
Archaeological Mounds in Marajó Island in Northern Brazil: A Geological Perspective Integrating Remote Sensing and Sedimentology

Dilce de Fátima Rossetti,^{1,*} Ana Maria Góes,² and Peter Mann de Toledo¹

¹*Instituto Nacional de Pesquisas Espaciais-INPE, Rua dos Astronautas 1758-CP 515, 12245-970 São José dos Campos-SP, Brazil*

²*Universidade de São Paulo-USP, Instituto de Geociências—Programa de Pós-Graduação em Geoquímica e Geotectônica, Rua do Lago, 562 Butantã 05508-080 São Paulo, SP, Brazil*

Earthen mounds with archaeological artifacts have been well known in Marajó Island since the 19th century. Their documented dimensions are impressive, e.g., up to 20 m high, and with areas as large as 90 ha. The mounds, locally known as *tesos*, impose a significant relief on the very low-lying landscape of this region, which averages 4 to 6 m above present sea level. These features have been traditionally interpreted as artificial constructions of the Marajoara culture, designed for defense, cemetery purposes, or escape from flooding. Here, we provide sedimentological and geomorphological data that suggest an alternative origin for these structures that is more consistent with their monumental sizes. Rather than artificial, the Marajoara *tesos* seem to consist of natural morphological features related to late Pleistocene and Holocene fluvial, and possibly tidal-influenced, paleochannels and paleobars that became abandoned as depositional conditions changed through time. Although utilized and modified by the Marajoara since at least 2000 years ago, these earthen mounds contain a significant non-anthropogenically modified sedimentary substratum. Therefore, the large Marajoara *tesos* are not entirely artificial. Ancient Marajoara cultures took advantage of these natural, preexisting elevated surfaces to base their communities and develop their activities, locally increasing the sizes of these fluvial landforms. This alternative interpretation suggests less cumulative labor investment in the construction of the mounds and might have significant implications for reconstructing the organization of the Marajoara culture. © 2009 Wiley Periodicals, Inc.

INTRODUCTION

Archaeological vestiges are widespread in the Brazilian Amazonia, with Marajó Island, in the northeast of the State of Pará, containing the most impressive sites studied so far, many dating at least 2000 ¹⁴C yr B.P. (Roosevelt, 1991; Schaen, 1997, 2000, 2004; Schaen & Veiga-Silva, 2004). The sites consist of mounds several hundreds of meters long and averaging 3 to 7 m high, but which can locally reach up to 20 m in height. Despite the very gentle undulation, these mounds, locally known as *tesos*, highlight

*Corresponding author; E-mail: rossetti@dsr.inpe.br.

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the landscape of eastern Marajó Island and have been recorded since the late 19th century (Hartt, 1871; Derby, 1879; Ferreira Penna, 1885; Farabee, 1921; Palmatary, 1950; Hilbert, 1952; Meggers & Evans, 1957; Napoleão & Simões, 1963; Meggers & Danon, 1988). Detailed investigations of many of these sites, undertaken in the past three decades, have suggested that they might represent one of the major complex cultures of Americas (Roosevelt, 1988, 1991, 1999; Meggers, 2001; Bevan & Roosevelt, 2003).

The Marajoara archaeological mounds are described as a series of elongated bodies, usually aligned parallel to main streams. Since their discovery, these features have been interpreted as artificial earthen constructions made by ancient Amazonian Indians for defense, funerary residential functions, or as an escape strategy from frequent flooding (Derby, 1879; Roosevelt, 1991).

The present study takes a geological approach to discuss the origin of the Marajoara *tesos*. Although several archaeological mounds have been regarded as entirely artificial (Muller, 1997; Cobb, 2003; Arco et al., 2006), the geological context of the Marajoara archaeological settlements leads to question of whether all *tesos* are in fact entirely artificial in nature, particularly those with anomalously large sizes of several hectares. Previous works have already suggested that not all the Marajoara mounds were man-made, with natural mounds prevailing to the north of the island (Meggers & Evans, 1957:399). Based on geomorphological descriptions provided by ground reconnaissance, remote sensing, and sedimentological data, it is proposed herein that natural mounds also occur on the eastern Marajoara landscape, being produced by the dynamic evolution of fluvial and tidal-influenced channel and bar depositional environments during the late Pleistocene and Holocene. As inhabitants of this island, the ancient Marajoara population might have selectively chosen natural uplands in this alluvial, and possibly tidal-influenced, plain for developing their main living activities. During several occupations, the Marajoara civilization might have built many small earth mounds on top of these natural preexisting hills, locally increasing their natural heights.

The main attempt of this work is to analyze the Marajoara mounds within a geomorphological and geological perspective, taking into account the evolution of paleolandscapes, an approach not frequently included in South American archaeological studies. This type of research has been applied to discuss the origin of archaeological sites from many other areas outside South America (e.g., Martín-Consuegra et al., 1998; Meltzer & Holliday, 2006; Arco et al., 2006; Dickinson & Burely, 2007; Heydar, 2007; Gliozzo, Vivacqua, & Memmi, 2008; Tastet et al., 2008). In this paper, we present a geoarchaeological analysis of the Marajoara mounds, focusing on their geomorphology and stratigraphy, and consequent implications regarding mound origin. We believe that our study may be relevant to understanding similar prehistoric large mounds attributed to human constructions documented in other areas of South America (e.g., Spencer & Redmond, 1992; Plazas et al., 1993).

METHODS

The information provided in this work is based on analysis of remote sensing imagery and sedimentological data. Landsat 5-TM (Ref. 224-060 and 225-061, INPE)

and Landsat 7-ETM+ (Ref. 223-060 and 223-061, GLCF) images, acquired in August 2001, were processed using compositions 4(R), 5(G), 7(B) and 5(R), 4(G), 3(B), which better highlighted the morphological features of interest for this study. This is due to the fact that the study area is mostly represented by exposed soil or open vegetation, mostly grassland savannas known as the Marajó open fields. Where present, forests are systematically developed over paleochannel areas.

The sedimentological data consisted of detailed descriptions of outcrops and cores collected in shallow drills using an RKS percussion drilling system, model COBRA mk1. This system allowed sampling of 5-cm-diameter cores up to a depth of 25 m. Additionally, one 120-m-deep core was obtained using a rotating drill. Descriptions included definition of sedimentary facies based on characteristics such as lithology, texture, and structure, which were recorded in lithostratigraphic profiles.

The paleochannel chronology was determined through radiocarbon analysis undertaken at the Beta Analytic Radiocarbon Dating Laboratory. Samples of peat, wood, and organic sediments extracted from cores were dated by scintillation spectrometer or, for small samples, accelerator mass spectrometer (AMS). The samples were pretreated with acid to remove carbonates and acid-soluble organics, washed with alkali to remove base-solid organics, and then re-acidified. Conventional ^{14}C ages were calibrated to calendar years using the Pretoria Calibration Procedure program, based on tree-ring data (Talma & Vogel, 1993).

PHYSIOGRAPHY AND GEOLOGY

Marajó Island encompasses a large area of up to 400,000 km² located at the mouth of the Amazon River. This region has an overall low-relief morphology, with the eastern part of the island displaying altitudes averaging only 4–6 m above modern sea level. Climate in this area is tropical, with mean annual temperature of 28°C and precipitation of 2500 to 3000 mm/yr. Vegetation is dominated by wet lowland forests to the west and a mosaic of wet lowland forests and open grasslands to the east of the island.

According to available geological maps, the majority of eastern Marajó (Figure 1) is covered by mostly late Pleistocene to Holocene alluvial sediments. Remote sensing mapping, combined with geological fieldwork, reveals that these are preserved in numerous paleochannels and, subordinately, related paleobars, the latter especially abundant in the eastern margin of Lake Arari (Figure 1). Previous studies have documented these features at Marajó Island (e.g., Bemerguy, 1981; Porsani, 1981; Vital, 1988), and recent studies have described them in more detail, providing a model to explain their evolution (Rossetti & Valeriano, 2006; Rossetti, Valeriano, & Thallês, 2007). In addition to paleochannels, recent work has also recognized that Lake Arari is developed upon a former estuary that became abandoned on the Marajó landscape, forming a typical funnel-shaped channel palimpsestic morphology (Rossetti, Valeriano, & Thallês, 2007). It is noteworthy that many archeological sites are located around this lake.

The paleochannels, which dominate in eastern Marajó, are represented by a series of continuous or locally discontinuous, elongated, and slightly sinuous belts displaying widths up to 1.2 km, with individual channels averaging 0.6 to 0.9 km wide

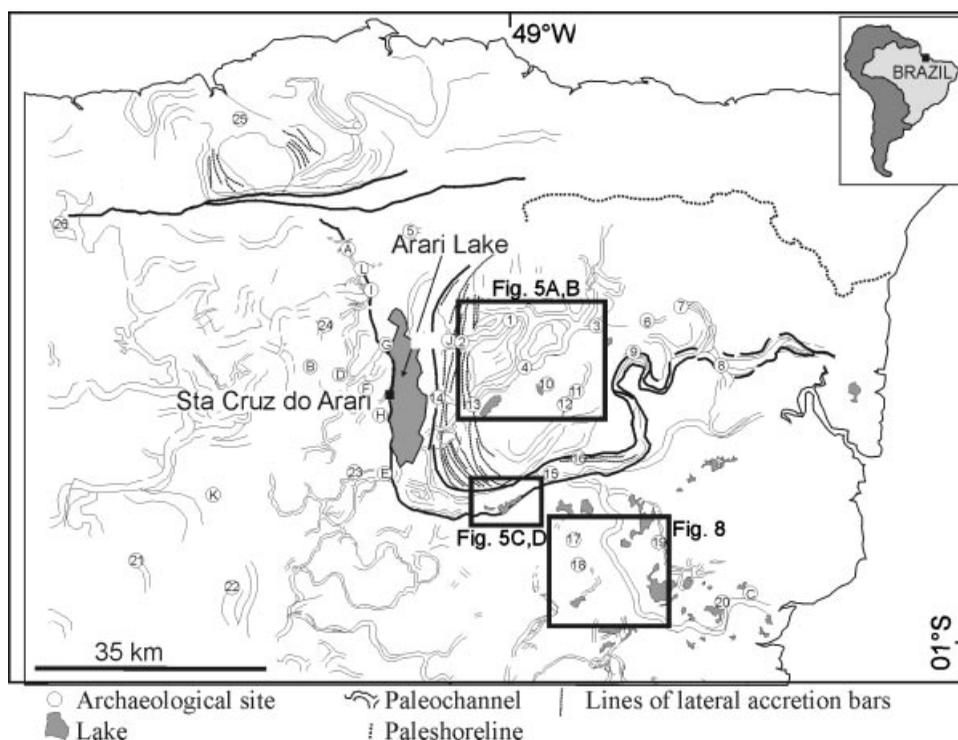


Figure 1. Location map of the study area in eastern Marajó Island, northern Brazil, with indication of paleochannels and paleobars recognized through remote sensing imagery. Numbers 1 to 26 mark the archaeological sites, as follows: 1. Sanharão; 2. Diamantina; 3. Matinados; 4. Sítio Pacoval; 5. Santa Luzia; 6. Laranjeiras-Desterro; 7. Macacão; 8. Curuxis; 9. Tapera; 10. China; 11. Pacoval dos Melos; 12. Caratateua; 13. Severino; 14. Pacoval de Arari; 15. Fortaleza; 16. Ilha de Fogo; 17. Bichos; 18. Taperebá; 19. Ilha dos Marcos; 20. Ilha de Casinhas; 21. Camutins; 22. Monte Carmelo; 23. Santa Brígida; 24. Nazaré; 25. Cajueiros; and 26. Pacoval do Cururu. Letters A to L mark the location of stratigraphic profiles, with the radiocarbon ages presented in Table I. The inside boxes locate Figures 5 and 8.

(Figures 2a, b). Unfortunately, topographic data at the resolution of a few meters, as requested for this work, are not available for the Amazonia region, but digital elevation models provided by the Shuttle Radar Topography Mission (SRTM) reveal that areas corresponding to paleochannels form smooth, convex-up morphologies, with heights of a few meters above adjacent areas (Figure 2c). In part, this is mostly due to differences in vegetation from forest to savanna over the paleochannel and surrounding floodplain areas, respectively. However, fieldwork revealed that the ground surface is systematically convex up over the entire paleochannel areas, which helped to increase the SRTM signal (Figures 2d, e). Additionally, ground investigation undertaken in western Marajó Island provided detailed topographic data further attesting that the paleochannels are, in general, higher (usually 4 to 5 m higher) than surrounding areas (Mantelli, 2008). Therefore, considering an average topography of 20 m indicated by SRTM data (Figure 2c), at least 15 m should reflect tree height.

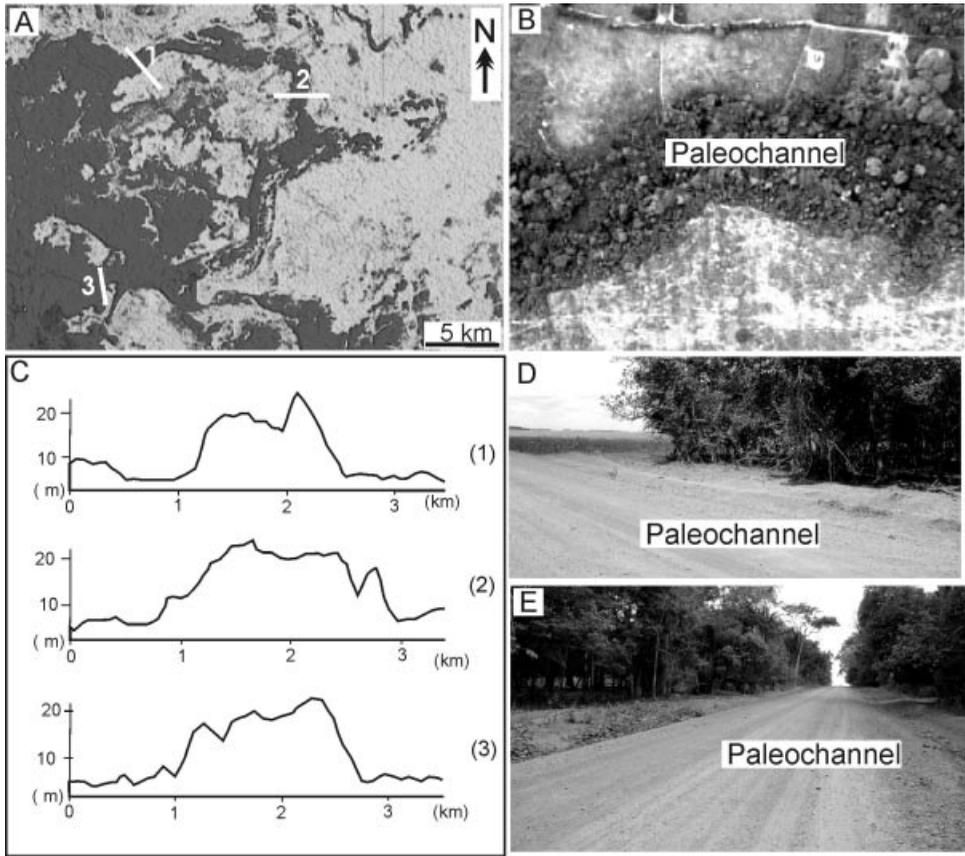


Figure 2. Characterization of paleochannels in the study area. (a) SRTM data illustrating typical paleochannels from Marajó Island, with darker colors indicating progressively higher topography. (b) Aerial view of a sinuous morphology highlighted by dense vegetation that contrasts with surrounded grassland areas. (c) Topographic profiles derived from SRTM data, which intercept transversally paleochannels areas (see Figure 2a for profile location). As observed during field surveys, the topography is exaggerated in at least 15 m due to the effect of vegetation cover. (d, e) Views of a road cutting through a vegetated sandy paleochannel. Note in 2e that, in addition to vegetation cover, the paleochannels are slightly convex up due to a true smooth terrain relief of a few meters. The background in 2d consists of low-lying muddy deposits.

The paleochannels form an interconnected drainage network characterized by slightly meandering to anastomosing patterns (Figure 1). Many channels have been disconnected, forming several segments that are still aligned, allowing the channel morphology to be reconstructed (Figure 3). A common feature is the intersection of paleochannels by modern channels, which are usually smaller than their ancient counterparts. In addition, many segments of paleochannels might continue into the modern drainage, indicating their partial abandonment.



Figure 3. A meandering paleochannel morphology (hatched lines) that has been segmented and slightly displaced due to the superposition of modern channels (black lines).

The paleochannel deposits consist of sandy, heterolithic, and muddy facies, typically fining upward (Figures 4a, b). The sandy deposits display normal grading of coarse to medium and fine to very fine grain sizes. These strata range in color from medium gray to brown in subsurface and, more rarely, white to pale yellow and yellow to dark brown near the surface, due to iron staining. Sands are, in general, well to moderately sorted, rounded to subrounded, and fine- to medium- or medium- to coarse-grained. When present, the dominant sedimentary structures consist of parallel and cross lamination or small to medium-scale cross stratification; otherwise, sands are massive. The sandy deposits are interbedded with or grade upward into muds, forming heterolithic facies. This consists dominantly of thin streaks or lenses of well-sorted, silty to fine-grained sands and gray muds. Sandier heterolithic deposits locally form flaser bedding. The heterolithic deposits may grade into either massive or laminated mud facies that might contain disperse plant debris.

Deposits laterally correlatable to the paleochannel successions are dominantly muddy, comprising laminated and massive mud and heterolithic facies similar to the ones recorded at the top of the fining-upward cycles described above. Thicker layers and lenses of well-sorted, fine- to very fine-grained sands are locally present within the muddy deposits, forming either fining or coarsening upward cycles.

Nineteen radiocarbon dates (Table I), obtained from organic sediment, charred material and peat contained within the cores, recorded ages up to 40,000 ^{14}C yr B.P. for the paleochannel, paleobar, muddy floodplain, and estuarine deposits (Rossetti, Valeriano, & Thallês, 2007; Rossetti et al., 2008b). Among these, five samples are late Pleistocene in age, while the remaining samples record Holocene deposition. Deposits

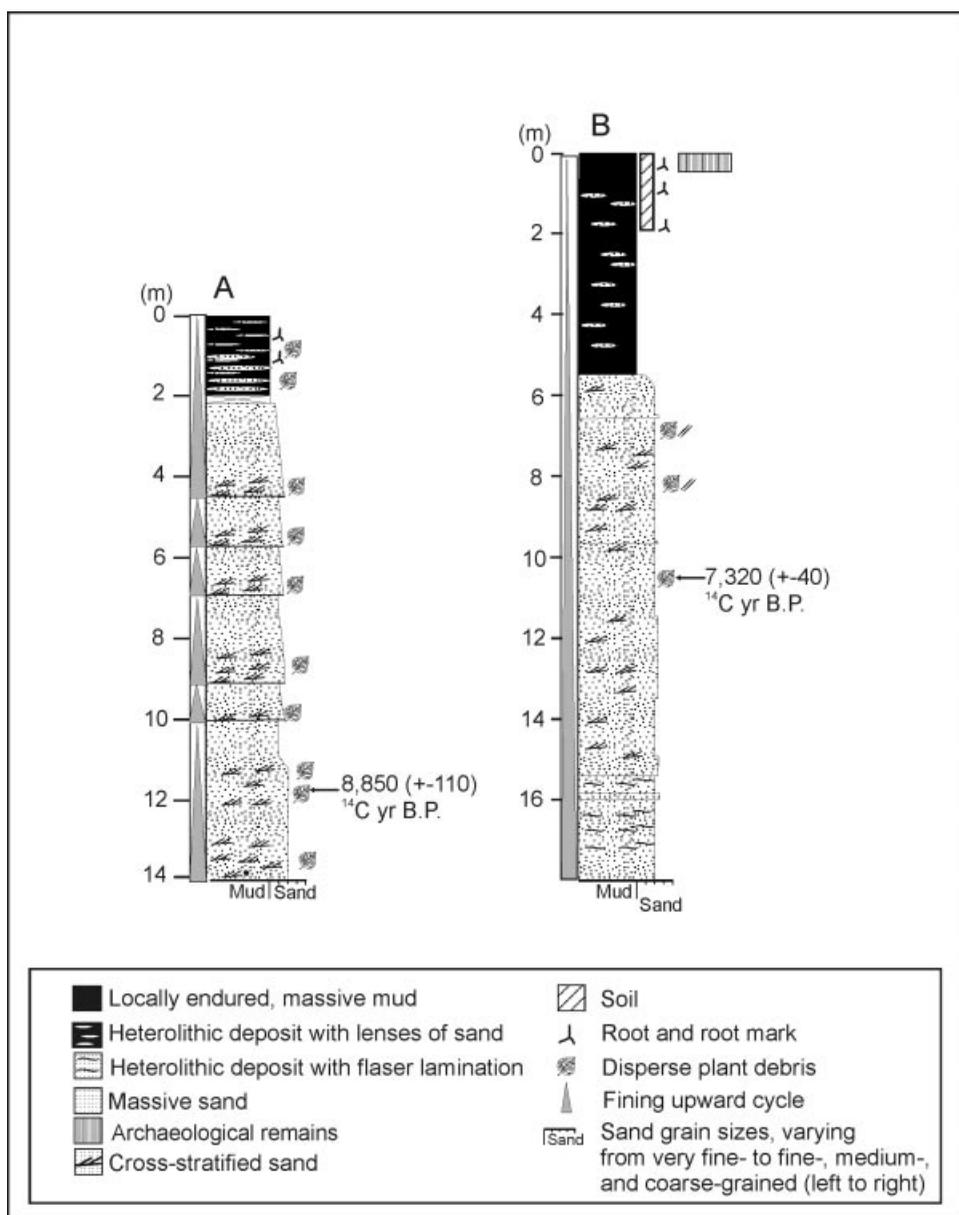


Figure 4. (a, b) Lithostratigraphic profiles representative of two paleochannels in Marajó Island. Note the prevalence of sand deposits at the base, which grade upward into muds, forming fining-upward cycles, the recorded radiocarbon ages suggesting channel fill during the early Holocene, and the human artifacts at the top of profile 4b.

Table 1. Radiocarbon ages for the sedimentary successions studied in Marajó Island.

Profile	Depth (m)	Location	Type of Material	¹⁴ C yr B.P.	Cal yr B.P.* (Type of Analysis)
A	0.7	0°27'08.49"S/49°13'49.77"W	organic sediment	3500 ± 40	3870–3670 (AMS)
B	0.8	0°36'36.65"S/49°16'24.02"W	peat	4370 ± 50	5050–4840 (radiometric)
C	1.3	0°55'30.39"S/49°39'48.51"W	peat	6190 ± 60	7250–6900 (radiometric)
	17.8		organic sediment	41,080 ± 810	(AMS)
D	2.4	0°37'02.36"S/49°14'15.38"W	wood	3960 ± 40	4520–4290 (radiometric)
E	2.6	0°36'09.95"S/49°11'28.37"W	wood	5520 ± 60	6410–6200 (AMS)
F	4.7	0°39'28.90"S/49°11'00.09"W	wood	4770 ± 40	5600–5460; 5380–5340 (AMS)
G	7.7	0°35'29.81"S/49°10'21.53"W	organic sediment	7450 ± 40	8360–8180 (AMS)
	12.5		organic sediment	42,580 ± 1,430	(AMS)
H	7.8	0°40'48.59"S/49°10'57.52"W	organic sediment	7900 ± 40	8980–8820; 8800–8600 (AMS)
	50.6		organic sediment	30,560 ± 330	(AMS)
	76.0		organic sediment	30,360 ± 250	(AMS)
	117.0		charred material	>40,200	(AMS)
I	8.8	0°31'02.44"S/49°12'09.50"W	peat	6630 ± 70	7610–7420 (radiometric)
	9.8		peat	6690 ± 60	7940–7680 (AMS)
	10.6		organic sediment	9770 ± 70	11,250–11,100 (AMS)
J	10.3	0°35'26.27"S/49°03'50.12"W	plant remains	7320 ± 40	8190–8020 (AMS)
K	12.0	0°48'39.70"S/49°22'52.22"W	peat	8850 ± 110	10,220–9550 (radiometric)
L	12.5	0°26'30.57"S/49°14'28.33"W	peat	6300 ± 80	7410–7000 (radiometric)

*2 sigma calibration using INTCAL04 Radiocarbon Age Calibration.
See location of profiles A to L in Figure 1.

displaying Holocene ages are found down to 12.5 m depth, while older deposits occur mostly below this depth.

Both remote sensing and sedimentological data are consistent with the prevalence of channel systems, which were mostly developed during the late Pleistocene and Holocene in eastern Marajó Island. First, the channel morphology reconstructed in the Landsat imagery conforms perfectly with a drainage network. Second, the described deposits are related to confined flows, as is typical of sedimentary channel successions. The lower sandy portion of the cycles are attributed to higher-energy sediment bedload deposition during active channel development, while the upper muddy deposits are related to sediment deposition from suspensions during channel abandonment, when flow energy was dominantly low. The channels became abandoned as Marajó Island was detached from the mainland, and significant continental inflows were cut off due to tectonic causes (Rossetti & Valeriano, 2006; Rossetti et al., 2008a). In addition to these works, there are many others (e.g., Costa & Hasui 1997, Costa et al., 1995, 2001; Bemerguy et al, 2002; Bezerra, 2003) demonstrating that, despite the location in a passive margin, the Brazilian Amazon shows frequent evidence of Tertiary and Quaternary fault reactivation. The continuity of tectonic activity dominated by lateral displacement after channel abandonment resulted in the break up of many of these features, producing the several disconnected segments that were recognized in the study area.

RELATION TO THE MARAJOARA ARCHAEOLOGICAL SITES

The main point of interest to be addressed is the coincidental occurrence of paleochannels and paleobars with the archaeological settlements in eastern Marajó Island, which are highly concentrated east of Lake Arari, where paleochannel density is the highest (Figure 1). Additional sites are dispersed throughout the study area, but always associated with sedimentary deposits that are elevated above in the Marajoara landscape. The archaeological sites occur as several small earthen mounds situated atop these natural elongated and locally sinuous elevations (Figures 1, 5a–d).

Most of these archaeological sites are younger than approximately 2000 ¹⁴C yr B.P. (Roosevelt, 1991, Schaan, 1997, 2000, 2004; Schaan & Veiga-Silva, 2004), and are found on smooth hills consisting mostly of sands, though a mixture of sediments varying from sands to muds might be present. These sediments have an average depth of 2–3 m in most of the sites, but elevations might be higher, reaching up to 20 m above present nearby floodplains in some sites (Roosevelt, 1991).

This pattern is well represented at Teso Santa Luzia and vicinity. This area displays a complex modern drainage distribution, consisting of a series of either continuous or segmented paleochannels that are intercepted by modern channels (Figure 6a). The *teso* itself is part of a nearly 2-km-long and few tens of meters wide segment of paleochannel (Figure 6a). In this area, archeological vestiges are confined to a smooth, elongated, sandy hill that stands 2–3 m above surrounding muddy flood plains (Figure 6b).

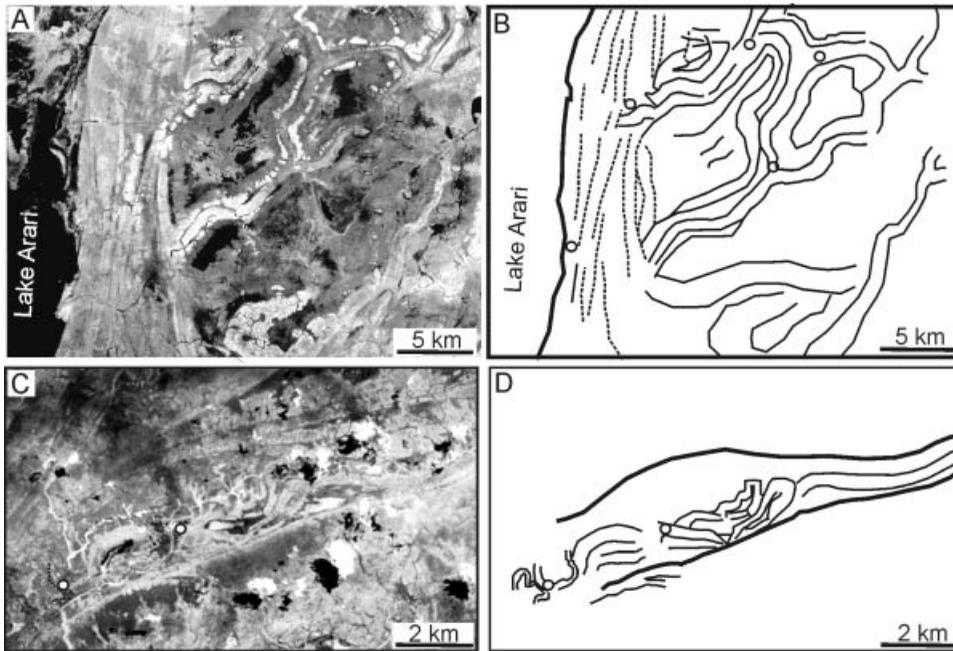


Figure 5. (a–d) Landsat 4(R), 5(G), 7(B) composition showing examples of paleochannel deposits from eastern Lake Arari (5a, c), with corresponding drawings (b and d, respectively), which typically contain archaeological earthen mounds at their tops (see Figure 1 for location). Circles denote archaeological sites.

An 18-m-thick continuous sediment core obtained at Teso Santa Luzia shows that human artifacts are confined to the topmost portions of the hills. Archeological vestiges occur in two horizons, one within the first 0.6 m and the other one between 1 and 1.8 m (Figure 7a). These beds are interbedded with thin sediment layers displaying well-preserved primary structures (i.e., stratification produced by water flows), and lack any evidence for anthropogenic disturbance. These deposits consist of flaser bedded and cross-laminated/stratified sands alternated with wavy and lenticular heterolithic beds and muds (Figures 7b–d), forming several fining- and, less commonly, coarsening-upward cycles that are inserted in a main coarsening- and thickening-upward succession. It is interesting to mention that this core is located in the outermost (i.e., seaward) portion of the palimpsestic estuarine setting that formed before the establishment of Lake Arari. In this area, tidal bars are a common depositional setting. Unfortunately, sedimentary structures diagnostic of tidal processes could not be recognized, but the overall facies organization is consistent with a bar setting, upon which channels became established after the estuary abandonment. The recognition of many primary sedimentary structures, which are recognized at 2.5 m below surface, and the arrangement of the lithologies forming typical fining- and coarsening-upward successions (Figure 7d), attest that these deposits have not been disturbed after deposition. Below the horizon bearing human artifacts,

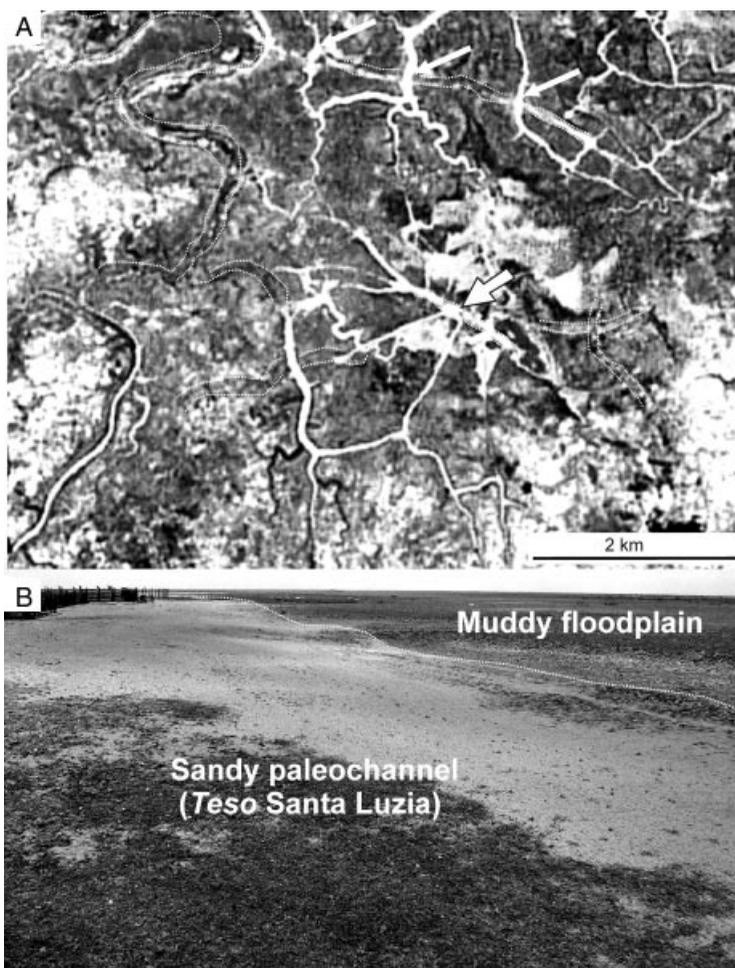


Figure 6. Teso Santa Luzia. (a) Landsat image derived from Google Earth illustrating the area surrounding the *teso* (large arrow), which is marked by several paleochannels (white dotted lines) that are locally segmented by a complex modern drainage network (narrow arrows indicate places of channel interception). Some modern channels show segments that are partly abandoned. Teso Santa Luzia records one these abandoned channel segments that is presently intercepted by active channels. (b) General view of the *teso* (see white arrow in 6b for location; see also Figure 1), illustrating the smooth relief (overall of a few meters) of sandy deposits, attributed to paleochannels, in contrast with surrounding muddy floodplain deposits, which is still the locus of sediment deposition during flooding periods.

there are only undisturbed sedimentary deposits related to channel and bar settings that might be interbedded with muddy deposits related to floodplain and central estuarine settings. The bars naturally form a positive relief in the landscape, and although channels are depressions made by flow scouring, their resulting deposits also form a smooth positive relief in the Marajoara landscape. In part, this is due to the presence of natural levees around channel margins. However, the convex-up

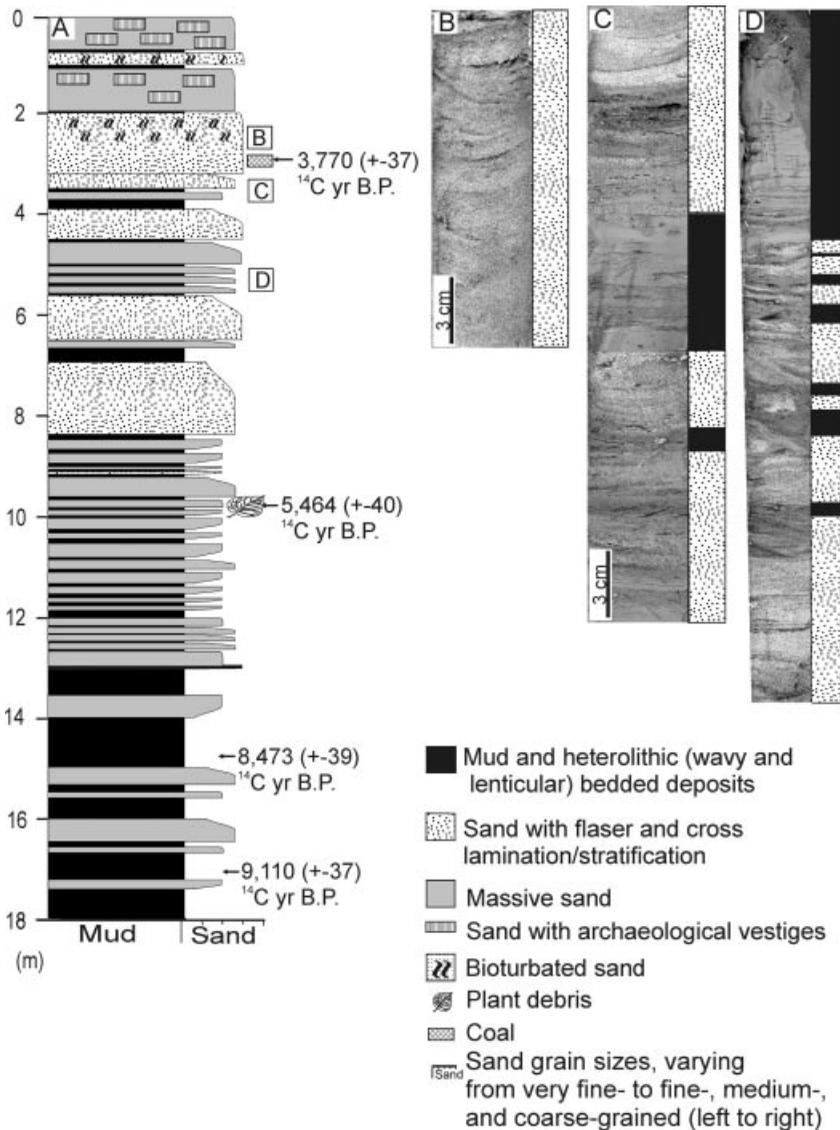


Figure 7. Sedimentology at Teso Santa Luzia, obtained from one continuous core that is up to 18m thick. (a) Lithostratigraphic profile from the core obtained in a paleochannel, illustrating the internal arrangement of the deposits into fining upward cycles formed by the upward gradation from massive or flaser laminated sands to mud or heterolithic (wavy and lenticular) bedded deposits. Note, at the top of the profile, the two intervals with archaeological vestiges, which are interbedded with anthropogenically undisturbed sediments. (b-d) Details of the profile shown in 7a, illustrating the sedimentary facies in three intervals (see locations b-d in 7a), with typical preservation of primary structures, mostly including flaser and cross lamination alternated with lenticular/wavy bedding and muds. Note in 7d that these facies are organized configuring a typical fining-upward succession.

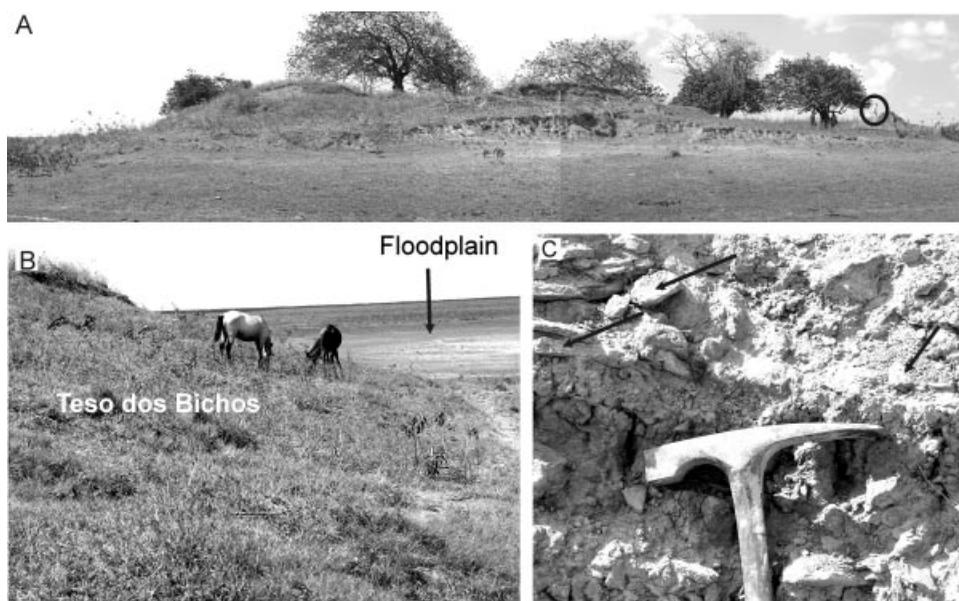


Figure 8. Teso dos Bichos. (a) General view. Circle indicates a person for scale and also the position of the lithostratigraphic profile shown in Figure 9. (b) Detail at the edge of the *teso*, illustrating its higher topography related to surrounding floodplains. (c) Detail of the interval with archaeological artifacts (arrows).

morphology is recorded over the entire paleochannel width, even along the central axis where deposits are dominantly sandy. This leads to the hypothesis that, together with natural levees, lithologic contrasts between sandy (channel) and muddy (flood plain) deposits might have promoted a differential compaction of the terrain, resulting in elevated paleochannel areas due to the less cohesive nature of sands relative to muds.

Although the majority of the Marajoara anthropogenic earthen mounds are associated with continuous paleochannels and bars, there are a few exceptions. A good example is the Teso dos Bichos, one of the best studied archaeological sites in Marajó Island (Roosevelt, 1991). This site (Figures 8, 9) is less than 8 m higher than surrounding floodplains and 150 m long, corresponding to an area of ca. 3 ha. It consists of a single elongated and slightly sinuous hill at the margin of an ephemeral channel. Human vestiges are found deeper in this site than in Teso Santa Luzia, although they are absent in the lowermost part of the mound. These artifacts occur in red sands within the upper 4 m, which overlie 0.3-m-thick package of a mottled sandy pelite related to a paleosol (Figure 8). The paleosol occurs at the top of a 1.0 m thick package of gray, fine-grained, massive sandstone that has a sharp, erosive base mantled by clasts of ferruginous sandstones and laterite. The lowermost portion of the hill is buried. Many paleochannels occur in this area, forming two drainage systems, characterized by large and narrow channels (Figures 10a, b). While many

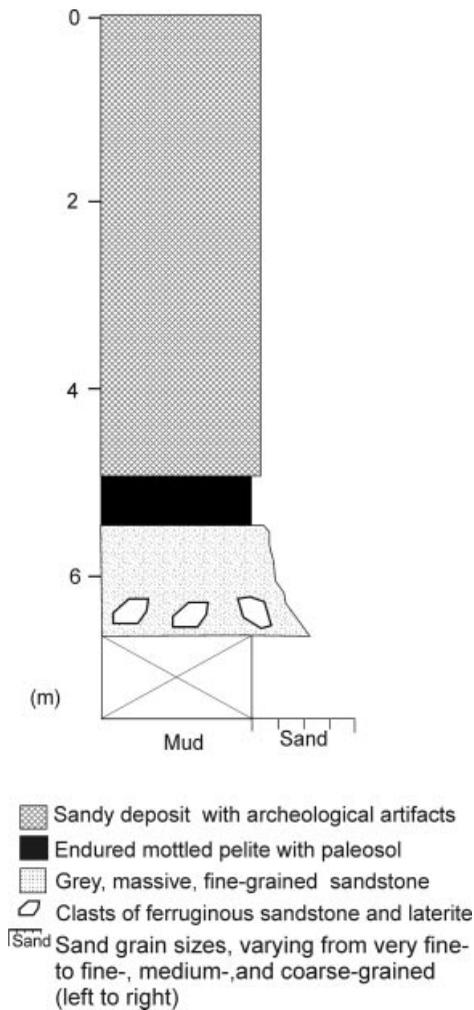


Figure 9. Lithostratigraphic profile from Teso dos Bichos (see Figure 1 for location), illustrating the superposition of sandy deposits with archaeological artifacts on anthropogenically non-modified sedimentary deposits. These are composed by a package of fine-grained massive sandstone sharply based by an erosive surface, which grade upward into mottled pedogenic massive pelite.

paleochannels are perfectly preserved on the landscape, forming continuous belts, others have been strongly displaced laterally and vertically due to tectonics, resulting in isolated short segments. Of interest is that these are still aligned, allowing delineation of the primary channel morphology.

DISCUSSION AND CONCLUSION

The origin of the Marajoara mounds has been a matter of debate among authors, who have defended that they are either mostly human constructions (e.g., Roosevelt, 1991),

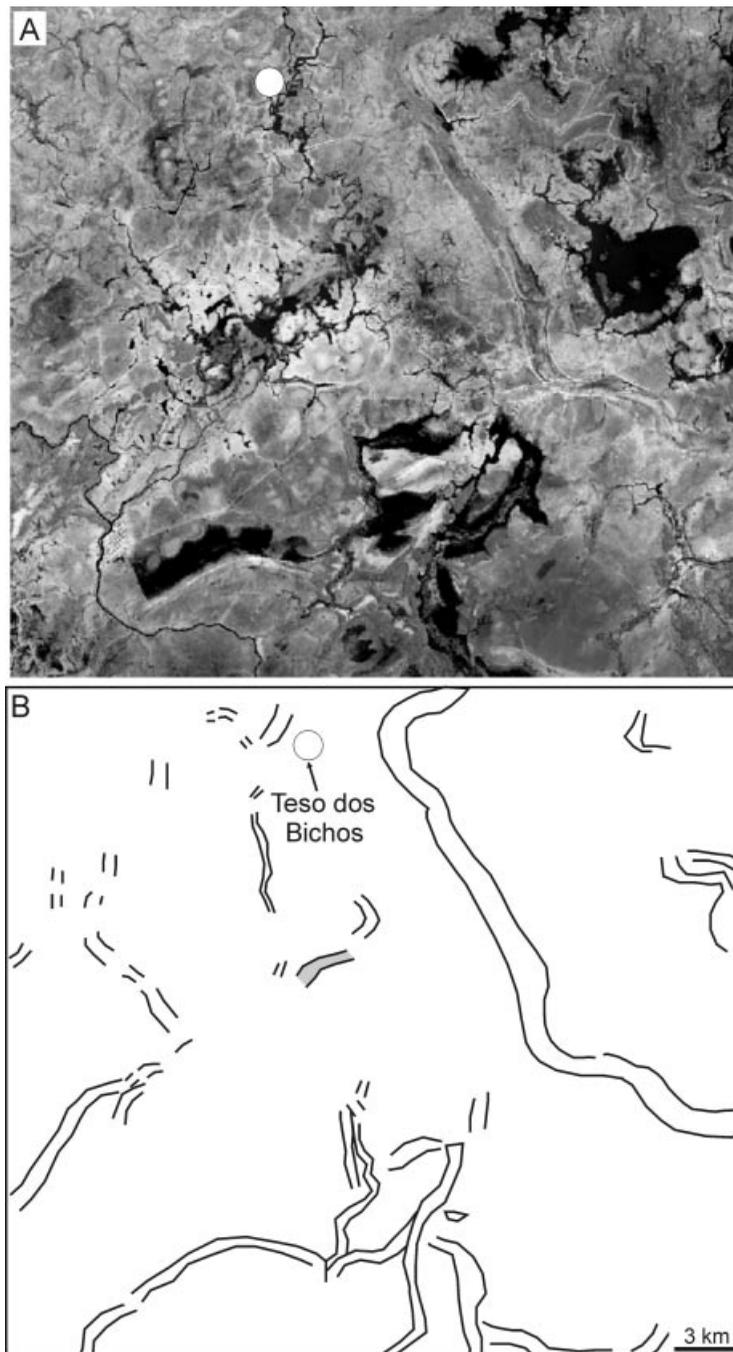


Figure 10. A Landsat 4(R), 5(G), 7(B) composition (a) with the corresponding drawing (b) illustrating an abundance of both continuous and segmented paleochannels in the vicinity of Teso dos Bichos, located to the east of Lake Arari. (See Figure 1 for location.)

or mostly natural elevations (e.g., Meggers & Evans, 1957). The combination of remote sensing and sedimentological data presented herein leads us to agree with the latter interpretation, defining these mounds as mostly natural elevations that were augmented by Marajoara earth-building activities.

There are many references to large mounds related to human activity in archaeological literature. For instance, Monk's Mound, the largest prehistoric earth mound in the Americas, has an unequivocal artificial origin (e.g., Muller, 1997; Cobb, 2003). Furthermore, there are many other artificial mounds documented in several areas of South America (Spencer & Redmond, 1992; Plazas et al., 1993). Despite evidence for a large amount of anthropogenic activity in Marajó Island, the geological context suggests that the Marajoara population was not responsible for the complete construction of earthen mounds.

Many ancient civilizations were motivated, for different reasons, to expend great effort in building impressive monuments. In the particular case of the Marajó mounds, the effort required to build so many mounds in their entirety, with average sizes of 3 to 5 ha, and the largest mounds attaining areas of 50 to 90 ha, would have been enormous. Such large mounds would require the removal, transport, and placement of approximately 630,000 m³ of earth (equivalent to about 105,000 full trucks). A great effort would have been needed for raising such structures, particularly taking into account that each settlement was composed of only a few thousand people, at most, and a few hundred people at smaller sites (Roosevelt, 1991; Bevan & Roosevelt, 2003; Schaaf, 2003, 2004). Comparisons with other historical human feats lead us to conclude that this would not have been impossible. However, Meggers and Evans (1957) raised the possibility that at least some of the Marajoara mounds, i.e., those from the northern part of the island, are natural features (Meggers & Evans 1957:399), a hypothesis also used to explain similar mounds in other areas of South America (Dougherty & Calandra, 1981, 1984). Our geological data support a non-artificial origin for most of the volume contained within the Marajoaran mounds, suggesting that humans utilized natural elevations on the landscape to establish their settlements and develop their living activities. There are several reasons to sustain this hypothesis. One is that not all of the Marajoaran mounds contain archaeological vestiges. In addition to the natural mounds recorded by Meggers and Evans (1957), eastern Marajó also displays a large number of mounds that are devoid of any preexisting human disturbance. The lack of evidence for human activity in many Marajoaran mounds, and their alluvial pattern and geomorphology, suggests that these features are in great part hills resulting from natural processes. Archaeological artifacts are systematically confined to the topmost portions of the *tesos*. This points to a natural origin for the middle to lower portions of these features, indicating that humans established communities atop preexisting elevated landforms.

Another important observation in support of a natural origin for the Marajó mounds concerns their lithology. The surface of many mounds, including those with archaeological remains, consists entirely of well-sorted, fine- to medium-grained sands, as in Teso Santa Luzia (Figure 6). In these instances, sands occur atop of the elongated mounds, but they are not found in adjacent areas, where muddy deposits dominate. Considering the hypothesis of artificial mounds, a question that arises is, from where

were all the large volumes of sand needed to build the mounds derived? In addition, the drill made on Teso Santa Luzia revealed that the sedimentary deposits atop of the mound display good preservation of physical sedimentary structures below a depth averaging only 1 to 3 m. This indicates that even mounds with archaeological artifacts had a natural foundation.

Many of the researchers who defend an artificial origin for archaeological mounds have claimed that these features were built chiefly for humans to escape from frequent flooding (Nordenskiöld, 1916; Meggers & Evans, 1957; Roosevelt, 1991; Erickson, 2000; Bevan & Roosevelt, 2003). For the particular case of Marajó, both archaeological and nonarchaeological mounds stand above flooding level. This fact leads us to support the hypothesis that the Marajoarans chose these highlands in order to escape from any eventual flooding, using these preferential sites for establishing their settlements, as modern Marajoara inhabitants are still obliged to do.

Therefore, we propose that the archaeological settlements associated with isolated or compound mounds were systematically developed on top of extensive elevated surfaces formed due to natural sedimentary processes. The extensively elongated mounds are, at least in part, related to the dynamic evolution of the Marajoara landscape, recording different phases of sediment deposition in channels and bars as they were abandoned due to changes in depositional conditions. The abandoned channels and bars have naturally produced a smooth topography, with some deposits occurring at higher elevations than others. Although previous investigators mentioned that many archaeological mounds in South America are located on abandoned channels (e.g., Roosevelt, 1991; Erickson, 2000; Bevan & Roosevelt, 2003), they have not adequately considered natural processes for the mounds' origins.

The strong relationship of abandoned channels or bars and ancient Marajoaran settlements leads us to propose that human activities had a lesser role in the origin of the Marajoara mounds than originally thought. This statement is grounded in an analysis of the archaeological data within a geological framework, particularly considering the dynamic evolution of the depositional settings. Most of the mounds are natural morphological features related to the dynamic evolution of riverine depositional settings during the latest Pleistocene and Holocene. Teso dos Bichos is apparently one case where the mound does not conform to a channel morphology. However, this site occurs within an area displaying several paleochannel segments, which leads us to invoke a fluvial origin. The paleochannel might have been segmented in this place due to the influence of tectonic reactivations. Marajó Island has strong evidence for tectonic disturbance, which has continued into recent times, a process that has resulted in lateral displacement of many abandoned channels, as illustrated in Figure 3 (see also Miotto, 1981; Costa & Hasui, 1997; Bemerguy et al., 2002; Rossetti & Valeriano, 2006; Rossetti et al., 2008a). This could explain a few archaeological earthen mounds where a channel or bar morphology cannot be promptly recognized, which might be the case of Teso dos Bichos. Despite the thick interval with archaeological artifacts in Teso dos Bichos, the anthropologically non-modified sedimentary succession at the base of this site is consistent with the presence of a natural elevation before human occupation. The sharp base of the sands, marked by a lag of clasts, and the upward gradation into pelites modified by pedogenesis, is coherent

with a channel fill deposition, followed by abandonment, when vegetation became established over the paleochannels, forming the paleosol horizon.

Outside of areas that have been cored, the internal stratigraphy of the Marajoara mounds is not well known. Geophysical studies were carried out in some mounds (e.g., Roosevelt, 1991; Bevan & Roosevelt, 2003), but these have low potential for distinguishing natural and human-constructed deposits (Dalan & Bevan, 2002). Therefore, the integration of geomorphological, sedimentological, and stratigraphic studies recorded herein provides additional data that are significant for understanding the establishment of the Marajoara archaeological mounds.

To conclude, paleochannels served as a substratum for Marajoara population to develop their living activities, which are preserved as isolated or grouped earthen mounds of much smaller scale than the associated highlands naturally formed throughout Marajó Island. Hence, much of the mounds' monumental sizes are natural rather than cultural. Geological and remote sensing data presented here might contribute to the formulation of further hypotheses aiming to reconstruct ancient Marajoara society and improve interpretations of similar mounds from other areas in South America.

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