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Application of Near-surface Geophysical Tools and GIS for Mapping the Ancient City of Lefkas

A. Sarris, S. Topouzi, F. Triantafyllidis, S. Soetens

Laboratory of Geophysical - Satellite Remote Sensing & Archaeo-environment, Institute of Mediterranean Studies - Foundation of Research & Technology (F.O.R.T.H.), Melissinou & Nik. Foka 130, PO. Box 119, Rethymnon 74100, Crete, Greece, asaris@ret.forthnet.gr

G. Pliakou

12th Eforia of Prehistoric and Classical Antiquities, Plateia 25th March 6, Ioannina 45221, Greece

Abstract: Whether it was called "Nirikos" or "Lefkas", the area opposite the Acarnanian coast was inhabited from the early times. At this strategic point the Corinthians founded their colony, "Lefkas", during the 7th century B.C. Excavations initiated in 1901 by the German Archaeological Institute revealed parts of the ancient wall and the theatre. Rescue excavations, contracted by the Greek Archaeological Service during the last two decades, enabled the partial reconstruction of the classical city's topography. The city walls are well preserved in the northern and western part, while some eastern parts are visible near the coast. Problematic, however, is the direction of the southern part of the wall.

Geophysical investigations were carried out in two phases, employing vertical magnetic gradient and soil resistance techniques. Mapping was focused in the southern limits of the ancient city. Geophysical data was able to identify a number of characteristics of the ancient city plan. The urban system was verified, consisting of parallel and vertical streets forming large building blocks. Drainage pipes were found to be running to the sides of the roads. Further to the south, the density of architectural remnants decreases, suggesting a potential location for the southern wall of the city. Similarly, a crossroad found in the SE corner of the surveyed region could be projected to lead towards the cemetery to the west and towards the port to the south.

Aerial images of the area were registered to the topographic map and enhanced using image processing techniques. A similar methodology was followed for the processing of hyper-spectral satellite imagery (ASTER). All geographical data was imported to a GIS, in which the different geophysical layers were overlaid. Interpretation of the geophysical anomalies (in vector format), together with the resulting images, can provide supplementary information and be used for conservation and development planning.

Περίληψη: Η νήσος Λευκάδα βρίσκεται απέναντι από τις ακτές της Ακαρνανίας και κατοικήθηκε από την Νεολιθική Εποχή. Από τον 7ο αι. π.Χ., η Λευκάς ή Νήρικος αποτέλεσε μία σημαντική αποικία των Κορινθίων. Οι πρώτες ανασκαφές που διενεργήθηκαν από την Γερμανική Αρχαιολογική Σχολή έφεραν στο φως τμήματα των αρχαίων τειχών και θεάτρου. Τις τελευταίες 2 δεκαετίες, σωστικές ανασκαφές από την Αρχαιολογική Υπηρεσία έχουν προσφέρει πολύτιμες πληροφορίες σχετικά με το πολεοδομικό σχέδιο της πόλης. Τα τείχη της πόλης βρίσκονται σε καλή κατάσταση διατήρησης προς τα βόρεια και δυτικά, ενώ κάποια τμήματα των τειχών είναι ορατά προς τα ανατολικά.

Οι γεωφυσικές διασκοπήσεις που διενεργήθηκαν σε 2 φάσεις κάνοντας χρήση μαγνητικών και ηλεκτρικών τεχνικών εστιάστηκαν στο νότιο τμήμα της πόλης. Οι μετρήσεις είχαν ως αποτέλεσμα τον εντοπισμό παράλληλων και κάθετων δρόμων που σχηματίζουν μεγάλα οικοδομικά τετράγωνα. Σε ορισμένα σημεία, αγωγοί αποχέτευσης φαίνεται να βρίσκονται δίπλα στους δρόμους. Στη νότια πλευρά της περιοχής, η κατανομή των υπεδάφειων στόχων μειώνεται δραστικά, ενώ υποδεικνύεται η πιθανή θέση της νότιας πλευράς των τειχών. Τέλος, μία διασταύρωση στο ΝΑ άκρο της περιοχής φαίνεται να οδηγεί προς το αρχαίο νεκροταφείο (προς τα δυτικά) και προς το αρχαίο λιμάνι της πόλης (προς τα νότια).

Η δημιουργία μωσαϊκού από ανορθωμένες αεροφωτογραφίες διαφορετικών περιόδων λήψης, σε συνδυασμό με την επεξεργασία δορυφορικών εικόνων ASTER συνείσφερε στην ανακατασκευή της μορφολογίας του τοπίου. Τα παραπάνω στοιχεία, σε συνδυασμό με την υπέρθεση των αποτελεσμάτων των γεωφυσικών διασκοπήσεων σε περιβάλλον των Γεωγραφικών Συστημάτων Πληροφοριών (GIS), βοήθησαν ουσιαστικά στην εξαγωγή συμπερασμάτων σχετικά με τον πολεοδομικό ιστό της πόλης και την οριοθέτηση των υπεδάφειων μνημείων, ενώ αναμένεται να χρησιμοποιηθούν για την προστασία και ανάδειξη αυτών σε σχέση με τα αναπτυξιακά σχέδια της περιοχής.

Introduction

The ancient city of Lefkas was founded in the end of the 7th century. B.C. as a Corinthian colony. The city was located on the north-eastern part of the island of Lefkas, at a distance of about 2.5km from the modern capital of the island (Figure 1). In this way, the port of the city was able to control the narrow sea passage between the north-eastern coastline of the island and the Acarnanian coast, and thus the navigation towards the Ionian and the Adriatic Sea (Murray 1982).

The city extends between the modern settlements of Kalligoni to the North and Karyotes to the South. The western part of the city follows the natural relief of the gentle slopes of hill Koulmos, while the eastern part extends to the offshore plain. The east and west sections of the city are divided by the modern provincial road leading from Lefkada to Nydri.

The area was not re-occupied after the depopulation of the city in the early 1st century A.D. During the Venetian period land use was limited to olive groves. The

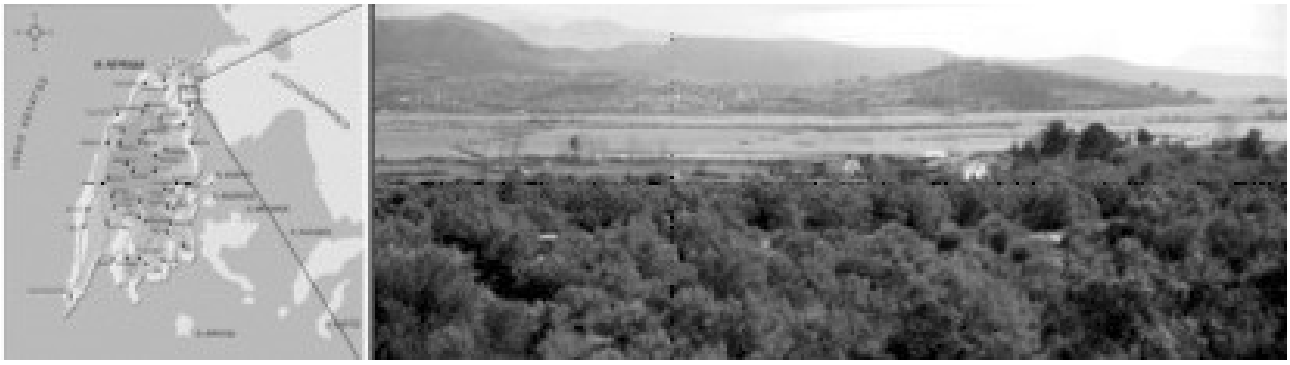

Figure 1: (Left) Map indicating the location of ancient Lefkas at the north-eastern part of the island. (Right) A section of the settings of the ancient city overlooking the Akarnanian coast.

development of the area, which begun in the 1960s, has been rather intensive during the last few years due to the rapid tourist development of the island. The city walls are preserved today at the north and southwest parts of the city at a height of 2-2.5m. Their estimated perimeter is 4.5km.

Although architectural remnants (from buildings, terraces, roads and defensive wall) of the ancient city are visible at the slopes of Koulmos, those situated on the plain have been covered by shallow deposits. Thus, specific construction constraints were imposed in the area aiming towards the protection of the monuments of the ancient city. Following the same directives and aiming towards a better outline of the architectural relics, it was decided to carry out an extensive shallow-depth geophysical prospection survey which could contribute in mapping the layout of the ancient city in relation to the new design of the urban planning of the area.

Design of the geographical information system

The development of a Geographical Information System was considered essential for the better representation of the results of the geophysical prospection survey in accordance with the new urban planning design. The specific Geographical Information System contains data in both vector and raster format, transformed in the same geodetic reference system (Hellenic Geodetic Reference System, EGSA '87).

The digital terrain model (in Triangulated Irregular Network / TIN format) was constructed by 3D topographic data, which was transformed from ASCII format to dbf files and then converted to shape-files containing elevation information for the 20m iso-lines. The area coverage of the Digital Terrain Model (DTM) included the extension from the modern city of Lefkada to the modern settlement of Lygia.

Three geographically registered ortho-rectified maps (date: 1998, scale 1:5000), provided by the Ministry of Agriculture and covering the same area as the TIN model, were joined creating a photo-mosaic (Figure 2). The mosaic was used to georeference the rest of the aerial photos, provided by the Hellenic Ministry for the Environment, Physical Planning and Public Works (Hellenic Mapping and Cadastral Organization). These 1:6000 scale photos, which were obtained at different dates (16/05/1985 and 12/10/1994), and were scanned in high resolution so as to achieve the optimum result in the quality of every image. These photos were also processed through histogram equalization and geometric registration in order to form a time sequence of aerial mosaics. Similarly, the proposed expanded town plan of the area was employed in order to see the degree of correlation with the geophysical anomalies. A number of thematic maps were created, including the road network, private properties, proposed protection zones, the layout of the geophysical grids, a.o.

Finally, the GIS system included thematic layers based on the available archaeological data, such as digital excavation plans.

Past archaeological research

In recent years, information about the relics of the ancient city of Lefkas has been provided by foreign travelers (Leake, Holland, Pouqueville, Goodisson, Dodwell) who visited the island during the 19th century.

The German Archaeological Institute was responsible for initiating the systematic excavations in the region of the ancient city during the beginning of the 20th century. Under the direction of W. Dörpfeld, excavation trenches were opened and remnants of the walls and the ancient theatre were revealed (Dörpfeld 1927). In the 1960s, archaeological research was re-initiated in the form of rescue excavations conducted by the local Archaeological Service, uncovering parts of the city's cemeteries, roads and private buildings and contributing to the reconstruction of the urban planning of ancient Lefkas (Fiedler 1999, Douzougli, 2001, Pliakou 2001, Andreou 2002).

According to the updated results of the archaeological excavations, the city seems to be divided in two parts: one on the hills of Koulmos to the west and one in the plain

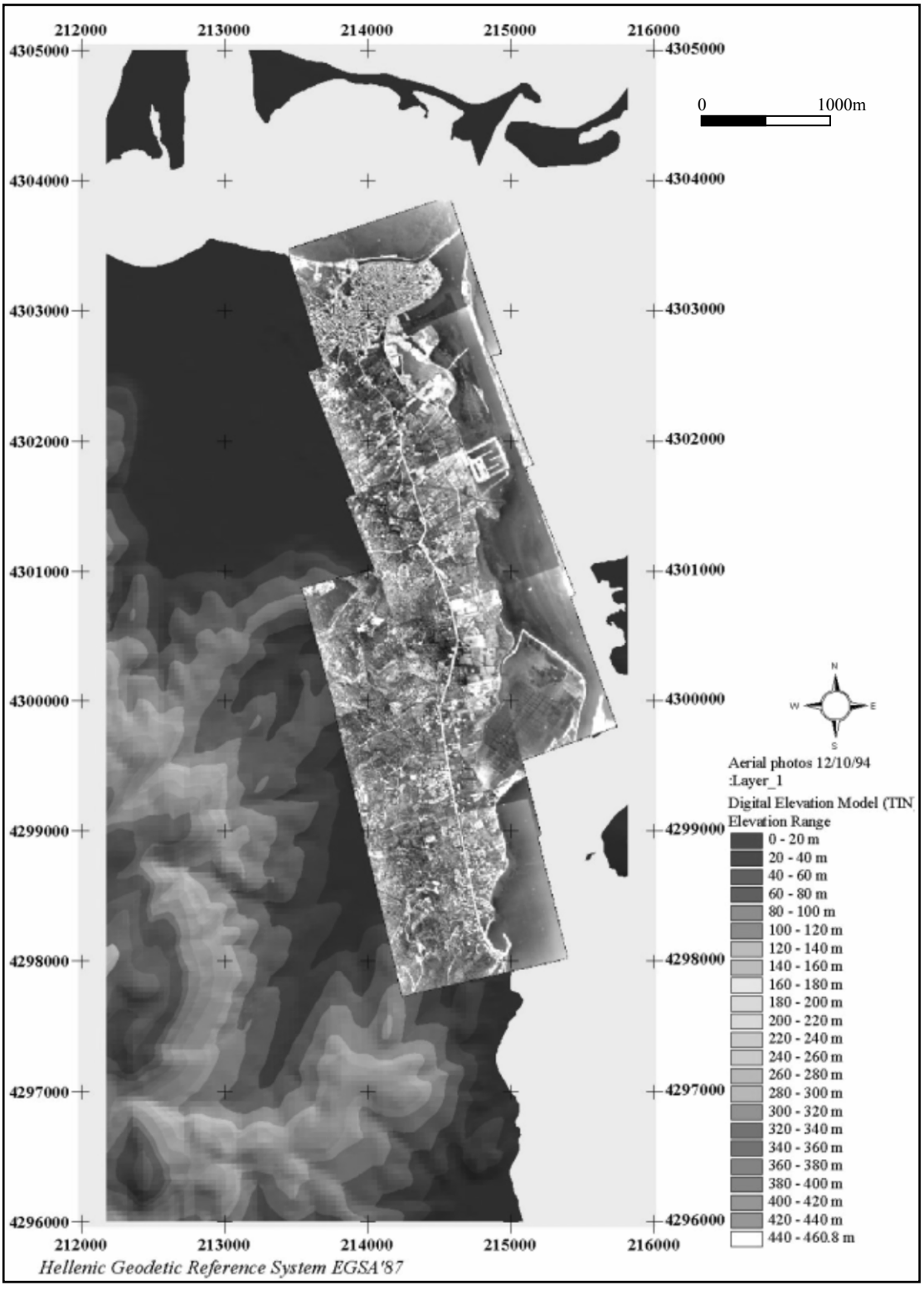

Figure 2: Digital Terrain Model (DTM) and overlay of the aerial orthophoto maps.

Figure 3: Aerial image of the wider region of interest and overlay of the outline of the geophysical grids, accompanied by their corresponding codes.

towards the coast to the east. The part that extends on the hills, where (possibly) ritual buildings and the remains of the ancient theatre have been found (Pliakou 1997, Pliakou 2001), has no specific urban planning, while the part at the plain was built according to an orthogonal system, very similar to the Hippodamian one. According to the information retrieved by different excavation trenches, the parallel streets, with average width 4.5m (Agallopoulou, 1971, Kalligas, 1972, Andreou, 1979, 2002), run across the city every 30m in an east to west direction, that is, from the hills to the sea. These streets intersect vertically with others of about 5.5-6m in width (Andreou, 1977, 1984, 2002), creating building plots with their long direction along the east-west axis. The study of the excavation results showed that two private houses, divided by a draining pipe, exist in every building plot (Douzougli, 1993, Pliakou, 1999). Other draining pipes run along the ancient streets (Agallopoulou, 1971, Kalligas, 1972, Andreou, 1979).

The aforementioned conclusions have been compared with other known examples in the wider area, like the city of Amvrakia (also a Corinthian colony), which is in the area of modern Arta (Andreou, 1993). It is worth mentioning that the orthogonal city plan system in ancient Lefkada was formed almost two centuries before the creation of the Hippodamian system.

Due to the increased pressure imposed by the recent expansion of construction and building works in the area, the archaeological service decided the protection of the area imposing certain restrictions in the building activities. At the same time, the use of geophysical investigations was considered of crucial importance, in order to provide further information regarding the degree of conservation of the architectural relics and their density in the southern section of the city.

Thus geophysical investigations, including magnetic and soil resistance measurements, were employed in a total area of about 80,000 square meters at the SE section of the ancient city. The specific region is surrounded by visible architectural parts, while it also included excavated

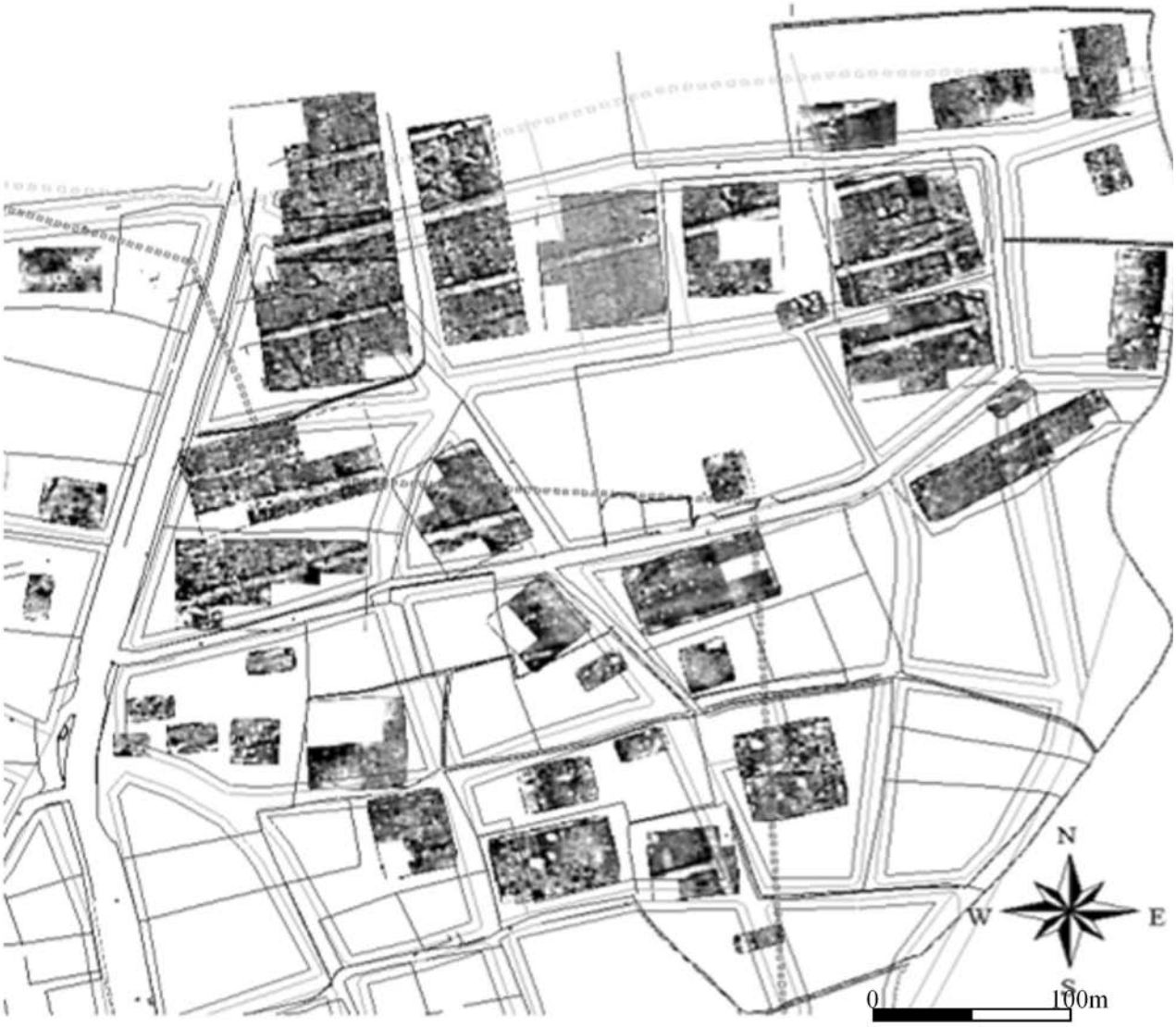

Figure 4: Synthetic magnetogram produced by the overlay of all the magnetic maps. The dynamic range of the values of the vertical magnetic gradient lies .etween -120 to 100 nT/m.

sections and trenches at the northern and western sections. One of the goals of the research plan was to locate the outline of the southern section of the ancient wall, which has remained without any significant traces, and which would contribute in defining the limits of the ancient city.

Geophysical prospection techniques

The geophysical survey of the archaeological site was carried out in two phases (April 13-23 and June 16-27, 2002). In the first phase of the campaign, both magnetic and soil resistance techniques were employed in selected grids in order to test the registered signals originating by the subsurface targets. The second phase of the fieldwork activities was devoted to the extended coverage of the site through the use of magnetic techniques.

A Geoscan fluxgate gradiometer (FM36) was employed for the measurements of the vertical magnetic gradient. The gradiometer readings were able to smooth away the geological trends and diminish the external noise. Measurements had an accuracy of 0.1nT/m.

In the measurements of the soil resistance, a Geoscan resistivity meter RM15 with a Twin Probe electrode configuration was used with a spacing of 0.5m between the mobile electrodes (Clark, 1990). Emphasis was given to the wide coverage of the site with a sampling interval of 1m, while high-resolution measurements were carried out in a limited number of grids of specific importance.

Returning to the design of the GIS used for the management of the results of the geophysical research, the outlines of the geophysical grids were also added to the system as a different layer (Figure 3). The location of the geophysical grids was defined through the use of a total station, a work which was carried out by the local archaeological service. Based on these measurements, the final geophysical maps were geometrically corrected and registered to the system as B&W or color images in a

Figure 5: (Left) Results of the magnetic measurements in the area coverage of grids C, B, A, U, X & Z. The dynamic range lies from –45 to 35 nT/m. (Right) Comparison between resistivity and magnetic data for grid X.

.jpg format (Figure 4). The processing and manipulation of the geophysical measurements included de-spiking of extreme values, grid and line equalization techniques, compression of the dynamic range of the initial values, application of directional filters in terms of the estimation of the first derivatives, application of high pass and low pass filters, shading relief techniques and construction of 3 dimensional images.

The magnetic measurements in grids C, B, A & U (Fig.3), east of the provincial road from Lefkada to Nydri, indicated the existence of a network of parallel streets, at a SWW-NEE direction, lying at a distance of 35m apart (Figure 5). They have a width of about 3.75-4.5m and appear as high anomalies lying within the range of 5-15nT/m above the background magnetic level. The dipole character of the anomalies suggests the existence of a drainage pipe running at the northern part of the roads. A road, perpendicular to the rest, appears at the northern part of grid B (see Fig. 4). Similar evidence comes from grids X and Z, suggesting that the town plan was consisting of a dense network of parallel and perpendicular roads, which divided the ancient city in building blocks.

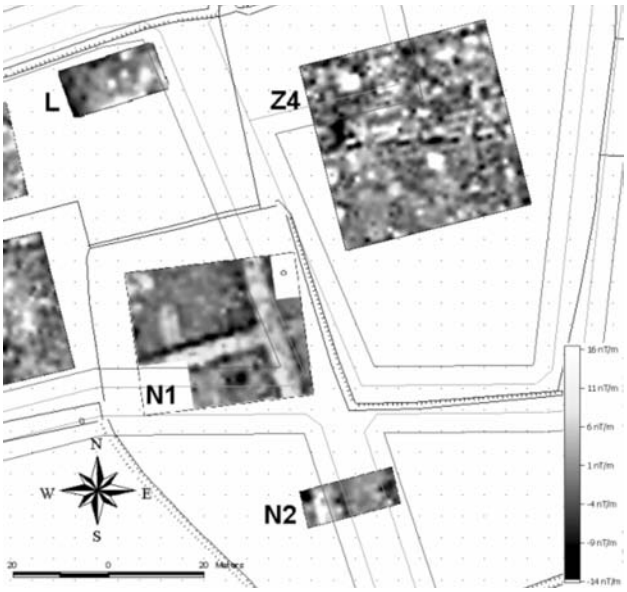

Figure 6: Details of the results of the magnetic measurements at the SE section of the surveyed region, where a perpendicular road intersection was located. One of the roads is leading to the ancient cemetery (to the west) and the other (to the south) towards the ancient port of Lygia.

Grids X and Z are of particular interest, since there are clear indications of architectural relics within the building blocks in both vertical magnetic gradient and soil resistance data (Figure 5). The outline of the magnetic anomalies suggests the good preservation condition of the particular structural remains. The roads appear as high magnetic anomalies within the ~3-15nT/m range and as high resistance anomalies within the ~8-15 Ohms range. The parallel road system seems to fade out towards the east. A vertical linear anomaly, which appears at the eastern side of the particular grids, seems to be of a different nature, probably consisting of two sections, and can be considered as a candidate target for the location of the wall surrounding the town. The rest of the grids (VOR1, VOR2, TH1, TH2, TH3) towards the north-east indicate a loose clustering of architectural remnants, which extend to the coast-line.

In contrast, areas which were surveyed in the western side of the road connecting Lefkas to Nydri did not indicate any significant anomalies. However, we need to consider that

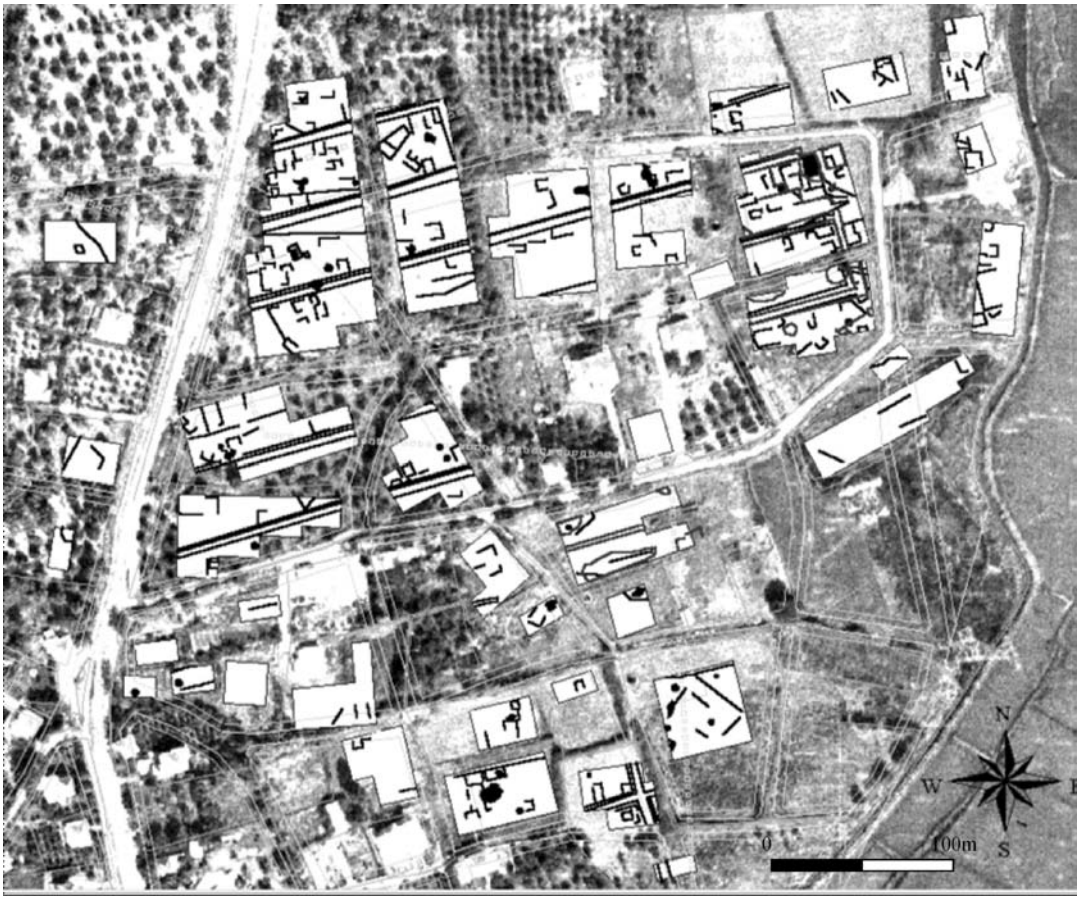

Figure 7: Diagrammatic interpretation of the geophysical anomalies and their overlay onto the aerial image of the wider region.

none of the above grids was located at the projection of the ancient road network which was identified in the east section of the surveyed area.

The area to the south of the SWW-NEE dirt-road, which divides the area of interest in north and south sections, exhibits a lower interest, as it is indicated by the decreasing density of geophysical features. The area of grids R1-R5 exhibits an elevation difference of about 3-4m with respect to the dirt road and the north section of the surveyed region. In the projection of the dirt road to the west, large stone blocks may be correlated to the ancient city wall. Similar evidence exists along the dirt road, reinforcing the hypothesis that at least a large section of the city wall is located along its length.

Finally, additional evidence of the extension of the city plan was provided by grids N1 and N2 to the SE (Figure 6). In grid N1, a cross-section is aligned in agreement to the street orientation at the north section of the surveyed region. The NW-SE road seems to be at the projection of the road registered at the NE edge of grid B, while there are also indications from grid N2 that the road continues further to the south. Due to its proximity to the coast, it is very probable that the road may lead to Lygia, where the ancient port facilities of the city were located. More specifically, in Lygia there is a mole used to connect the Eastern coast of Lefkada with the Akarnanian coast, where the fortress of Agios Georgios-Plagia is located (Murray 1982). The mole was constructed to protect the southern entrance of the canal, was cut by the Corinthians, and it is probably dated to the same period, namely about 600 B.C. Similarly, the SW-NE road seems to lead to the ancient cemetery, which has been located to the west of the provincial road.

Final remarks

Through the use of geophysical survey and GIS techniques it was possible to collect information which can be used to clarify the city plan of the ancient city of Lefkas. A detailed plan of subsurface anomalies was identified enhancing the information context of the up to date excavations and offering an integrated image of the southern section of the ancient city.

A road network, structural relics, drainage pipes, kilns, and wall remains are included among the candidate targets that were registered by the soil resistance and magnetic techniques. The results of the geophysical survey are in perfect agreement to the surface monuments and the excavation results, completing to a large degree the fragmentary image of the ancient city.

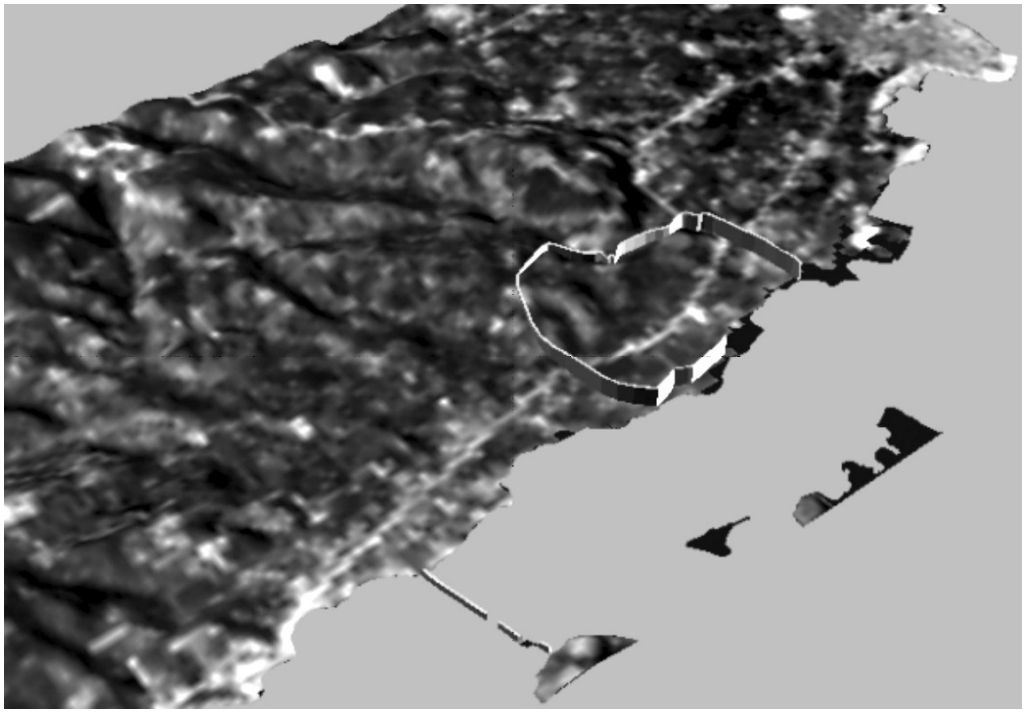

Figure 8: Overlay of the photomosaic of the region to the DTM and a 3D model of the proposed outline of the ancient wall.

More specifically, the city plan seems to extend to the north of the area of interest (namely, north of the SWW-NEE dirt-road and east of the provincial road) (Figure 7). In contrast, the south section of the area exhibits a lower density of architectural remains and an increasing number of candidate kiln structures (anomalies at grids I and K), suggesting workshop activities. The above observations, together with the surface monuments along the dirt-road and the elevation difference between the north and south sections in the other sides of the dirt road, suggest that part of the southern city wall is probably running along the dirt-road.

The design of the Geographic Information System was extremely helpful in registering the different information layers and correlating the results of the geophysical survey with the rest cartographic material (Figure 7), including the topographic maps and the aerial mosaics. In this way, it was possible to have an accurate picture of the distribution of the geophysical anomalies and their correlation with the surface relics, while the time sequence of the aerial imagery contributed to the analysis of the evolution of the landscape.

A three-dimensional representation of the research area combining the digital elevation model, draped with an aerial photo mosaic and the architectural remnants, found in the previous excavations and geophysical survey has been also constructed (Figure 8). The above approach will contribute in the management of the archaeological relics of ancient Lefkas.

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