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# GPR Survey at the Jenipapo Submerged Archaeological Site, Eastern Amazon

**Henrique Lellis Manrique (Universidade de São Paulo), Jorge Porsani (Universidade de São Paulo), MARCELO STANGARI (UNIVERSIDADE DE SÃO PAULO (USP) - INSTITUTO DE ASTRONOMIA; GEOFISICA E CIENCIAS ATMOSFERICAS (IAG).)**

# GPR Survey at the Jenipapo Submerged Archaeological Site, Eastern Amazon: Preliminar results



## Abstract Summary

This pioneering study applies Ground Penetrating Radar (GPR) to the investigation of submerged archaeological sites in the Amazon. Focusing on the Jenipapo site, located along the Turiaçu River in Maranhão State, Northeastern Brazil. The research examines pre-colonial lakeside dwellings constructed with wooden pillars. The study aims the mapping of these submerged structures and to guide archaeological prospection. GPR profiles acquired with a 270 MHz antenna successfully delineated the riverbed and identified multiple diffraction hyperbolas, interpreted as the tops of wooden pillars. GPR 2D finite-difference modeling was done to simulate the expected radar signatures of such features. By comparing real and synthetic data, the study seeks to improve interpretative accuracy and support future underwater archaeological investigations.

## Introduction

Pre-colonial stilt-house settlements, known locally as *estearias*, are significant archaeological indicators of early human occupation in the Eastern Amazon. Built between 100 and 1000 AD, these dwellings were supported by wooden pillars driven into the beds of rivers and lakes (Navarro, 2018a, 2018b). The Jenipapo archaeological site, located along the Turiaçu River in the Baixada Maranhense region (Figure 1), provides a rare opportunity to study the submerged remnants of such settlements. This region experiences seasonal hydrological fluctuations, with a rainy season from January to June and a dry season from July to December (Franco, 2012). These environmental conditions have contributed to the preservation of the wooden structures, many of which remain partially or fully submerged.

Ground-Penetrating Radar (GPR) has become a valuable tool in archaeological geophysics, primarily due to its non-invasive nature and high-resolution imaging capabilities (Conyers & Goodman, 1997). While its application in terrestrial archaeological contexts is well established, its use in submerged environments remains comparatively limited. Nonetheless, recent studies have demonstrated the technique's potential for detecting underwater features, including submerged wooden structures and archaeological artifacts (Jol & Albrecht, 2004; Porsani et al., 2023; Siqueira Neto et al., 2024).

At the Jenipapo site, previous archaeological fieldwork conducted by researchers from the Federal University of Maranhão (UFMA) enabled the manual georeferencing of exposed wooden pillars using a total station during the dry season. However, significant portions of the site remain submerged throughout the year, hindering comprehensive manual mapping. To address this limitation, the present study employs GPR in a pioneering effort to improve the mapping of submerged wooden pillars and to validate their interpretation through 2D numerical modeling. This integrated methodological approach seeks to enhance archaeological interpretations and contribute to the advancement of submerged cultural heritage studies in the Eastern Amazon.

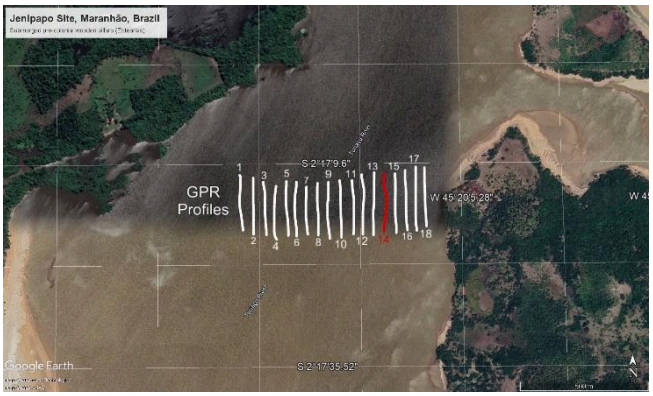


**Figure 1:** *Location of GPR profiles acquired on December 6, 2021, at the Jenipapo submerged archaeological site along the Turiaçu River, Maranhão State, Brazil. Image adapted from Google Earth.*

**GPR Method**

GPR data were collected using a 270 MHz shielded bistatic antenna connected to a SIR-4000 system (GSSI). The antenna was mounted on the underside of a rubber boat and oriented perpendicular to the survey direction to ensure maximum amplitude of the GPR signal. The survey was carried out through a collaboration between researchers from IAG-USP, UFMA, and IPT, under the coordination of Prof. Dr. Jorge Luís Porsani. Figure 2 shows the GPR data acquisition on the Turiaçu River.


**Figure 2:** *GPR data acquisition using a rubber boat on the Turiaçu River. Source: Porsani et al., 2023.*

A total of eighteen profiles were collected and processed using RADAN 7.0 software (GSSI). The processing workflow included zero-time correction, bandpass filtering (40–200 MHz), application of linear gain, background removal, spatial filtering (3 traces), and time-to-depth conversion using a dielectric constant of 81 for water. These processing steps significantly enhanced the visibility of key reflection patterns, such as hyperbolic diffractions, which were interpreted as submerged wooden pillars.

GPR 2D numerical modeling was performed using Reflexw to simulate the radar response of the interpreted features. The modeling process included the following steps: (i) defining the simulation domain and geometry of the riverbed and pillars, based on field observations (1 m height and 0.2 m width); (ii) assigning appropriate electromagnetic properties; and (iii) conducting finite-difference time-domain (FDTD) simulations using an explosive source. The

synthetic results, converted to depth for direct comparison with the field data, provided essential support for validating the interpretations.

**Results**

The processed GPR profiles from the Jenipapo site revealed a series of reflection patterns crucial for interpreting submerged archaeological structures. Figure 3(a) presents one of the representative profiles, where a prominent continuous reflector between 1 and 1.9 meters in depth is interpreted as the riverbed of the Turiaçu River. Above this surface, hyperbolic diffractions are visible and are interpreted as reflections from the tops of submerged wooden pillars, associated with pre-colonial stilt-house settlements. These findings support and reinforce previous analyses and interpretations of such features (Navarro, 2018a; Porsani et al., 2023). To further enhance the visibility of these diffractions, Figure 3(b) presents a zoomed-in segment of the profile, where the features are more clearly visible.

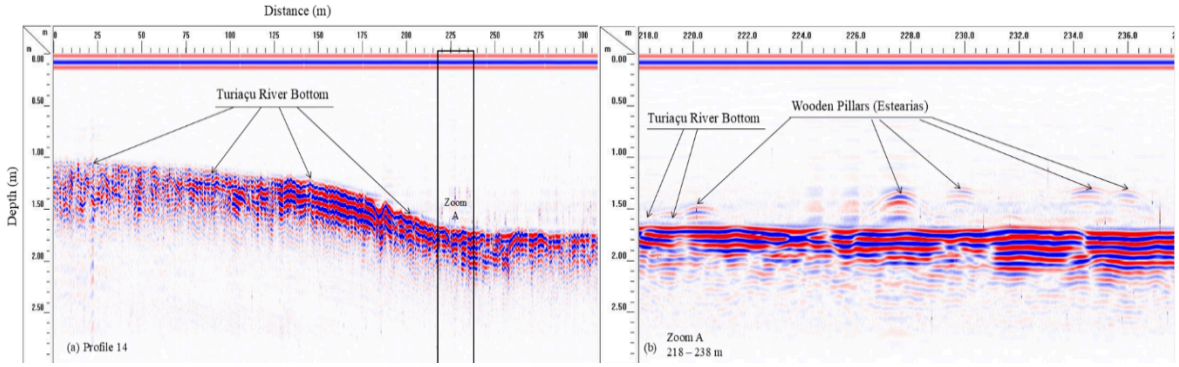


**Figure 3:** (a) GPR Profile 14, obtained with a 270 MHz antenna, covering a length of 310 m in the S-N direction (red profile shown in Figure 1). (b) Zoom A, highlighting the hyperbolic diffractions.

Figure 4(a) displays the synthetic model constructed based on the interpretation of the real data presented in Figure 3(b), while Figure 4(b) shows the simulated GPR profile generated from this model. The synthetic diffractions closely resemble those observed in the field data, thereby validating the interpretation and demonstrating the effectiveness of GPR 2D numerical modeling in identifying submerged structures and reducing ambiguities in the interpretation of real data.

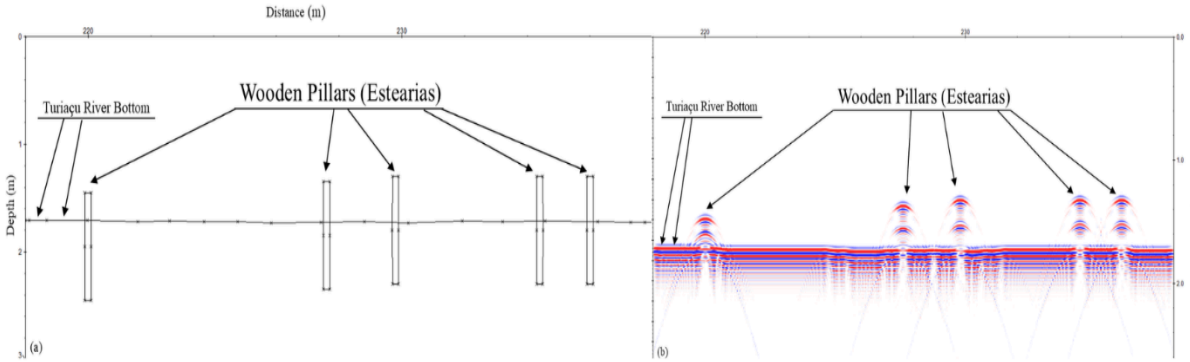


**Figure 4:** (a) Synthetic model of submerged wooden pillars, constructed based on the interpretation of the real data shown in Figure 3(b). (b) Synthetic GPR profile corresponding to the model in (a).

## Conclusions

The integration of real GPR data and 2D numerical modeling proved to be an effective approach for investigating submerged archaeological structures at the Jenipapo site. The processed radargrams revealed clear reflectors corresponding to the riverbed, along with several hyperbolic diffractions interpreted as reflections from submerged wooden pillars. The numerical modeling successfully replicated these diffraction patterns with high accuracy, validating the interpretations and minimizing the ambiguities inherent in the field data.

These results highlight the effectiveness and potential of combining GPR with numerical modeling in advancing submerged archaeological research. The successful mapping of wooden pillars in permanently submerged areas enhances previous archaeological surveys and provides a reliable methodological framework for future prospections in the Amazon and similar environments.

## Acknowledgments

HLM and JLP acknowledge the financial support of CNPq – Conselho Nacional de Desenvolvimento Científico e Tecnológico (grant numbers 125404/2023-9 and 304104/2021-3). JLP also acknowledges FAPESP (grant numbers 2020/15560-5 and 2023/16834-0). The authors thank IAG-USP, UFMA, and IPT for their infrastructure and logistical support throughout the development of this research.

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