Transgressive barrier estuarine system on a macrotidal coast in Amazon Region

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Introduction

The northern Brazilian coast is 1,200 km long and encompasses two geomorphologic world records: the largest mangrove system (Souza Filho 2005) and the gorge of the largest river in length, water and sediment discharge, the Amazon. The study site is located in a the tide-dominated mangrove coast of Pará-Maranhão in the east. The tide-dominated eastern sector is 480 km long with 7,600 km² of continuous mangrove forests (Souza Filho 2005), almost twice as large as the Sunderbands in India-Bangladesh (Kjerfve et al. 2002). The coastline is extremely irregular and jagged, harboring 23 estuaries and 30 catchment areas that drain an area of 330 mil km² (Martins et al. 2006). The geological control coupled with Quaternary sea-level changes, large fluvial sediment supply and the reworking of relict sediments on the continental shelf have controlled the Amazon coastal evolution. The purpose of this paper is to provide an overall characterization of the coastal geomorphology of the tide-dominated mangrove coast of the Bragança coastal plain, with special attention to the barrier-estuarine system of Caeté (Figure 1), that will be used as a proxy for the morpho-sedimentary evolution of this coastal sector.

Figure 2 - A) Landsat TM images (Band 3) showing the spatial distribution of sand flats (light gray tones) and mangroves and marshes (dark gray tones). B) Map of the coastal environments in the area (Souza Filho and Paradella 2005). C) Topographic map with coring sites in both stations (Cohen et al. 2005).
Stratigraphy, sedimentology and palinology of the transgressive barrier island system

On the basis of morphology, lithology, sedimentary structures, texture, color, elevation and contact, 10 sedimentary facies overlaying the Miocene substrate were identified by sedimentary facies and pollen analysis in barrier and in the estuarine intertidal zone. Two facies were interpreted as Miocene in age; one was interpreted as Pleistocene, and the remaining eight as Holocene. The substrates for the Quaternary sedimentation include the Tertiary siliciclastic sands and muds of Barreiras Formation at the bottom (17 m in depth) and the Miocene carbonates of the Pirabas Formation at the base of the cores. From the oldest to the youngest, the facies are: (1) Pre-Holocene fluvial channel, (2) Transgressive-mud, (3) Tidal meanders, (4) Aeolian sand, (5) Subtidal sand-flat, (6) Intertidal sand shoal, (7) Barrier-island with three generation of transgressive barrier system, (8) Mudflat, (9) Mangrove mud, (10) Marsh mud.

Transgressive barrier estuarine system evolution
The basement depth below the Quaternary deposits was reached around 17 m. Based on the vibracores, the basement surface shows a steep paleo-cliff carved in the Barreiras formation in direct contact with Quaternary deposits. At the base of the paleo-cliff is observed a wide undulated Tertiary surface, composed of carbonaceous deposits of the Pirabas Formation and siliciclastic sediments of the Barreiras Formation. The base of the Quaternary sedimentation is represented by the Pre-Holocene fluvial sand and gravel facies deposited in a fluvial channel section carved into the Tertiary deposits. According to Dalrymple et al. (1992), estuaries in a mixed energy (tide plus wave) coast may be associated with short barrier islands. Besides the present barrier-island, two older ones were identified on the coastal plain overlying intertidal shoals and underlying old mangrove mud. The first (innermost) transgressive barrier-island is associated with the Holocene transgression maximum, dated at 5,913 cal yr BP, when the coastline was situated some 12 km landward from the present one. The first barrier-island emerged 10 km seaward of the active coastal cliffs, providing shelter for the growth of mangroves at its rear. In accordance to Behling (2002), there is a general decrease of the pollen content in the mangrove deposits of the State of Para between 5600 and 3600 \(^{14}C\) yr B.P., suggesting a fall of sea level and a decrease of the forested area. This may also be the reason for the apparent existence of mangrove deposits only around the barrier island at 5913 cal yr BP and from 3736 cal yr BP onwards. In the last 2000 years there has been a swift mangrove progradation internal to the estuary, from the paleo-cliffs all the way to the 2\(^{nd}\) barrier-island. It is initially suggested that such progradation may have occurred in a more sheltered environment that came about with the development of a larger barrier island(s). According to Cohen et al. (2005), a fall of relative sea level up to 1 m below modern sea level has apparently occurred between 1800 and 1400 cal yr BP. It was then followed by a gradual rise until 1000 \(^{14}C\) yr B.P, when sea level was reestablished to the present level. The cross-normal stratigraphic profile shows mangrove sediments progressively younger seaward, indicating that mudflat progradation was responsible for the infilling of Caeté estuary. Such infilling finally restricted the estuarine flow inside the present day channels. The last sea-level rise episode has apparently started around 1550 cal yr BP, and is apparently associated with the retrogradation of the 3\(^{rd}\) generation of barrier-island, that is burying back-barrier mangrove deposits. Transgression is apparently a still ongoing process, as indicated by washover fans and especially drowned (within the intertidal level) aeolian sand dunes at the rear of the barrier.

Conclusions
Contrary to the generally accepted idea that macrotidal settings (tidal range > 4 m) are not conducive to barrier formation (Davis and Hayes 1984), estuaries in this macrotidal coast are barred by sand bars in a truly transgressive fashion. The Caeté barrier estuary system evolved from a riverine environment into an intertidal muddy area accompanying the last eustatic sea-level rise.

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