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## **GPR Investigations at the Cacaria Submerged Archaeological site, Lake Cajari, Eastern Amazon: Preliminary Results**

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## GPR Investigations at the Cacaria Submerged Archaeological site, Lake Cajari, Eastern Amazon: Preliminary Results

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### Abstract Summary

This study presents preliminary results from Ground Penetrating Radar (GPR) surveys conducted at the submerged Cacaria archaeological site, located in the municipality of Penalva, state of Maranhão, Brazil. Aiming to map the wooden piles that supported pre-colonial stilt-house settlements built by Indigenous peoples, a 270 MHz antenna was employed. The survey enabled the identification of the lakebed of Lake Cajari and the detection of diffraction hyperbolas, likely associated with the wooden piles. These results underscore the effectiveness of GPR in mapping submerged archaeological features and advancing research on ancient settlements in the Eastern Amazon.

### Introduction

Held up by wooden piles or tree trunks, the stilt-house settlements are a traditional form of indigenous dwelling found throughout the South American lowlands since pre-colonial times (Navarro, 2018). A notable yet understudied example exists in the Maranhense wetland, Brazil, where radiocarbon dating indicates these villages date back to the first millennium AD. Although previous research, such as (Neves, 2008), provide evidence that several river floodplains across the Amazon were densely populated prior to colonization, archaeological sites in the Eastern Amazon remain poorly explored due to methodological limitations, leading to the lack of proper preservation of indigenous cultural and historical heritage. In this context, Ground Penetrating Radar (GPR) has emerged as a valuable non-invasive tool in archaeology, enabling detailed investigation and discovery of submerged sites (Conyers & Goodman, 1997).

The Cacaria Archaeological site (Figure 1) is located in Lake Cajari, near the city of Penalva, Maranhão, Brazil, and remains permanently submerged (Silva, 2024). In this site, artifacts such as ceramics and wooden amulets have been found (Corrêa et al., 1991). Accordingly, the goal of this research is to map wooden piles, delineate the lakebed, and assist divers in locating new material that may aid in the historical preservation of ancient cultures in the Eastern Amazon.



**Figure 1:** GPR profiles at Cacaria submerged archaeological site, Lake Cajari, state of Maranhão, Brazil. This research uses the highlighted profiles 1 and 2.

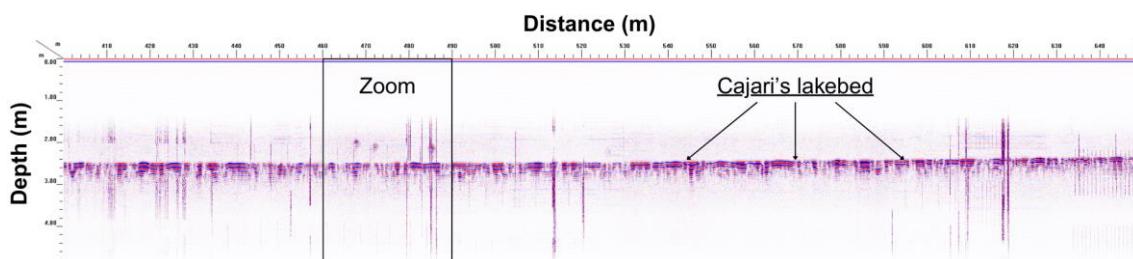
## Method

Ground Penetrating Radar (GPR) is a non-invasive geophysical method that enables detection of geological structures and buried objects through the transmission and reflection of high frequency electromagnetic waves (10 MHz to 2.6 MHz), as described by Daniels (1996) and Porsani (1999). It has several applications in geosciences and archaeology, with the significant advantage of being non-destructive to the studied environment. Data acquisition was conducted using a 270 MHz shielded antenna, a SIR-4000 computer (GSSI), and a Geode GPS equipment. The acquisition setup followed the configuration previously used by Porsani et al. (2005), in which the antennas were mounted inside a wooden boat. The profiles acquired for this study at the Cacaria archaeological site are depicted in blue in Figure 1.

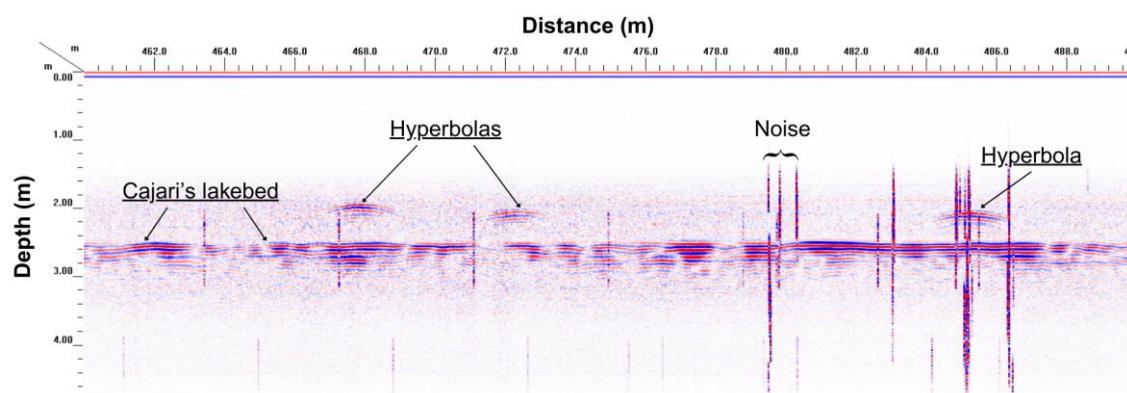
The data consist of reflected and refracted waves recorded as a function of the two-way travel time. These signals are amplified, digitized and stored on a computer hard drive for further processing, enabling the generation of high-resolution images of the subsurface. RADAN 7.0 software (GSSI) was used to process GPR data with usual procedures such as zero-time correction for air-wave arrival, filtering frequencies, gain adjustment, background removal and time/depth conversion, considering 81 as the dielectric constant of water.

## Results

Figure 2 presents GPR profile 1 (see Figure 1), where a strong horizontal reflector is observed at approximately 2.4 meters depth, interpreted as the lakebed of Lake Cajari. Figure 3 shows a zoomed-in view of profile 1, between 460 m and 490 m, in which several diffraction hyperbolas are visible suspended within the water column. These are associated with point-source anomalies, likely corresponding to the wooden piles that once supported indigenous stilt-house dwellings. Recent studies using numerical modelling corroborate with this interpretation (Porsani et al., 2023). Additionally, vertical signals appear throughout the profile, attributed to high-frequency noise generated by nearby urban telecommunication systems, which differ significantly from the studied signal.

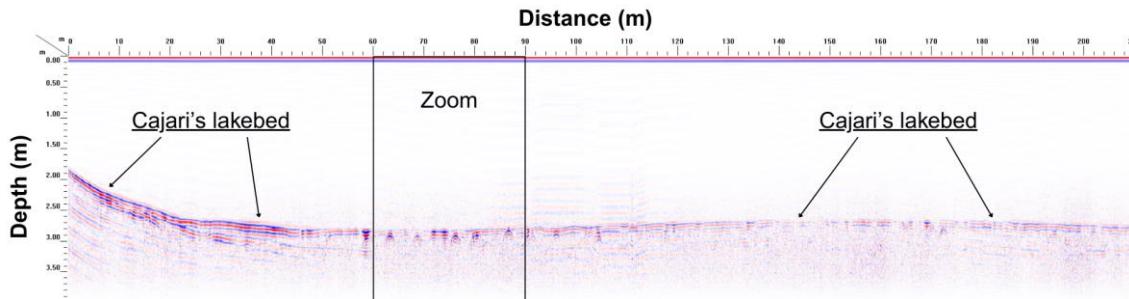


**Figure 2:** GPR profile 1 acquired in the N-S direction at the Cacaria submerged archaeological site, Lake Cajari, Penalva, Maranhão, Brazil.

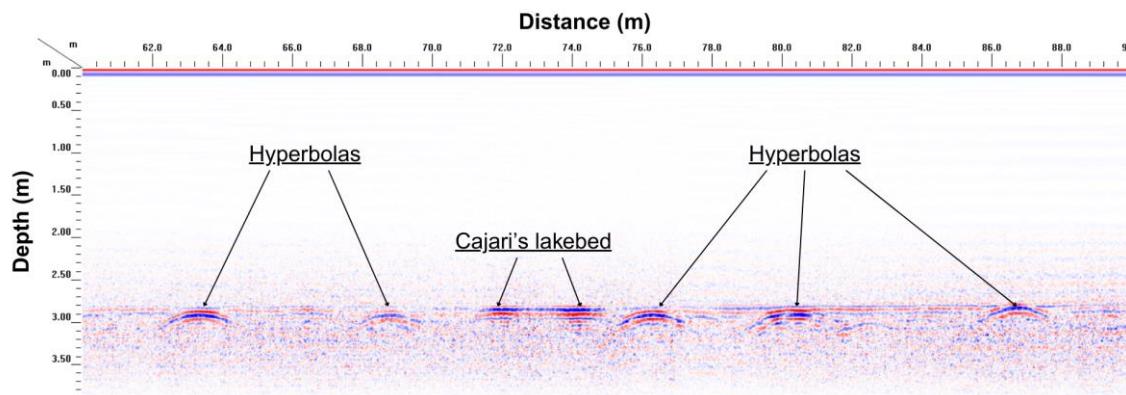


**Figure 3:** Zoom of GPR profile 1, presented in Figure 2.

Figure 4 displays GPR profile 2, showing a prominent horizontal reflector at approximately 2.5 meters depth, similarly interpreted as the lakebed. Figure 5, in turn, offers a zoomed-in view between 60 and 90 meters along profile 2, where additional diffraction hyperbolas are observed beneath the lakebed, indicating they are buried under sediment. As with the anomalies in Figure 3, these are also interpreted as remains of wooden piles.



**Figure 4:** GPR profile 2 acquired in the SE–NW direction at the Cacaria submerged archaeological site, Lake Cajari, Penalva, Maranhão, Brazil.



**Figure 5:** Zoom of GPR profile 2, presented in Figure 4.

## Conclusions

The results demonstrate the effectiveness of the GPR method in characterizing and mapping the Cacaria submerged archaeological site, located in Lake Cajari, in the municipality of Penalva, Maranhão, Brazil. The acquired and processed data enabled the identification of the lakebed depth, the delineation of distinct geological features, and, most notably, the detection of targets interpreted as wooden piles. These preliminary results can significantly contribute to advancing archaeological research on stilt-house villages in the Eastern Amazon, not only by providing spatial data that suggest the layout of pre-colonial settlements, but also by guiding the collection of new archaeological remains from the lakebed.

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