THE MAIN RESULTS OF ARCHAEOLOGICAL RESEARCH AT REȘCA-ROMULA (1869-2019) AND CONSIDERATIONS ON THE GEOPHYSICAL APPROACH – PART II

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ABSTRACT

This chapter is a continuation of presenting the Romula archaeological site, this time from the perspective of the geophysical investigations deployed. It contains an overview of the geophysical investigation methods and type of geophysical equipment which are of particular utility for archaeological objectives, with a closer look at the ones that were so far applied in Romula. Our evaluation of the past geophysical measurements is based on the official reports

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* Cite as: Chitea F. and Negru M., 2023. THE MAIN RESULTS OF ARCHAEOLOGICAL RESEARCH AT REȘCA-ROMULA (1869-2019) AND CONSIDERATIONS ON THE GEOPHYSICAL APPROACH – PART I, DOI: 10.5281/zenodo.8103490 in Chitea F. (Ed). Insights of Geosciences for natural hazards and cultural heritage. ISBN print 978-606-537-637-3; ISBN e-book 978-606-537-638-0, Cetatea de Scaun Editorial House.

included in the CIMEC database and the recent works of the authors. This review of the geophysical techniques and observations on the field implementation and results are part of the FCS project sustained by the Research Institute of the University of Bucharest.

In the Romula archaeological site were performed measurements using magnetometers (in 3 campaigns, various types of sensors), electrical resistivity meters (multi-electrode systems with various numbers of electrodes), conductivity meters (operating at low induction number - LIN), ground penetrating radar (with antennas of various central frequencies: 210MHz, 200MHz, 600MHz) and a gravimeter. The evaluation of the outcome, from different perspectives - archaeological and geophysical - gives the opportunity of observing both the advantages as well as outcomes of the non-invasive and non-destructive investigation methods in the way they were applied for studying the Romula archaeological site.

All geophysical results obtained so far are considered extremely important and valuable as allows the assessment of best practice for future geophysical campaigns designed to investigate this site, which proved to have a certain complexity. The overview of geophysical approaches discussed in this chapter can also be useful when planning geophysical investigations in other archaeological sites, as similar situations may be encountered.

Keywords: Archaeogeophysics, Electrical Resistivity Tomography for archaeological studies, Roman bricks, Walls detection, GPR signal attenuation.

INTRODUCTION

Geophysical survey is a term covering a group of detection methods applied in general for underground investigation for various objectives. Among these methods, some non-invasive and non-destructive techniques proved to have great applicability in locating buried archaeological remains in various environments, including in water-covered areas (underwater archaeology). Moreover, some geophysical equipment has been adapted or even developed on purpose for responding better to the necessities of a survey for archaeological targets.

Among the geophysical methods with applicability for locating archaeological buried constructions (walls, cellars, cisterns, paved roads, necropolis) or traces of habitation (fireplaces, modified land for defending purposes or for agriculture) are preferred the ones which do not require direct contact with the ground and the ones operating in quasi-continuous mode and fast-scanning speed. In this category, we can include the shallow-depth electromagnetic investigation methods and magnetometry surveying method, preferably performed using a gradiometer.

The following sections are an overview of the geophysical methods that were applied in Romula at various moments, with a focus on past campaigns (respectively 2003, 2004, and 2019) which were reported so far in the CIEM database. Discussions are completed by the observations on geophysical field experiments made by the authors in 2021.

Considerations on magnetometry measurements and results in Romula

Method presentation - general aspects

We may say that, in the past, among the geophysical methods for archaeological investigations, magnetometry prospection was the preferred one due to the data-fast acquisition and because it responded well in sites of various eras. Best results were obtained in sites containing ferrous objects, in sites where constructions were made by burned bricks or rocks with magnetic properties (granite, basalt, andesite), and as well as in sites with burning points in clay-containing soils. Good results with this method can also be obtained when applied for detecting construction remains of materials with low-very low magnetic susceptibility, if a certain contrast with the surrounding material (possessing higher magnetic properties) exists.

Among the inconveniences when using a magnetometer is the fact that the acquired data (total magnetic field) contains not only the signal provided by the archaeological remains but also the influence of the deeper buried geological layers that possess magnetic properties. As the geological layers geometry and composition are variable, the induced effect along a profile or perimeter can sometimes be much stronger than the signal coming from shallower archaeological buried remains. To overcome this inconvenience, as a field technique, it becomes necessary to double the measurements on a point by taking the measurements with the sensor (coil) positioned at 2 different heights. For making field procedure easier, it was developed a piece of equipment called a magnetic gradiometer, which practically records the data using a pair of sensors mounted on a rigid axe. The sensors are kept at a fixed distance during the survey. Sometimes the axis is telescopic, allowing the field technician to choose at the start of the survey the optimal distances between sensors, for the given case study. Each magnetic sensor registers the strength of the geomagnetic field. If they are stalked at the edges of a vertical-positioned axe, the value registered by the sensors is subtracted, resulting a value that mirrors the local impact of the shallow buried structure on the geomagnetic field. This acquisition system is less affected by the diurnal changes of the magnetic field, magnetic storm influences and is more efficient in detecting shallow-depth buried targets displaying a contrast of magnetic properties with the surrounding material. For the single-sensor magnetometer, the variation of the magnetic field due to external factors must be corrected in the processing stage by using the data registered by the base-station magnetometer (strongly recommended in applications for archaeology) or provided by the permanent geomagnetic observatory network (based on registrations at a fixed point, seldom far away from the investigated location).

It is worth mentioning that, in recent years, a new trend in making magnetometric measurements has been developed, which makes use of unmanned aerial vehicle (UAV or aerial drones) capabilities of carrying ultra-light pieces of geophysical equipment, such as a magnetic sensor. The surveying magnetometric kit can be as light as 1kg, meaning less energy consumption for the caring vehicle. Among the advantages that this acquisition technique is bringing is the possibility of making investigations even in areas difficult to be accessed for ground-based measurements (for example a remote location surrounded by water or dense vegetation formed by bushes and shrubs, shallow water-covered areas, swampy zones) or areas where local conditions may put at the risk the technicians (for example due to unstable terrain conditions or possible wild animals attack). Results obtained by using the UAV-magnetic investigations in Romania for archaeological purposes are presented in the paper of Dimitriu et al., 2021.

Magnetometric measurements at Romula

At Romula, so far, according to the CIMEC database, only ground-magnetic measurements were performed in a few campaigns. Actually, the first geophysical investigations reported for Romula archaeological site were deployed in 2002, in the Northern Sector, more precisely at the North of the Resca village, in the area of the former C.A.P. and were continued in 2003 in two new perimeters (Scurtu 2004, Scurtu 2014). Both campaigns consisted of ground-magnetometric measurements, aiming to locate archaeological buried structures and other traces of inhabitation. Results of the mentioned two campaigns (total field and filtered data maps) are available at *Link 1* and *Link 2* as well as published in Scurtu 2014.

The principal investigator interpreted that some of the profiles executed in the 2003 campaign (see Figure 4, chapter 10) intercepted a section of the Filip the Arab defensive wall. An archaeological excavation executed in the Northern Sector with the aim of finding the mentioned wall identified a construction of 1.20m thickness. The wall remains revealed that it was built mainly using bricks and mortar. The embedded pieces of stones (limestones and riverstones) were probably added during the latter reinforcement stages (Negru et al. 2007). Results from magnetometric survey of the Central Fortress that took place in 2020 are presented in Niculescu et al., 2021.

Considerations on electromagnetic measurements and results in Romula

Related to ground measurements for archaeological objectives, we consider that nowadays it is more advantageous to use electromagnetic methods rather than magnetometry surveys for several reasons:

-with EM systems, the detectability is no anymore restricted to archaeological objects that contain iron or features that pose a thermo remnant magnetic field (fireplaces, hearths) which provides a measurable contrast with the surrounding earth materials

-using EM system, the depth of investigation can be confined to the depth of interest for the archaeological survey (like the maximum possible depth for the presence of buried archaeological targets), therefore the influence of geological changes below the interesting depth can be cut off from the data since acquisition stage.

- 3D imaging capabilities for certain types of EM equipment (multi-coils ground conductivity meters or GPR arrays) and corresponding field acquisition procedure

The position of the areas investigated by means of electromagnetic techniques in the 2021 campaign is given in Figure 7 -Chapter 10.

Electromagnetic induction measurements (LIN) and data interpretation

Method presentation - general aspects

Among the geophysical electromagnetic type of instruments that can be used for field surveys, there is a specific class that operates on the principle of electromagnetic induction under the low induction number (LIN) condition. The principle of operating was described by McNeill (1980) for measurements on the ground surface, and then by other authors (Wait, 1945, Wait, 1955; Beamish, 2011) for non-zero elevation measurements.

Simple versions of ground conductivity meters are based on two coils (loops) one operating as a transmitter (Tx) and the other as a receiver (Rx) of the magnetic field. A time-harmonic current is passed through the transmitter coil generating a primary magnetic field (H_P) that is propagating through the air and ground. Within the electrically conductive volumes from the ground (stationary conductor), the time-varying primary magnetic flux generates Eddy currents, which in turn will produce a weak secondary magnetic field (H_S).

The measured signal ($H_T = H_P + H_S$) at Rx is decomposed in In-Phase (P) and In-Quadrature (out of phase), providing therefore (when operating at low frequencies) information on both magnetic susceptibility and electrical conductivity variation at shallow depth.

The magnitude of the In-Phase components will be higher over zones with increasing magnetic susceptibility content.

When the ratio between the intercoils distance (d) and the electromagnetic plane-wave skin depth (δ) is less than the unity (the induction number B<<1), the variation of the ratio between the secondary (Hs) magnetic field measured at the receiver (Rx) coil and the primary magnetic field (Hp) is used to assess the earth conductivity variations across the investigated profile using a simplified formula described by McNeill (1980):

$$B = \frac{d}{\delta}$$

Where, B – is the induction number (dimensionless)
d is the spacing between the dipoles
δ – is the skin depth

$$\left(\frac{H_s}{H_P}\right)_V \cong \left(\frac{H_s}{H_P}\right)_H$$

$$EC_a = \frac{4}{\omega\mu_0 d^2}\left(\frac{H_S^Q}{H_P}\right)$$

ECa -electrical apparent conductivity
$H_S{}^Q$ represents the measured in-quadrature component of the secondary magnetic field at the receiver coil
H_P primary magnetic field at the transmitter coil,
d is the spacing between the dipoles
μ_0 is the permeability of free space
ω = 2πf is the angular frequency, where f is frequency

Depending on the complexity of a site and study objectives, a single pair of transmission (Tx) and reception (Rx) sensors may be sufficient for locating areas where the underground was disturbed due to anthropogenic works, but, when available, is preferred the equipment with multi-receiver coils. Ground conductivity meters designed for operating within the limits provided by the low induction number physical concept are available in the following coils setups: Tx-Rx, Tx-Rx-Rx, or Tx-Rx-Rx-Rx. By using a single-pair type of equipment one will obtain maps of electrical conductivity and magnetic susceptibility down to a certain depth, which is influenced by the operating frequency, the distance between the coils, and magnetic dipoles direction or coils orientation (vertical dipole or horizontal dipole). Ground conductivity meters operating with multiple Rx will permit to obtain cumulated information from various depths, which can be used in inversion routines to obtain sections that reveal the true variation with depth of the petrophysical investigated parameters.

The electromagnetic induction method applied at Romula

The electromagnetic induction method was tested at Romula in the 2021 campaign, in a sector where the investigation target was down to 1.5m depth. The data field acquisition was performed by a terrain conductivity meter using the vertical dipole mode and Tx-Rx positioned at a 1m distance. This setup restricted the depth of investigation to the planned depth. Operating in this mode, a separation of the shallow targets from the influence of deeper sources was obtained (Chitea et al., 2022).

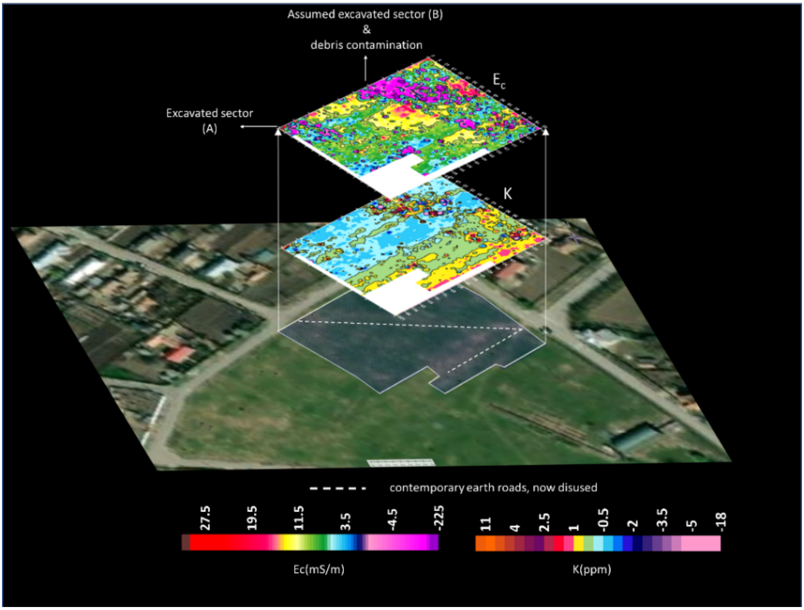

Figure 1 - Maps of electrical conductivity (Ec) and magnetic susceptibility (K) obtained using a Tx-Rx couple positioned at 1m distance.

The depicted maps of electrical conductivity (Ec) and magnetic susceptibility (K) (Figure 1) revealed the variation of buried elements signatures along the investigated area. As no dig-up works were executed after this geophysical survey, the observed changes in the petrophysical parameters are not yet fully understood.

Based on a time-lapse evaluation of satellite images, it was noticed that the EM survey overlaps with an excavated sector marked as "A" (which was estimated to have been opened like 8-9 years ago). From the geophysical measurements perspective sector A (with no record of the depth of excavation and findings) can be described as a cluster of Ec anomalies characterized by rapid fluctuation from high electrical conductivity to very low (even negative values). Similar results were noticed in the "B" sector, therefore it is assumed that also in this area some excavation works were done in the past and then refilled. The magnetic susceptibility map (K) was used as a support for understanding better the buried features signals and correct interpretation of the Ec data. For example, the electrical conductivity rapid fluctuation (max/min-negative values) corresponds with K bipolar anomalies. The bipolar K anomalies in this archaeological setup can be linked to the presence of metallic ferrous objects (most likely modern-type debris), burnt points and burnt brick accumulation. Apart from the cluster of bipolar K anomalies, there is a small variation of this parameter along the measured zone.

The GPR signal from the B sector (Figure 2) also confirms the presence of multiple sources of anomalies positioned near surface, contaminating practically the geophysical data (discussed in the GPR dedicated section). Given this situation, it is concluded that the top layer with excavation debris and dumped pieces of burnt bricks are masking a coherent signal that might come from a deeper-positioned archaeological target.

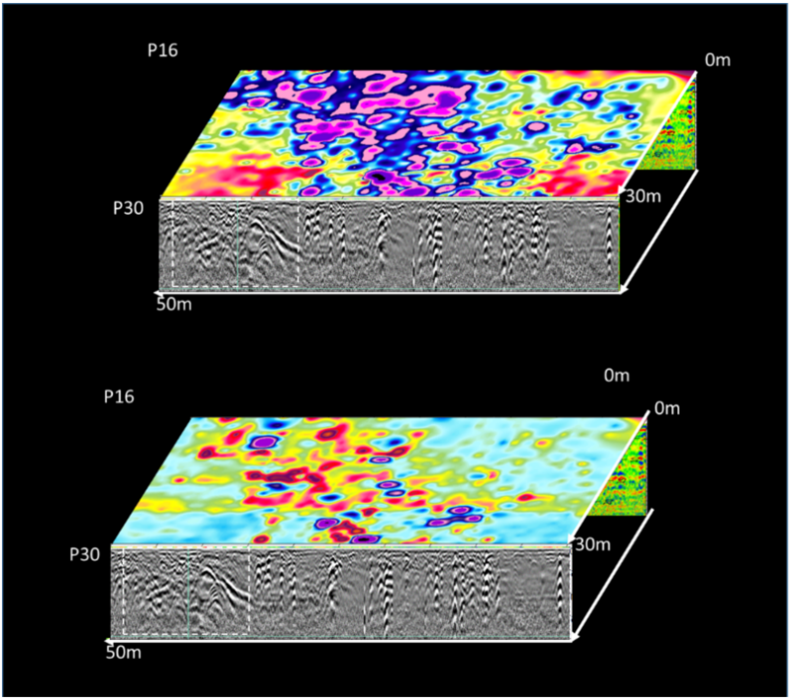

Figure 2 - 3D visualization of the electrical conductivity and magnetic susceptibility maps between profiles P16-P30 in correlation with GPR radargram for profile P30.

Interpreting the B sector in conjunction with ERT (Figure 9) data, it was noticed that part of it is crossed by the remains of the Roman-age defending wall. In the analyzed area, there are some sectors with Ec varying from 8.4-19.5 mS/m, and given the context are interpreted as not affected by the invasive research works and possessing archaeological remains such as walls and pavements.

In conclusion, despite the complex situation in the analyzed perimeter (including the differential soil compaction due to car traffic on old roads which crossed the actual perimeter of the central fortification, the presence of old excavated sectors not present on working plans, the presence of the inhomogeneous layer of variable thickness containing construction debris, as well as the high degree of damage of the buried archaeological structures which remained in-situ), from the results obtained by using a terrain conductivity meter on parallel lines at 1m distance and quasi-continuous acquisition along the profile, it was possible to contour zones that are likely to contain ruins not evaluated before.

GPR measurements and data interpretation

Method presentation - general aspects

Another type of electromagnetic measurement that is adequate for archaeological investigations implies using very high frequencies, by means of Ground Penetrating Radar (GPR). This method consists in transmitting pulses of high frequency (MHz-GHz) that travel into the ground and record the arrival time of the backscattered signal. In this way, the buried objects which pose contrasting dielectric properties with the surrounding geological formation or boundaries between layers of distinct dielectric properties can be detected. When choosing to work with a GPR, one important decision is the antenna frequency to be used as it is necessary to find the balance between the desired resolution and depth of investigation.

Another technical aspect that complicates the interpretation of the GPR data is related to the way the GPR antenna crosses over the target and, of course, the target geometry. If the antenna crosses perpendicular over a target that can be approximated as a point-type object, it is expected to generate an anomaly of hyperbolic shape. Point-type targets are usually considered buried pipes and cables (in cross-section), small voids, and sometimes walls. If the profile intersects the same point-type target at a different angle, the hyperbola will appear a bit wider than obtained at the 90 degrees crossover. And then, it will result in another anomalous shape when, during the acquisition, the GPR antenna is on top of the target and for a while runs parallel with it. If the buried target maintains its composition, shape, and thickness and there is no variation in the burial depth, then reflections will result at the same value for the travel –time and will form a linear-type anomaly. Therefore, there are many options in terms of the expected signal that can be received from a buried source, especially from a non-metallic one. Interpretation of the GPR data in the presence of multiple types of sources is not an easy task, as some of them might display similar hyperbolic reflections in the B-scans (Liu et al., 2021, Huang et al., 2022). Also, in the given setting where destructive interference or signal attenuation may occur, the GPR method may sometime fail in providing evidence of buried elements that might be of interest for archeological surveys (Barone et al., 2021).

GPR measurements at Romula

In 2019, a geophysical survey took place in the central-eastern part of the Central Fortification (marked in Figure 7, Chapter 10). For this purpose, the methods of electrical resistivity tomography and georadar were used. The very first GPR investigations were performed using a 210 MHz center frequency antenna and were reported as not successful (Studiu Arheogeofizic, 2019). At that moment, the investigators considered that the measurements were affected by a noise source.

The GPR measurements performed in a later campaign (2021) in a different perimeter from the Central Fortification did not encounter problems related to external geophysical noise (high-frequency electromagnetic signal which can jam the signal received by the GPR antenna in use for the survey) that could jeopardize the survey. However, in some sectors, on the 2D reflection profiles (B-scans) were noticed numerous thin, vertical high-amplitude reflections which extend downward, practically contaminating the results. These multiples or ringing effects are often associated with metallic scraps (bolts, nails, horseshoes, cans, lost utensils) positioned near the surface. In this particular location, it is considered that some bouncing effect of the electromagnetic waves which starts below 0.15m could be caused by numerous slabs of construction materials embedded more or less randomly into the soil (Figure 3), overlapping and possessing variable dimensions.

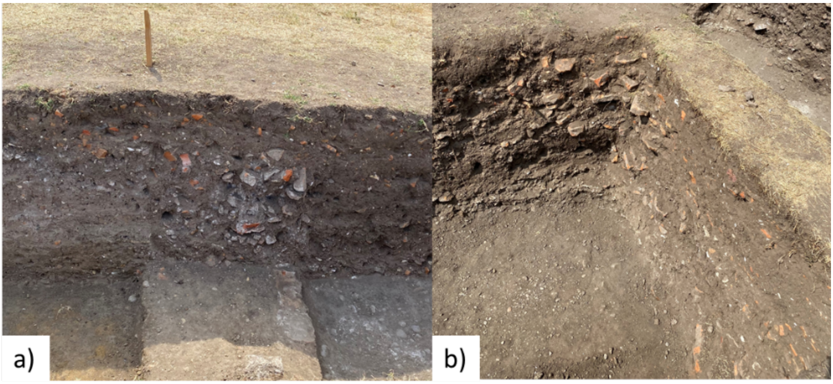

Figure 3 - Open cuts for archaeological survey showing a top layer with lots of fragments of Roman tiles, bricks, and river stones of various dimensions. The main archaeological interest is to discover the Roman age structures placed below this layer of construction debris, whose thickness along the site is variable.

For example, the thickness of an individual brick can reach up to 7.5 cm. The largest ones were found to have 49cm in length and 30 cm in width. Given these dimensions and shallow burial depth, it was estimated that they are detectable targets when scanning at 600MHz center frequency of the wavelength of the radar energy (Figure 4). Target detectability can be estimated based on the approximative dimension of the footprint at a certain depth (or time) calculated using the formula given in Figure 4.

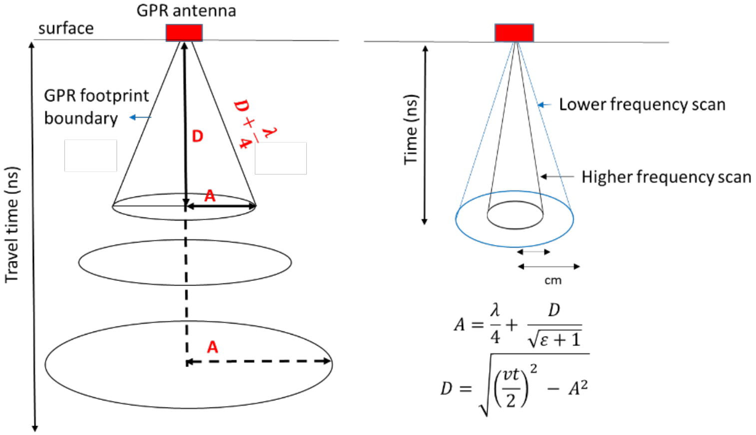

Figure 4 - Simplified sketch of the GPR footprint concept and its dependency on time, frequency, and dielectric property. A- approximate dimension of the footprint radius, λ- center frequency of the wavelength of the radar energy, D- the distance between the reflector and the center of the antenna, ε-dielectric permittivity

For the GPR measurements performed during the 2021 campaign was used an array of multi-central frequency antennae (200MHz and 600MHz). Theoretically, when performing measurements at 2 frequencies, a high-resolution survey is assured for the upper part following the transmission of higher frequency pulses but also it is enhanced the depth of the investigation by the usage of the lower frequency pulses (Figures 5-6).

Observations made on the resulting radargrams showed that most of the reflectors were visible for both central frequencies used in the survey. On a few occasions, the 200MHz B-scans brought more precision in data interpretation for the deeper targets that were slightly visible on the 600Mhz B-scans (Figure 5). The layers with construction debris and archaeological load are followed by a zone with remains of old constructions of interest for archaeological research. Just on 2 profiles (distance between them of 6m) was noticed a reflection coming from deeper targets (40ns travel time), which currently is suspected to be caused by a piece of a fortification wall.

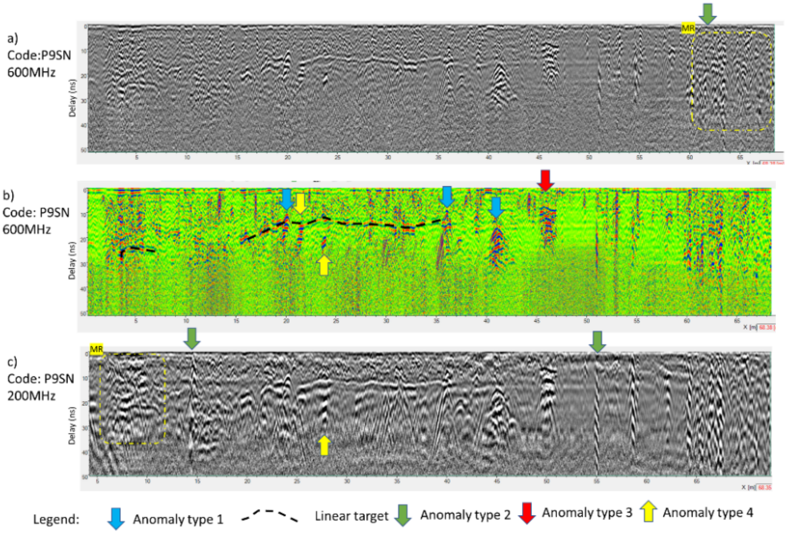

Figure 5 - Example of GPR results on profile P9SN (a) with exaggerated vertical scale and anomalies of archaeological interest marked on the colored version of the radargram (b) and results from the second antenna of the array, frequency 200 MHz, antenna approximated at 0.5m distance from the other. Anomaly type 2 is associated with multiples or ringing effects. MR zones are sectors where the results are contaminated by small-target reflectors positioned near the surface. Interpretations of other anomalies are discussed in the text.

Following the 2021 GPR survey, hyperbolic (anomaly type 1 in Figures 5 and 6), linear-type anomalies as well as typical GPR artifacts - ringing effect (anomaly type 2 in Figures 5 and 6), were observed in the resulting radargrams. Anomaly type 3 (Figure 5) can be related to objects with a larger cross-section than the ones that generated the type 1 anomaly or deploying different orientations with respect to the GPR antenna. Type 1 anomalies are given by strong contrasts, which in this case were interpreted to be given by walls or stacks of dumped construction materials (as revealed by the archaeological excavation -Figure 8).

In the radargram from Figure 5c, which presents the results of one of the lower frequencies antennas of the array, the type 3 anomaly is better depicted, and it is easier to distinguish the hyperbolic tails in its end part.

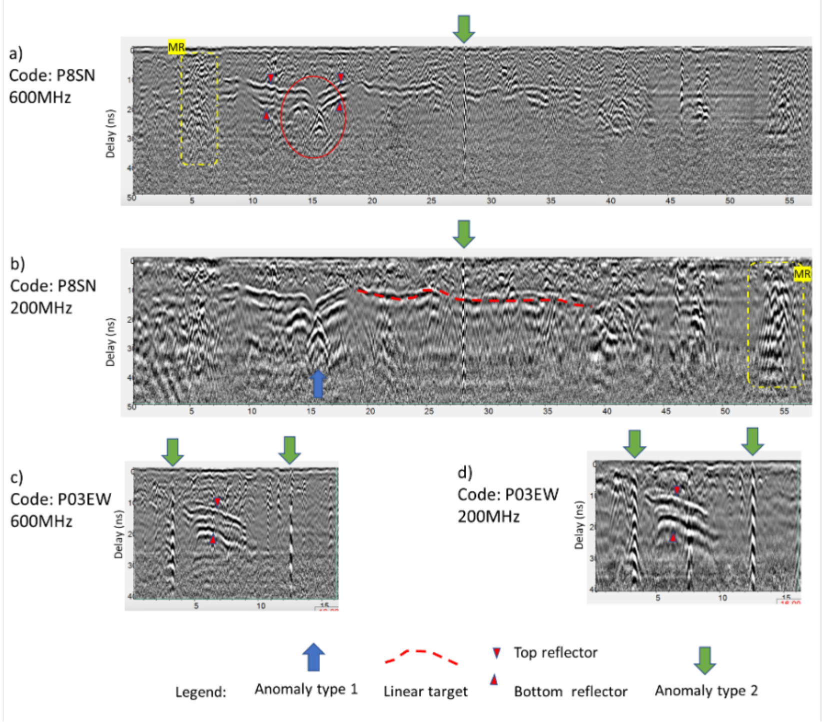

Figure 6 - Radargrams obtained by scanning with the 600MHz (a,c) and 200MHz (b,d) central frequencies along profiles P8SN and P03EW with examples of anomaly types. The yellow rectangle is an example of zones with multiple reflectors (MR) whose effect obstructs the visibility of deeper targets. The area marked with a red oval is interpreted as a collapsed sector.

Even though it might be considered an anomaly composed of the signal coming from two overlaying targets, we attribute the type 3 anomaly also to a buried wall, but there is a great probability to be formed by layers of various types of materials. As a support for this interpretation is the similarity with the anomaly pattern depicted on the 200MHz central-frequency B-scan when crossing a target revealed by the excavation works (see Figure 8).

In Figure 6 is provided for comparison radargrams obtained on the same profile when scanned at the 600MHz and 200MHz center frequency. A feature observed on the P8SN profile which is marked between 2 triangles, was interpreted as zone with a better conserved archeological built elements. This type of anomaly was also tracked on other profiles (Figure 6c) on various lengths. Given the characteristics, it is possible to be a signal resulting from a double floor of a hypocaust or just a superposition of two planar reflectors, the upper one being part of a newer construction stage.

A hypocaust (Figure 7) was a typical construction in Roman times for increasing thermal comfort in domestic houses, in thermae but also replicated in military units. Buildings with underfloor heating structures have been previously excavated in the Resca archaeological site. The gap below the pavement had a role in recirculating the hot air provided by the “praefurnium” (wooden woven). The upper part of the floor was supported by a regular network of pillars made of stacks of bricks.

A more complex situation is marked with a red oval on the 600MHz radargram, the anomaly being visible also on the 200MHz B-scan. Additionally, on the latter one, under the linear target, it appears additional reflectors. Given the interruption in the linear anomaly, it is assumed that the deeper hyperbolic anomaly is given by the stack of material from the collapsed section.

On an approximative length of 20m, a linear reflector continues to be visible and it remains at the same depth as the top reflector of the possible zone with hypocaust. The same type of anomaly is recognizable on other 4 parallel profiles even though sometimes it is interrupted or with sectors where its pattern is hard to be distinguished due to overlaps with other sources of reflections.

These observations are making us consider that the liner anomaly observed is part of a larger construction partially preserved.

Figure 7 - A reconstruction of a room with hypocaust. Picture from the Jidova, Campulung-Arges. 1-bottom level, 2-pillars made of stalks of bricks, 2b – another possible type of bricks arrangement for sustaining the walking floor, 3-upper layer formed by bricks, 4-"opus signium" – pieces of brick bound with mortar usually placed over #3, 5-double-walls in communication with the double-layer floor with the role in recirculating the heat.

Given the 2021 GPR results it is obvious that this method is appropriate for archaeological investigation at Romula. However, it remains necessary to calibrate in various points the depth of the investigation and thus to evaluate better the dielectric permittivity of the upper layer.

A better interpretation of the GPR data can be done after establishing the reflection pattern given by the buried structures, considering their various composition: burnt bricks, unburnt bricks and mortar, river stone and mortar, limestones, or a layered mixture of the various construction materials in this particular location. Such an attempt for evaluating the GPR reflection pattern was performed on a small portion of the archaeological trench presented in Figure 8.

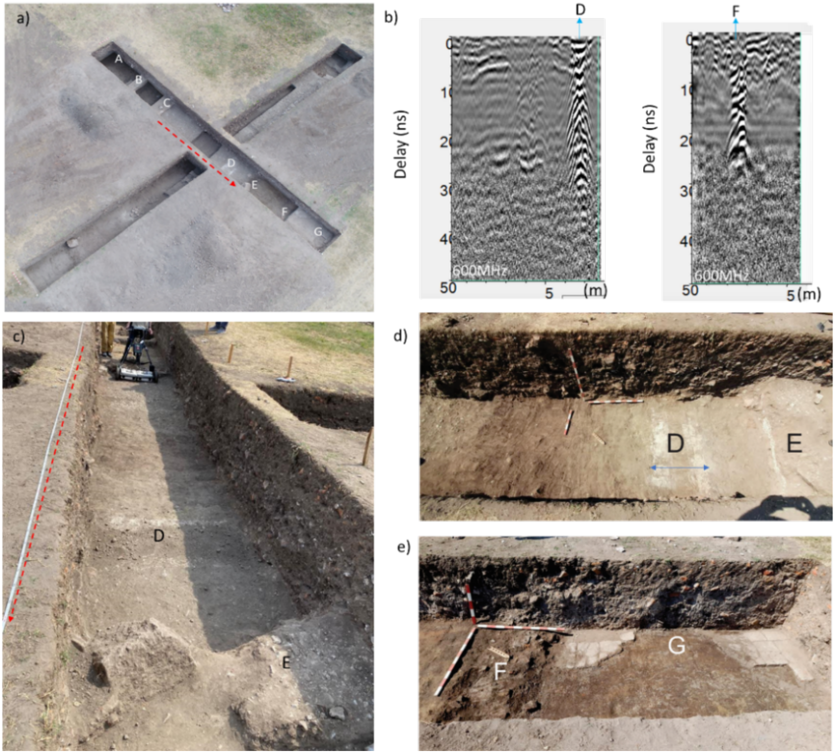

Figure 8 - Archaeological excavation trenches from the 2021 campaign at different stages (a,b,d,e) and B-scans for the sectors C-E and E-G (b). At the time of the GPR tests (c) the sector marked as "E" could not be crossed and sector F-G was covered with a layer of soil and debris. D: Roman wall with a foundation made of large river stones (8-12 cm) placed in several rows, with mortar and a row of Roman bricks. Height 30cm, width: 83cm; F: Roman wall with gravel foundation and a row of bricks on top. Height 30cm, width 60cm; G: Roman brick pavement. Height 7cm, width:60cm

The archaeological excavation was ongoing at the time of the GPR test, presenting variation at the bottom level and crossing thresholds which prevented the execution of a continuous profile and neither positioning on all targets (Figure 8c). A relatively flat zone was between sectors C-E and F-G, allowing therefore to capture the signals from a few buried archaeological remains (marked as D and F). Target "D" gave a strong and well-defined anomaly composed of multiple reflections. The top part of the signal appears like reflections from a linear structure but with time, hyperbolas begin to dominate the anomaly pattern. At the completion of the archaeological campaign, for the sector marked as "D" was reported a 30cm thick wall, consisting of large river stones (8-12 cm) placed in several rows, bounded with mortar, and on top with a single row of bricks. The wall width had 83cm and has been found at a depth of 1,17 m from the top surface.

Again, a strong anomaly was detected when the GPR passed perpendicular across the target marked as "F". At the time of the GPR tests (Figure 8c) the sector marked as "E" could not be investigated, while sector F-G was covered with a thin layer of soil and debris. Below the detected anomaly marked as "F", was later excavated a Roman wall with a gravel foundation and a row of bricks on top. Its unveiled geometry was 30cm in height and 60cm in width. Wright after wall "F" were unveiled pieces of pavement made of bricks with a thickness of 7cm.

From the examples presented above, it can be noticed that the buried wall presents a complicated signature, presenting an anomaly with multiple reflections, seemingly the signal is bouncing inside the wall itself. This distinct reflection pattern associated directly with the wall was observed at many points in the investigated area.

Considerations on electrical resistivity tomography method and results obtained at Romula

Method presentation - general aspects

There is quite often that direct-ground-contact methods such as the electrical tomography method (ERT) are applied in archaeological sites, even though if compared with other survey methods it is a more time-consuming investigation method. Despite this inconvenience, it is worth mentioning that the ERT is a robust method and when judiciously applied gives good results even in environments that are considered difficult for other geophysical investigation methods. Resistance surveys were quite a lot applied in archaeology, long before the ERT systems started to be developed, as implied by the usage of lighter equipment composed of a resistance meter and a mobile twin probe array. The electrodes were fixed on a rigid bar (seldom made of wood or light material) part of a carrying system. The horizontal rigid bar had the role of keeping fixed the distance between the electrodes and making it easier to push the electrodes into the ground and therefore speed up the survey.

ERT method applied at Romula

The first investigations with the ERT method in Romula archaeological site were performed in 2019. Another prospection executed in 2020 also comprised a few ERT lines (Link 4 and Niculescu et al., 2021). As the 2019 ERT survey was more detailed, in the following will be analyzed the applicability of the method, based on the reported results (Link 3 and Șerbănescu et al., 2020) and test profiles performed by the authors. The ERT survey from 2019 (Șerbănescu et al., 2020) consisted in the execution of 32 profiles +7 (extension profiles) deployed in the N-S direction and E-W (8 profiles + extensions). Data acquisition was made using Dipole-Dipole and Wenner arrays, but the results were only presented for the Dipole-Dipole data set. It is common to be preferred the surveys using Dipole-Dipole array, due to the fact that for the same number of deployed electrodes (when compared with other arrays) more measurements are made, therefore a larger dataset is obtained and later used to construct the model. The first group of ERT profiles consisted of 24 parallel lines positioned at a spaced distance of 4m, with the exception of the interval between ERT 12-13, this being larger for avoiding an excavated perimeter. A second group of ERT lines was designed to be perpendicular to the first group, overlapping partially the surveyed perimeter. This approach would have been helpful in filling the gaps due to the large distance between the parallel profiles of the first group if an inverted 3D model obtained by simultaneous inversion of all 2D data would have been made. The data interpretation for the 2019 ERT survey was based on a 2D inversion for each surveyed line and a 3D inversion for a selection of parallel lines with the same orientation (Șerbănescu et al., 2020). From the resulting data was noticed various types of high-resistive anomalies (some restricted as dimensions others expanding along the profile for a few meters) and zones where such types of anomalies are rarer. From the perspective of the materials that were used frequently for construction in the Romula archaeological site (bricks, river stones, and mortar) the high resistivity anomalies are of interest as they can signal the presence of buried construction remains. However, on the ERT data, it is easy to depict zones where archaeological excavation should be focused as well as zones that are not so rich in construction remains.

One practical question which needs to be addressed when performing a 2D-ERT survey refers to the optimum distance between the electrodes. When measuring in the archaeological site of Romula there is no simple answer, due to the fact that there is a diversity in the objectives of the study and not all of them can be achieved simultaneously, as the required degree of resolution is different. We give an example in Figure 9 which presents 2 ERT profiles executed in the NW part of the Central Fortification. The approximative distance between the presented ERT lines was of 90m, both being acquired using 1m equidistance between electrodes, Wenner array and a multi-electrode system that comprise 48 electrodes.

The ERT #1 and ERT #2 sections reveal a top layer characterized by high resistivity values (>141Ωm) displaying a variable thickness, overlying on a high conductive layer that extends down to 8-9m. On ERT #1 section there is an interesting lateral variation in resistivity below 2m depth, with higher values observed in the first part of the profile, continuing with resistivity values specific to the local geology. When analyzing the results at full depth scale (A and C in Figure 9), the effects of the high resistivity targets appear cumulated, making it difficult to extract information about the individual targets. High-resistivity shallow buried targets which are embedded in the top layer are better depicted in the trimmed on depth version of the same profile (Figure 9 -B and D). So, from this perspective, if the target we are looking for is at a shallow depth, we might say that acquiring data using a 1m distance between electrodes is inappropriate and the survey should continue using a smaller distance between electrodes. But, if the distance between the electrodes would be set smaller, deeper buried targets (like the deeper one observed in ERT #1-A and associated with remains of a fortification wall and additional works in its surroundings) might not be detected. In the case of the ERT survey, the resolution is directly correlated with the distance between electrodes and array type, and therefore, when small size targets are expected at shallow depth it is recommendable to use a smaller distance between the electrodes but, at the same moment it is mandatory to comply with the assumption of the point-source electrode (Georgescu & Chitea, 2016).

Even though there is this rule of thumb in terms of resolution and depth of investigation, it is important to highlight that the selected array influences both. There is a preference for a Dipole-

Dipole array because the possible combinations between the role of the electrodes (for injection of electrical current or potential measurements) are increased when compared with other classical arrays (like Wenner or Schlumberger) and, if a multi-channel resistivity meter is used, the measuring time with this array is quite fast.

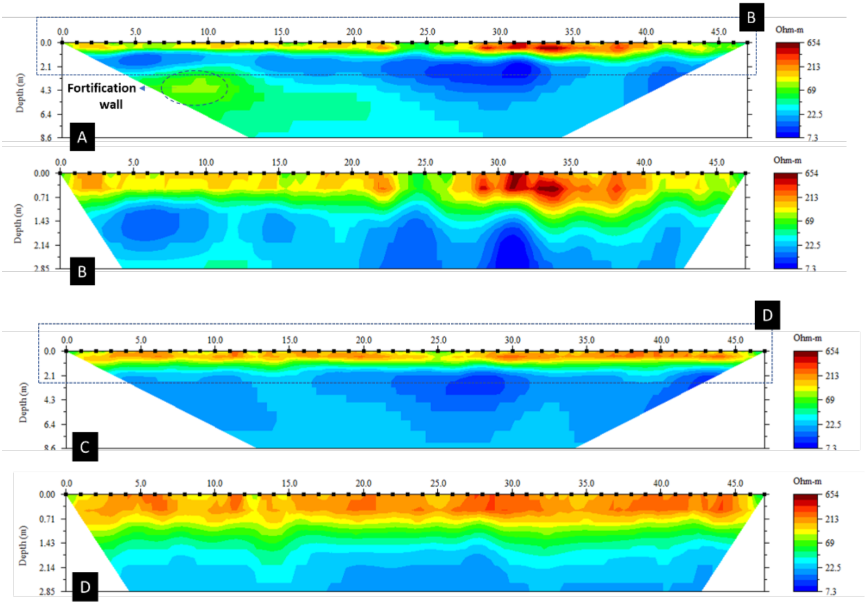

Figure 9 – ERT #1 profile at full depth (A) and trimmed on 2.85m depth (B), ERT #2 profile at full depth (C) and ERT #2 trimmed on 2.85m depth (D)

However, it is also worth mentioning that in complex environments, Dipole-Dipole data processing may lead to more distorted anomalies than obtained using symmetrical arrays. Considering also the changes in the burial depth of the Roman artifacts as revealed so far during excavating campaigns in the Central Fortification, it is obvious that an ERT setup that gave good results in one part of the site may not be the best solution for another part. Moreover, the poorly documented position of the excavated sectors from early archeological studies as well as the unauthorized digging followed by extraction of construction material and refilling the excavation pit with debris complicates severely the data interpretation.

Considerations on other geophysical methods for archaeological investigations

It is important to highlight that the following comments on geophysical methods applicability are addressing the part of geophysics for locating buried remains and site assessment in "classical" conditions (on-shore locations, general habitat), excluding the situation of archaeology in mining areas and underwater archaeology. For the mentioned exceptions the geophysical approach is more specific and the subject goes beyond the purpose of the present chapter.

Besides the "conventional" (Magnetometry, Electromagnetic methods, Electrical Resistivity) methods seldom applied for starting a survey in search for evidence of buried archaeological remains, the panel of geophysical methods contains also other techniques that can be deployed when necessary. Microgravimetry, the group of seismic methods, Induced Polarization, Self-Potential Method and Radiometry can be deployed in certain special contexts in which the "conventional" methods either cannot be applied (for example due to physical obstacles or geophysical strong noise) or when the results obtained are difficult to be interpreted and an additional technique might help to reduce the uncertainties.

Theoretically, all geophysical methods will bring additional and useful information for the investigated location, but the working performance with some of them is really low. Hence, even though it could be useful in a certain context, it would consume too much of the resources necessary to complete the survey, this being one of the reasons for their relatively rarer utilization on archaeological sites.

For example, a microgravimetry survey can be deployed for locating extended and thick buried construction remains, tunnels, underground chambers, or large cisterns (used for rainwater harvesting or water storage), as the contrast of density between these and surrounding material can give a distinct signal on recorded data. The acquisition requires making measurements in stations, after calibration of the gravimeter at each point. The distance between the stations must be small, therefore the time of acquisition for a gravimetry profile requires much more time than it would be necessary to cover it using the ERT method, which can be deployed for the same objectives and it also might detect features (such as pavements) that in rare conditions could give a distinguishable effect on gravimetry data. Moreover, in archaeological sites, there is frequently a vertical superposition of anomalous sources as well as a cumulation of the geophysical signal on a horizontal scale. Taking as an example the ground condition from Romula archaeological site, it is appreciated that it would be quite laborious work to process adequately the gravity data and compute models that could explain the extent and amplitude of an observed anomaly and assess the contribution of overlapping sources in the condition of thickness variation in the uppermost layer and the possibility to have influence from deep-seated geological-anomalous sources.

Cumulation of the signal arising from close-positioned sources it is an issue also for other geophysical methods, but from some methods (ERT, EMI multi-receiver, GPR) it is possible to obtain the parameter variation with depth and to cut off deeper sources of anomalies, resulting to a more accurate evaluation.

Based on the acoustic impedance contrast, anthropogenically strongly disturbed layers, with a high load of construction materials can be separated from the undisturbed geological layers by means of seismic investigation technique. But again, due to the low productivity in acquisition when compared with other geophysical methods (M, EM, ERT methods) and more time-demanding processing stage, as well as the difficulties in locating smaller targets, the seismic methods are not frequently requested for archaeological surveys. When applied, in a majority of the cases, the seismic measurements are more of an additional survey method that is performed on a limited number of profiles in order to help reduce the incertitude in data interpretation of results provided by the fastest acquisition method. However, in a certain context, seismic measurements might be at the core of ground investigation when it is important to understand the shallow stratigraphic features or for investigating the ground resonance for site seismic assessment (Castellaro et al., 2008) when buildings of historical value (tall monuments, amphitheaters, castles, triumphal arches) need to be protected from natural hazards such as earthquakes or various forms of land instability.

Additional to the ERT measurements, the Induced Polarization Tomography (IPT) method can also be deployed, as basically, the chargeability factor can be evaluated by extending the readings of the potential difference among pairs of electrodes after the electrical resistivity determination is completed. Practically, in time-domain, the decay of the electrical potential is evaluated in several time-frames, after switching off the source of the electrical current, an option that is available on all modern types of resistivity meters.

The Spontaneous Potential (also known as Self Potential) is also part of the Electrical Prospection methods, but its applicability for archaeological sites is quite low. Its deployment is justified in cases when there is an objective of tracing underground water passages. Also, the Self Potential (SP) measurements can be of a certain utility for cases where the groundwater movement is interacting with buried elements in such a way that results in a local modification of water downward or upward movements. It might be of use for cases that imply woody materials and water-circulated tunnels or voids, thermal or saline water outflows.

The utility of the IPT and SP methods for archaeological surveys can be only in conjunction with ERT data. Less practical, but with a good potential of obtaining additional information about the presence of buried archaeological remains it would be to deploy IPT/SP and ERT measurements in different weather conditions and then compare the results.

CONCLUSIONS

All geophysical methods applied in the Romula archaeological site provided evidence of the underground buried remains existence in the studied locations, primarily by delineating sectors where the archaeological loads were higher when compared with other zones from the site. From this perspective, we may say that the geophysical methods are extremely useful in planning excavating campaigns.

It was generally admitted by the investigators that in the Central part of the Fortress, was not encounter the most favorable soil conditions for the appliance of the geophysical methods but, according to our evaluation, neither insurmountable problems. The most affected technique by the general soil conditions proved to be the GPR. The heterogeneous soil layer that covers and fills the gap between the walls and pavements of the historic structures leads to complicated electromagnetic scattering phenomena. Nevertheless, despite this inconvenience it was still possible to identify on the radargrams reflectors of interest for archaeological research. A test with the GPR in an excavated ditch was a good opportunity to evaluate if some of the anomalies observed in the radargram made at the earth surface were caused by internal geophysical noise or external interferences. Even though a continuous profile could not be made, due to the irregular depth of excavation (with ups and downs due to the encountered features), the few testing places were conspicuous, leading to the conclusion that improved results can be obtained with the use of GPR arrays with antennas of different frequencies. Synthetic modeling of the GPR setup revealed that if at least the top layer (0.75m) which is a sterile-archaeological layer (in terms of the historical structure remains) would be removed, the chances of seeing better the buried artifacts would increase, especially for the ones that are not easily detectable to geophysical methods due to vertical superposition or small thickness.

The deployment of the geophysical profiles should be done in order to highlight the much-expected rectangular-shaped anomalies that are easy to be attributed to the presence of buried walls or house floors. Such types of anomalies are extremely useful for archaeologists as from their position within the site and estimated size an experienced archaeologist can evaluate the role of that specific building in the life of the ancient fortification and appreciate if it is necessary to be unveiled, better protected or left as a witness. We appreciate that at Romula, the ERT and EM methods have the best perspective for tracing such types of anomalies in the given context. However, in order to reach such a result by ERT method, there is the necessity of performing the electrical resistivity tomography at a much denser network than seen in previous campaigns. Also, the data interpretation should be made in conjunction with results from a second geophysical investigation method (EM or M) to reduce the uncertainties in data interpretation triggered by the excavation and refiling works from past actions.

However, at Romula, there are multiple stages of building as well as destruction stages of the construction which resulted in a vertical superposition of archaeological remains as well as lateral interconnection. All these will result in a cumulus of anomalies. Sometimes this might be helpful when the effect increases the signal, but as well sometimes it happens for the signal to get complicated and, in such a stage, can make difficult the reconnaissance of the targets or makes it difficult to trace the development of the detected structures.

The electromagnetic measurements performed so far gave promising results, as on the electrical conductivity map (campaign

2021) some regular-geometrical shaped anomalies were seen. The recognizable rectangular shapes are on low magnetic properties and low electrical conductivity. Given the single-level results obtained so far by the electromagnetic induction method and the yet ambiguously GPR results in some sectors, we consider that measurements with a multi-coil conductivity meter will be a best option for further research in the area.

ACKNOWLEDGEMENTS

The authors would like to thank to the geophysical team members who participated in the field campaign. This review of the past geophysical campaigns presented in this chapter was made as part of the ROMULA Scientific Research Project financed by the Research Institute of the University of Bucharest, project in which multi-disciplinary research teams comprising researchers from University of Bucharest, Romanian Society of Applied Geophysics (SGAR) and National Institute of Earth Physics (INFP) will continue to explore the Romula - Roman City with the aim of bringing to light additional information on the cultural heritage of Roman period.

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Internet resources:

Link 1: Resume of the geophysical campaign 2002
http://cronica.cimec.ro/detaliu.asp?k=2069

Link 2- Resume of the geophysical campaign 2003 http://cronica.cimec.ro/detaliu.asp?k=2325&d=Resca-Dobrosloveni-Olt-Villa-suburbana-Atelierele-ceramice-2003

Link 3- Resume of the geophysical campaign 2019 http://cronica.cimec.ro/detaliu.asp?k=6419&d=Resca-Dobrosloveni-Olt-Romula-2019

Link 4 -Resume of the geophysical campaign 2020 http://cronica.cimec.ro/detaliu.asp?k=6587&d=Resca-Dobrosloveni-Olt-Romula-2020