GPR IMAGING - HIGH-RESOLUTION GEOPHYSICAL TECHNIQUE FOR INTERDISCIPLINARY RESEARCH

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Abstract. The geohazard team at the Geological Institute of Romania works in hazard estimation for land instability phenomena (landslides), in the field of archaeology and in the development of landslide hazard maps. To collect useful data, and thus to provide notable research, the team uses geophysical electrometry equipment, 3D Laser terrestrial scanner, high-precision GPS receivers and a GPR system. In this paper we will refer to the use of the GPR system in the field of archaeology. Being a method of prospecting/geophysical investigation of the subsoil based on the study of the propagation of electromagnetic waves with frequencies of the order of MHz or GHz, georadar records the dielectric permittivity contrasts in the subsoil. The method is considered to be fast, because it can be covered daily from 1.5 km of profile in the case of geological applications and up to 70-80 km in the case of investigations on roads or railways. The technique is non-destructive, the transmitter and receiver assembly are not affecting the investigated environment in any way. The digital analogue acquisition of the GPR system allows quasi-continuous measurements, the "in situ" highlighting of buried structures and the rapid processing of the obtained records. In recent decades, it has become apparent that GPR and other geophysical methods can really help in probing archaeological sites at fairly large investigation depths in a non-destructive manner.

Keywords: GPR, geophysical technique, prospecting, archeology.

Rezumat. Imagistica GPR – tehnică geofizică de înaltă rezoluție pentru cercetare interdisciplinară. Echipa de geohazard a Institutului Geologic din România lucrează în estimarea hazardului pentru fenomene de instabilitate a terenului (alunecări de teren), în domeniul arheologiei și, de asemenea, în elaborarea hărților de hazard la alunecări de teren. Pentru a colecta date utile, și pentru a oferi astfel o cercetare notabilă, echipa folosește echipamente de electrometrie, scaner terestru Laser 3D, receptoare GPS de înaltă precizie și un sistem GPR. În această lucrare ne vom referi la utilizarea sistemului GPR în domeniul arheologiei. Fiind o metodă de prospectare/investigare geofizică a subsolului bazată pe studiul propagării undelor electromagnetice cu frecvențe de ordinul MHz sau GHz, georadarul înregistrează contrastele de permitivitate dielectrică din subsol. Metoda este considerată rapidă, deoarece poate fi parcurs zilnic de la 1,5 km de profil în cazul aplicațiilor geologice și până la 70-80 km în cazul investigațiilor pe drumuri sau căi ferate. Tehnica este nedistructivă, ansamblul emițătorului și receptorului nu afectează în niciun fel mediul investigat. Achiziția digitală analogică a sistemului GPR permite măsurători cvasi-continue, evidențierea „in situ" a structurilor îngropate și prelucrarea rapidă a înregistrărilor obținute. În ultimele decenii, a devenit evident că GPR-ul și alte metode geofizice pot ajuta cu adevărat la sondarea siturilor arheologice la adâncimi de investigare destul de mari într-o manieră nedistructivă.

Cuvinte cheie: GPR, tehnici geofizice, prospecțiune, arheologie.

INTRODUCTION

The main subject proposed in this paper deals with the application of the GPR technique for the investigation of litho-stratigraphic successions of shallow-medium depth, in sedimentary terrains, in two types of situations, in the field of geo-archaeology:

a) when the investigated substrate (e.g., soils, cover/burial deposits) includes built structures (walls, roads, other solid constructions), and

b) in historical sites, where knowledge of the geological substratum is necessary from a scientific point of view, but invasive/destructive research methods should not or cannot be applied (e.g. drilling, ditches, other excavations).

As a result of the progress made in recent decades in the performance of non-invasive soil and subsoil investigation equipment, the technique called GPR (Ground Penetrating Radar) now provides continuous, high-resolution data that other geophysical investigation tools cannot. The GPR technique has proven useful in a wide range of environmental, geological, and engineering applications, with very encouraging perspectives regarding the results in fields such as, in this case, archaeology.

The specificity of the activity, the remarkably high vulnerability of archaeological sites, the excessive costs for excavations within a site and the insufficient funds require the accretion and correlation of as much information as possible, that can help to direct and rationally plan the excavation works, by knowing, before excavation, the placement of buried structures such as walls, foundations, floors, roads, ovens, graves, huts, former pits, synthetic hills and plugged ditches.

In this project, the principles, advantages, and limitations of the GPR technique will be specified and we will describe the activity of the preliminary measurement session undertaken within the Sultana archaeological site – part of the Gumelniţa Neolithic culture, the tell type settlement – located in the village of Sultana in Calarași county.

METHODS

Ground-penetrating radar (GPR) is a geophysical method that uses radio waves to render images of the subsurface materials (CONYERS, 2004) in a minimally invasive way. The system transmits, through an antenna, impulses to the basement, on electromagnetic frequencies that vary between 10 MHz and 1000 MHz. The wave propagation speed changes depending on the electrical properties of the materials/layers encountered, allowing the identification of materials based on the contrast generated by the dielectric constant (DANIELS, 2004). The advantage of georadar is that it allows users to identify the location of underground utilities without disturbing the ground, but the operating principles of this geophysical method have also been successfully applied in sedimentological studies, precisely because the GPR system detects changes in the electrical properties of the subsoil and strata encountered, based on their dielectric permittivity (DANIELS, 2004). If the electromagnetic pulse hits an object, its electrical conductivity is reflected and scatters the signal. The receiver detects the returning signals and records the variations within the measurements. The GPR system, by means of software, "transforms" these signals into images of underground objects - in the form of hyperbola. This is how GPR is also used to map structures and utilities buried in the ground or in artificial structures. Using the GPR technique for the investigation of litho-stratigraphic successions of shallow-medium depth, in sedimentary lands, two types of situations are revealed in the field of geo-archaeology:

a) when the investigated substrate (e.g., soils, cover/burial deposits) includes built structures (walls, roads, other solid constructions) and

b) in historical sites, where knowledge of the geological substratum is necessary from a scientific point of view, but invasive/destructive research methods should not or cannot be applied (e.g. drilling, ditches, other excavations).

As a result of progress made in recent decades in the performance of non-invasive soil and subsoil investigation equipment, the technique called GPR now provides continuous, high-resolution data that other geophysical investigation tools cannot offer. The GPR technique has proven useful in a wide range of environmental, geological, and engineering applications, with very encouraging perspectives regarding the results in fields at the border with other sciences, such as, in this case, archaeology.

The specificity of the activity, the very high vulnerability of archaeological sites, the relatively high costs for excavations within a site and the insufficient funds, require the accretion and correlation of as much information as possible that can help to direct and rationally plan the excavation works, by being aware, before excavation, of the existence of buried structures such as walls, foundations, floors, roads, ovens, graves, huts, former pits, man-made hills and plugged ditches.

The GPR is an extremely cost-effective and non-invasive geophysical method of underground surveying. This method, without limitation, can be used to identify/determine/detect:

Figure 1. GPR AKULA - Operation principle (original).

- the local and regional structure;
- buried metallic and non-metallic bodies;
- old engineering works and underground voids;
- archaeological sites hidden by superficial formations;
- resistance structures, location of foundation reinforcements;
- the thickness of the ballast layers and the geological layers under the railway;
- thickness and continuity of the asphalt layers of the roads;
- groundwater;
- relief on the bottom of rivers and lakes.

The GPR includes two main pieces of equipment (Fig. 1) a transmitter and a receiving antenna. The radar works by sending a pulse into the ground and recording the "echoes" that result from intercepting underground objects, also detecting some variations in the composition of the subsoil material. As part of the information gathering, specialists should pay special attention to the topography of the land. The GPR equipment must be pushed in a straight line and the antenna must be on the ground; if the area has excess vegetation, it must be cleared before performing a GPR survey. GPR surveys should always be carried out in a linear grid spatial pattern. The use of geophysical techniques in archaeology is necessary and beneficial, knowing that these techniques precede and guide archaeological excavations that can be expensive and long-lasting, replace in certain situations archaeological excavations, are non-destructive and last but not least, contribute significantly to the accumulation of knowledge for a field of knowledge that investigates the relationship between past human communities and the environment. (CATANI et al., 2002). Through excavation, archaeological research turns archaeology into a destructive discipline. To find out and understand what is below, you must destroy what is above.

GPR works by transmitting electromagnetic waves (in the range of 10~1000 Hz) into the probed material and receiving reflected pulses as it encounters discontinuities. The discontinuity could be a contact or interface between materials of different dielectrics, or it could be an underground object. The amplitudes of the received echoes and the corresponding arrival times can then be used to determine the nature and position of the discontinuity.

The acquisition software performs the first level of data post-processing. This step is necessary because georadar recordings are not images of the substrate but reinterpretations of its physical characteristics. By means of the algorithms implemented in the control unit, the noise level of the determinations is reduced, corrections are applied based on the sampling of the studied region and the wave propagation speed. Interpretation also takes place at this stage.

The propagation of electromagnetic waves traversing a real medium is mainly controlled by the following two factors:

ε - electrical permittivity of the medium (dielectric constant of the medium) and

σ - electrical conductivity.

The characteristics for different materials that can be commonly encountered in GPR measurements are shown in Table 1.

Table 1. Approximate values of conductivity (σ), permittivity (ε r) and propagation speeds of electromagnetic waves (v) (according to BAKER et al., 2007).

Material	σ (mho/m)	εr	v (m/ns)
Air	0	1	0,3
Sweet water	10-4	81	0,034
See water	4	81	0,034
Sand (dry)	10-7 - 10-3	4 - 6	0,13
Sand (saturated)	10-4 - 10-2	30	0,06
Dust (saturated)	10-3 - 10-2	10	0,10
Clay (saturated)	10-1 - 1	8 - 12	0,10
Costal dry sands	0,002	10	0,10
Swampy soil	0,008	12	0,09
Ice (sweet water)	10-3	4	0,15
Frozen soils	10-5 - 10-2	4 - 8	0,13
Granite (dry)	10-8	5	0,13
Limestone (dry)	10-9	7 - 9	0,12
Quartz	-	4	0,15
Coal	-	4,5	0,15
Concrete	-	6	0,12
asphalt	-	3 - 5	0,15 - 0,13
PVC	-	3	0,15

For this type of investigative method, the advantages are significant. GPR can be used in a wide variety of sites. It can detect metallic and non-metallic objects, as well as underground voids and inhomogeneities. The way to interpret the measurements is exemplified in Fig. 2. GPR makes it possible to measure the dimensions, depth and thickness of targets. The data is provided quickly and can cover a large area of the site.

The emission frequencies can be adjusted to provide a range of resolutions and penetration depths. As with other types of radar imaging, GPR offers varying levels of accuracy depending on the conditions encountered in the scan.

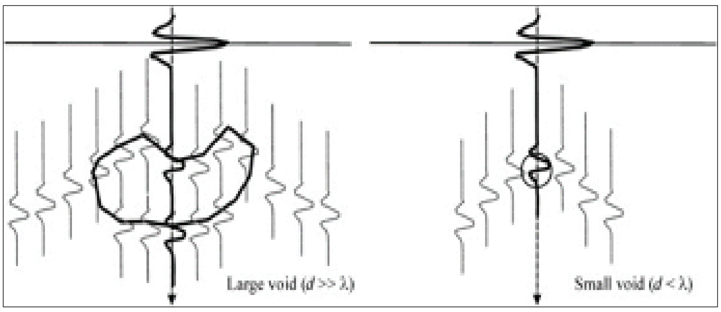

Figure 2. Detection of underground voids using GPR - signal amplitude (after AL-NUAIMY et al., 2000).

These conditions include:

a. the conductive properties of the basement (the rate of signal dissipation varies, depending on the properties of the materials). As the energy pulse reaches a material with different electrical properties, it is reflected. The strength or amplitude of the signal is influenced by the contrast between the dielectric constants and the conductivities of the investigated materials. For example, a pulse moving through wet sand and then through dry sand will produce a strong reflection, compared to the relatively weak reflection produced by going from dry sand to limestone.

b. depth of investigation. The layering itself can limit the depth of investigation by dissipating the signal when passing from one layer to another. The depth to which conclusive measurements can be made depends on the type of soil or rock characteristics and the frequency of the signal generated by the transmitting antenna. For example, the maximum investigation depth in concrete is usually approximately 160 cm. In wet clays and other highly conductive materials, the depth of GPR signals is significantly lower, reaching approximately 1 meter or less.

The relationship between the speed of electromagnetic waves and the properties of materials is the basic rule for using GPR in scans.

The speed is different for materials with distinct electrical properties: a signal that has passed through two materials with different electrical properties, although traveling the same distance, will arrive at the receiving antenna at different time intervals. The collected data are passed through a series of filters, depending on the objectives pursued, but can also be viewed in real time, which allows establishing their quality directly on the ground. The usual values of the frequency in correlation with the depth of investigation, for the device used by the authors, Akula 9000C, according to the instruction manual, are given in the Table 2:

Table 2. Usual values of the frequency in correlation with the depth of investigation. (CASSIDY, 2000).

Antenna frequency f(MHz)	Depth Zmax(m)
10	20
50	10
100	8
250	6
400	5
900	1

The GPR method is mostly effective when there is a significant difference between the electromagnetic properties of a buried object and those of the surrounding material. GPR is also often used for mapping objects made of the following materials: metal, PVC plastic and even concrete (being useful in soil and subsoil remediation actions). The principle of the GPR method is transmitting electromagnetic waves (in the range of 10~1000 Hz) into the probed material and receiving reflected pulses as it encounters discontinuities. The discontinuity could be a contact or interface between materials of different dielectrics, or it could be an underground object. The amplitudes of the received echoes and the corresponding arrival times can then be used to determine the nature and position of the discontinuity. The acquisition software performs the first level of data post-processing. This step is necessary because GPR recordings are not images of the substrate but reinterpretations of its physical characteristics. By means of the algorithms implemented in the control unit, the noise level of the determinations is reduced, corrections are applied based on the sampling of the studied region and the wave propagation speed. Interpretation also takes place at this stage.

GPR makes it possible to measure the dimensions, depth and thickness of targets (CASSIDY, 2000). The data is provided quickly and can cover a large area of the site. The emission frequencies can be adjusted to provide a range of resolutions and penetration depths. It is not necessary to dig, excavate or otherwise disturb the soil. Before even starting the scan, it is absolutely essential to get as much information about the site as possible. GPR practitioners should look for any historical maps and ensure that they have access to pass survey results showing concentrations of archaeological features and artefact density and at the same time have an idea of what the GPR is expected to show them so that to be able to understand what they should be looking for. As part of this information gathering, specialists should pay special attention to the topography of the land. The GPR equipment must be pushed in a straight line and the antenna must be on the ground; if the area has excess vegetation, it must be cleared before performing a GPR survey. GPR surveys should always be carried out in a linear grid spatial pattern.

Context is everything, so the appropriate topography parameters will always be based on the type of site and the findings of the initial archaeological investigation. Collection parameters will vary depending on site type and feature density. Ideally, the parameters of the measurement network should be carefully considered based on the specific characteristics of the site.

Instrumental and interpretation problems: case study in loessoid formations - Sultana archaeological site, Călărași county. The tell-type settlement of Sultana (Fig. 2) (www.sultana-archaeology.ro) is located on the right bank of the Iezerul Mostiştei lake, on an entrance of the terrace in the waters of the lake. It is separated from the rest of the terrace to the southeast by a deep valley, and to the northwest by a valley (HEGYI, 2018) Towards the southwest, a sinking of the land probably indicates the existence of a ditch that separated the tell from the rest of the terrace. From a geological point of view, the area of interest is part of the Moesic Platform structural unit, and from a morphological point of view, it belongs to the Romanian Plain unit, the Mostiștei Plain subunit.

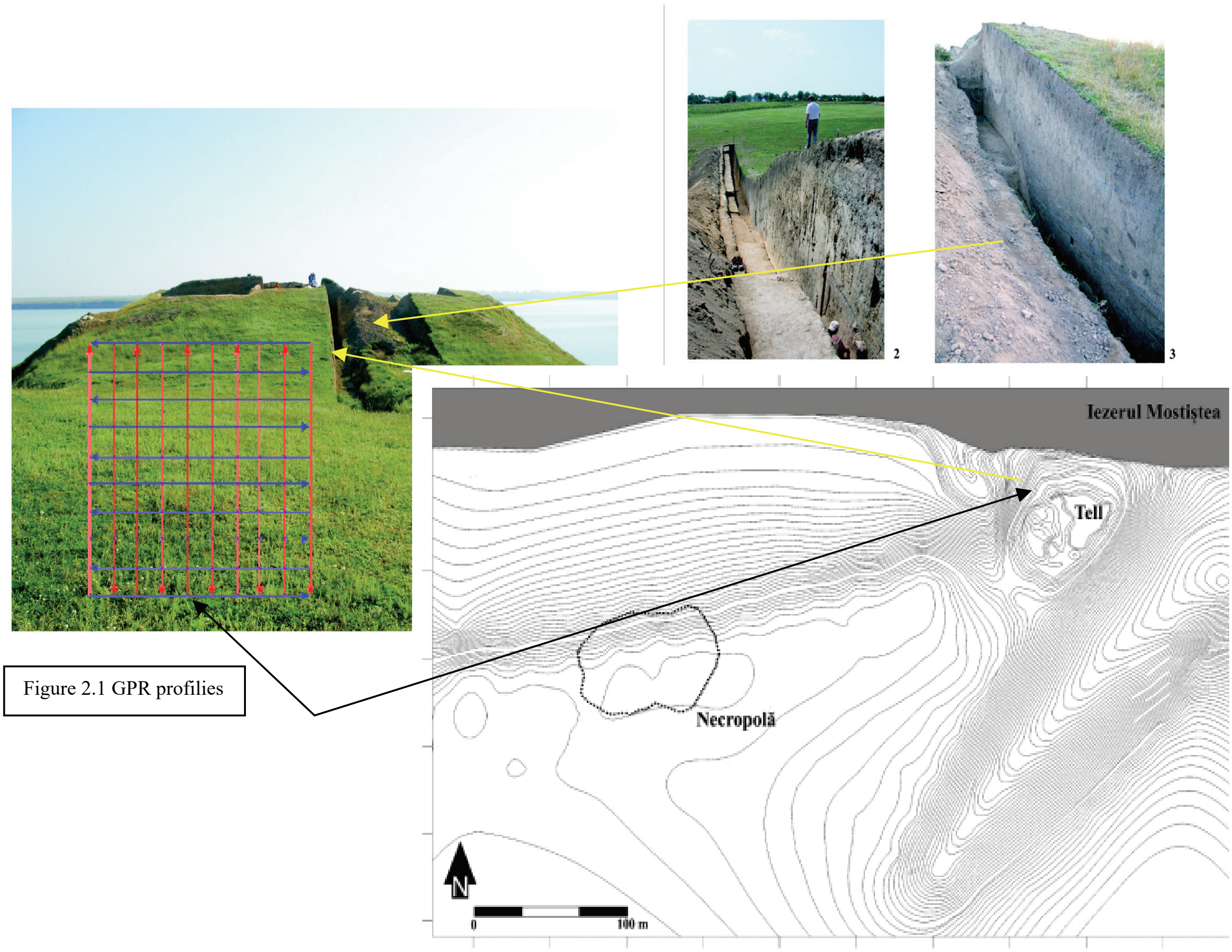

Figure 2. The Gumelnița settlement from Sultana – Malu Roșu Mostiștei Valley (after ANDREESCU & LAZAR, 2008).

The area of interest is represented by deposits of Quaternary age (Upper Pleistocene- Middle Pleistocene) of the type of Mostiștea sands and loessoid deposits. (Fig. 3). The Mostiștei Field, a smooth formation but which in some places also has a series of “roofs”, develops between the Mostiștei Valley to the East, the old terrace of Argeș to the South and that of Dâmbovița to the West. In the eastern part, the Mostiștei Field is furrowed by the valley of the same name, with a valley depth of 25-30 m and with a slightly inclined longitudinal profile, which causes the water from precipitation and the aquifer to stagnate along the way, forming a series of ponds strung together.

The loessoid deposits (LITEANU, 1953) are constituted of sandy dusts, yellowish clays with calcareous concretions with a thickness of 15-20 m, in which the existence of some intercalations of clayey dusts of a reddish brick colour can be observed, whose thickness ranges from 1 to 5 m.

The location is unusual for tell-type settlements that are usually placed at the base of terraces. (ANDREESCU 2010). Unfortunately, the settlement and its surroundings have undergone substantial changes over time. Thus, at least in the last decades, the terrace on which it is located, like all the terraces in the area, have been subjected to intense erosion processes due to the waters of the lake, as well as other phenomena (precipitation, freeze/thaw processes, etc.). Periodically, parts of it fall into the water along with the remains of the settlement.

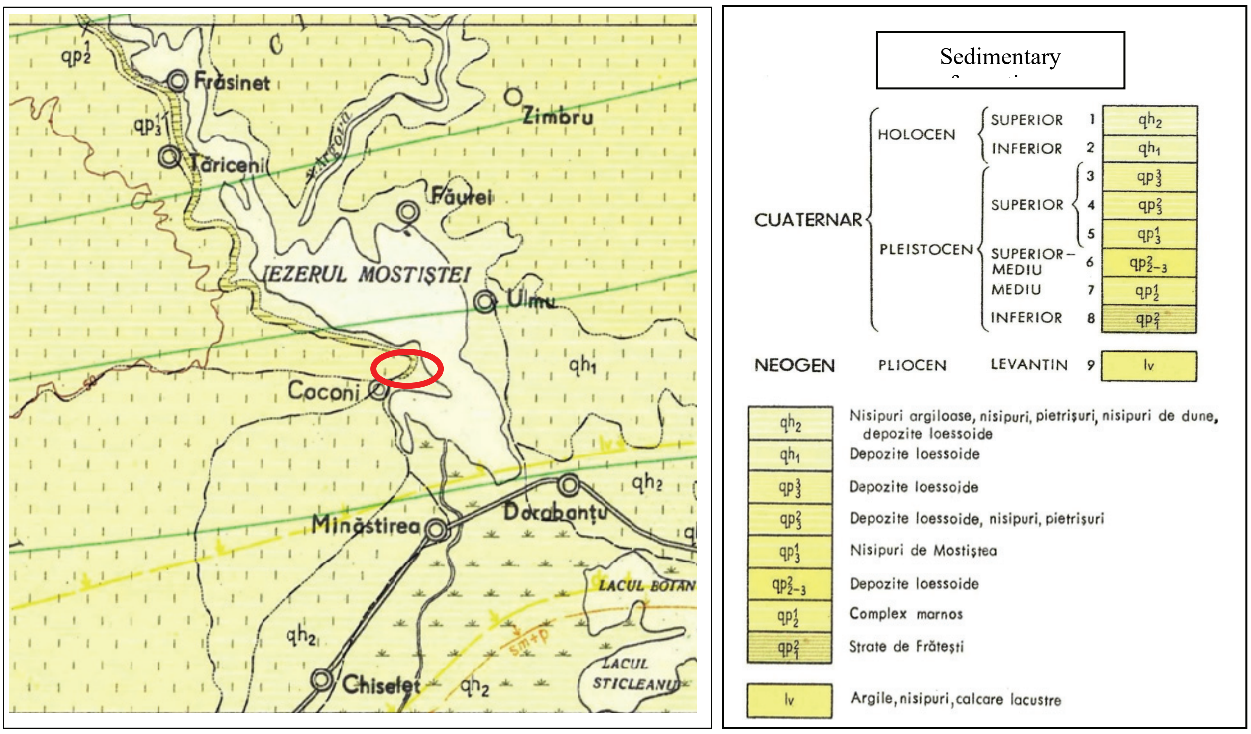

Figure 3. Extracted from the geological map of Romania 1:200.000 – IGR (1965).

RESULTS AND DISCUSSIONS

The main objective, as part of the investigations, was to highlight on the radargrams the existence of some walls in the continuation of the settlement to the south. The antenna used in the measurements was 350 Mhz, so that the method can provide information from the basement up to approximately 5-6 m deep. The area of interest was delimited by a rectangular network of 24 X 50 m (Fig. 2.1), and with 1 m distance between the profiles. In this way, 116 profiles were collected, which were later compiled, resulting in an east-west and a north-south profile.

The first step was to enter the parameters necessary for the measurement and the calibration of the device to the field conditions. It should be noted that the measurements took place in summertime, during an arid and dry period, with no rain in the area for more than 3 weeks. From this point of view, the measurement conditions were optimal.

The signal shape in a homogeneous soil does not change. However, if aspects characterized by other physical and chemical properties (anomalies) appear in the soil, discontinuities or deviations from the classic wave form will appear on the graph. The anomalies will induce particular refractions and reflections of the waves, characterized by the change of refraction indices or reflection angles. These anomalies usually consist of various rock types, sediments, water content variations, density changes at stratigraphic interfaces, or simply buried objects. 116 profiles were collected, which were later compiled, resulting in an east-west and a north-south profile.

After processing the data, it was observed that the GPR signal is homogeneous, with no hyperbola being recorded on the radargrams (Figs. 4; 4.1). This led us to conclude that for the measurements taken in this type of material (loess), the horizontal limits of other layers could not be located. At the same time, it demonstrates a homogeneous and compact material at a statistical level (any voids, characteristic of loessoid formations, are small and relatively evenly distributed).

What the measurements brought out was the fact that the material is homogeneous, we could even say undisturbed, in the basement, which may mean that the settlement has an extension in a different area than the one in which the measurements were made, or its limits established according to previous research already represent the maximum extension of the settlement, so no new information could be obtained from the measurements made with the GPR, which would help to outline the limits of the tell settlement in space.

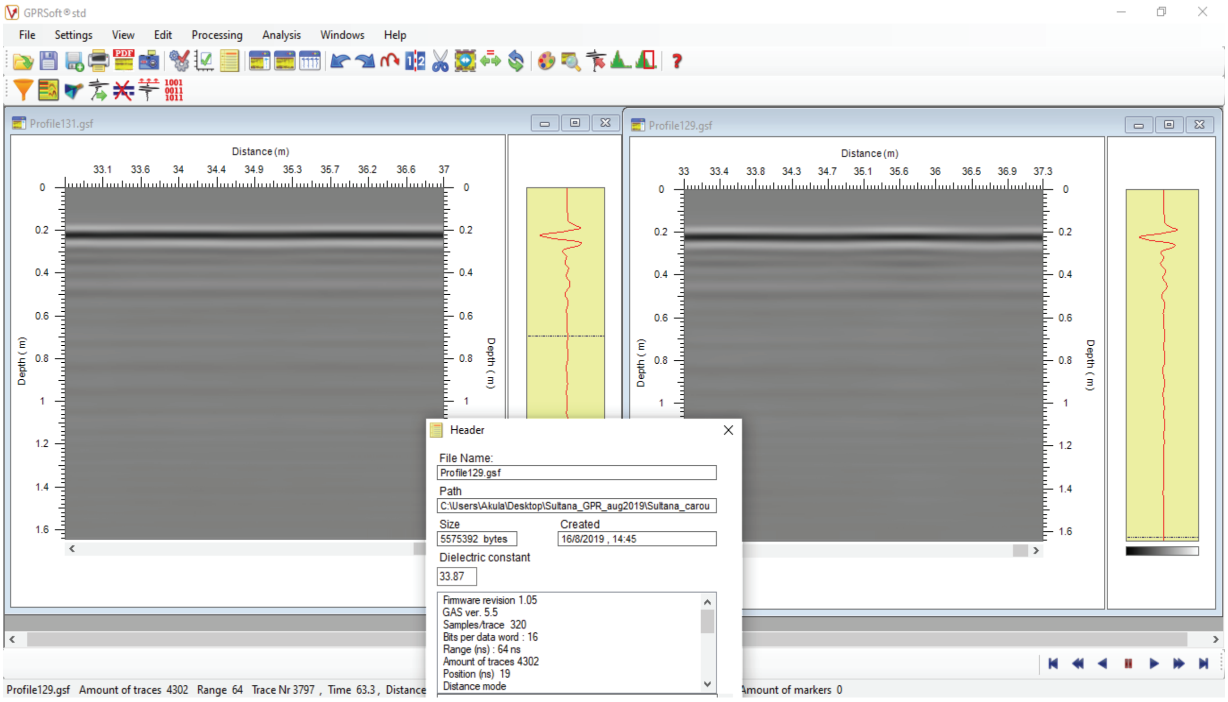

Figure 4. Analysis of collected data - examples of individual profiles, compiled to obtain the final profile.
4.1 Profile obtained by compiling 116 radargrams as shown in fig. 4 - measurements made at the Sultana archaeological site.
NS profile (a), EW profile (b)

CONCLUSIONS

Geophysics offers an alternative for non-destructive research tools in archaeological research. That is why archaeological excavation, expensive and most often destructive, no longer represents the only option for the reconstruction of the distant past (AL-NUAIMY, 2000). Thanks to the technological advances in the last decades, it is now possible to obtain geophysical information for large areas and in a short amount of time. The Georadar (Ground Penetrating Radar - GPR) method is a non-destructive technique, based on the principle of the propagation of radar waves (electromagnetic) in soils, rocks or in any other investigative environments (mountainous massifs, concrete). This method is used for defining structures that present contrasting electrical characteristics (conductivity and permittivity) in relation to the surrounding environment.

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REFERENCES

AL-NUAIMY W., HUANG Y., NAKHKASH M., FANG M.T.C., NGUYEN V.T., ERIKSEN A. 2000. Automatic detection of buried utilities and solid objects with GPR using neural networks and pattern recognition. *Journal of Applied Geophysics.* Elsevier. Amsterdam. **43**: 157-165.

ANDREESCU R.-R. & LAZĂR C. 2008. Valea Mostiştei. Aşezarea gumelniţeană de la Sultana-Malu Roşu. *Cercetări arheologice*. Muzeul Național de Istorie a României. Bucureşti. **14-15**: 55-76.

ANDREESCU R.-R., MOLDOVEANU K., BEM C. 2010. The Eneolithic settlements from Gumelniţa, Sultana and Căscioarele. An environmental analysis. *Studii de Preistorie.* Asociaţia Română de Arheologie. Bucureşti. **7**: 81-93.

BAKER G., THOMAS E., PARDY J. 2007. *Special Paper of the Geological Society of America.* Geological Society of America. Boulder. **432**: 1-18.

CASSIDY N. J. 2000. Electrical and magnetic properties of rocks, soils and fluids, in Ground Penetrating Radar: Theory and Applications. Elsevier. Amsterdam. 41-72.

CONYERS L. B. 2004. *Ground-penetrating Radar for Archaeology*. AltaMira Press. Walnut Creek. 318-320.

CATANI F., FANTI R., MORETTI S. 2002. Geomorphologic Risk Assessment for Cultural Heritage Conservation. In R. J. Allison (ed.): *Applied Geomorphology: Theory and Practice*. Wiley. Hoboken. 317-334.

DANIELS J. L. 2004. *Ground Penetrating Radar*. 2nd Edition. Institution of Engineerig and Technologies. London. 726 pp.

HEGYI A. 2018. *Modalități de aplicare a metodelor specifice geoștiintelor în cercetări arheologice din sud-vestul Romaniei.* Teză de doctorat. Universitatea de Vest. Timișoara. 65 pp.

LITEANU E. 1953. Geologia ținutului de câmpie din bazinul inferior al Argeşului și al teraselor Dunării. *Studii Tehnice și Economice.* Comitetul Geologic. București. Seria E2: 5-80.

www.sultana-archaeology.ro (Accessed January 12, 2023).

***. *Harta geologică a României 1:200000, foaia 44 București*, 1965. Institutul Geologic al României. București.

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