Ground-penetrating radar applied to forensic expertise in archaeological site: Tekoha Jevy indigenous village, State of Paraná, southern Brazil*

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Abstract

This paper discusses the results of 2D and 3D investigations in the Tekoa Jev indigenous village, located in the Guaíra County, State of Paraná, southern Brazil. Thirty-two parallel sections of GPR, with 250 MHz and 700 MHz shielded antennas were acquired, with the intention of associating geophysical anomalies with archaeological targets. The results evidenced several anomalies, two of which were subject to field checks (excavations), which revealed several artifacts (ceramic fragments), and other materials not yet diagnosed. Therefore, the GPR method proved effective in guiding new archaeological excavations. The discovery of several ceramic artifacts was credited to be ancient indigenous occupations on the alluvium banks of the Paraná River, in addition to answering some of the questions formulated by the forensic experts.

Introduction

In Brazil, as in other countries, laws protect the preservation of the archaeological heritage, and any damage caused to archaeological or prehistoric materials is subject to arrest or fine. In the State of Paraná the archaeological sites related to indigenous tribes are recorded from the coast to the left margin of the Paraná River. In the western region of the State of Paraná, between the cities of Terra Roxa and Guaíra, thirteen indigenous villages of the Avá-Guarani ethnic group were identified, among them Tekoha Jev. This village is located under an archaeological site related to the Tupi-Guarani tradition, whose characteristic feature is the presence of ceramic fragments (IPHAN, 2015). With the implementation of a port project in the county of Guaíra, the Brazilian Federal Public Prosecutor's Office (MPF) denounced the breach of an archaeological site. From this fact, the MPF delegated to the Technical-Scientific Sector of the Federal Police Department of the State of Paraná an expert examination to investigate the alleged destruction of archaeological artifacts belonging to the site. Thus, a multidisciplinary team composed of Federal Police experts, geologists from the Federal University of Paraná, and archaeologists and anthropologists from the Institute of Historical Heritage and National Artistic (IPHAN) went to the site to detect archaeological artifacts and possible funeral urns. Numerous authors deal with the efficiency of the applicability of geophysical methods to map archaeological sites and guide excavations. Authors (*e.g.,* Goodman et al., 1995; Malagodi et al., 1996; Groenenboom et al., 2001; Novo et al., 2008) discuss the efficacy of 2D and 3D GPR investigations for archaeological sites or test fields, especially the influence of acquisition parameters (spacing between profiles, spatial and temporal sampling interval, sampling frequency, etc.) for creating 3D / time slice results. In Brazil, various researchers applied the geophysical methods to investigate archaeological sites (Alves, 1979; Roosevelt, 1991; Rodrigues et al., 2009; Aragão et al., 2010; Cezar et al. 2001; Porsani et al., 2010; Souza, 2012; Gouvêa et al., 2013; Rocha et al., 2014).

Geologic setting and the localization of the study area

The study area is located in the Paraná-Etendeka Igneous Province (PEIP), which represents a major magmatic event of the Lower Cretaceous (135 to 131 Ma, according Janasi *et al.*, 2011) and precedes the fragmentation of southern Gondwana and opening of the South Atlantic Ocean (e.g. Licht, 2016 and references therein). The province covers 1.2 × 10^6 km^2 mostly over South America continent, and in its counterparts in Africa. The lava pile is formed mainly of basalts and basaltic andesites (97.5%) with minor quantities of acidic rocks (2.5%). Figure 1 shows the location of the study area in the municipality of Guaíra, State of Paraná, near the margins of the Paraná River, where the natives live in the Tekoa Jev village (Avá-Guarani family).

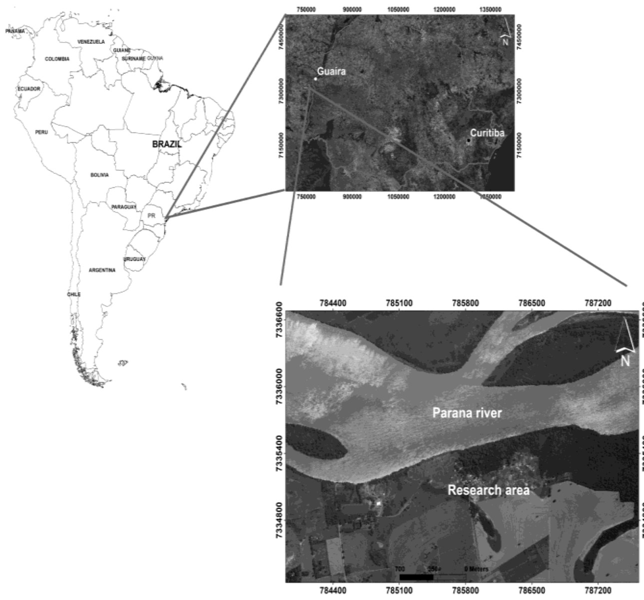

Figure 1 - Location map of the study area (Google Earth Pro, SIRGAS 2000 UTM 21S).

Method

The ground penetrating radar (GPR) method consists on the emission of electromagnetic waves with high frequencies, between 10 MHz and 3 GHz, by means of a transmitting antenna located on the surface of the terrain, which propagate in depth. Variations of the electrical properties that occur at the interfaces cause part of the transmitted signal to be reflected, which is then captured by another antenna, called a receiver, also positioned on the ground surface. In this way, the captured signal is amplified, digitized and stored in a control unit to be viewed and processed (Davis & Annan, 1989). Rocks, soils and objects in general have specific physical properties, such as dielectric permittivity (ε), electrical conductivity (σ) and magnetic permeability (μ). However, the same material can present variations of physical properties, due to the amount of water, percentage of porosity, clay content, mineralogical composition, among other aspects. For GPR applications, dielectric permittivity is the most important parameter (Jol, 2009), and is often expressed as $k = \varepsilon/\varepsilon_o$, where k is the dielectric constant and ε_o is the dielectric permittivity in the vacuum. The dielectric permittivity directly influences the velocity of propagation (v), of the electromagnetic wave in the investigated medium, while the electrical conductivity (σ) is reflected in the attenuation of the electromagnetic signal (α) (Davis & Annan, 1989). The relationships among the variables are indicated in the expressions: $v = c/(k)^{½}$; $\alpha = 1.63\sigma_o/(\varepsilon_o)^{½}$, where c is the velocity of the electromagnetic wave in the vacuum ($3x10^8$ ms^{-1}). In the GPR method, to generate significant expressive reflections a significant contrast of dielectric permittivity is required between the interfaces, that is, between the host (ε_1) and the target (ε_2) (Annan & Coways, 1992). Therefore, the reflection coeficiente (r_{gpr}) can be expressed by $r_{gpr} = [(\varepsilon_1)^{1/2} - (\varepsilon_2)^{1/2})]/[(\varepsilon_1)^{1/2} + (\varepsilon_2)^{1/2})]$.

Data acquisition and processing

After the inspection in the indigenous village, the selection of the site for the expert examination was based on three fundamental aspects. (i) indication of the most preserved area of the site, made by the IPHAN archeology team, in which archaeological materials could be identified in the original deposition context; (ii) presence of surface artifacts; and (iii) verification of the soil profile in situ. In the test site were suppressed pebbles, rock fragments and other materials that could compromise the acquisition of geophysical data. The geophysical data were acquired through the Duo Detector (Ingeneria Dei Sistemi - IDS), composed of three interconnected modules. The first module consists of a set of shielded antennas with frequencies of 250 MHz and 700 MHz; the second corresponds to the control unit and the third includes a data storage unit or netbook (IDS, 2009). Data were recorded continuously, with the following acquisition parameters: (i) trace spacing of 0.02 meters; (ii) 512 samples per trace; and (iii) temporal window of 120 ns. The geophysical survey resulted in 32 profiles with E-W direction, spaced of 0.02 m, whose lengths vary between 1.72 m and 4.68 m, due to irregularities of the terrain (Fig. 2). The results of the survey were analyzed *in loco*, through the visualization of the respective sections, and the main anomalies were identified in the terrain by means of flags. The data were processed in ReflexW® software, version 7.0, whose processing routine for 2D and 3D sections is the following; (i) subtract-mean dewow (removes low-frequency electronic noise); (ii) static correction (sets the first record of the GPR signal to zero time in the ground); (iii) time cut (limits GPR time logging by maximizing processing time to 25 ns); (iv) energy decay (raises the signal amplitude because of the wave attenuation during its propagation); (v) background removal (eliminates coherent events such as horizontal reflectors); (vi) 1D filtering (removes incoherent noises); and (vii) migration and time/depth conversion (positions reflection events in real position).

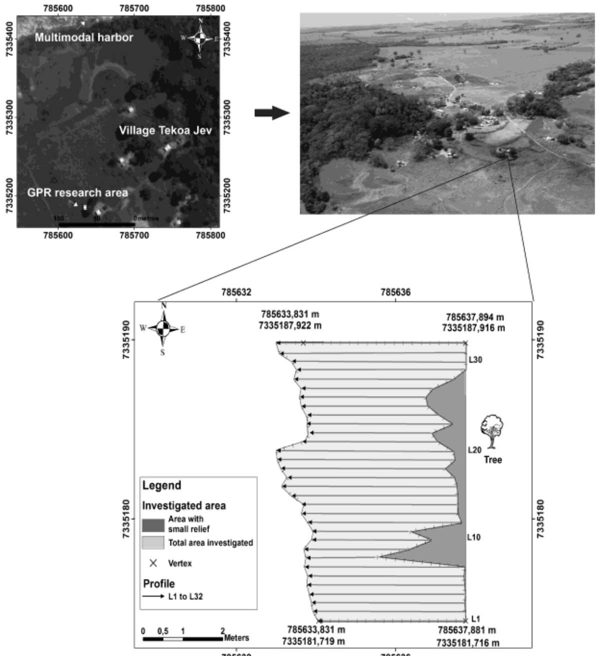

Figure 2 - Map of the study area indicating GPR profiles.

To obtain the electromagnetic velocity of the medium was buried the metal part of a hoe in a cavity with 0.25 m of depth. The velocity obtained was approximately 0.10 m/ns, which were used on the data (conversion time-to-depth). In the elaboration of the depth-cut maps, the instantaneous amplitude, trace envelope, was applied to better define the archaeological artifacts. This parameter is a measure of the reflectivity force, which is proportional to the square root of the complete energy of the signal at an instant of time and allows an evaluation of the distribution of reflected energy along the trace (Hahn, 1996).

Results and discussion

In the location of archaeological artifacts, it is common to apply GPR with high frequency antennas due to their lower depth of investigation and results with higher lateral resolution. For this reason, will be presented only the interpretations of the results of 2D sections and 3D models, resulting from the acquisition with the 700 MHz antenna. The results of the interpretations for sections 2D showed reflectors up to 20 ns, that is, up to a depth of 1.20 m (Fig. 3a, 3b and 3c). In these sections anomalies with different dimensions, between 0.10 m and 0.35 m, are displayed in the depths between 0.12 m and 0.35 m and were associated with fragments of indigenous ceramics. At depths between 0.50 m and 0.80 m, larger anomalies between 0.60 m and 0.80 m of dimension were characterized as funerary urns (e.g.

Fig. 3a and 3b). The anomalies interpreted as funerary urns were based on the dimensions of urns observed in the village and on the interruptions of surface reflectors indicating excavations in the ground. It is important to note that in none of the excavations were found rock fragments that could be related to the indicated anomalies. Based on the results of Figures 3a and 3c (with excavations), Figure 3b was interpreted by comparing the geophysical responses. Based on the interpretations of GPR sections 2D, 3D block (Fig. 4a) and two excavations at the site (Fig. 3a and 3c) were elaborated a stratigraphic profile at the archaeological site. Figure 4a show the characterization of three distinct layers: I - sandy-silty soil, brown color, with levels of organic matter and small roots (0.00 to 0.15 m); II - sandy soil with roots, reddish-brown coloration, ceramic artifacts of varying size and concretions of charcoal close to archaeological material (0.15 to 0.50 m); III - sandy soil with probable funerary urn material suggested by geophysical anomalies (0.50 m -?). The profile derived from the geophysical interpretation (Fig. 4b) is similar to the sketch prepared by the team of IPHAN archaeologists (Fig. 4c). According to the IPHAN (2015), through this sketch, it was possible to indicate the depth of 0.70 m of the site, whose archaeological layer is characterized by very dark (anthropogenic) soil and a large amount of ceramic archaeological material.

Conclusions

The acquisition of GPR with the 700 MHz antenna resulted in more adequate responses to the objective of the expertise. In several 2D profiles anomalies with different dimensions were observed, that is, small size anomalies were related to indigenous ceramic fragments, which in turn correlate with soil layers at depths between 0.15 and 0.5 m, evidenced by the two excavations. In contrast, the largest hyperboles were diagnosed at depths between 0.5 and 1.20 m, and may represent funerary urns.

Acknowledgments

The authors thank the Federal Police Department of Paraná, Federal University of Paraná, University of Brasília, and the Institute of Historical Heritage and National Artistic for their collaboration in this research. F. J F. Ferreira was supported in this study by Conselho Nacional de Desenvolvimento Científico e Tecnológico (CNPq), under contract 306978/2015-6.

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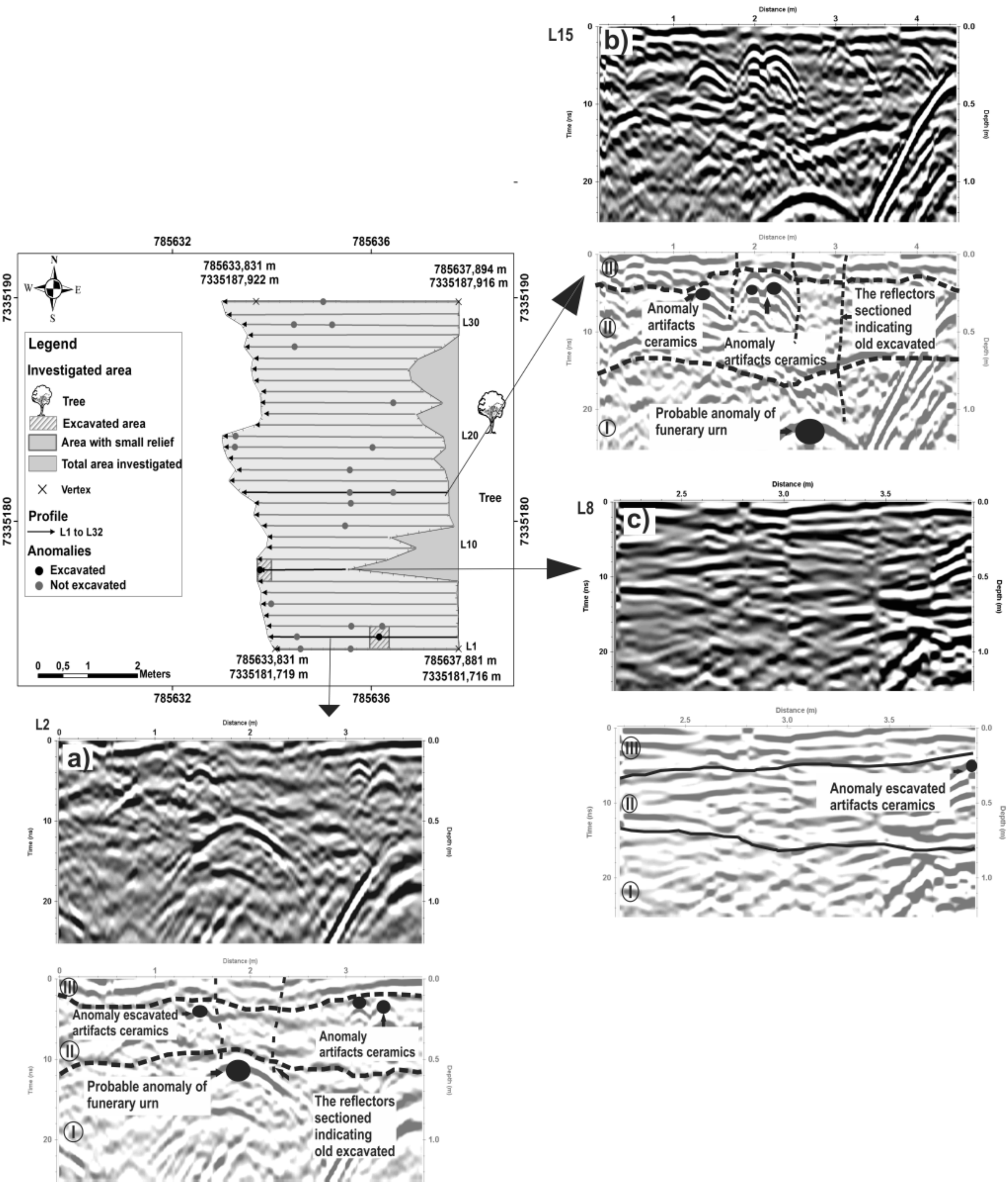

Figure 3 - Results of sections 2D characterizing the anomalies evidenced at the site.

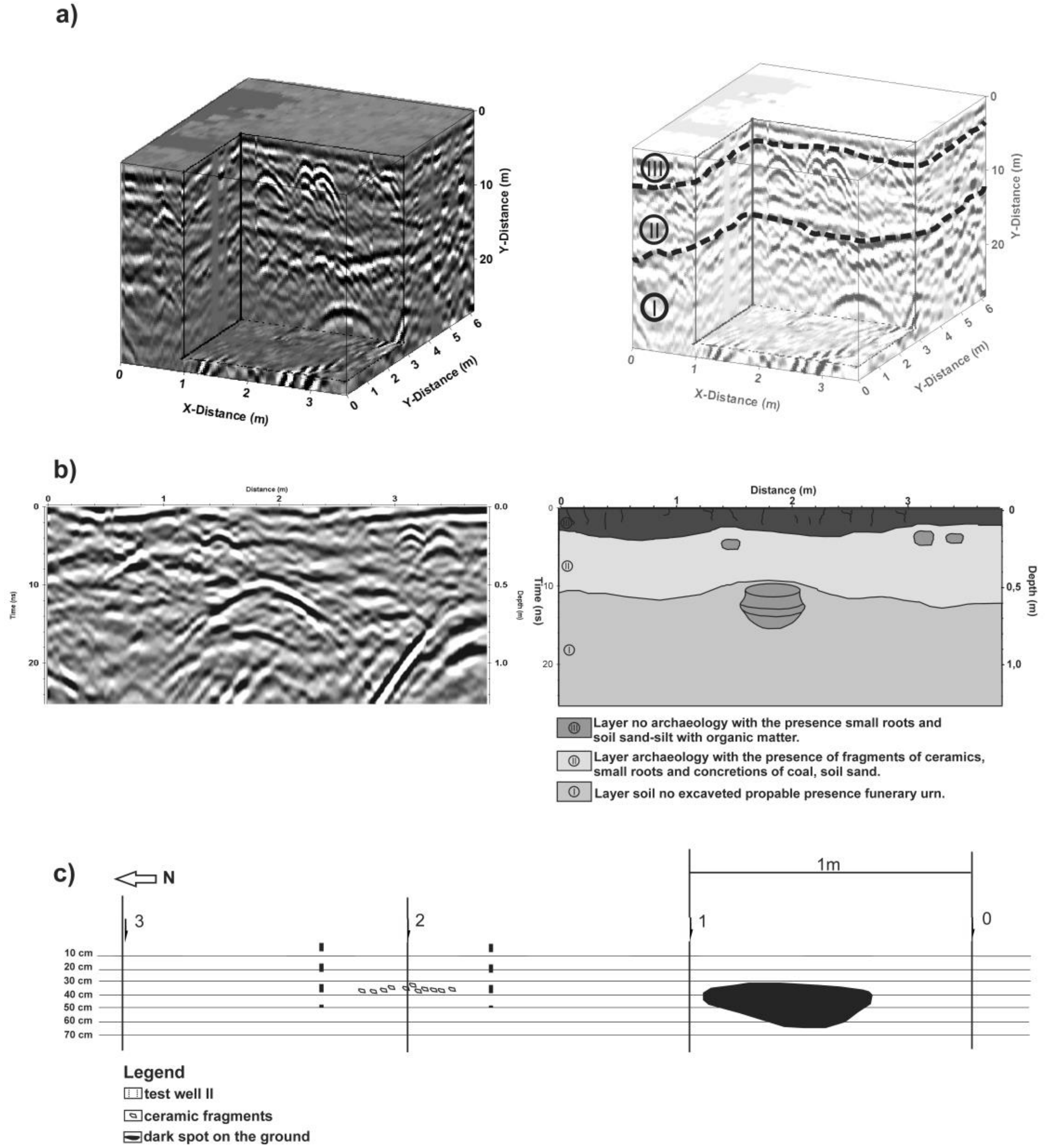

Figure 4 - a) Illustration of stratigraphic in 3D block. b) Illustration of the stratigraphic profile of the archaeological site through the indirect and direct method. (c) Stratigraphic representation of part of the exposed profile (modified from IPHAN, 2015).