An archaeological study using GPR in the Madeira-Mamoré railroad, Porto Velho (RO).

Tarciana V. Silva Farias[1], Marcos W. C. Silva[1], Karolina A. Correia[1], Renato Kipnis[2]

Graduate Program in Geophysics, Federal University of Pará[1]

Scientia Consultoria Científica[2]

Abstract

This study employs Ground Penetration Radar (GPR) to more effectively evaluate and determine potential structures buried in the Madeira-Mamore Railroad (MMR) yard in the port area of the city of Porto Velho (RO), Brazil. In addition to identifying prospective locations for future excavation and preservation, the aim is to include some of these structures in the MMR Patio revitalization plan while avoiding damage to the archaeological legacy. The excavations identify the type of associated structure, and the findings were utilized to determine the significance of each anomaly. Based on the excavation findings, five anomalies were analyzed in this paper. According to the results, GPR is a practical tool for evaluating buried structures and can assist in identifying prospective locations for future excavation and preservation.

Introduction

The Madeira-Mamore Railroad, constructed under the jurisdiction of Brazil and Bolivia, was a crucial element in the process of territorial expansion to facilitate international trade. In addition, besides representing a profitable alternative, the railroad sought to foster the integration of the interior regions into the country's major economy through the expansion of the railroad networks (Pacheco, 2020). The main objective of the construction of the railroad was to facilitate the flow of rubber production rubber extracted from Brazil and Bolivia to the Atlantic Ocean to export it to Europe and the to Europe and the United States (da Silva et al., 2014).

The federal and municipal authorities are working to restore and revitalize the locomotives and facilities where the museum and the old railroad workshop used to be. However, until this task is completed, the work is in a partial stage of execution (dos Santos Coimbra and Fantin, 2020).

Due to the listing of the Madeira-Mamore Railroad as a historical and cultural heritage site by IPHAN (National Historical and Artistic Patrimony Institute), it is necessary to conduct a preventive archaeological investigation before the revitalization to identify objects and ruins of historical and cultural relevance (IPHAN, 2020). Therefore, the company responsible for the revitalization sought the advice of Scientia to conduct this research, using the geophysical tool of Ground Penetrating Radar (GPR) to delimit excavation areas.

Geophysical techniques such as GPR have assisted archaeology in various archaeological contexts in recent decades (Goodman et al., 2013; Sanchez et al., 2021; Emmitt et al., 2020). With this tool, it is possible to acquire *a priori* information to mapping and delimiting sites of interest in the archaeological field, contributing to better research planning and planning of the research and enabling punctual excavations of possible targets in subsurface (Correia et al., 2018).

GPR was employed with excavations in the MMR Patio to locate artifacts and structures for archaeological study before revival. This technique makes it possible to identify significant archaeological structures by removing buildings like floors, masonry, metal, rubble, and slope stabilization.

Materials and Methods

GPR surveys were done in the MMR courtyard using a 400 MHz shielded antenna to identify potential subsurface structures up to 2 meters deep; the profiles are spaced 5 m apart (Figure 1), with the SIR-3000 equipment from Geophysical Survey Systems, Inc (GSSI). This research aimed to guide mechanical excavations during the revitalization of the Madeira Mamore Railroad Patio and avoid damaging potential archaeological artifacts. The data generated from the surveys can help mitigate these risks.

The technique employed to perform the geophysical surveys in the study in question was the reflection profile with constant distance (Figure 2B), which is widely used in the operation of the GPR (Zheng et al., 2019). The result obtained was a 2D profile, where the antenna positions (distances) are represented on the horizontal axis and the double time of the reflectors, i.e., the travel and return time of the GPR signal, is represented on the vertical axis (Correia et al., 2018). However, most of the profiles are not continuous due to the presence of built structures, wagons, and flooded areas observed in Figure 2.

Data processing was done using ReflexWin software. The filters and corrections used in the processing of the acquired data were: (1) editing the orientation of the profiles; (2) zero time correction; (3) header gain removal; (4) manual gain filter application; (5) temporal bandpass filtering; (6) running average; (7) fk migration (Figure3).

Results

From a geophysical perspective, profile L0680-113 reveals the presence of an extensive horizontally trending anomaly, with dimensions of approximately 5 meters (Figure 4A). This anomaly stands out horizontally about the rest of the ground. It displays a significant contrast in

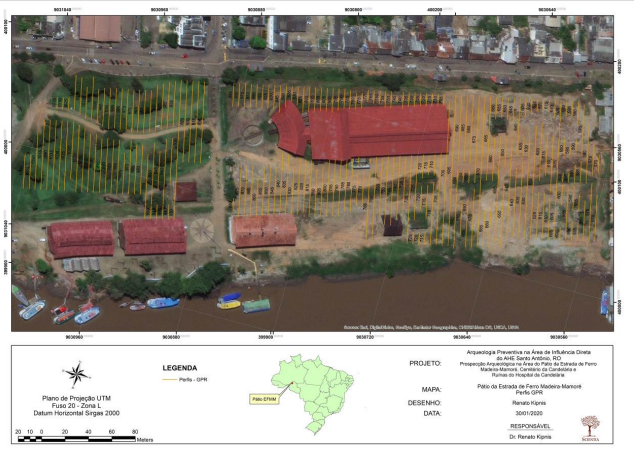

Figure 1: The location of the GPR surveys was done in the central area of the railroad yard of the Madeira-Mamoré Railroad by means of a previously defined methodology

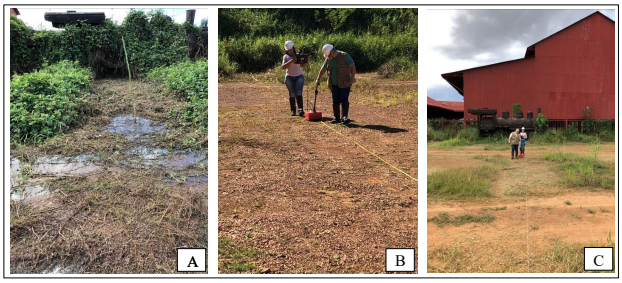

Figure 2: (A) Wet area where the profiles were interrupted (B) GPR data acquisition along one of the lines drawn in the area of the MMR (C) Data collection near abandoned wagons abandoned wagons.

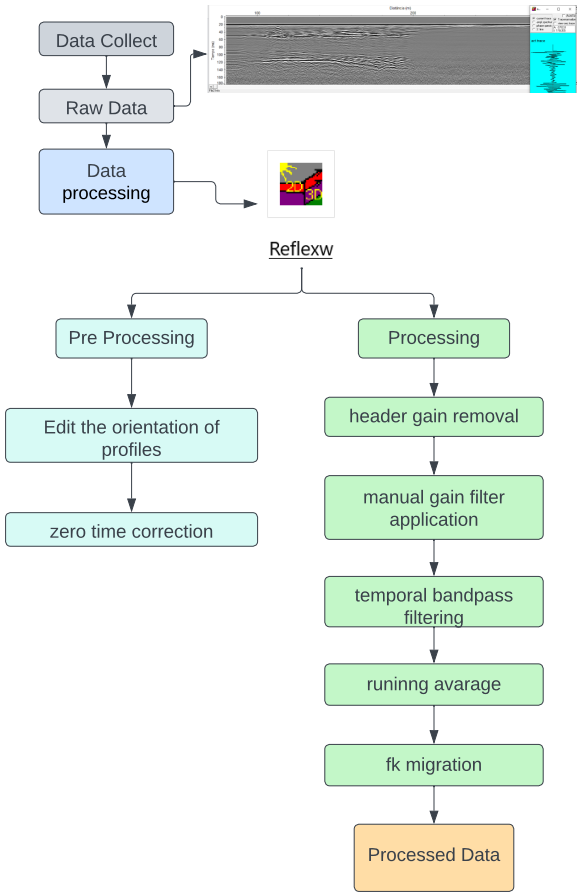

Figure 3: Flowchart illustrating the processing steps conducted in this study. It starts with raw data, followed by the pre-processing stage, where editing and correlation of profile directions occur, along with set time zero correction. Subsequently, header gain removal is performed, and time-based filtering (1D) and 2D filtering (running average) are applied. Afterward, fk migration is conducted, resulting in the processed data.

electrical properties, which characterizes it as an area of archaeological interest, especially considering its relatively shallow location in depth.

The excavation of unit L0675:107-U1, with dimensions of 50x50 cm, carried out on-site, revealed the presence of a concrete structure near the surface, as illustrated in Figure 4B. Two additional units were added to obtain a more detailed analysis of that structure, as depicted in Figure 4C. The structure in question probably consists of an old concrete floor located at depths between 5 and 20 cm, showing widespread fragmentation and evidence of parallel and longitudinal cuts, possibly related to the installation of pipes. During the excavations of this anomaly, a metallic component containing glass, apparently an oil-level sight glass, and a fragment of ferrous material were recovered, as illustrated in Figure 4D.

In profile L0680-113, the GPR method detected the anomaly in a surface layer, as shown in Figure 5A. We observed a contrasting variation of properties in the resulting radargram. Additionally, due to the shallow location of the anomaly, it has potential archaeological interest.

During the excavation of unit L0680:113-U1, of dimensions 50x50 cm, on-site, the following elements were observed at different depths: at a depth of 5 cm, the presence of a black tarp was identified, covered by reddish gravel; just below this tarp, a layer of the rubble of approximately 3 cm thick was found, composed of concrete fragments. Next, at 15 cm depth, a well-consolidated concrete floor was noted, and further north, a nail used to fix rails was located. Finally, a fragmented concrete column in the unit's center was observed in the north-south direction, which became evident from a depth of 10 cm, as illustrated in Figure 5D.

The profile L0685-106 was selected in which a strong contrast pattern was observed, presenting an elongated shape, which suggests a significant difference in contrast between the medium and the structure. The interpretation is that this structure is located at a shallow depth since the anomaly appears at a superficial level of the radargram. Below this structure, a hyperbolic pattern was identified, which may indicate the presence of more compacted structures in the subsurface (Figure 6A).

From the archaeological point of view, the area for

excavation L0685:106-U1 of 50x50 cm (Figure 6B) was selected from the information the radargram provided us. At the first level, it was possible to identify reddish gravel rejects, and just below this, there was a black plastic tarp (Figure 6C). From the 20 cm depth, a trail was found in the north-south direction, and at the 30 cm depth, a concrete floor in the same area (Figure 6D).

In profile L0730 from the GPR analysis, we observed two anomalous patterns. The first pattern, located to the left of the radargram and illustrated in Figure 7A, presents small extensions and well-defined points and may be related to small objects in the subsurface or railroad tracks. Three pottery fragments were recovered at surface levels during the excavation associated with this anomaly, as illustrated in Figure 7B. In addition, a layer of clayey silt was found in the lower levels with mineral coal.

The hyperbolic reflections observed in Figure 7A, located to the right and associated with pattern 2, are shallow hyperbolic anomalies, usually related to point objects in the subsurface. In the excavation unit corresponding to this anomaly, two pieces of metal were exhumed at level 20-30cm (Figure 7C), possibly a locomotive wheel. In addition, seven glass fragments were found at the 30-40cm level of the excavation (Figure 7D), while four glass fragments were found at the 50-60cm level (Figure 7E).

Discussion and Conclusion

The research consisted of an integrated approach that involved the application of a geophysical method, archaeological excavations, and analysis of recovered materials. This integrated approach was critical to ensure more effective and accurate results regarding applications in the study area.

Given the results presented, the GPR method has proven highly effective in identifying zones susceptible to being targeted for archaeological excavations. The use of GPR in archaeology is mainly significant as a non-invasive approach since this technique preserves the integrity of the historical heritage, which is one of the main goals of preventive archaeology.

For future archaeological work, it is recommended that a preliminary non-invasive analysis be conducted at the beginning of the research. Subsequently, it is important to delimit the areas of archaeological interest based on this initial assessment and then conduct excavations and analysis of the exhumed materials. This process minimizes disturbance to the archaeological heritage and obtains relevant information for studying a region's history and culture.

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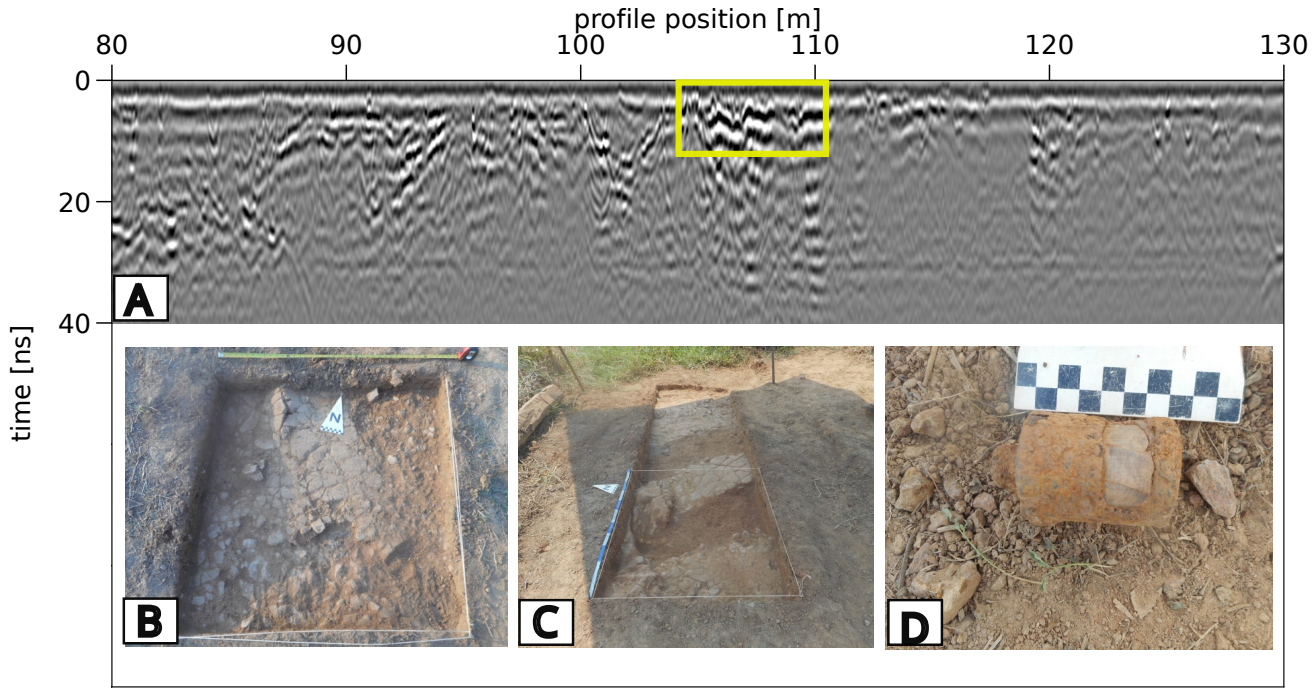

Figure 4: A) GPR survey showing an abnormal pattern of fairly shallow depth relative to the surface. B) Superficial excavation identifying the continuity of the structure found in the first unit. C) Extension of the structure revealed after excavations in the units. D) Excavation of the 0-10cm level was probable exhumed oil display was exhumed.

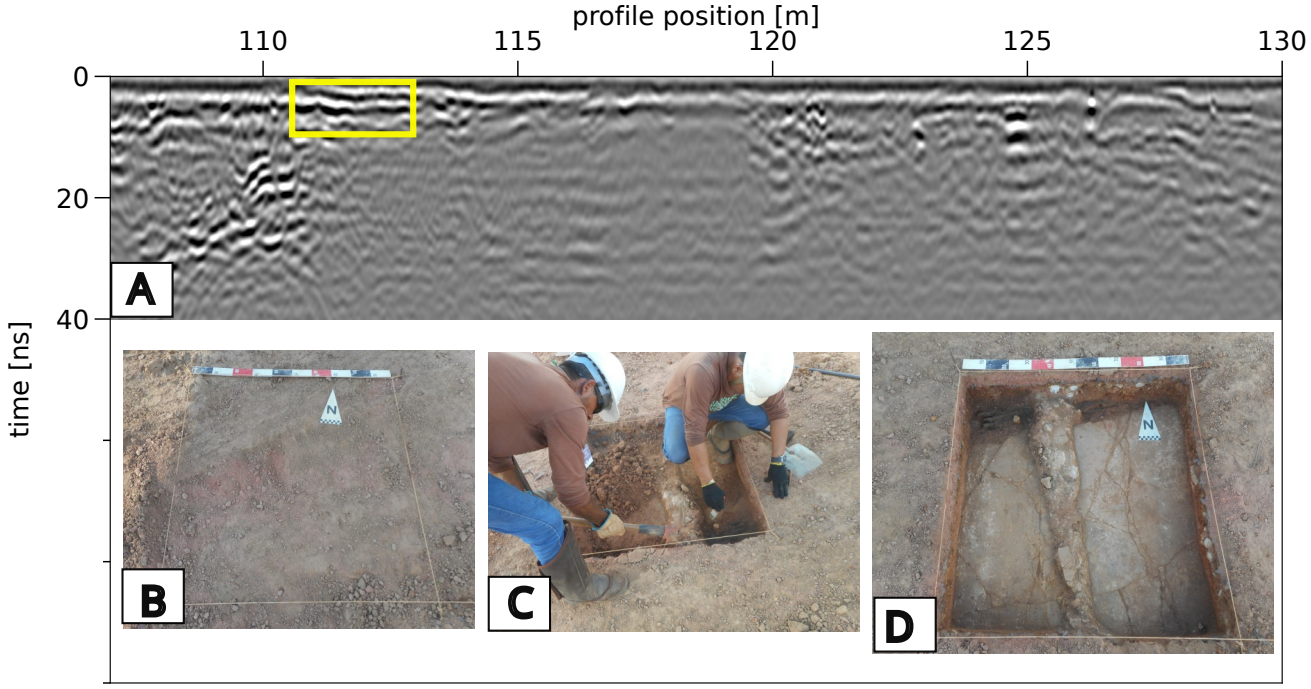

Figure 5: A) GPR survey showing an anomalous surface pattern in the sub-surface. B) Demarcation of Excavation Unit L068:113-U1. C) Excavation of the 10-20 cm level of unit L068:113-U1, showing a concrete column. D) A rail nail was found near the concrete floor at a 15 cm depth. In the North-South direction, there is a fragmented concrete column.

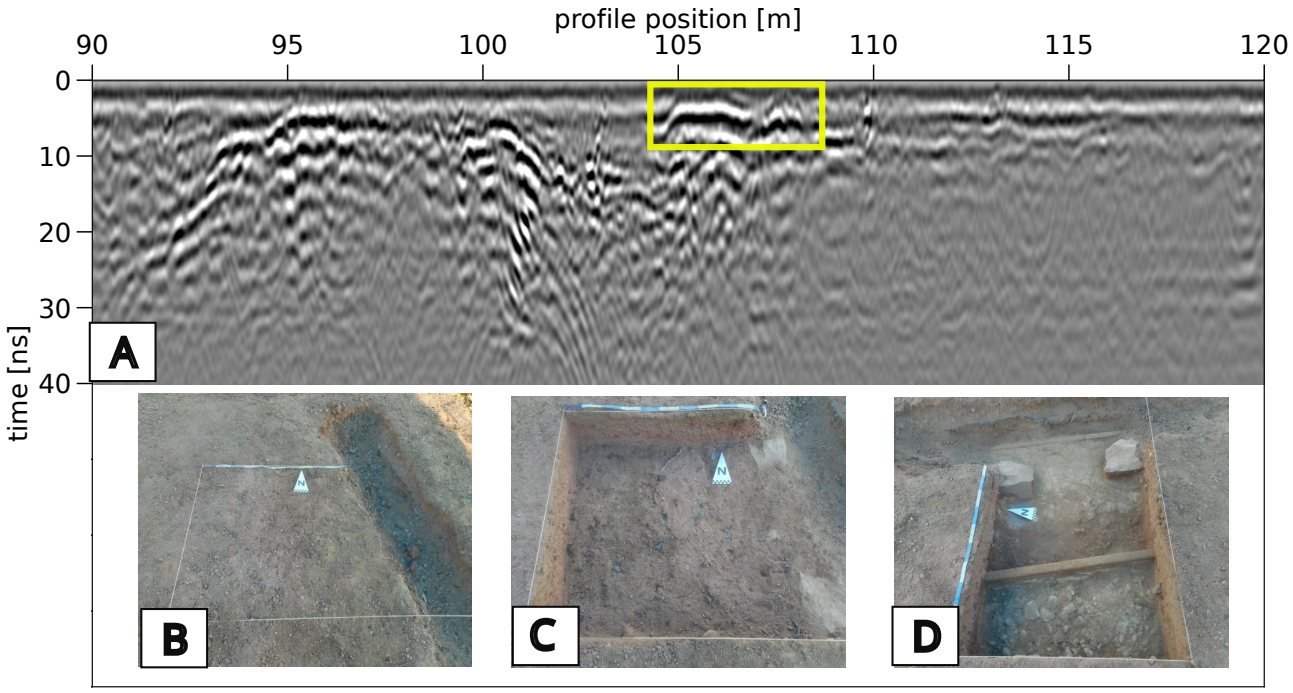

Figure 6: A) GPR survey showing an extended anomalous pattern at surface level on the radargram, just below this anomaly, hyperbolic patterns associated with more compact structures were detected in the subsurface. B) Surface demarcation on unit L0685:106-U1. C) Excavation at the 20cm level found a black tarp with rejects in unit L0685:106-U1. D) At the 30 cm deep level in the excavation, we identified concrete floors, rails and granitoid blocks in the northeast and southeast section of the unit.

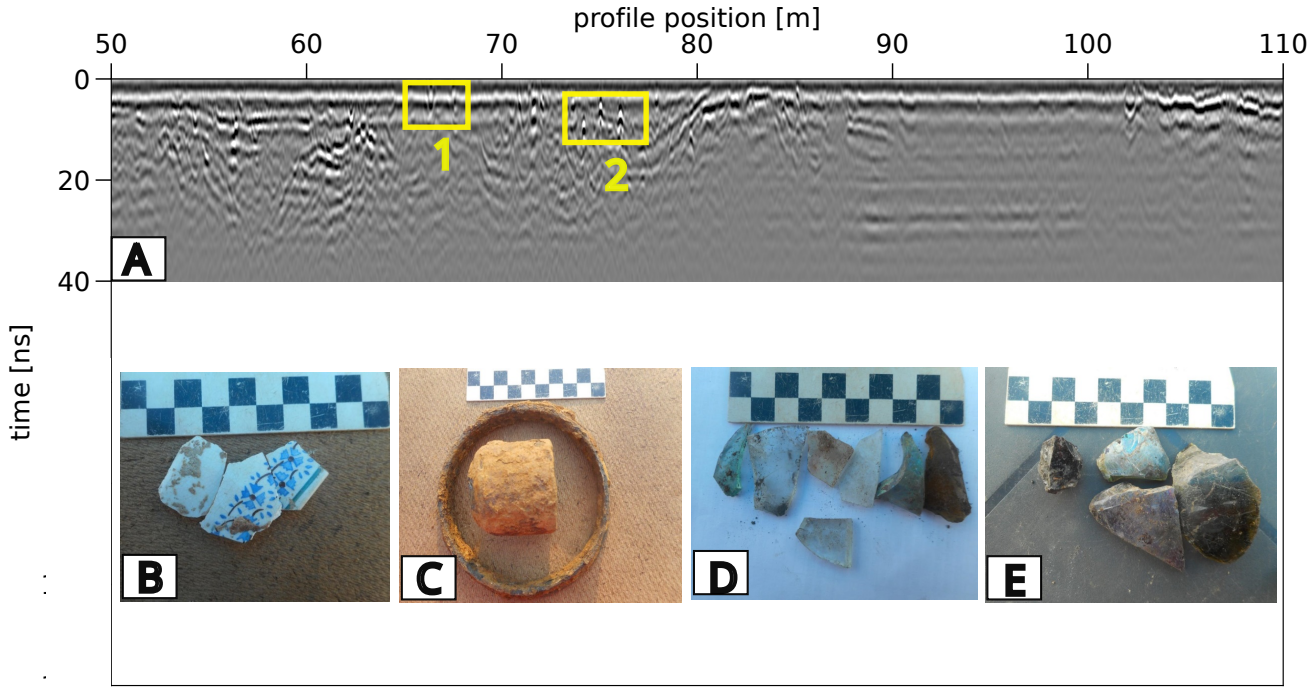

Figure 7: A) GPR survey showing two anomalous patterns located on the left in the radargram, a point and a hyperbolic anomaly. On the right, we have a set of hyperbolic surface reflections. B) Fragments of Fine Faience ware with Printed-transfer decoration, probably from the last quarter of the 19th century. C) Metal pieces exhumed at the excavation unit's 20-30cm level. D) Glass fragments exhumed from the 40-50 cm level of the excavation unit E) Glass fragments exhumed from level 50-60cm.