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GPR Survey at the Lake Formoso Underwater Archaeological Site, Eastern Amazon: Preliminary Results

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Abstract Summary

The Eastern Amazon region holds significant archaeological potential due to the presence of prehistoric stilt villages built between 100 and 1100 AD. Recent discoveries of wooden structures and ceramic remains during dry seasons have motivated geophysical investigations in submerged areas. This study aims to locate and map remnants of wooden stilts at the Formoso Lake archaeological site using Ground Penetrating Radar (GPR), thereby enhancing understanding of pre-colonial settlement patterns and guiding future archaeological exploration. GPR profiles were acquired using a 270 MHz shielded antenna. Processing involved filtering and gain adjustments. The radargrams revealed hyperbolic reflections indicative of buried or submerged wooden elements, consistent with prior GPR imaging and numerical modeling. The results reinforce the effectiveness of GPR for underwater surveys and also contribute to reconstructing pre-colonial habitation in the floodplain environments.

Introduction

The Ground Penetrating Radar method is already known for its usage in subsurface archaeological research and characterization, also when searching for underwater targets (Conyers and Goodman, 1997, Qin et al, 2018). Following the significant archaeological finds during the dry season at stilt villages, lakebeds and riverbeds (Navarro, 2018) at the Eastern Amazon region, there were several campaigns of GPR data acquisition, following notable development about the utilization of the method at the same region at different study sites, such as Jenipapo, Turiaçu River (Porsani et al. 2023) and Cacaria, Cajari Lake (Silva, 2024). Both mentioned water bodies are located at the Maranhão wetland, where the very defined rainy and dry seasons tend to fill up and dry the watersheds.

The lakes are located approximately 200 kilometers away from São Luís, the state's capital (Mendes et al., 2015, Silva, 2024), and the total extent of the area is 20 thousand square kilometers, environmentally protected. The great motivation for the campaigns was the construction method used by the natives. Between the years 100 and 1100 AD, as the ceramic finds indicate, there were numerous wooden buildings located on top of the lakes and rivers, in the form of stilt villages (Navarro, 2018). These were heavily populated before the colonial period in Brazil, and archaeological findings related to them play a significant role in the studies of the native populations. One of these villages was sited at Formoso Lake (Figure 1), where the GPR profiles were acquired. The acquisition consisted of a total of 22 profiles, of which only 2 were chosen to be presented in this work.

Ultimately, the primary objective of the study was to locate new wooden stilts in the radargrams, with the intention to guide divers to search for more ceramic objects buried in the lakebed. The data shall help to make new estimations of the village's geometry and distribution too, besides the understanding and mapping of the lakebed and sedimentary distribution at the bottom.

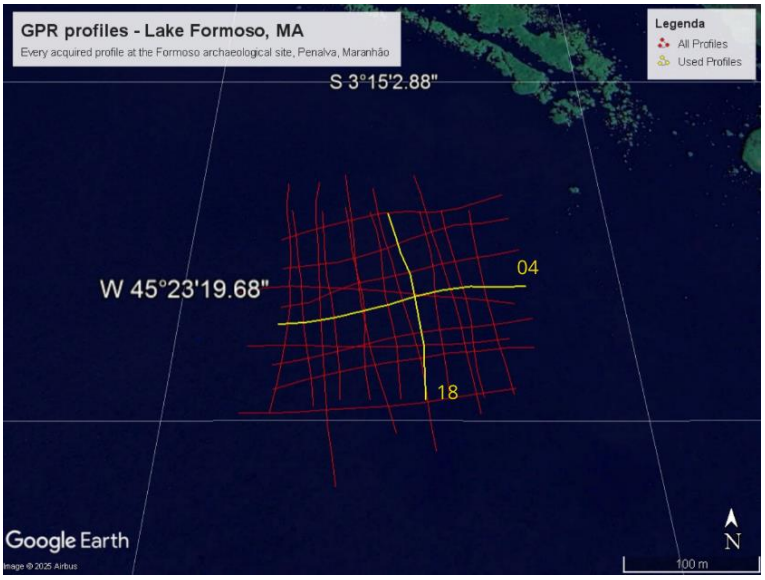

Figure 1 – All 22 GPR profiles acquired at the Formoso Lake, Penalva, Maranhão.

Method and/or Theory

The GPR method is based on transmission and reflection of electromagnetic waves at a strict band of frequencies, that varies from 10 to 2600 MHz, inside the radio frequencies. One of the biggest advantages of the usage of this method is that the acquisition is completely non-invasive, making it possible to detect buried or soaked human made structures without having to perturb its surroundings in damaging ways (Porsani, 1999). Concerning acquisitions for lakebeds and riverbeds morphology, the GPR method has been widely used in water surveys (Porsani et al., 2005) and even helped to identify underwater logs and other remains of human interaction with nature (Jol and Albrecht, 2004, Qin et al, 2018). The utilization of the antennae in boats requires a fixed Tx-Rx distance arrangement method, acquired at time domain. The data is converted to distance considering the total distance recorded in the GPS and a constant travel speed (Neto et al., 2024), and the depth of the reflections registered are converted considering double travel time of the EM-waves, which speed in the geological mean is calculated by the estimation of the dielectric constant which, for water, is 81 (Porsani, 1999). The data used in this research was acquired with a 270 MHz GSSI shielded antenna, plugged into a GSSI SIR-4000 computer. To acquire the profiles positions, a handheld Garmin GPS system was manually triggered, and all the acquired profiles were processed using the RADAN 7 software, also developed by GSSI. Common processing techniques were used, like filtering, time-zero correction and gain varying in time. The arrangement of the equipment on a wooden boat and processing was used in previous studies (Porsani et al, 2005, 2023, Silva, 2024).

Results

Figure 2 shows the processed radargrams for profile 18. It was observed that there is diffraction hyperbola above the lakebed, seen as a strong and horizontalized reflection, indicating the presence of punctual targets above the bed substrate. The profile was divided into blocks and processed by parts. Some of the strong reflections show a horizontalized and undisturbed reflection, possibly indicating a flat lakebed. Other parts show a noisy and disturbed lakebed reflection, indicating irregular limits and possibly filled with water plants, sometimes observed in the field acquisitions. In Figure 3, which is the 30 to 60 meters data block of profile 18 (from South to North), there are clear hyperbolic reflections at positions 38.5, 44, 45.5 and 46 meters, with the presence of irregular lakebed reflection. Likewise, there may be another hyperbole just before position 58, from an almost buried log, probably surrounded by sediment or aquatic plants.

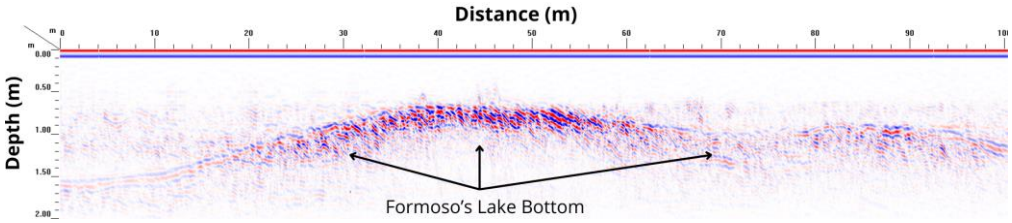

Figure 2 - First 100 meters of GPR profile number 18, acquired with the 270 MHz antenna, in the S-N direction, Formoso submerged site, Penalva, Maranhão.

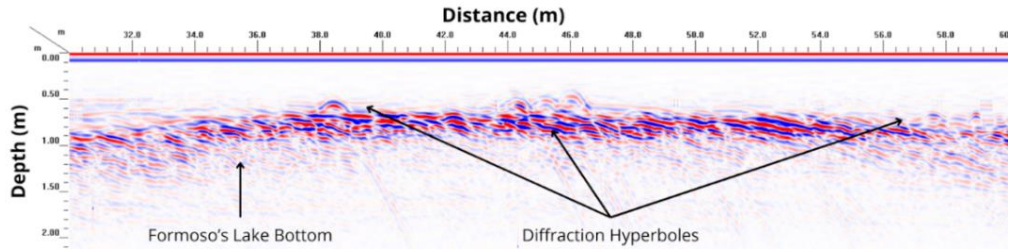

Figure 3 - GPR profile 18, zoomed in between positions 30 to 60 meters, acquired with the 270 MHz antenna, S-N direction. Formoso submerged site, Penalva, Maranhão.

Figure 4 shows the GPR profile 04 delimited from 150 to 250 meters, where we can see a strong reflection interpreted as the lakebed, and some hyperbolic diffraction patterns between the surface of the water and the bottom of the lake. Figure 5 shows a zoom of Figure 4, between 152 and 188. It is possible to observe clear hyperbolic diffractions on positions 168 and 187 meters that are interpreted as wooden pillars. The diffraction patterns indicated as hyperbolas are interpreted as logs by previous mathematical modeling done by other authors (Porsani et al., 2023; Silva, 2024), which show great correlation for this type of buried material. The numerical modeling in these profiles permits to reduce the ambiguity in data interpretation, being a possible future development for this study.

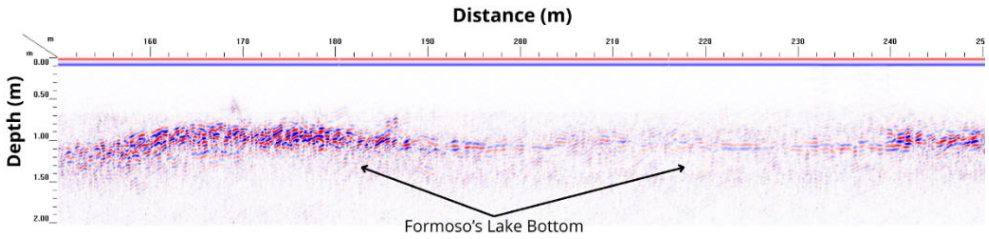

Figure 4 - GPR profile 04, between positions 150 to 250 meters, acquired with the 270 MHz antenna, headed from E to W. Formoso submerged site, Penalva, Maranhão.

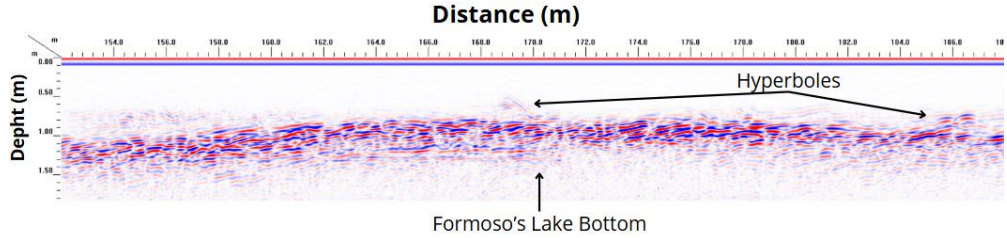

Figure 5 - GPR profile 04, zoomed in from 152 to 188 meters, acquired with the 270 MHz antenna. Formoso submerged site, Penalva, Maranhão.

Conclusions

The GPR method permitted mapping non-destructively the bottom of the lake and wooden pillars and proved necessary for helping further archaeological research at Lake Formoso. The data processing of the profiles shows punctual underwater targets that suggest the presence of new stilts to be studied, which must be investigated for new artifacts. The hyperbolic reflections show great correlation between the previously processed data from other types and acquisitions, based on the mathematical models for the problems available in literature. Nevertheless, there is further development to be made for modeling the uneven lakebed distribution observed in the lake data based on the interpretation of the profiles shown.

Acknowledgments

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