagoons constitute the low-lying areas occupied by wetlands that separate the beach-ridges sets in the vicinity of the Ponta do Catoeiro cape. The sedimentary record in vibracore 11 shows the progressive isolation of one of those lagoons. In this vibracore grain size decreases upwards in association with the following succession of sedimentary facies from base to top: muddy shoreface facies (A3), tidal channel facies (B4a), intertidal or mangrove facies (B3), freshwater marsh facies (B1) and peat.

Stage V: The erosional episode associated with the 2,100 cal. years B.P. (2,400 years C^{14} B.P.) rapid rise in relative sea-level (Fig. 13)

During the Holocene, the coastline progradation didn't occur in a continuous manner. It was marked by erosional episodes associated to: (i) tidal channel dynamics, (ii) fluctuations in relative sea-level and (iii) changes in longshore drift direction. These episodes were recorded in the strandplain as truncations in beach-ridge alignments. The most dramatic erosional episode recorded in the strandplain is the one shown on figure 13 which resulted

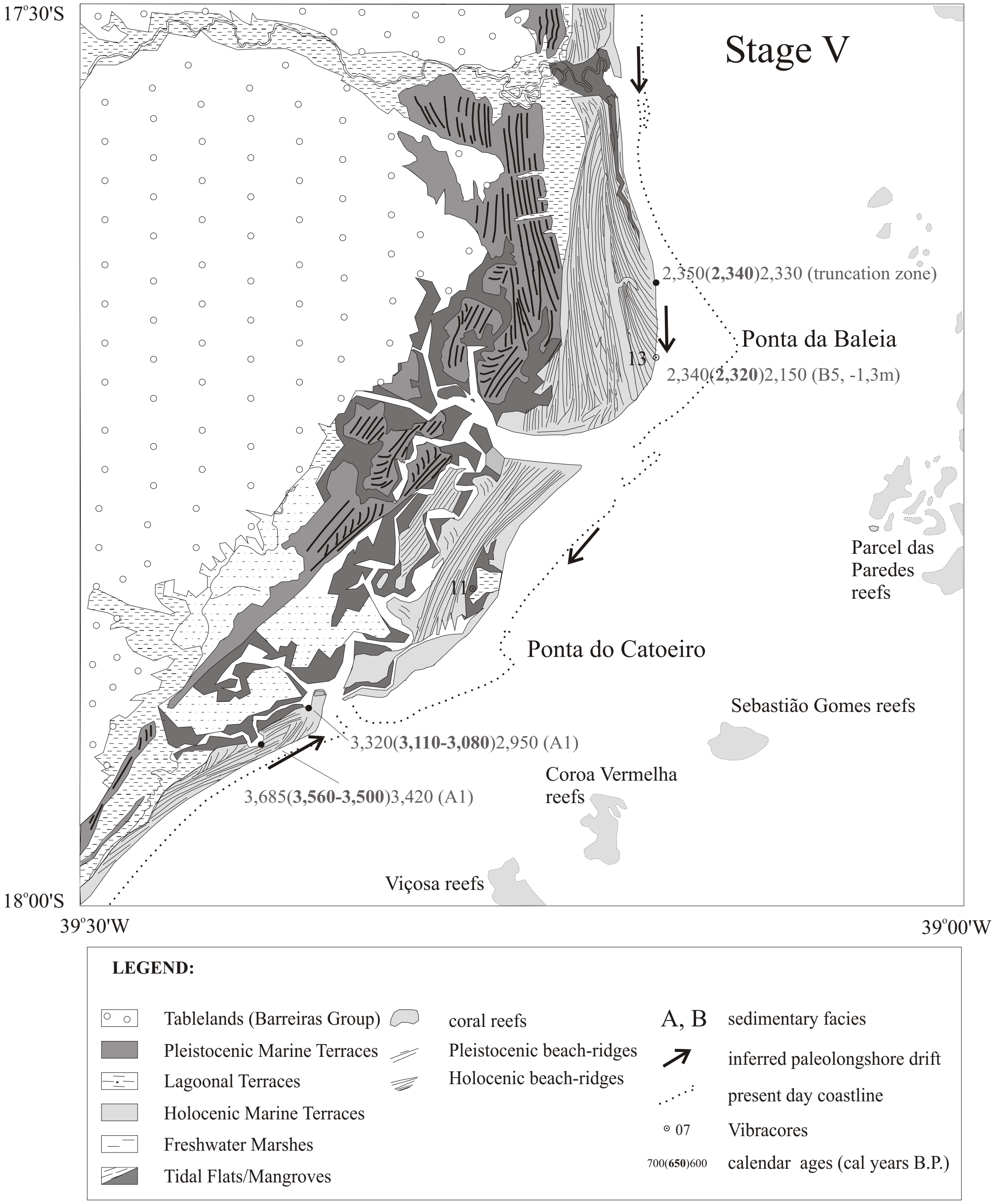

Fig. 13 – Quaternary evolution of the Caravelas strandplain: Stage V – The erosional episode associated with the 2,100 cal. years B.P. (2,400 years C^{14} B.P) rapid rise in relative sea-level.

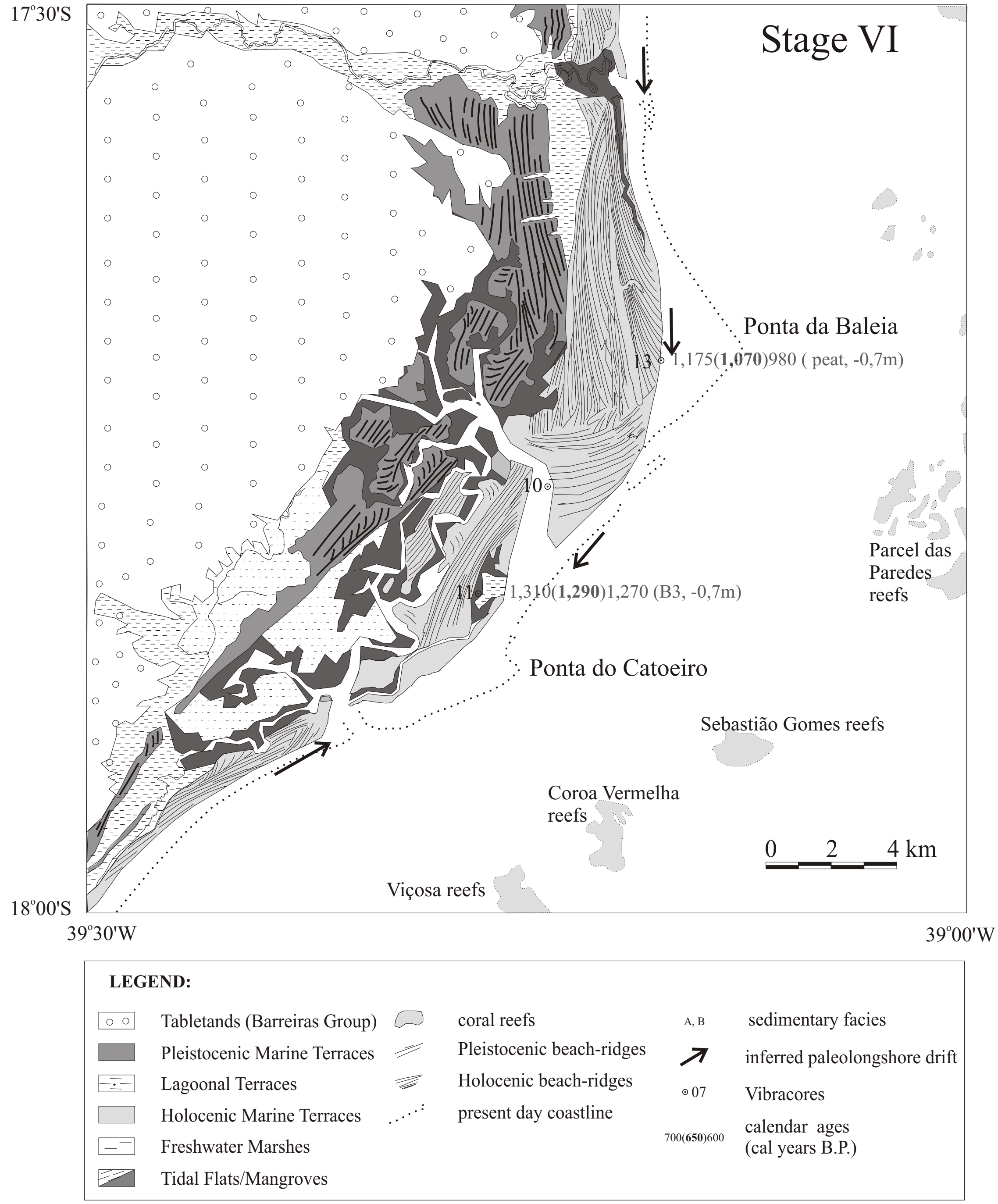

Fig. 14 – Quaternary evolution of the Caravelas strandplain: Stage VI – Severe coastal erosion at Caçumba island.

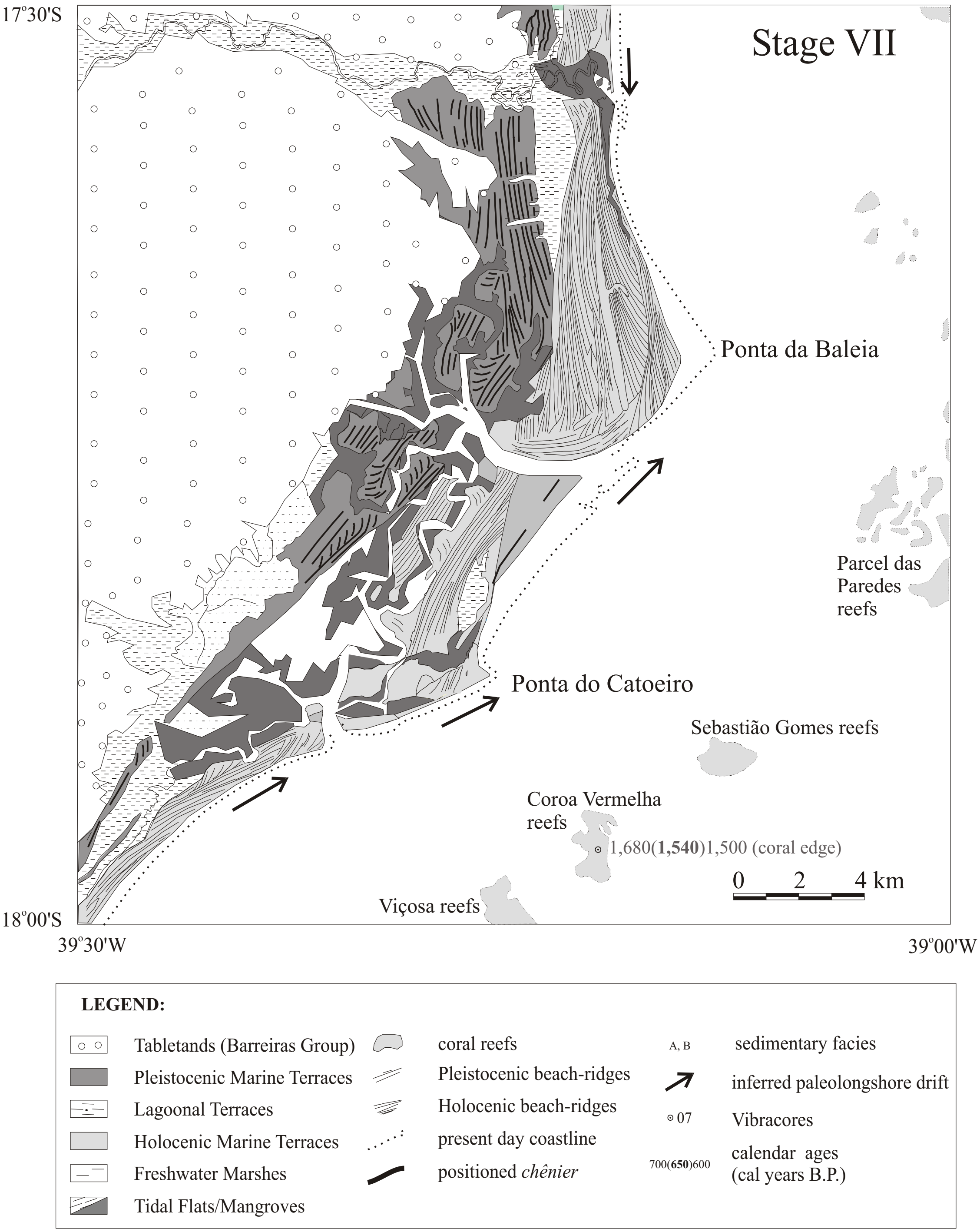

Fig. 15 – Quaternary evolution of the Caravelas strandplain: Stage VII – Renewed coastline progradation.

in erosion of the paleo-Ponta da Baleia cape. This event is probably the result of the rapid rise in relative sea-level that occurred around 2,100 cal. years B.P. (2,400 years C^{14} B.P.), as depicted in the Salvador sea-level curve. The radicarbon ages of 2,338(**2,317**)2,153 cal. years B.P (CA96-13/134-136 cm) (vibracore 13) from vegetable debris collected from the lagoonal facies (B5) that infill the low-lying area associated with the beach-ridge truncation referred above and 2,353(**2,344**)2,331 cal. years B.P. (CA 96/30) from shells collected from the beach-ridge located closest to the truncation seem to corroborate this interpretation.

Stage VI: Severe Coastal Erosion at Caçumba Island (Fig. 14)

The erosional episode described above was possibly followed by an intensification of the southward-directed longshore drift, which favored the displacement of the Caravelas channel as depicted in figure 14. This displacement can be responsible for the severe erosion that affected the Caçumba Island by that time. The existence of a possible paleochannel with a geometry like that presented in the figure 14 is suggested by the presence of a tidal channel facies (B4a and B4b) in vibracore 10. Mollusks shells collected in the mangrove facies (B3) in vibracore 11 provided an age over 1,310(**1,290**)1,273 cal. years B.P. (CA96-11/70 cm). This provides a maximum age for the paleogeography depicted on figure 14.

Stage VII: Renewed coastline progradation (Fig. 15)

This final evolutionary stage corresponds to the renewed coastline progradation. The growth of the Ponta da Baleia cape in association with further emergence of the coral reefs of Sebastião Gomes, Coroa Vermelha and Viçosa created a low energy zone in the neighborhood of the Caçumba Island, favoring the deposition of fine sediments, in extensive tidal flats. As a result, a change in sedimentation style occurred in this sector of the strandplain, which began to present characteristics more typical of a tide-dominated environment.

VIII CONCLUSIONS

This paper has presented the Quaternary evolution of the Caravelas strandplain. This evolution was strongly controlled by relative sea-level changes and the concomitant development of the Abrolhos coral reefs. Whereas sea-level behavior has controlled progradation, erosional retreat and barrier island formation at the strandplain, reef development affected wave refraction/diffraction favoring cape development and a significant inversion in longshore direction. The knowledge of this evolutionary history represents an important tool for prediction of coastal zone response to future global changes in climate and sea-level, therefore allowing better management of this coastal area.

ACKNOWLEGMENTS

Financial support was provided by the Brazilian Research Council (CNPq) and Institut de la Recherche pour le Développement (IRD).

RESUMO

Um modelo evolutivo foi proposto para a planície costeira de Caravelas. Este modelo engloba a integração do: (i) mapeamento dos depósitos Quaternários, (ii) cartografia dos alinhamentos dos cordões litorâneos e truncamentos destes, (iii) história do nível relativo do mar, (iv) história do desenvolvimento dos recifes de corais de Abrolhos, (v) testemunhos e (vi) datação C^{14} dos depósitos Quaternários. Foram identificados sete principais estágios evolutivos. Estes estágios mostram que a planície costeira teve sua evolução Quaternária fortemente controlada pelas variações do nível relativo do mar. Além disso, o desenvolvimento dos recifes de corais de Abrolhos também desempenhou um papel importante na dispersão e acumulação de sedimentos ao longo da costa, causando inversão no transporte de sedimentos.

Palavras-chave: evolução costeira, variações do nível do mar, facies sedimentar, geomorfologia costeira.

REFERENCES

Andrade ACS. 2000. Evolução Quaternária da Planície Costeira de Caravelas – Extremo Sul do Estado da

Bahia. Curso de Pós-Graduação em Geologia, Instituto de Geociências, Universidade Federal da Bahia, Salvador, Tese de Doutorado, 162p.

Angulo R and Lessa GC. 1997. The brazilian sea-level curves: a critical review with emphasis on the curves from the Paranaguá and Cananéia regions. Mar Geol 140: 141-166.

Bittencourt ACSP, Martin L, Vilas Boas GS and Flexor J-M. 1979. The marine formations of the coast of the state of Bahia. In: International Symposium on Coastal Evolution in the Quaternary, 1, São Paulo. Proceeding..., IGCP, Project 61, 1978. p. 232-253.

Bittencourt ACSP, Dominguez JML, Martin L and Silva IR. 2000. Patterns of sediment dispersion coastwise the State of Bahia – Brazil. An Acad Bras Cienc 72: 272-287.

DHN 1998. Tábuas das marés. Marinha do Brasil, Diretoria de Hidrografia e navegação.

Dominguez JML. 1983. Evolução quaternária da planície costeira associada à foz do rio Jequitinhonha (BA): influência das variações do nível do mar e da deriva litorânea de sedimentos. Salvador-BA, Dissertação de Mestrado, IGEO-UFBA, 79p.

Dominguez JML. 1987. Quaternary sea-level changes and the depositional architecture of beach-ridge strandplains along the coast of Brazil. Ph.D. Dissertation, University of Miami – Florida/USA. 288p.

Dominguez JML, Martin L and Bittencourt ACSP. 1987. Sea-level history and quaternary evolution of river mouth associated beach-plains along the east/ southeast brazi1lian coast – a summary. In: Nummedal D, Pilkey DH and Howard JD (Eds.), *Sea-level Fluctuation and Coastal Evolution*. Soc Econ Paleontol Mineral Spec Publ 41: 115-127.

Dominguez JML, Bittencourt ACSP and Martin L. 1992. Controls on Quaternary coastal evolution of the east-northeastern coast of Brazil: roles of sea-level history, trade winds and climate. In: Donoghue JF, Fletcher CH and Suter JR (Eds.), Quaternary Coastal Evolution. Sediment Geol 80: 213-232.

Dominguez JML, Bittencourt ACSP, Vilas Boas GS, Lessa GC, Martin L, Mello e Silva SCB and Leão ZMAN. 1998. Diagnóstico ambiental da zona costeira na Bacia de cumuruxatiba-BA. Convênio Laboratório de Estudos Costeiros-UFBA/ PETROBRÁS. Salvador-Bahia (unpublished).

Leão ZMAN. 1982. Morphology, geology and development history of the southernmost coral reefs of western Atlantic, Abrolhos Bank, Brazil. Ph.D. Dissertation, Rosenstiel School of Marine and Atmospheric Sciences, University of Miami/USA. 218p.

Leão ZMAN and Kikuchi RKP. 1999. The Bahian coral reefs – from 7.000 to 2.000 years AD. Ciência e Cultura, Journal of the Brazilian Association for the Advancement of Science 51: 262-273.

Leão ZMAN and Kikuchi RKP. 2000. The Abrolhos reefs of brazil. In: Coastal Marine Ecosystems of Latin America, V. Seeliger et al. (Ed.). Berlin: Springer-Verlag.

Leão ZMAN, Kikuchi RKP and Testa V. 2000. Corals and coral reefs of Brazil. In: Latin America Coral Reefs, Cortez (Ed.), Elsevier Science CO., Amsterdam.

Martin L, Bittencourt ACSP, Vilas Boas GS and Flexor J-M. 1980. Mapa geológico do quaternário costeiro do Estado da Bahia – Esc. 1:250.000. Salvador-BA, SME/CPM. 60p. (Texto explicativo e mapa).

Martin L, Bittencourt ACSP and Vilas Boas GS. 1982. Primeira ocorrência de corais pleistocênicos na costa brasileira: dotação do máximo da Penúltima Transgressão. Rev Cienc da Terra 1: 16-17.

Martin L, Flexor J-M and Suguio K. 1984a. Enregistrement des périodes de fortes et faibles énergie à l´embouchure d´un fleuve. Le cas du Paraíba do Sul (Brésil). Implications paléoclimatiques. C.R.Ac.Sc. Paris, série II, T. 299: 661-667.

Martin L, Suguio K, Flexor J-M and Dominguez JML. 1984b. Evolução da planície costeira do rio Paraíba do Sul (RJ) durante o Quaternário: influências das flutuações do nível do mar. In: Congr Bras Geol 33. *Anais...*, SBG 1: 84-97.

Martin L, Suguio K, Flexor J-M, Dominguez JML and Bittencourt ACSP. 1987. Quaternary evolution of the central part of the Brazilian coast – the role of relative sea-level variations and longshore drift. Unesco Rep in Mar Sci 43: 97-115.

Martin L, Suguio K and Flexor J-M. 1988. Haut niveaux marines pleistocenes du littoral bresilien.

Palaeogeography, Palaeoclimatology, Palaeoecology 68: 231-239.

Martin L, Bittencourt ACSP, Dominguez JML, Flexor J-M and Suguio K. 1998. Oscillations or not oscillations, that is the question: Comment on Angulo RJ and Lessa GC. The Brazilian sea-level curves: a critical review with emphasis on the curves from the Paranaguá and Cananéia regions. Mar Geol 150:179-187.

Martin L, Dominguez JML and Bittencourt ACSP. 1999. Reavaliação das variações do nível relativo do mar ao longo do litoral leste-sudeste brasileiro: idades calendárias e informações adicionais. In: Congr. ABEQUA, VII. Porto Seguro. Anais: viiabequa_zco001.pdf.

Martin L, Dominguez JML and Bittencourt ACSP. 2002. Fluctuating Holocene sea-levels in Eastern and Southeastern Brazil: evidence from multiple fossil and geometric indicators. West Palm Beach – USA, J Coastal Res v. 18.

Rios EC. 1985. Seashells of Brazil. Fundação Cidade do Rio Grande, Fundação Universidade do Rio Grande, Museu Oceanográfico. Rio grande, RS, XII, 1985. 328p.

Suguio K, Martin L, Bittencourt ACSP, Dominguez JML, Flexor J-M and Azevedo EGA. 1985. Flutuações do nível relativo do mar durante o Quaternário superior ao longo do litoral brasileiro e suas implicações na sedimentação costeira. Rev Bras Geoc 15: 273-286.

Suguio K, Martin L and Flexor J-M. 1988. Quaternary sea-levels of the brazilian coast: recent progress. Episodes 11: 203-208.

Swift DJP. 1975. Barrier-island genesis: evidence from the Central Atlantic Shelf, Eastern U.S.A. Sediment Geol 14: 1-43.