Applying SRTM topographic data to characterize a Quaternary paleovalley in northern Brazil

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Abstract Morphologic features obtained from SRTM data, integrated with geologic information, are emphasized in this paper in order to provide the basis for understanding the development of the lowest Amazon drainage basin, focusing on the history of one of the largest Amazonian tributaries, the Tocantins River, and on the origin of the Marajó Island, throughout the Quaternary. This approach led to the recognition of a fan morphology related to the record of a tectonically controlled N/NW-S/SE orientated paleovalley cut down into Miocene and older rocks. The incised valley was fed by a paleo Tocantins River, which deposited its sediment load continuously to the north-northwest, reaching the Marajó Island and producing a deposit with a fan-morphology during the Plio-Pleistocene/Pleistocene. As characterized in the SRTM images, this channel system became abandoned due to capture by NE-SW orientated faults and establishment of the Pará River by W-E strike slip movements. This event, which probably took place in the Mid-Holocene, was responsible for the detachment of the Marajó Island from the mainland.

Keywords: SRTM imagery, topographic model, landscape evolution, Quaternary, Amazonian, geology.

1. Introduction

The lack of detailed studies, the great size and, many times, the inaccessible nature of Amazonia, are aspects favorable for the application of remote sensing as an important tool for the characterization of the physical environments in this area (Moran and Brondizio, 1994). Given that processes involving sediment transport, erosion and weathering are directly imprinted in the land surface, the study of morphological properties is important to help understanding the geological history in this area. In particular, interpretations derived from remote sensing data might be of great help for identifying features of the physical environment developed throughout the Quaternary, as these have a great potential to be still preserved on the modern landscape.

In this paper, a general morphologic characterization of the lowest Amazon drainage basin is provided with basis on the interpretation of data provided by the Shuttle Radar Topographic Mission (SRTM). Application of this resource had the advantage of furnishing digital elevation information with a minimum influence of vegetation and perennial clouds, both representing major problems when using other remote sensing imagery (i.e., Landsat) in the Brazilian Amazonia (Asner 2001). The goal was to combine spatial analysis with geological data available in the literature in order to: 1. create the basis for discussing the geologic history of this area during the Late Tertiary-Quaternary, attempting to reconstruct the evolution of one of the main Amazon tributary in its lower course, the Tocantins River; and 2. understand the origin of the largest fluvial island in the world, the Marajó Island. Herein, it is also discussed how tectonic reactivations have contributed to the geological evolution of this area.

3. Methods

This work was based on the integration of geological information available in the literature and new morphologic and topographic data derived from SRTM-90 data. These were downloaded in August 2003 from USGS Seamless Data Distribution System (http://srtm.usgs.gov/data/obtainingdata.html), in the first version, now known by "unfinished" dataset, in TIFF format. Though seamless in its origin, SRTM data were downloaded in tiles corresponding 1:250,000 quads to facilitate storage and avoid overflow. More information about SRTM data is presented by Rabus *et al.* (2003), as well as an increasing number of papers dealing with it.

SRTM-90m data were resampled (from 3" to 1") in order to achieve improvements for morphometric derivations, as well as interpretation in detailed scales. This procedure followed a geostatistical approach through kriging, using the following computational programs: ENVI (Research Systems Incorporated 2002) for failure correction, sampling and ASCII data export; MINITAB® (MINITAB Incorporated 2000) for trend analysis and calculation of residues; VarioWin (Pannatier 1996) for geostatistical analysis; and Surfer (Golden Softwar 1995) for kriging interpolation. These procedures, depicted in Valeriano *et al.* (2006), were shown to improve the results of derivative techniques. Consequently, shaded relief presentations (which are essentially a function of the derivatives slope angle and aspect), were also improved, with significant gains for visual interpretation (**Figure 1**).

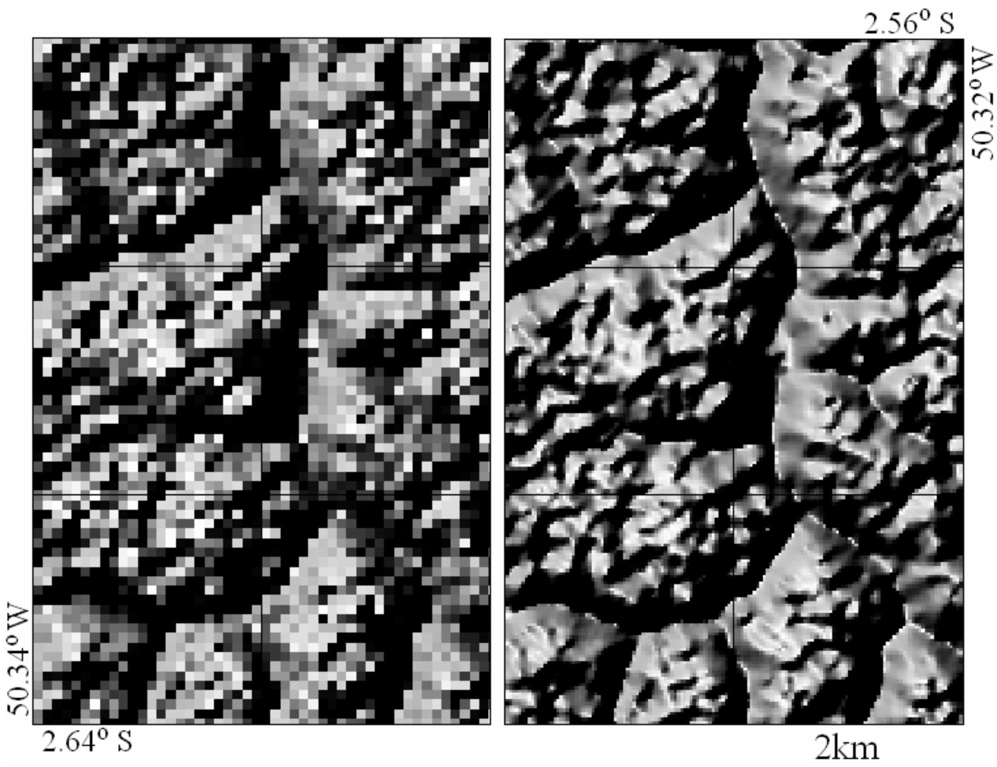

Figure 1: Shaded relief of SRTM-90m original data (left) and resampled DEM (right).

Image interpretation of elevation data was made possible by the use of the software Global Mapper (Global Mapper Software LLC). Given the very low topography, the study area had to be visualized accordingly using customized shade schemes and palettes to efficiently highlight the morphologic features of interest to this paper. Color schemes were rearranged to present strong hue transitions near the height of terrain units boundaries, often requiring adjustments from a local to another.

4. Morphologic characterization

Extensive previous, combined with the analysis of the available geological maps, reveal that deposits of Pleistocene, and possibly also Plio-Pleistocene ages, referred generically as the Post-Barreiras Sediments, prevail in the study area. These strata define a NNW/SSE elongated belt that starts southward at the locality of Tucuruí, and spreads out continuously northward from the mainland, reaching the southwestern and central parts of the Marajó Island (**Figure 2**). Because in plan view these deposits display a triangular shape that defines a morphology resembling a fan, this term will be used throughout the text for descriptive purpose only. The fan-like feature characterized below is sharply entrenched into rocks that vary northward from Paleozoic, to Cretaceous, and then Miocene ages.

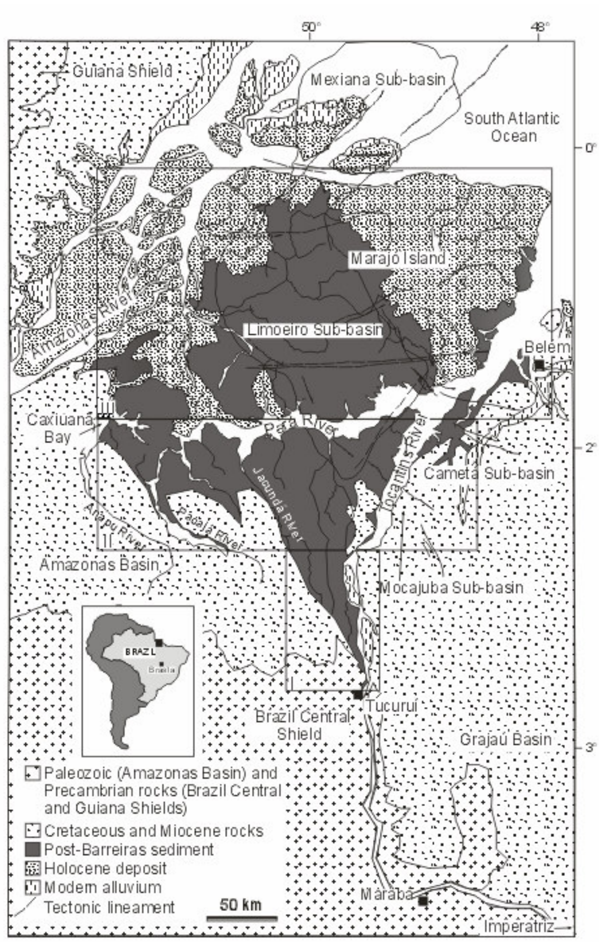

Figure 2: Geologic map of the study area in the lowest Amazon drainage basin. Note the distribution of the Plio-Pleistocene/Pleistocene Post-Barreiras sediments, configuring a fan morphology that spreads in the north/northwest direction from the locality of Tucuruí. Observe also that the Tocantins River suddenly change from east-west (between the towns of Imperatriz and Marabá) to north-northwest, and then northeast direction. The inside boxes numbered I, II and III locate respectively fan sectors 1, 2 and 3 described in the text.

Analyses of radar data revealed the main morphological aspects of the Post-Barreiras Sediments and of the associated deposits, to be described herein according to their occurrence in the southern, mid and northern sectors of the fan. If in one hand the processed SRTM data did not add much to define the overall fan-like deposits, they were crucial to characterize each individual fan sector described below, allowing a much better description of their morphological aspects, recorded by paleochannels of various sizes.

Hence, the southernmost and narrower tip of the fan configures a funnel shape ranging from 140 km long and 2-3 km wide upstream of Tucuruí, to 25 to 50 km in the mid and upper reaches, respectively. A few NNW/SSE orientated paleochannels up to 2 km wide were recognized in the Post-Barreiras Sediments located in the extreme western portion of the funnel, paralleling the basement. Several straight segments displaying NNW-SSE orientation characterize the funnel margins along this sector (**Figure 3A**). A few NNW/SSE orientated paleochannels up to 2 km wide were recognized in the Post-Barreiras Sediments located in the extreme western portion of this sector, paralleling the basement (**Figure 3B**). The Quaternary deposits display edges configuring slope profiles that are smooth in the western side and abrupt in the eastern side. In the latter, the margin stands almost vertically, reaching an altitude of 80 m (**Figure 3C**).

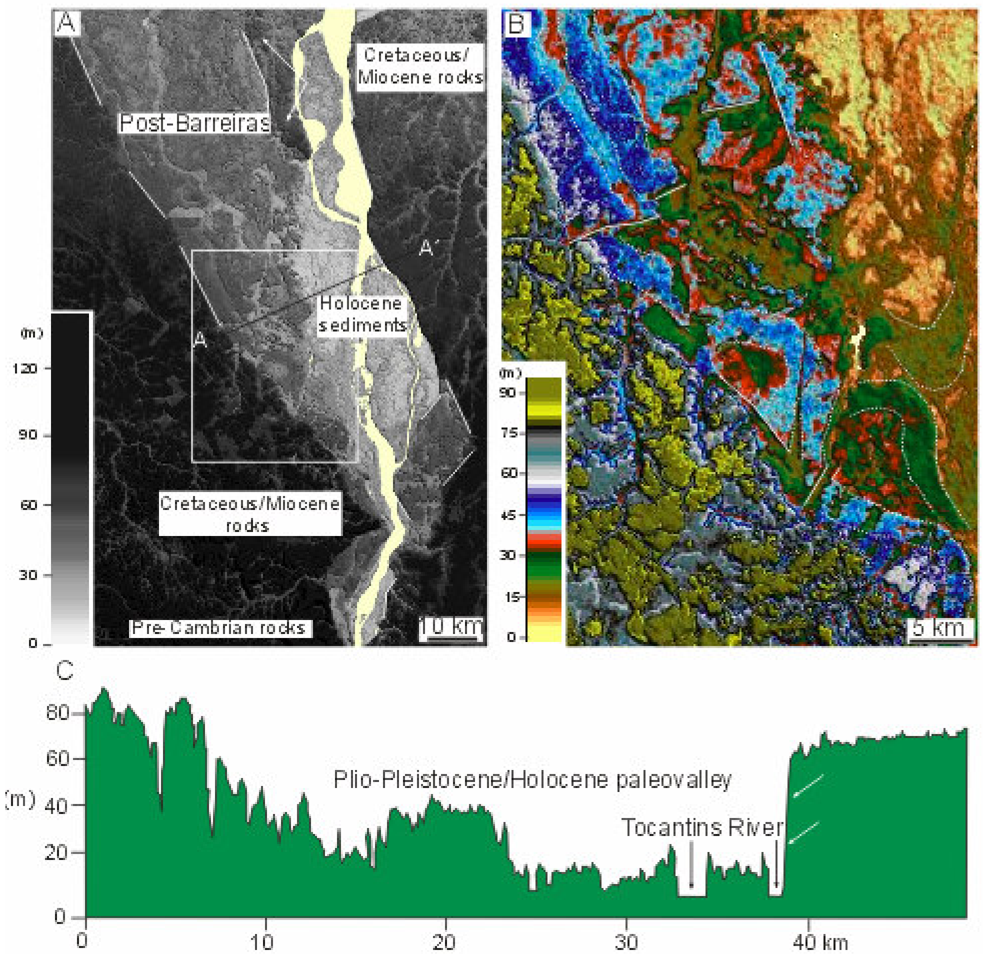

Figure 3: SRTM data illustrating the southern fan sector. A) The funnel-shaped fanhead, where the margins of the paleovalley form straight segments related to faults (white lines) that disrupted Miocene and older rocks. The arrows in the upper side of this figure indicate remains of these rocks within the paleovalley, which is filled mostly by the Post-Barreiras sediments of Plio-Pleistocene to Pleistocene age (Box locates figure B and A-A´ locates the topographic profile shown in C). B) Detail of figure A, highlighting abandoned meandering channels related to a paleo Tocantins River (dotted white lines). Note that might be channels segmented abruptly forming straight edges, which is related to faults (continuous white lines). C) Topographic profile obtained from the transect A-A´ located in figure A, which shows the asymmetric nature of the paleovalley margins, represented by a more

gradual western side, and a sharp, almost vertical eastern margin adjacent to the present course of the Tocantins River (white arrows). (All figures obtained from SRTM images).

The mid fan sector, which represents the point where the fan becomes the largest, includes a central area located between the Tocantins and the Jacundá rivers, and two lateral wings. The central sector extends for 90 km in the north/south direction, and 170 km in the east/west direction. The wing located to the west of the Jacundá River extends throughout almost 90 km northwestward, reaching the Caxiunã Bay. The wing to the east of the Tocantins River forms a NE/SW elongated belt that is 165 km long and up to 50 km wide, and displays few channels running mostly to NNE. Noteworthy in this sector is the eastward inflexion of a main paleochannel at the transition of the southern and the mid fan sectors, a pattern that is followed by the Tocantins River, which turns to east through a distance of almost 20 km at this same position.

The northern fan sector is the largest, encompassing great part of the Marajó Island, where it is characterized by mostly by the Post-Barreiras sediments. This unit extends throughout the Marajó Island, forming a continuous from the mid fan in the mainland. A typical feature of the northern fan sector is the abundance of paleochannels, which are particularly well developed in the western side of the Marajó Island. Some large channels from the southwestern margin of the Marajó Island are in continuity with the NNW-SSE orientated channels described in the southern and mid fan sectors.

5. Discussion and conclusions

The several NNW-SSE orientated straight segments of the valley margins in the southern fan sector are taken as evidence that the Plio-Pleistocene/Pleistocene paleovalley resulted from faulting, an interpretation that is consistent with the several structural lineaments displaying this orientation in the study area. The evolution of the Plio-Pleistocene/Pleistocene paleovalley and of the Tocantins River, which runs paralleling the eastern paleovalley margin, seems to be closely related. The rapid changes in the modern course of this river coincide with the location of main E-W, NNW-SSE and NE-SW strike-slip fault zones. These faults were recurrent through time since, at least, the Late Tertiary, but the details of their evolution remain to be better discussed (Costa *et al*. 1996, 2001). The NNW segment of the Tocantins River ends exactly at the head of the fan, promptly leading to the argument that the paleovalley was established along the same fault zone responsible for the deviation of this river from its E-W course. Furthermore, the fan geometry of the Post-Barreiras sediments, with spreading to NNW, implies in a southeast clastic supply. This morphohological characteristics, taken together, readily lead to invoke a time when an ancient Tocantins River would have discharged into the Equatorial South Atlantic Ocean through a NNW course, as opposed to its modern NE drainage, feeding the paleovalley with sediments brought from the southeast, and accumulating the succession recorded by the Post-Barreiras sediments.

The NNW fault zone that promoted the development of the paleovalley discussed herein must have being active during the Pliocene. This is revealed by the fact that the paleovalley truncates deposits of Miocene and older ages and is filled mostly by Plio-Pleistocene/Pleistocene sediments. Thus, after deposition of the underlying mid-Miocene

Barreiras Formation within an estuarine incised paleovalley formed along a main NW/SE fault zone, there was a prolonged quiescence in the late Miocene, as recorded by an unconformity with a well developed lateritic paleosol that is correlatable throughout the northern Brazilian basins (Rossetti 2001, 2004; *Costa et al.* 1996). A subsequent instability took place, with tectonic reactivation and sediment accumulation along the new accommodation space promoted by fault displacement.

The detachment of the Marajó Island from the mainland is proposed to be as young as the latest Pleistocene to Holocene. As mentioned above, the origin of this island is related to migration of the Tocantins River to east, and establishment of the Pará River to the south. The course of the Pará River consists of several WNW-ESE and ENE-WSW orientated segments located along a main E-W strike-slip fault zone attributed to the Holocene (Costa *et al*., 1996, 1997, 2001). Good evidence that the main E-W fault system is younger than the NE-SW one are: 1. the deflection of the NE orientated course of the Tocantins River to ENE throughout one of these segments; and 2. the deviation of several NE-SW orientated rivers to ESE in the western wing of the fan. The rhombic shape of this fan sector, which is typical of areas that have undergone strike-slip motions, is further evidence attesting the existence of these two faults zones.

The present geomorphological characterization based on SRTM data was crucial for recognizing the incised paleovalley in the study area. Application of this method might contribute to substantially increase the geological knowledge in similar areas with difficult access, and characterized by an overall lack of information. The great advantage of this procedure is to provide overall models that can serve as the basis to optimize fieldwork aiming to reconstruct the evolution of depositional systems that still keep relics of their past physical environment imprinted on the modern landscape. When combined with regional geological information, the interpretation of geomorphological features using SRTM data was of great contribution for reconstructing the geological history of the lowest Amazon drainage basin. Based on this work, it could be demonstrated, for the first time, that one of the largest Amazon tributaries, the Tocantins River, had a complex evolution, changing its position according to tectonic reactivations, which might have taken place even during the Holocene. In addition, the data presented herein served to approach the origin of the Marajó Island, the largest fluvial island in the world, allowing discussions of the mechanism that would have promoted its detachment from the mainland. These issues, not emphasized in detail in previous publications, are of wide relevance for studies focusing on the Quaternary tectono-sedimentary history of the North Equatorial Brazilian Margin. This work serves also to suggest that the Amazon drainage basin, as presented in the modern landscape, might be a relatively recent scenario. Many possible changes in the river positions due to tectonics might have taken place in past times. These results are important for studies focusing on the distribution of the Amazon biodiversity (e.g., see Rossetti and Toledo 2006 for a discussion related to this issue).

Acknowledgement

This work was funded by FAPESP (Project # 004/15518-6). The authors are fellowship holders of CNPq. MINITAB® is a trademark used with permission of Minitab Inc. in the United States.

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