Geophysical approaches applied in the ancient theatre of Demetriada, Volos

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ABSTRACT

The city of Demetriada was constructed around 294-292 BC and became a stronghold of the Macedonian navy fleet, whereas in the Roman period it experienced significant growth and blossoming. The ancient theatre of the town was constructed at the same time with the foundation of the city, without being used for 2 centuries (1st ce. BC - 1st ce. A.D.) and being completely abandoned after the 4th ce. A.D., to be used only as a quarry for extraction of building material for Christian basilicas in the area. The theatre was found in 1809 and excavations took place in various years since 1907. Geophysical approaches were exploited recently in an effort to map the subsurface of the surrounding area of the theatre and help the reconstruction works of it. Magnetic gradiometry, Ground Penetrating Radar (GPR) and Electrical Resistivity Tomogrpahy (ERT) techniques were employed for mapping the area of the orchestra and the scene of the theatre, together with the area extending to the south of the theatre. A number of features were recognized by the magnetic techniques including older excavation trenches and the pilar of the stoa of the proscenium. The different occupation phases of the area have been manifested through the employment of tomographic and stratigraphic geophysical techniques like three-dimensional ERT and GPR. Architectural orthogonal structures aligned in a S-N direction have been correlated to the already excavated buildings of the ceramic workshop. The workshop seems to expand in a large section of the area which was probably constructed after the final abandonment of the theatre.

Keywords: Geophysical Prospection, Ancient Theatre, Demetriada, Volos

1. INTRODUCTION

The city of Demetriada was founded by the Macedonian king Demetrio in 294-292 BC and comprised a large naval strongholds for the Macedonian navy fleet. It was actually flourished during the period when Macedonian kings where the dominant power in Greece and was protected by strong walls indicating its really strategic importance. The city was not a simple another "city ally" but it was rather organized in the prototypes of the Macedonian kingdom cities. Its growth and blossoming has been constant since the mid of 2nd century B.C. until the Roman period [1].

The ancient theatre of Demetriada was constructed at the same time with the foundation of the city but remained unused for a period of two centuries between 1st century B.C. and 1st century A.D due to extensive damages. It is located at the south west side of the modern city of Volos in Thessaly. The theatre was completely abandoned after the 4th century A.D. with the prevail of Christianism and the modified socio-political transformations that were experienced during that period in the cities. This resulted in using parts of the theatre as construction materials to build new Christian basilica churches.

W. Leake was the first to recognize the theatre in 1809. The first systematic excavations were initiated in 1901 by Valerio Stai and continued for two more periods in 1907 and 1912 by Apostolos Arvanitopoulo. The excavation activities by Demetrios Theoxaris (ephoros of Thessaly archaeological service) were actually those that revealed the theatre in late 1950's (1957-1958; Fig. 1). A smaller excavation project was started again in 1986 that continued with smaller or larger gaps until 2000 [1]. From architectural point of view the theatre exhibits all the basic characteristics of an ancient Greek theatre: namely the koilon, the orchestra and the scene (Fig. 1).

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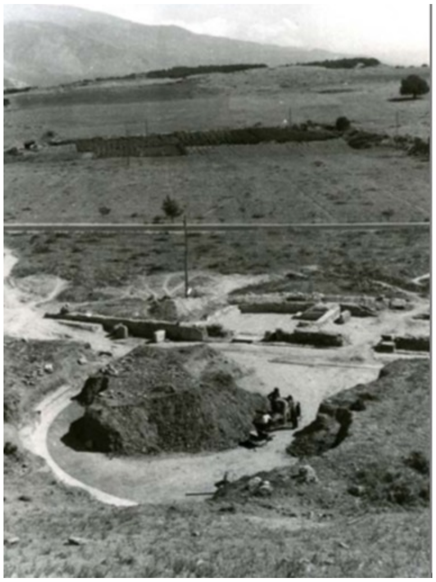

Figure 1. (l*eft*) View of the theatre from the west during the excavation program of 1957-1958. (*right*) Oblique aerial photo from the east showing the present preservation of the theatre of Demetriada. The geophysical investigations were focused on the areas that are outlined by the yellow rectangular.

2. GEOPHYSICAL SURVEY IN THE THEATRE OF DEMETRIADA

The geophysical investigations in the theatre of Demetriada were completed within a period of six days in autumn of 2010, covering a total area of 4,709 square meters (Fig. 1).An integrated suite of different geophysical techniques was employed to map the subsurface structures in the site (Fig. 2). More specifically, the magnetic gradiometry, the ground penetrating radar (GPR), the multiplexed electrical resistance mapping and the three-dimensional (3-D) electrical resistivity tomography (ERT) were systematically used to accomplish the goals of the project. Overlapping regions were approached with at least two and in some cases with three different geophysical methods trying in this way to maximize the subsurface information content. Special care was given to the collection of high quality data with dense sampling interval. Table 1 shows the area that was covered with the different techniques as well as the acquisition parameters that were employed to collect the field data.

Table 1. Acquisition parameters and area coverage with the different geophysical methods in the theatre of Demetriada.

Methodology	Area covered in m^2	Acquisition Parameters	Investigation depth
Magnetic Gradiometry	3,120	dx = 0.5 m dy = 0.25m	2-3m
GPR	4,709	dx = 0.5 m dy = 0.05m Total length of lines: 9.2 Km	3-4m
Multiplexed resistance	2,278	dx = dy = 1.0 m Multiplexed Twin Probe array with mobile electrode distances a = 0.5 and 1 m	1-1.5m
ERT	1,250	44 parallel lines with Dipole-Dipole array inter-line spacing and basic electrode distance 1 m	6-7 m

Figure 2. Details of the geophysical survey in the theatre of Demetriada with the magnetic gradiometry (a), the GPR (b), the ERT (c), the multiplexed resistance (d) and the GPS (e).

The GPP package [2] was used to process the gradiometer and multiplexed electrical resistance data. Processing options of the GPP include geometry correction of the grids, evaluation of statistical parameters, mutation of dummy values, shifting of the X, Y coordinates, application of de-spiking filters, grid equalization and line equalization filters to smooth out the data and avoid stripping effects. The ERT sections were inverted using a three-dimensional inversion algorithm [3] in order to recover the true resistivity distribution within horizontal depth slices. A systematic workflow was applied in processing the GPR data (coordinate correction, first peak determination, application of AGC, Dewow and DC shift filters) and finally horizontal depth slices were created by the original vertical sections assuming a velocity for the electromagnetic waves equal to 0.1m/nsec. The final geophysical maps were exported and rectified on the geo-referenced satellite image of the area for the integrated interpretation of the geophysical anomalies which were attributed to possible buried archaeological relics. A GPS unit (Fig. 2e) was used to map the outline of the geophysical grids and acquire the coordinates of known points for the geometric correction of the satellite image of the site. The GPS data exhibited an accuracy of less than 0.5m in the horizontal plane after the application of post-processing corrections.

3. RESULTS OF THE GEOPHYSICAL SURVEY

The general environmental setting around the theatre imposed difficulties in the data collection. The older excavation trenches, the scattered bushes and trees in the site and the modern constructions hindered the geophysical survey mainly in the part of noise that contaminated the data. The plan view of the theatre and a Google Earth Quickbird satellite image were rectified in the Greek Geodetic System based on the ground control points that were mapped with the GPS unit (Fig. 2e). The satellite image exhibited a white area due to an error by the provider of the images (Google Earth) to match two adjacent satellite images (an error that was corrected in the latest images of Google Earth). The visible and the excavated archaeological remains were also digitized and superimposed on the satellite image.

The magnetic gradiometry data exhibited high levels of disturbance due to the metal fence at the south and east of the site, the modern construction that protects the excavated remains at the north-east corner of the site and the electricity power source at the north. An extra source of error was due to the scattered metal stakes that the older excavation projects used to outline the limits of the excavations trenches. The two intense magnetic anomalies at the west entrances of the middle and northern rooms of the scene were caused by older test trenches that are visible even today. The low magnetic anomaly in front of the southern entrance of the scene is also probably related to such a trench since it is in line with the previous magnetic anomalies. Some dipolar anomalies at the north-east of the scanned area probably indicate the continuation of excavated structures (Fig. 3).

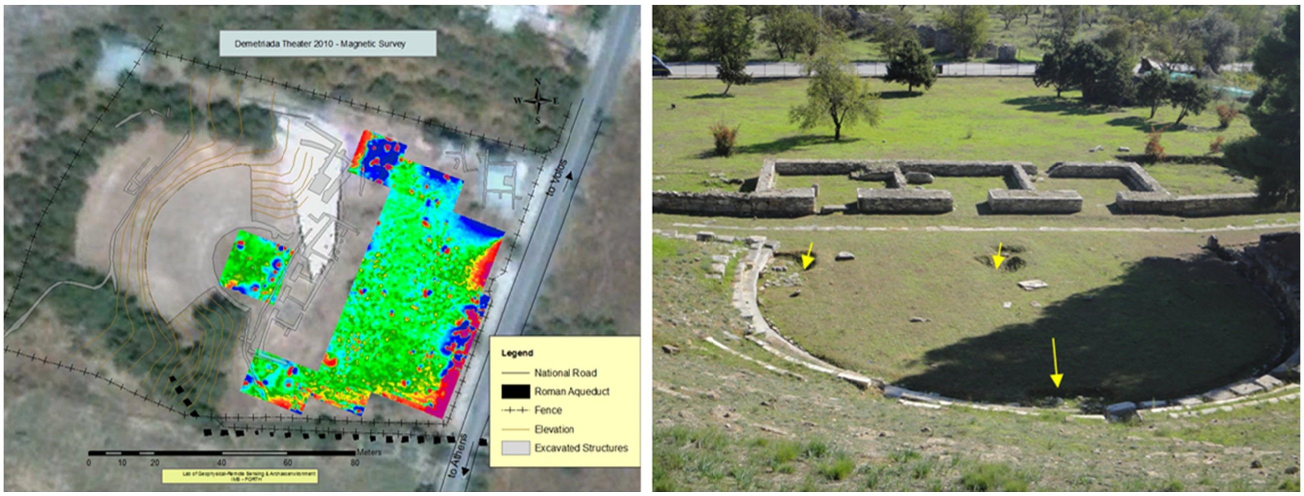

Figure 3. (*left*) Overlay of the magnetic gradiometry map on the satellite image of the site. The warm (reddish) and cold (blue) colors show intense and weak magnetic anomalies respectively. Dynamic range of the magnetic values +/- 55 nT/m. (*right*) The arrows indicate the position of the older trenches that caused the intense magnetic anomalies in the respective sites in the magnetic map within the orchestra of the theatre (the view of the image is from west).

The Twin Probe resistance map indicated areas of increased resistivity values mainly due to the root system of the trees. The long high resistivity anomaly that runs parallel to the fence at the east is correlated with an older test excavation trench that was back filled after the completion of the archaeological research. The 10.5m linear feature, that is pinpointed with the yellow arrow in Fig. 4, exhibited the higher interest as it has the same orientation with the excavated structures exactly at the north.

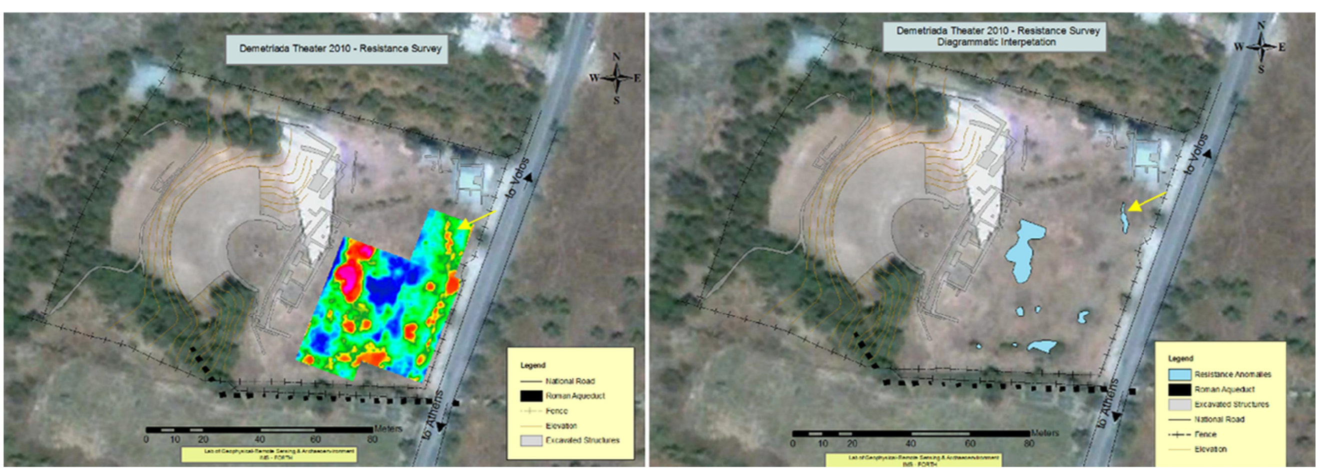

Figure 4. (*left*) Overlay of the multiplexed electrical resistance map on the satellite image of the site with a=0.5. The warm and cold colors show intense and weak resistance anomalies respectively. Dynamic range of the apparent resistivity values is within 55-130 Ohm-m. (*right*) Diagrammatic interpretation of the high resistance anomalies.

The area of 1,250 square meters that is extended to the north-east of the theatre's scene was surveyed with both 3-D ERT and GPR methods. The combined use of these geophysical techniques allowed the reconstruction of the dimensions and orientation of the buried structures in this specific part of the area (Fig. 5). The diagonal NE-SW anomaly (black line) was caused by a series of trees located in the specific location. At the north-east of the grid, a number of ERT and GPR linear anomalies form a complicated triangular complex with maximum dimensions 28m by 14m, reaching the maximum depth of 2-2.5 meters below the ground surface. The existence of rectangular features with inner compartments is also obvious. The distribution of the particular features reveals the existence of at least two different construction phases with different orientations. A group of features is aligned along the north-south orientation of the excavated structures of the ceramic workshop at the north-east corner of the archaeological site. On the contrary, the NE-SW anomalies seem to follow the same orientation with theatre's scene (Fig. 5c).

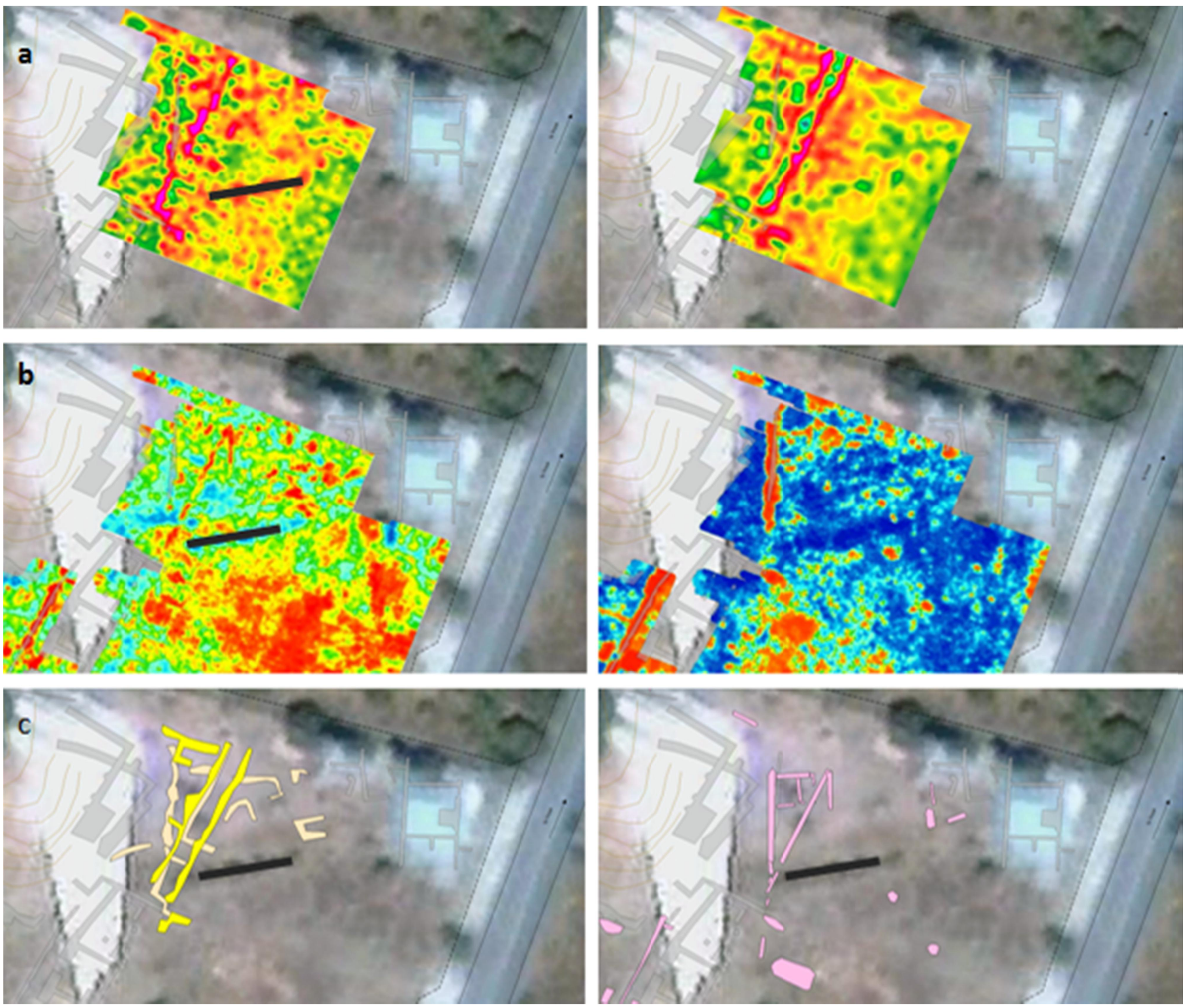

Figure 5. a) Horizontal depth slices of Z = 0.5-1.0 m (*left*) and Z = 1.0-1.5m (*right*) that extracted from the 3-D resistivity inversion model and overlaid on the satellite image of the site. The warm and cold colors show intense and weak resistivity anomalies respectively. Dynamic range of the resistivity values 3-1000 Ohm-m. b) GPR horizontal depth slices of Z = 0.32-0.42 m (*left*) and Z = 0.76-0.85m (*right*). The warm and cold colors show strong and weak reflectors respectively. c) Diagrammatic interpretation of the high ERT (*left*) and strong GPR reflection (*right*) anomalies.

The GPR practically covered the whole area of interest. The results in the orchestra verify the findings of the magnetic gradiometry method regarding the older excavation trenches. The altar shaped platform in the middle of the orchestra is registered as a round high GPR reflector. Within a depth of less than one meter below the ground surface, the GPR managed to outline some rectangular features in front of the central and northern entrance of the scene (pink diagrammatic interpretation in Fig. 6). The long linear anomaly that is located in similar depth in the southern room of the scene may indicate either the existence of inner partition or a different construction phase. Some linear anomalies in depth more than one meter at the east of the scene (red diagrammatic interpretation in Fig. 6) are related with earlier construction phases of the scene.

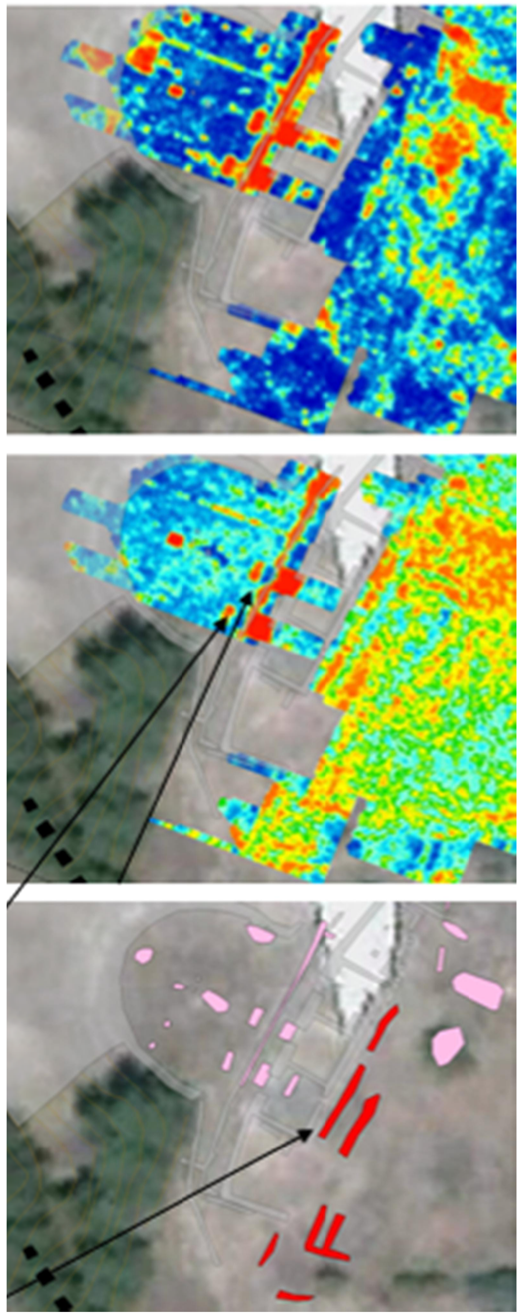

Figure 6. GPR horizontal depth slices of Z = 0.55-0.63 m (*up*) and Z = 1.19-1.29m (*center*). The warm and cold colors show strong and weak reflectors respectively. (*down*) Diagrammatic interpretation of the strong GPR reflectors. Pink and red colors indicate the structures buried in depth less and more than one meter below the ground surface respectively.

A small grid at the north of the koilon was surveyed with the GPR in order to test the hypothesis for the continuation of the supporting wall to the north section of the theatre. The results were quite encouraging to this direction as the GPR managed to identify as a number of strong reflectors located in a depth of less than one meter. The degree of preservation for these features is closely related to the intensity of their relative reflection (see Fig. 7).

4. CONCLUSIONS

The application of different techniques in the area signifies the importance of the manifold geophysical strategy [4] in order to extract the maximum subsurface information in a more efficient way. Each one of the methods applied has been able to suggest specific targets in terms of the physical quantity measured and the properties of the subsurface. The employment of different methods for the scanning of the site was valuable, since they provided complementary information and thus helped the delineation of the most significant features that were suggested by the various approaches.

Despite the field difficulties the geophysical campaign in the theaters of Demetriada in Volos can be considered successful as it managed to reconstruct the complex of the main buried archaeological relics in the site. These features are related to the already excavated structures and buildings. The combined diagrammatic interpretation of all the geophysical methods clearly indicates the high degree of archaeological interest at the north-east of the theatre's scene (Fig. 7) which is recommended for a more detailed archaeological investigation.

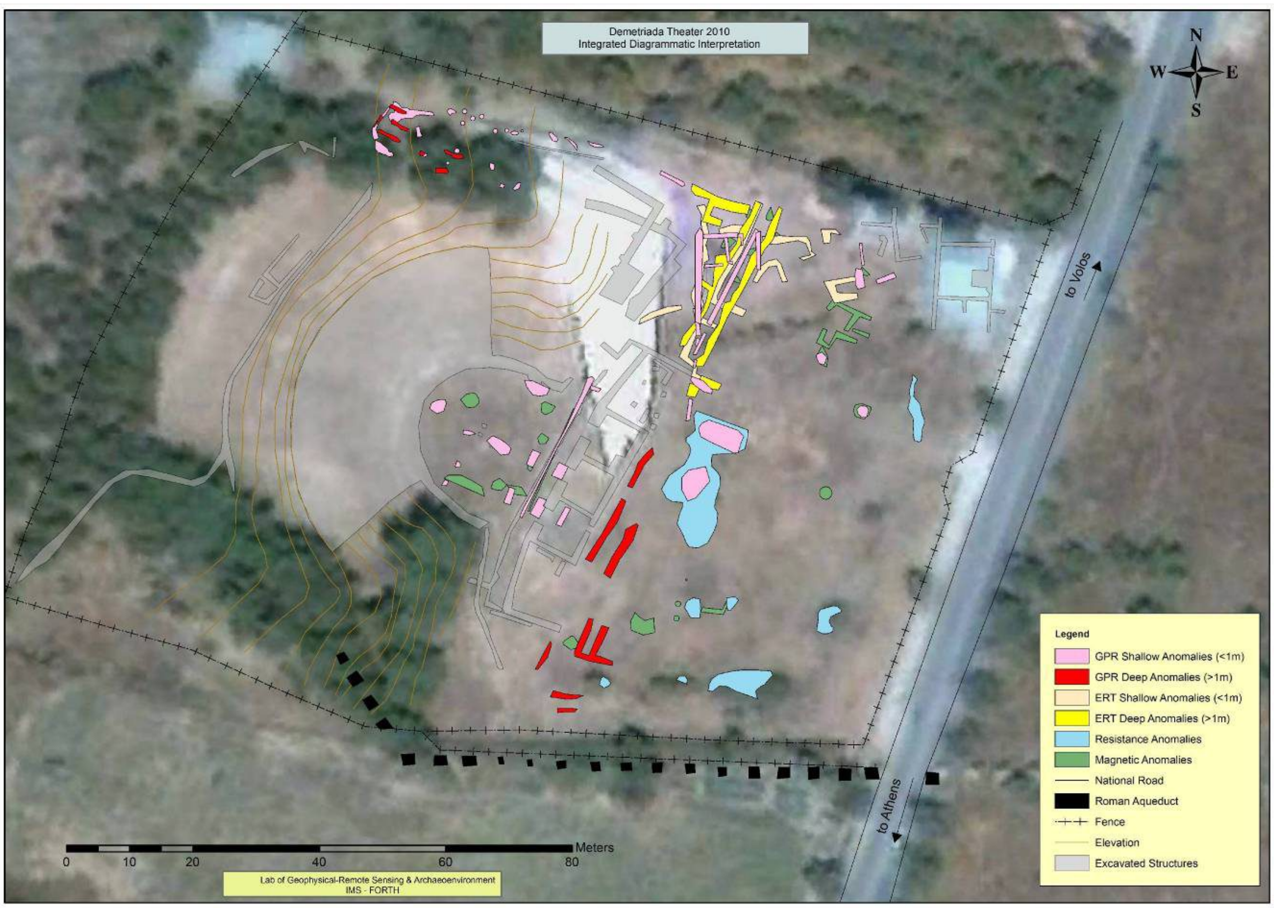

Figure 7. Combined diagrammatic interpretation of the geophysical anomalies indicated by the different methods that applied in the survey of the theatre of Demetriada.

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