Journal of Field Archaeology

ISSN: 0093-4690 (Print) 2042-4582 (Online) Journal homepage: http://www.tandfonline.com/loi/yjfa20

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JOURNAL OF FIELD ARCHAEOLOGY, 2017
VOL. 42, NO. 5, 450–467
https://doi.org/10.1080/00934690.2017.1365565

A Regional Approach to Ancient Urban Studies in Greece Through Multi-Settlement Geophysical Survey

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ABSTRACT

The systematic exploration of large archaeological sites in the Mediterranean has evolved considerably since the "big dig" excavations. Pedestrian field surveying and remote sensing applications, including satellite and airborne image analysis, are now practical and relatively cost-efficient methods of characterizing large and diachronically diverse landscapes on regional scales. However, the use of geophysical techniques as a means for exploring manifold archaeological contexts is still in its infancy. In this paper, we highlight the advantages of archaeological geophysics to conduct regional surveys in the Mediterranean. Through a multi-site geophysical fieldwork campaign to investigate the patterns and dynamics of ancient cities in Greece, we show how geophysics offer new opportunities for characterizing the spatial attributes and regional dynamics of urban landscapes, and, in doing so, we make an argument for its wider adoption on regional survey projects.

KEYWORDS

integrated geophysics; regional survey; urban archaeology; ancient town-planning; remote sensing

Introduction

The large spatial extent of ancient cities presents challenges for investigating urban contexts with conventional methods of archaeological exploration. Excavations provide detailed evidence of the material culture and chronology of a given site but the time intensive nature of this approach restricts them to comparatively small areas. Pedestrian surveying can convey the big-picture range and diachronic usage of urban space and its rural environs, but without providing significant information on what lies below the ground. Geophysics fits in between these approaches as it provides high spatial resolution data of the subsurface over an expansive area. The relative speed of data acquisition, especially with newer generations of geophysical and positioning equipment, has the potential to radically transform the dimensions of archaeological investigations and how archaeologists understand the urban past in the 21st century. Not long ago, geophysics was principally used as a secondary method to supplement excavations and pedestrian surveying on a targeted level of single-site proportions. Nowadays geophysical techniques are increasingly applied as principal tools of site exploration (Sarris and Jones 2000; Donati and Sarris 2016a). Multi-sensor systems can cover several hectares of surface area per day while also providing high-resolution data if ground conditions permit. Therefore, a wide and detailed corpus of archaeological data can be gathered in a relatively short amount of time and analyzed from a broad, multi-contextual perspective. The information gathered is ideal for city-scale and regional investigations, providing a range and level of detail otherwise unavailable concerning the spatial organization of urban centers.

This paper reviews the results of a multi-site fieldwork campaign undertaken in Greece at ancient settlements in the Peloponnese and Thessaly. The data collected from geophysics were effective in highlighting major urban features, such as street plans and architecture. These are some of the expected and quantifiable outcomes associated with geophysical prospection in archaeology. What is distinctive here is the spatially extensive sampling methods of investigations and their rapid execution, which guided the emphasis of research towards broad urban characteristics, including settlement size, urban density, city organization, modes of movement, and urban modifications, from a cross-regional point of view. Such an approach cultivates a healthy blend of targeted site analysis and widespread multi-site analysis, opening enticing new avenues in the urban archaeology of the Mediterranean.

In Greece, geophysics has played a prominent role in documenting the spatial parameters of ancient urban contexts. Extensive surveys have been carried out at Plataiai and Tanagra in Boeotia (Konecny et al. 2012; Bintliff et al. 2013), Sikyon in the Peloponnese (Lolos and Gourley 2011), and Philippi in Macedonia (Provost and Boyd 2002). On a broad platform, the Ancient Cities of Boeotia Project has applied geophysics to study the spatial parameters of urban sites in support of its regional survey (Bintliff et al. 2013). It should be emphasized that multi-sensor push- and towed-systems were first employed in Greece very recently. Before, single-site geophysical surveys of small- to medium-scales were the norm. The IGEAN Project (igean.ims.forth.gr), an integrated geophysical campaign to examine the settlement structure and surroundings of Neolithic farming communities in eastern Thessaly, was a

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forerunner in the application of rapid coverage geophysics in Greece and in introducing a multi-settlement scope (more than 20 prehistoric sites) using integrated geophysics (Sarris et al. in press).

Methods

Near-surface geophysical methods can detect and map buried archaeological features in a non-destructive manner by measuring differences in the physical properties of the Earth's subsurface. Since each geophysical technique collects information about a different physical property, the application of multiple techniques provides more detailed information about the nature of subsurface material. An integrated approach complements the information extracted from each technique to enhance the interpretation of the results (Keay et al. 2009; Simon et al. 2015). Local environmental conditions, including matrix composition of soil, depth and size of features, soil saturation, and geology, all potentially impact the detection capabilities of each method. A manifold approach maximizes the ability to detect buried features and draw meaningful conclusions about them. In the fieldwork discussed here, the scope of geophysical exploration was extensive and the methods of extracting archaeological data were diverse. A team of between five and seven people directed four types of geophysical techniques: 1) electromagnetic induction (EMI), 2) electrical ground resistance, 3) ground-penetrating radar (GPR), and 4) magnetic gradiometry. Some pieces of equipment were multi-sensor push- and towed-systems, which enabled the survey team to investigate more surface area per day compared to conventional instruments. This was a major factor in being able to carry out research at multiple settlements within a finite timeframe.

In the field, geophysical equipment providing rapid spatial coverage was combined with targeted surveys using conventional instruments to clarify the nature of specific features. For large area coverage, the survey team employed a SENSYS Magnetometer MX with an array of eight fluxgate gradiometers and an in-line sample density of 0.5 m (FIGURE 1). The device is attached to a frame with four wheels and can be towed with a quad bike or similar vehicle, but it can also be pushed by two people. Since the topography in Greece varies greatly from flat open areas to steep inclines with moderate to heavy vegetation and ground stone densities, towing the wide ~4 m frame with a vehicle was often not as practical (and safe) as pushing the device by hand. Although flat topography and low vegetation density are ideal for a multi-sensor magnetometer, it can be adapted to a diverse range of landscapes with experience. For even broader coverage, EMI surveying with an in-line sample density of 1 m was simultaneously carried out by a single person using a multi-frequency Geophex GEM-2 EMI. An advantage of EMI is that it provides information about both electrical conductivity and magnetic susceptibility, making it useful for investigating a range of both archaeological and geological material (Simon and Moffat 2015). Both the magnetometer and EMI were equipped with GPS rover stations that communicated with a differential base station (dGPS) providing a positioning accuracy of less than 1 cm.

Electrical ground resistance and GPR surveys were used to target smaller areas after the initial results from magnetics and EMI. These methods are generally slower in operation, but their ability to map buried anthropogenic features in 2D and 3D are sometimes superior. Two GPR devices were employed: the MALÅ "Mini" MIRA, a 400 MHz frequency eight-channel system consisting of an array of nine antennae with five transmitters and four receivers, and the Sensors and Software NOGGIN Plus-Smart Cart single channel system fitted with a 250 MHz antenna. The eight-channel GPR can be towed with a quad bike and can be linked to a dGPS base station for rapid site assessment. It was best employed on level ground with minimal vegetation and stone density. The single channel GPR is lighter weight and more flexible in demanding topographical conditions. However, survey grids usually must be laid out with additional personnel, which reduces the speed and efficiency of data acquisition. The single antenna also means that it covers a far smaller proportion of the site during each survey line. Electrical ground resistance mapping was carried out using a Geoscan resistance meter RM85 with a twin probe configuration set to a

Figure 1. SENSYS Magnetometer MX in use at Mantinea. The device is equipped with a GPS rover station that communicates with a dGPS base station.

Figure 2. Map of Greece showing sites explored with integrated geophysics.

= 0.5–1 m. Although resistance is one of the most popular—if not the most widely used—geophysical technique in the Mediterranean, its slower application due to the need to directly couple the electrodes to the soil did not make the device appealing for the research goals of high spatial coverage.

Study Areas

Geophysics was directed at six settlements on the Greek mainland (FIGURE 2). The target sites form a diverse range of case studies with major habitation activity dating from the middle of the first millennium B.C.E to the first few centuries of the Common Era. In some cases, earlier and later material was documented. The sites were selected by considering those that could benefit from expansive survey methods (e.g., large cities, with limited understanding of urban morphologies) and those with ideal conditions for rapid coverage geophysics (e.g., flat topography, minimal vegetation, and tree density).

The total surface coverage by geophysical surveying at each city, along with the average coverage rate per day, is shown in Table 1. From the 91.55 ha surveyed in 28 days, magnetics and EMI attained a coverage of 54.81 ha (60%) and 26.89 ha (29%) respectively. These high percentages are a result of their rapid use in the field compared to GPR and electrical ground resistance, which, being constrained by survey grids or requiring direct ground contact, were employed less frequently. The coverage area of these supporting techniques came to 8.29 ha (9%) for GPR and 1.56 ha (2%) for electrical ground resistance. The number of working days in the field ranged from only two days at Halos to 11 days at Mantinea. Overall, the average survey rate at all sites was 3.27 ha/day. The slower rate of 1.71 ha/day at Heraia was attributed to the challenging terrain of high vegetation and piles of branches from recently pruned olive trees. Furthermore, the below average rate at Demetrias of 2.96 ha/day was due to the density of wild vegetation growth and metallic features scattered throughout the site, such as iron fences and metal wires.

Table 1. Total surface coverage (in hectares) of geophysical methods, and rate of surface coverage (in hectares).

	Demetrias	Elis	Halos	Heraia	Mantinea	Pherai
GPR	1.83	0.65	0.68	1.29	3.41	0.43
EMI	3.29	5.49	2.85	1.59	10.07	3.60
Magnetics	5.12	9.34	3.06	5.68	25.51	6.10
Resistance	0.12	0.36	0.68	-	0.40	-
Total	*10.36*	*15.84*	*7.27*	*8.56*	*39.39*	*10.13*
Working Days	*3.5*	*3.5*	*2*	*5*	*11*	*3*
Rate ha/day	***2.96***	***4.53***	***3.64***	***1.71***	***3.58***	***3.38***

Different geophysical methods usually overlap in area coverage (TABLE 2). This was done as a practical means to obtain complementary datasets and to test the effectiveness of each technique in various soil conditions. Other times the survey team was constrained to certain areas, either from the cultivation cycle of crops or the accessibility of private land, and a more targeted approach needed to be implemented. This was the case at Halos and Demetrias, where there were higher percentages (more than 50%) of overlap between geophysical methods. However, in normal working conditions, the overlap from surveying approached about one-quarter to one-third of the total surface coverage. These ratios can be modified depending on the needs and constraints of the research team (e.g., large coverage, time

Table 2. Total surface coverage (in hectares) and the total unique surface coverage without overlap (in hectares).

	Demetrias	Elis	Halos	Heraia	Mantinea	Pherai
Total	10.36	15.84	7.27	8.56	39.39	10.13
Unique Coverage	4.87	13.23	3.12	5.94	30.91	6.49
Overlap	***53%***	***17%***	***57%***	***31%***	***22%***	***36%***

limitations, and targeted analysis of specific features) and the nature of the archaeological material at the site. The nearly 31 ha of unique coverage at Mantinea counts as one of the largest geophysical surveys at a single archaeological site in Greece. It surpasses the 27 ha achieved at Plataiai and approaches the largest surveys to date at Sikyon and Tanagra, which reached approximately 40 ha. Impressively, the coverage at Mantinea was achieved in only 11 days while these other examples were undertaken over the course of multiple seasons and years. It is estimated that the entire urban zone within the city walls (119 ha) at Mantinea can be surveyed in 30 more working days, even with reasonable overlap. Total or near-total urban surveys across multiple (big) sites using integrated geophysical methods are now possible within finite timeframes, and fieldwork in Greece and elsewhere over the next decade is expected to solidify this new reality in urban archaeology.

Results of the Regional Survey

Mantinea

The size of the classical city was substantial (119 ha) as determined by the exceptional preservation of elliptical fortification walls (Winter 1989). Fieldwork in the 19th and 20th centuries (Fougères 1898; Hodkinson and Hodkinson 1981), and more recently, focused on the public and religious monuments in the *agora* (commercial and civic center) (Karapanagiotou 2015). A geophysical survey from 1988 to 1991 using electrical ground resistance explored a small area (1 ha) northwest of the agora, finding some evidence for buried streets and buildings (Papamarinopoulos 1993). An important discovery of late was the identification of an extensive orthogonal street system by satellite remote sensing methodologies using feature enhancement filters (Donati 2015; Donati and Sarris 2016b).

The recent geophysical survey at Mantinea uncovered considerable new evidence for buried streets and architecture. Magnetics and EMI were effective in mapping street systems because of their rapid area coverage and due to the clear magnetic and electric signatures of these features (FIGURE 3). Most streets appear as elevated magnetic anomalies in comparison to the surrounding soil matrix. This is a probable indication that road surfaces consist of hard packed dirt with clay materials that have been heated such as crushed tile, pottery, and slag. Darker anomalies of lower magnetic values on the street edges are likely from stone curbings or even structures bordering the streets. The metrology of city blocks at Mantinea is remarkably diverse, but there is a consistent spacing sequence. City blocks, as measured from the corners, are rectangular with general dimensions of 80 m × 50 m; however, these dimensions often expand by factors of 20 m and 25 m respectively. For instance, city blocks might be 80 m × 50 m, 100 m × 50 m, 120 m × 50 m and so forth, or 80 m × 50 m, 80 m × 75 m, 80 m × 100 m and so forth. The range of dimensions is underscored by the tiered or stepped arrangement of streets, especially along the margins. Streets rarely, if ever, continue from one side of the city to the other, but they are instead broken up into smaller units. Also evident is a uniform shift in the placement of north-south streets in the city's central region around the agora. Streets that originate at the fortification walls do not continue unbroken from the northern to southern sides of the city but they are offset by a factor of 20 m. Other details that emerged from the survey were the discovery of smaller roads or alleyways dividing city blocks in half, and the identification of a ring road inside the perimeter of the fortification walls (FIGURE 4).

Many subsurface buildings were identified, including probable private dwellings and public structures. Magnetics mapped concentrations of structures throughout Mantinea, although the clearest evidence comes from regions north of the agora and at the southern side of the city. Building walls typically have lower magnetic values compared to the surrounding soil matrix, which indicates the likely use of stone materials. At the same time, it is important to stress that there are sizeable zones with limited or no architectural traces. For example, magnetics identified a few buildings along roads in the city's southwestern region yet many areas here are without traceable architecture, while GPR mapped a concentration of buildings in the city's south-central region that contrasts starkly with the apparent lack of architectural features further north (FIGURE 5).

Elis

Fieldwork since the early 20th century has mainly focused on a concentrated area of Elis around the agora (Eder and Mitsopoulos-Leon 1999; Heiden 2006) and more recently on a residential zone to the south (Andreou and Andreou 2007, 2012). The urban extent of the city is difficult to assess, since there are no fortification walls of any period visible on the surface. A geophysical survey in 2003 using magnetics and electrical ground resistance investigated regions near the agora and it was successful in mapping some streets and buried structures (Tsokas et al. 2012). The basic urban arrangement was further clarified by satellite remote sensing, which outlined a general plan of the city and its orthogonal street system (Donati and Sarris 2016b).

The latest geophysical survey mapped a more widespread group of organized streets with magnetics and EMI (FIGURE 6). In the southern region, a north-south street and bisecting east-west streets were found more than 800 m from the agora. Curiously, the east-west streets do not extend along an uninterrupted axis but are repositioned 10 m apart in a tiered arrangement as measured from the center of the streets. The north-south street is of special interest since it aligns with one uncovered during excavations near the agora (Andreou and Andreou 2012); surveying also mapped the southern extension of this same street in the field south of the excavations. Other organized streets were discovered 600 m from the agora in the western region. The widths of city blocks in

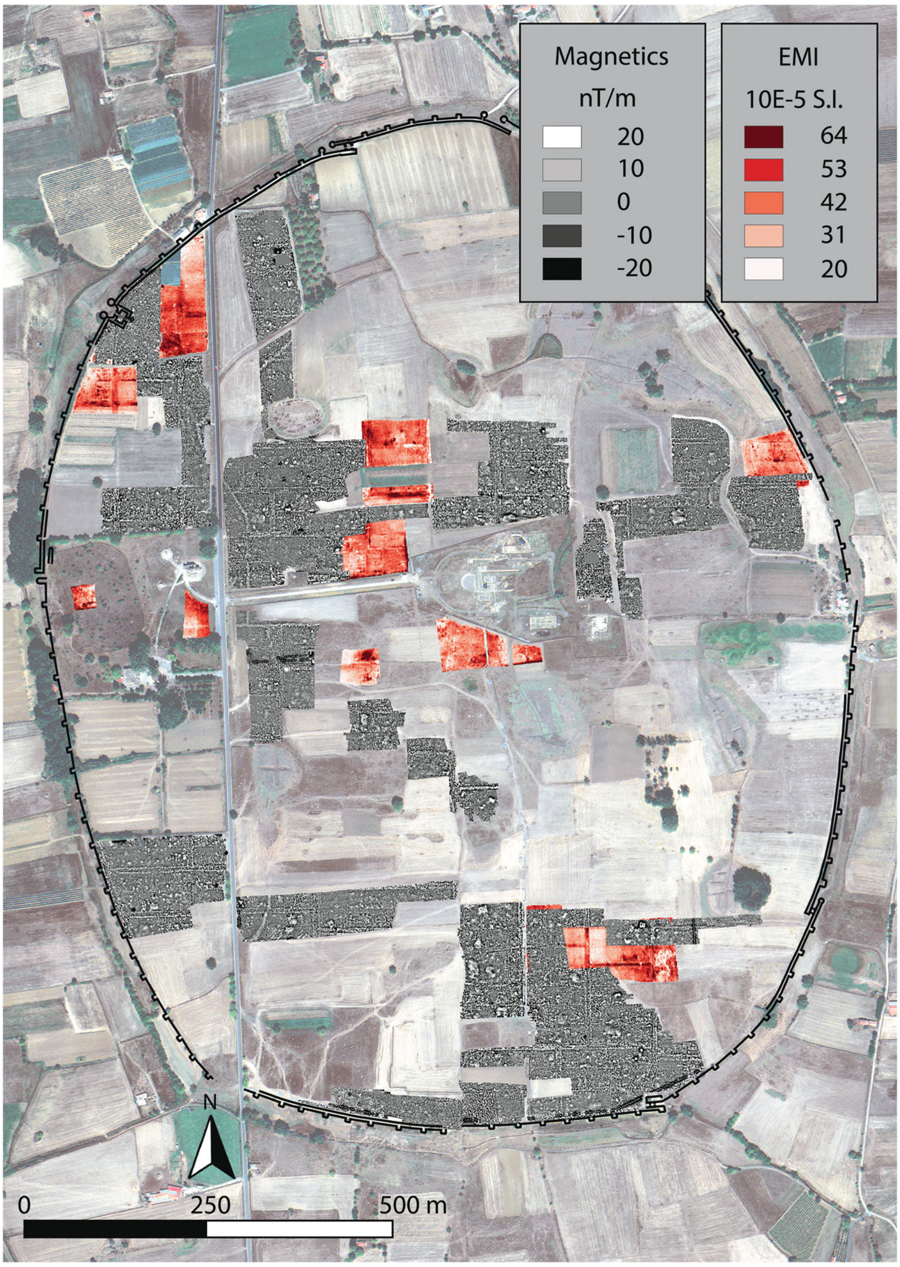

Figure 3. Mantinea. Magnetics and EMI magnetic susceptibility.

the southern and western sectors of Elis are consistently 50 m as measured from the corners. The complete dimensions of city blocks are still unknown, since fewer north-south streets have been identified. However, enough area has been surveyed (particularly west of the agora) to indicate that the town plan adopted elongated city blocks with few north-south crossroads. The apparent continuation of streets, beyond those identified, also implies a further extension of the urban zone towards the south and west that remains to be determined with future surveying.

There is less evidence for an organized street system in other regions of Elis. The city's northern periphery is defined by the Peneios River, which may have acted as a natural edge only a few hundred meters from the agora. Some features from probable streets were noted in a field north of the agora from the magnetics survey, although instead of conforming to the orthogonal grid found elsewhere, they have diagonal alignments. Another diagonal street was identified during the 2003 geophysical survey west of the agora. The eastern region of Elis is hilly, rising gently to an ancient acropolis, yet there are few indications of the urban makeup around these hills. Magnetics, EMI, and GPR southeast of the agora verified the location of a few subsurface buildings, but not a clearly defined street system. This area seems to have been impacted by soil depositions or erosion activity, which may be a factor that limits feature detection with geophysics.

Heraia

The lack of prior archaeological research at Heraia, beyond a few excavation trenches in the 1930s (Philadelpheus 1935), necessitated a broad geophysical survey to resolve basic questions of urban morphology. The location of the ancient city has long been known based on the descriptions of ancient authors, and, more recently, from surface finds such as pottery and coins (Papagiannis 1996). There is little to see at Heraia today as architectural blocks on the surface were thoroughly pillaged in the 19th century for reuse in nearby villages; however, early travelers commented on seeing

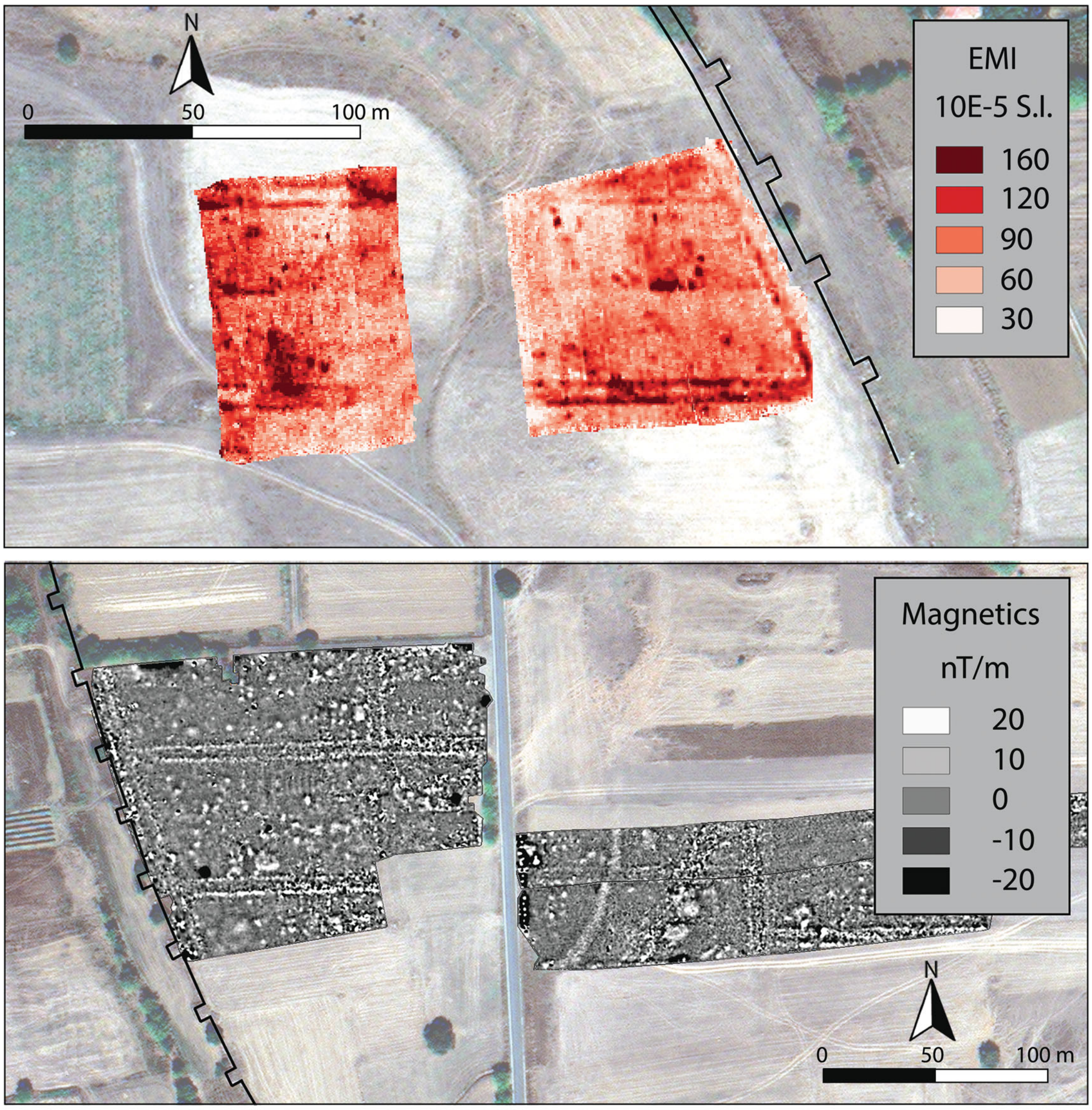

Figure 4. Mantinea. Ring road inside the fortification walls: EMI magnetic susceptibility in the eastern region (top), magnetics in the southwestern region (bottom).

buildings and walls (Gell 1828: 113; Leake 1830: 91–93; Wyse 1865: 70–74; Frazer 1898: 295–296).

The results of geophysics now provide much more substantial evidence for the town plan of Heraia (FIGURE 7). The survey mapped a dense cluster of organized streets and buildings without any clear signs of fortification walls or a decline in the intensity of subsurface features. The data show that streets are aligned to the cardinal points, and city blocks, where measurements are possible, are rectangular with dimensions of 78 m × 50 m as measured from the corners. Deviations in the positioning of some streets imply that a variable town plan was likely implemented (as at Mantinea). Many subsurface buildings were also identified at Heraia, and, in general, they appear to conform to the alignments of the urban grid. In one outstanding example, magnetics and GPR mapped a large building almost square in shape with an internal courtyard surrounded on all four sides by what would appear to be *porticos* (colonnaded walkway) (FIGURE 8). A rectangular feature in the center of the courtyard has high magnetic values, which might suggest burning activity here or organic construction materials. Other structures were found around this building, including a row of seven rooms at the east forming a façade along a nearby street.

Demetrias

Archaeological investigations were initiated at Demetrias more than one hundred years ago (Batziou-Efstathiou 2002). The most important finds were an extensive circuit of fortification walls, one of the largest from an ancient city in Greece, a monumental stone theater, and the palace that was residence of the Antigonid dynasty of Hellenistic rulers. Beginning in the 1960s, excavations and surface survey provided evidence of an orthogonal grid plan with the palace and agora at the center (Milojić and Theocharis 1976, 1978; Marzolff 1994). The basic metrology of the urban grid consists of rectangular city blocks measuring 50 m × 100 m from the street corners. Although the application of town planning is well documented at Demetrias, its extent beyond the core of the city remains unknown.

The geophysical survey confirmed the accuracy of the street system reconstruction at locations south and southeast of the palace (FIGURE 9). However, a wider picture of the extent of town planning at Demetrias remains unresolved as negative field conditions limited the survey to concentrated areas. A northern extension of the urban grid was likely confirmed by the discovery of a monumental building aligned with the street plan. The structure, mapped in both magnetics

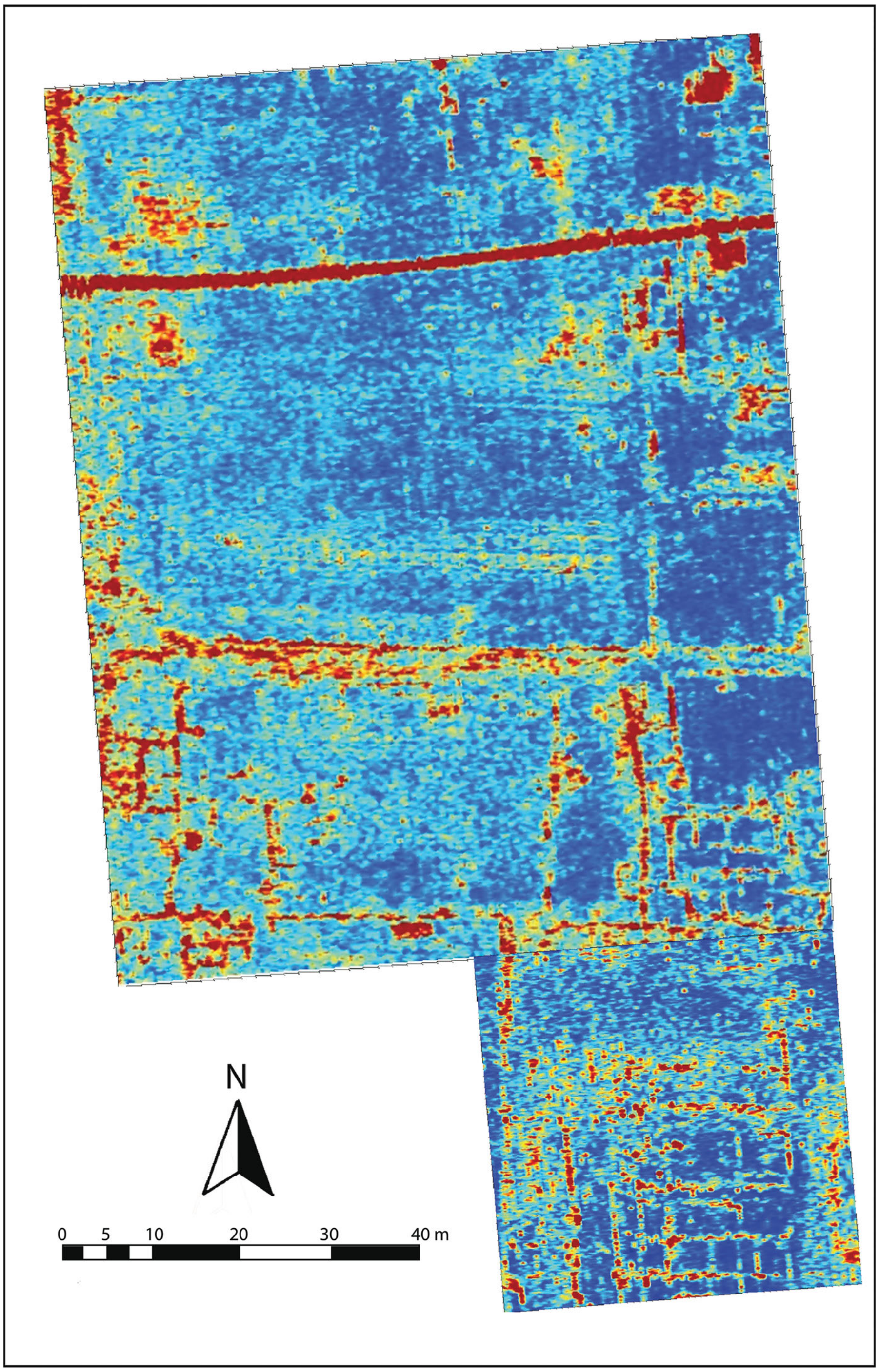

Figure 5. Mantinea. GPR single channel 250 MHz antenna (depth slice: 0.70–80 m) in the south-central region. The intense anomaly at the top is from a modern gravel footpath.

and EMI, consists of a semicircular western half adjoining a rectilinear complex with individual rooms. The northern end of the building lies below a paved street and could not be surveyed. The structure is a building of considerable size and importance near the harbor of Demetrias, and its form is most suggestive of a small theater, a covered concert hall (*odeion*), or part of a monumental bath complex.

Other important details emerged concerning the town plan of Demetrias. Surveying west of the agora mapped a dense collection of buried architectural features with strict alignment to the urban grid. The location of these buildings along the western side of the agora favors an identification as a group of buildings, commercial or civic, that provided a monumental architectural backdrop to the public square. East of the agora, the survey identified a planned residential quarter (FIGURE 10). Here, city blocks are filled by large structures with accompanying rooms and possible courtyards or gardens in the back. The overall arrangement of the architecture recalls Hellenistic and Roman urban houses with shared partition walls between lots. Rooms along the streets could be related to residential quarters, but some of them may also have functioned as commercial buildings. In this respect, the proximity of this region of the city to the agora should be stressed.

Halos

The Classical settlement of Halos, on an oblong artificial hill called Magoula Plataniotiki close to the modern shoreline, is distinct from the Hellenistic settlement of the same name. Historical sources indicate that the Classical site was sacked

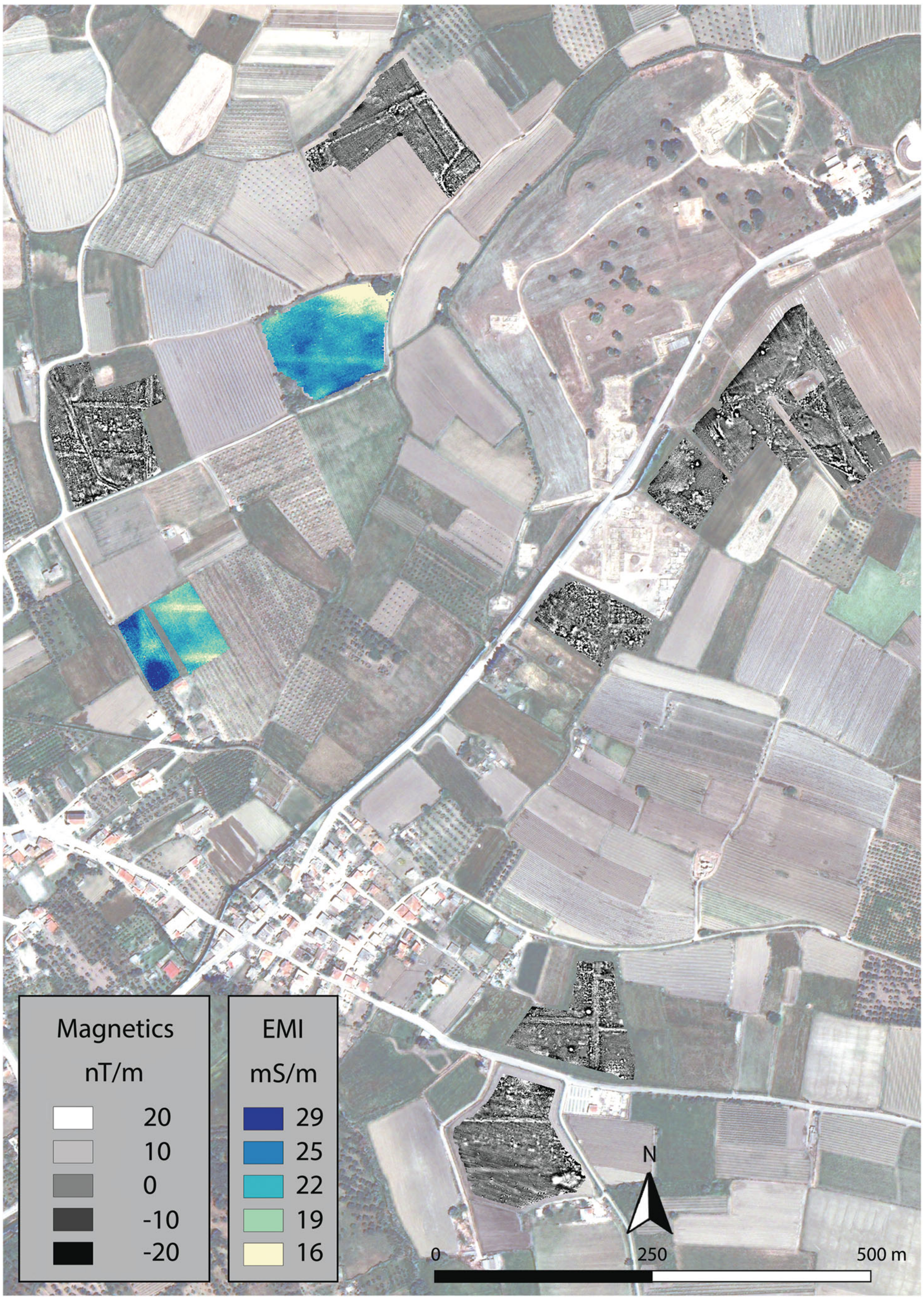

Figure 6. Elis. Magnetics and EMI soil conductivity.

and destroyed in 346 B.C.E. by the Macedonians. Much of the city was left abandoned until 302 B.C.E. when the former inhabitants resettled at a new site 1.5 km further inland. The Hellenistic town was adopted from a former military camp, and, as such, it has a strict rectilinear plan with a regular arrangement of streets and city blocks. This second town had a short lifetime and was itself abandoned by 265 B.C.E., apparently after an earthquake. Occupation was subsequently transferred again to the former city near the coast. Archaeological research at the Hellenistic site was initiated in the 1970s (Reinders 1988, 2014), and the houses offer unique insights into the nature of domestic life during the period (Reinders and Prummel 2003). The Classical settlement has been the focus of Dutch excavations beginning in 2013.

Along the northern side of Magoula Plataniotiki, in an area that is elevated a few meters above the nearby coastal plain, magnetics and EMI illustrate a tight arrangement of architectural features bookmarked by peripheral zones of few remains (FIGURE 11). The results give a good indication of the east-west span of Halos, which measures approximately 250 m wide in this part of the city. The elevated soil conductivity at the eastern and western ends of Magoula Plataniotiki suggests clay rich sediments, which probably reflect deposition in a brackish marsh environment, supporting previous coring investigations (Bottema 1988). The evidence for fortification walls is not clear in the data despite the distinct separation between built and unbuilt areas. The central and west-central regions of Halos are occupied by rectilinear structures with orientations slightly west of true north. The internal makeup of some buildings appears as strong magnetic anomalies. Walls are typically targeted as low (black) magnetic values (probably stone) surrounding high (white) magnetic values of square or rectilinear shape. The latter gives an indication of the area of individual rooms, and the high magnetic values could be from organic material packed in the ground or from burnt mudbrick and roof tiles

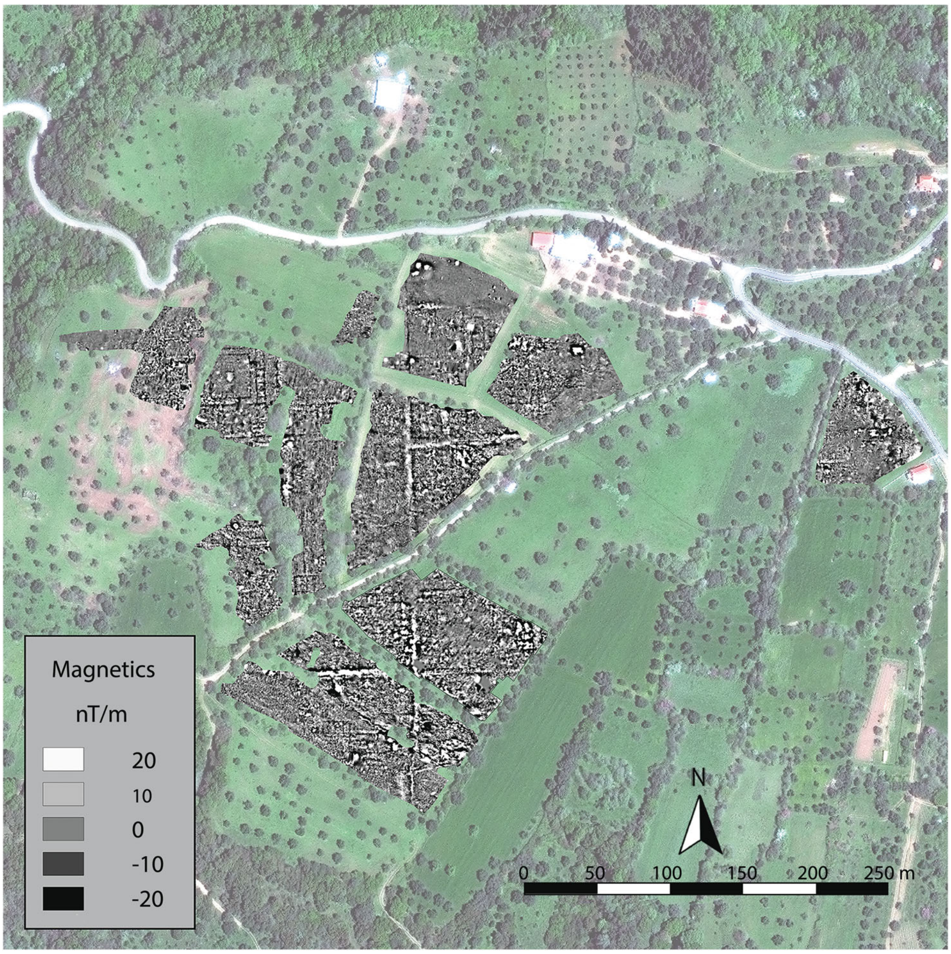

Figure 7. Heraia. Magnetics.

that have collapsed from the superstructure. Conversely, the south-central region seems relatively open, and the sharp division between the two zones is unmistakable. It is difficult to say whether this region of the city was always free of architecture or whether the open space was intentional and used for a specific purpose, like an agora. Halos' eastern region is even more densely packed with structures. Here again there are substantial contrasts between magnetic values coming from buried features in a crowded landscape of square and rectilinear structures.

Following these initial results, GPR mapped a rich collection of near-surface walls and buildings, providing a very detailed record of the architecture at the city (FIGURE 12). Multi-roomed buildings with rectilinear walls are everywhere except along the eastern periphery. Structures are oriented slightly west of north apart from a large building with a diagonal northwest-southeast alignment. The large structure is visible in all geophysical methods and even in satellite and airborne imagery as crop marks. The thickness of typical walls at Halos varies between 0.5–1.0 m; however, the large structure has walls or foundations of much wider dimensions between 2–4 m. Another large feature in the northwest has similar wall thickness. The large structure has three parallel walls that originate from an eastern wall and continue to the northwest. The minimum dimensions of the building are 45 m × 40 m. Besides having a divergent orientation, its walls and foundations are deeper than other architecture on site. For most structures, the strength of the GPR reflection signals from walls is intense at depths of 0.7–1.0 m below the surface. The large building has strong signals quite a bit further to depths of 1.6–1.7 m. The only other feature reaching these depths is the other large structure with thick walls at the northwest.

Pherai

Pherai was an important Thessalian city with signs of continuous occupation from the Late Neolithic period until Roman times. The site was apparently abandoned and it was not settled again until the 13th century C.E. As the later town, Velestino, covers the ancient settlement, archaeological investigations at Pherai have been limited (Doulgeri-Intzesiloglou 1994; Doulgeri-Intzesiloglou and Arachoviti 2009). Fortification walls are visible at the northwestern corner of the city on the Agios Athanasios hill and a few sections have been excavated in other regions. Elsewhere, rescue excavations have identified some ancient roads and residential structures preceding the construction of new buildings. A stoa and a Classical structure with circular form in the city's eastern region may indicate the location of the ancient agora.

Because of the older and continuous occupational history of Pherai with substantial prehistoric and Iron Age phases, a rather unexpected discovery from geophysics was the identification of town planning (FIGURE 13). Magnetics and EMI combined with satellite remote sensing to identify a group of streets with slanting orientations spaced approximately 30 m from each other. Most streets terminate at a northern anomaly whose full extent could not be mapped because of a ravine. This feature is either a bisecting street or the remains of the northern fortification walls. Defensive walls are not

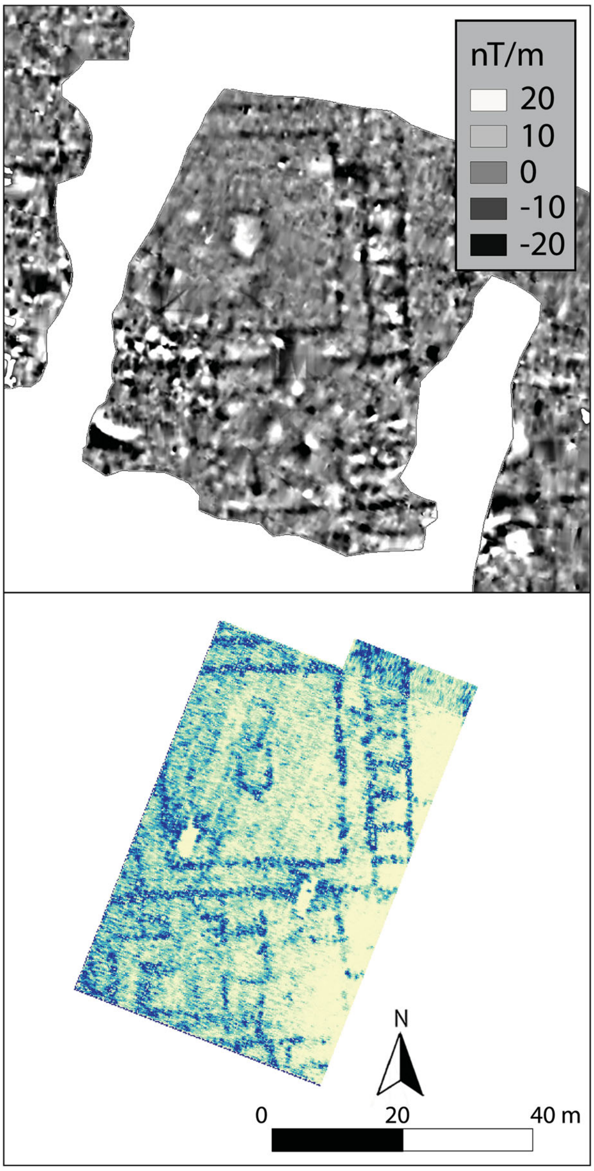

Figure 8. Heraia. Large courtyard building: magnetics (top), GPR single channel 250 MHz antenna (depth slice: 0.90–1.00 m) (bottom).

evident here on the surface, but sections are visible a few hundred meters towards the west on the Agios Athanasios hill along the same ravine. Furthermore, the convergence of two groupings of diagonal streets towards a common location at the north suggests the presence of an access point nearby, such as a city gate. The streets' southern extensions end at a bisecting road mapped only at the southwestern corner of the survey zone. Many features were also mapped as clusters of subsurface material between the roads. These are likely the remains of (residential?) buildings like those found by excavations at the southeastern corner of the plateau (Doulgeri-Intzesiloglou 1994). The data from magnetics and EMI enable the partial reconstruction of these buildings, but not in a detailed and consistent manner.

Discussion

Settlement Size

Geophysical prospection has an advantage in defining urban margins and settlement size based upon the detection of near-surface anthropogenic features. Broad spatial coverage maximizes the chances of identifying subsurface elements that are informative, especially when there is little or no prior evidence. This method proved beneficial at several case-studies where the urban scope was vague prior to surveying. In these instances, one must determine what evidence from geophysics can define urban margins and what can elucidate the urban dimensions. Since many ancient Greek cities were protected by a defensive wall (Hansen 2006a), one solution is to find direct evidence for fortifications. However, in the absence of such findings, geophysics can clarify the size of settlements by identifying zones with (organized) streets and by monitoring changes in the density of architecture. The street system at Elis provides the best indication to date for the total size of the city, which extends a minimum distance of 800 m south and 600 m west of the agora (FIGURE 14). The full dimensions are still unclear because other regions require additional investigations. An approximation of the urban extent from geophysics indicates that Elis was vast at some point, as much or even more than 150 ha in size judging from the location of streets and certain topographical landmarks (e.g., river, acropolis). The street system at Heraia was equally useful in determining the approximate size of the urban environment. Accounting for the presumed extension of streets between fields surveyed and the wide distribution of buried architecture, geophysics has conservatively verified around 12 ha of the urban environment. Yet the size of Heraia is certainly much larger (over 70 ha) considering the dimensions of the plateau around the survey zone, the position of the Alpheus River bordering the southern edge of the city, and the distribution of surface finds noted by 19th century travelers.

The distinction between densely constructed zones and zones free of architecture was more revealing than streets at Halos in determining the size of the settlement. Here, there is a clear line of demarcation at the city's western and eastern ends, which also corresponds to zones of elevated soil conductivity. The geological evidence from coring, showing that Halos was a coastal ridge largely surrounded by brackish seawater in classical antiquity, finds support from geophysics. The southern half of the site was not accessible for surveying, but the size of Halos should be approximately 10 ha based on the general dimensions of Magoula Plataniotiki. This is a fraction of the estimated urban zones of Elis and Heraia.

The urban proportions of the other examples are better defined from sections of fortification walls visible above ground. Mantinea is an exceptional example of a Greek city with walls preserved almost in their entirety surrounding an urban area of 119 ha. At Pherai and Demetrias, geophysics contributed to a better understanding of the extent of intramural urban space. The street system at Pherai offers good evidence for the northern continuation of the urban zone, while the arrangement of the central group of streets indicates the probable presence of fortification walls and even an access point along the northern ridge. The exact size of Pherai remains elusive due to the inaccessibility of much of the site beneath the modern town. Estimates have been postulated to range from 80–120 ha (Hansen and Nielsen 2003: 705), but in the future, a better understanding will probably hinge upon a combination of non-invasive methods and targeted excavations. At Demetrias, the size of the city was already well-documented prior to geophysics from an extensive fortification system (one of the largest in Greece) still visible above ground. The proportions and extent of the urban grid within the walls remain in question. The northern extension was

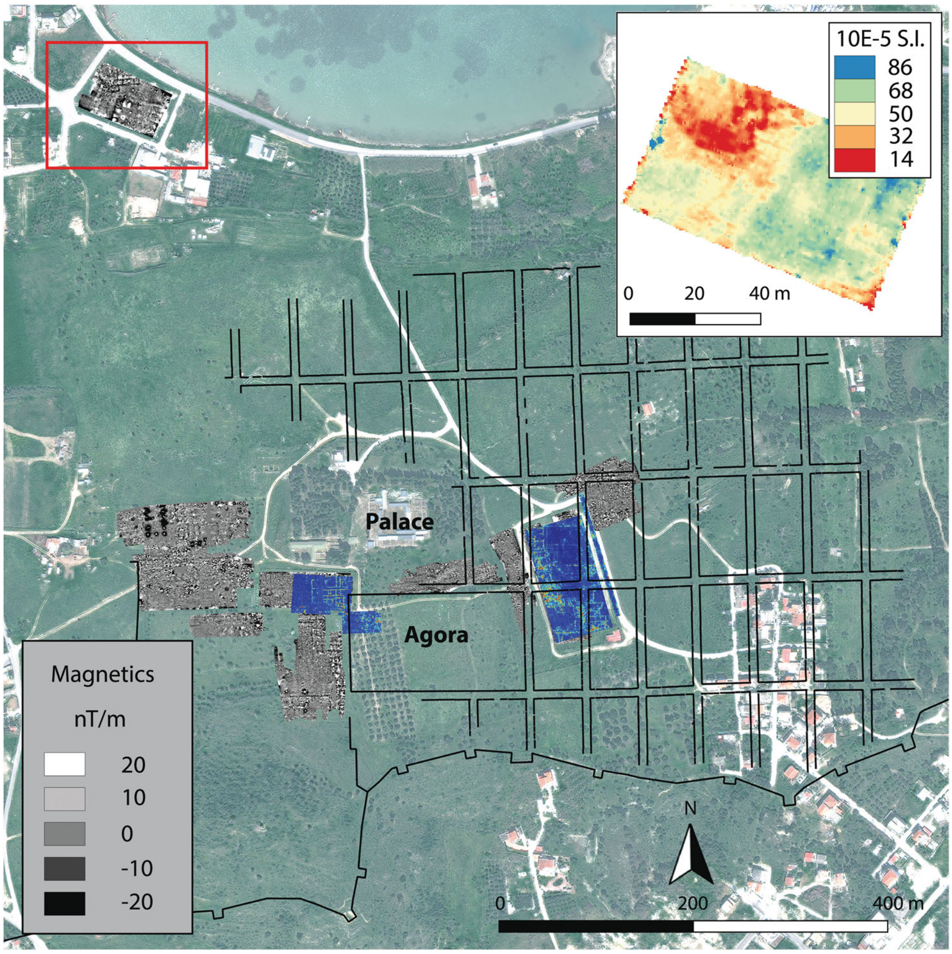

Figure 9. Demetrias. Magnetics and GPR single channel 250 MHz antenna along with the previous reconstruction of the street system and fortification walls. Inset: EMI magnetic susceptibility showing a semicircular structure.

confirmed by the discovery of the monumental building aligned with the street system. Yet a more expansive application of geophysics will be needed to address these issues in the future.

Organization and Town-Planning

The identification or confirmation of town planning was a significant discovery that highlights the wider adoption of rational urban forms on the Greek mainland, where, up to the present, examples are rather thin in the archaeological record. Additionally, the extensive mapping of some sites—Mantinea in particular—provides unique insights into the broader spatial organization of planned Greek cities, leading to a more comprehensive awareness of structured urban contexts. Town planning and the rational organization of space and mobility are defining elements of Greek urban culture (Hoepfner and Schwandner 1994; Cahill 2002). The earliest examples mainly come from Greek colonies in South Italy and Sicily of the seventh and sixth centuries B.C.E. (De Angelis 2003; Mertens 2006), although early experiments have been noted in other corners of the Mediterranean (Boyd and Jameson 1981; Melander 1988). The phenomenon of town planning took longer to develop elsewhere, including the Greek mainland, in part because of a more conservative process of urban aggregation and adjustment. The new evidence from large-scale geophysical surveys should begin to recalibrate perceptions and processes of town planning in the region.

Rather than from colonization, a key factor in the creation of rational urban forms on the Greek mainland was the establishment of new cities following a synoecism of surrounding communities. New urban foundations required new urban landscapes to accommodate their citizens. Demetrias was established in 294 B.C.E. and the layout of streets, the palace, and other public and private venues soon followed. The foundation of Mantinea precedes the middle of the fifth century B.C.E., but whether the orthogonal street system dates to the earliest phase of the city or whether it was implemented afterwards can only be answered by future ground truthing. The evidence from Elis is more secure, as excavations of road surfaces south of the agora confirm a fifth century B.C.E. chronology for the town plan that is contemporary with the 471 B.C.E. foundation date mentioned by historical sources (Roy 2002). The origins and reasons for town planning at Heraia and Pherai are still obscure. Heraia began minting coins in the sixth century B.C.E., but whether there was already human occupation at the site or whether it was a new foundation around this period is unknown. Pherai was certainly not a new city, since there are signs of continuous occupation from prehistory until the early Roman period in the archaeological record. The street system identified at the northern edge of the city was implemented within a preexisting built environment. The discovery of buildings and roads in the lower town with the same diagonal alignments would suggest that the town planning system extended to other regions of the city.

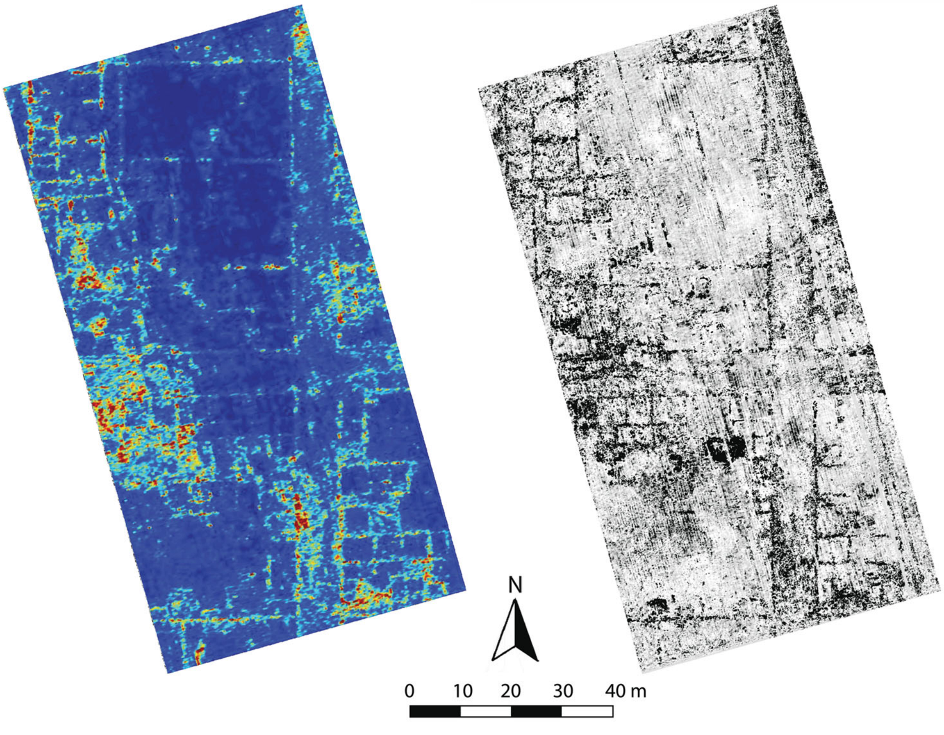

Figure 10. Demetrias. Housing blocks east of the agora: GPR single channel 250 MHz antenna (depth slice: 0.70–80 m) (left), GPR eight-channel 400 MHz antennas (depth slice: 0.47 m) (right).

Urban Density

Reconstructions of ancient Greek cities are often illustrated as continuously inhabited zones with dense clusters of housing blocks and public architecture framed by a structured communication network of streets (Hoepfner and Schwandner 1994; Hoepfner 1999). It is worth underscoring that such representations, while not entirely inaccurate, are often based on limited site explorations. Because of the potential for total or near-total site analysis, geophysics can be useful in gauging gradations of urban density in ways that surpass conventional methodologies. Its wider application could fundamentally redefine perceptions of the spatial assemblages of ancient Greek cities.

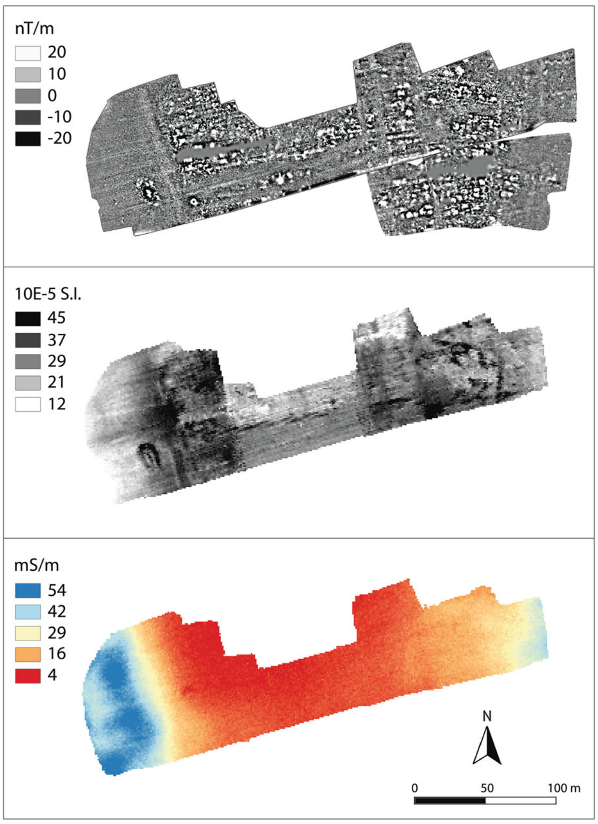

Figure 11. Halos: magnetics (top), EMI magnetic susceptibility (middle), EMI soil conductivity (bottom).

During fieldwork, it became clear that the density of urban constructions and the ubiquity of urban city blocks are variable elements with temporal distinctions among other factors. Town planning initiatives do not appear to inevitably lead to densely structured urban environments, even after many centuries of settlement occupation or whether this was the intention of the original town planners. Mantinea underscores this concept quite well. What surveying did not find was often just as helpful as what it found. The absence of traceable architecture in many regions of the city suggests that sizeable zones were left unbuilt even though they are inside an organized street system. At Elis, architecture was noted along the north-south road in the southern region of the city, but the density of architecture elsewhere in the same zone was limited. Empty space within the city was not restricted to large settlements, as the evidence from Halos demonstrates. Open space in the south-central region of the survey zone contrasts with the very dense elaboration of the built environment elsewhere. Halos serves as an interesting case study on the degrees of urban density present within a small and compact settlement. While not conclusive in the absence of ground truthing, the evidence from Mantinea, Elis, and Halos raises questions on the nature of urban land use, which may have included activities suited to open space (e.g., cultivation and animal husbandry), or which may be simply a sign of stationary urban growth, either intentional

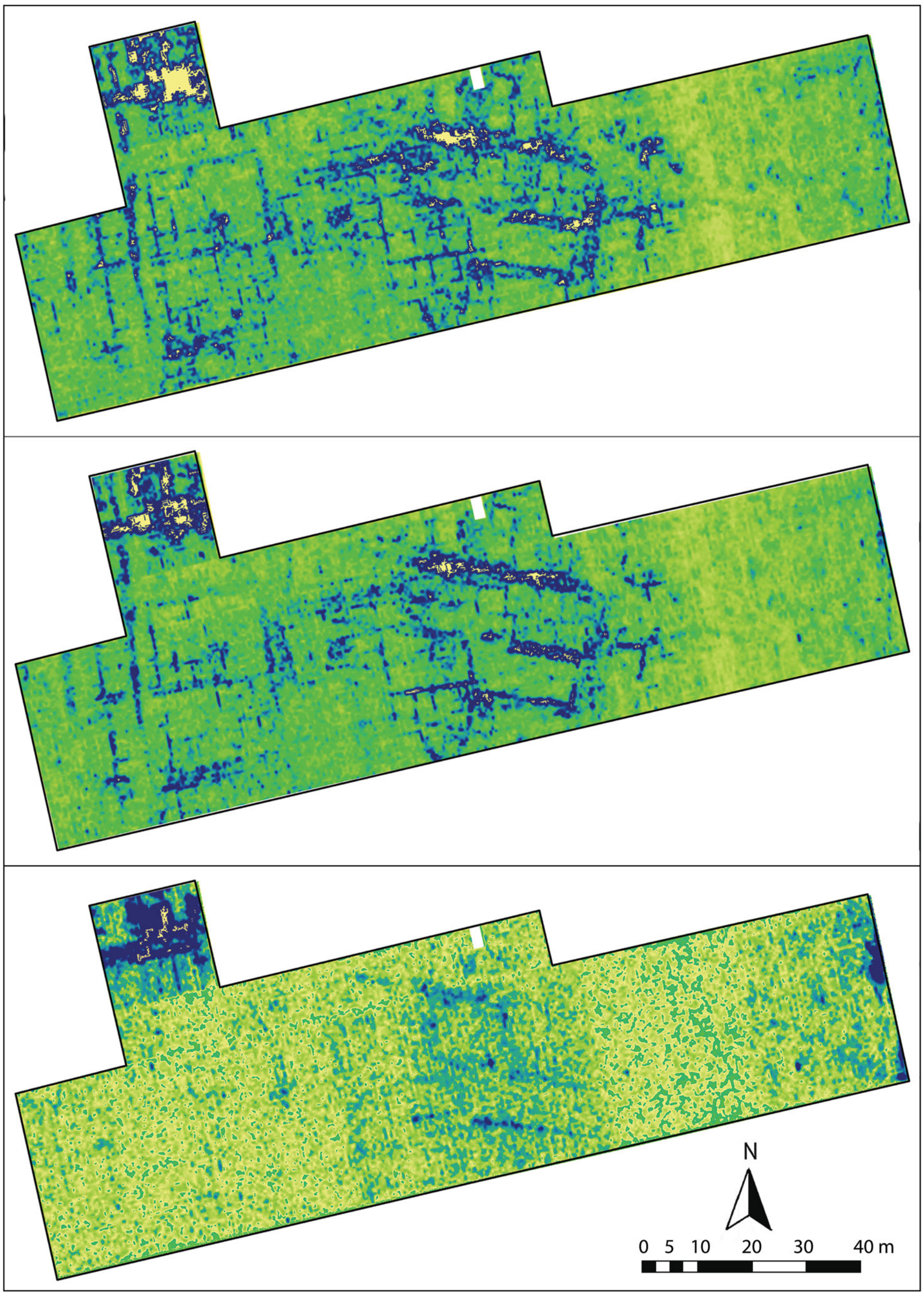

Figure 12. Halos. GPR single channel 250 MHz antenna. Depth slices: 0.70–80 m (top), 0.90–1.00 m (middle), 1.60–1.70 m (bottom).

or unintentional. These are important facets of Greek urbanism that cannot be fully appreciated without an expansive overview of the material culture of the subsurface. The data leads to other interpretations of urban space distinct from one continuous architectural ensemble.

Undeveloped land and open space within cities, especially large ones like Mantinea and Elis, were perhaps common in classical antiquity (Hansen 2006b). The ancient geographer Strabo in *Geography* 8.8.1 reports a joke by a 4th century B.C.E. comic playwright that describes Megalopolis, a city near Mantinea, as a "great desert." The anecdote was based on contemporary impressions of the city as being empty. This is peculiar since Megalopolis was a new city established in the 4th century B.C.E. However, the immense size of the city, as indicated by ancient sources, was probably a factor that constrained development or at least gave this impression. Modern historians believe that the foundation of Megalopolis was intended to achieve a greater population than it ended up having (Roy 2007). It was an optimistic endeavor and large expanses of space remained empty. Regrettably, excavations have only explored a concentrated area of the city (Gardner et al. 1892; Lauter 2005), and, lacking any coverage from non-invasive methodologies, one cannot know the wider spatial assemblage of the city or the extent and framework of its urban density and emptiness.

Modes of Movement

A broad overview of street plans and architectural ensembles reveals intra-urban and extra-urban communication networks. Built features within the city structure urban life by giving spatial definition that directly impacts human activity and mobility. In planned settlements, the location of city gates, organized street plans, city blocks, uniform housing units, and carefully integrated public venues have obvious ramifications on modes of movement and interaction. The

Figure 13. Pherai. Magnetics. Linear anomalies from vegetation stress in the accompanying satellite image confirm the extension of streets identified from geophysics.

use of a parallel system of slanting streets at Pherai to funnel traffic out of the city and the controlled composition of rectilinear city-blocks at Demetrias, defining a coordinated public and private architectural landscape, demonstrate these ramifications well. Still more revealing is the remarkable evidence from Mantinea (FIGURE 15). Here, city blocks of different dimensions and irregularities in the positioning of roads indicate a multifaceted system of town planning. From present evidence, it appears that the street system was influenced by the distribution of city gates and modes of communication between these external access points and internal urban venues. A key concern was the facilitation of movement from the outside towards the agora. Seven of ten gates at Mantinea lead directly to the agora at the heart of the city. The importance of channeling traffic to the center is emphasized by the shift in the arrangement of north-south streets in the city's central region. The northern gates are not in exact alignment with the southern gates, and this circumstance may have necessitated adjustments in the positioning of streets for proper communication to the agora. Although the evidence is not as clear, the same could be said for the western gate and the now destroyed eastern gate, where there are similar adjustments in the positioning of streets. An analogy for this kind of juxtaposition of orthogonal streets was also noted at Elis, where east-west streets were intentionally offset from one another. The precise reasons for this remain uncertain, but urban access points and intra-urban communication networks were likely a factor.

If Mantinea draws one closer to understanding how ancient Greek town planning facilitated modes of movement within the city, Halos offers a counterpoint where movement is more restricted within a smaller habitable environment. Dense clusters of architectural features at the east and northwest stand out against the lack of major street systems in the geophysical data. Small alleys and pathways between structures probably served as the main channels of movement at least in the northern region of Magoula Plataniotiki. It is useful to contrast this urban arrangement with the systematic organization of New Halos in the Hellenistic period. The new town was adopted from a former Macedonian military camp, and, as such, it had a strict rectilinear plan with a regular arrangement of streets, city blocks, and housing units.

Modifications

The structure of the city is in a constant state of fluctuation and modification based on a diverse range of temporal, sociopolitical, and environmental circumstances. Town plans can be changed, a city might be destroyed and rebuilt, city walls expand and contract, economic booms and busts cycle through, population levels vary, and urban venues expand or fall into disuse. Even rational town planning is not a static urban phenomenon and can itself be transformed along with the individual component parts that comprise a city's built environment. Because the results of geophysics expose a palimpsest dominated by

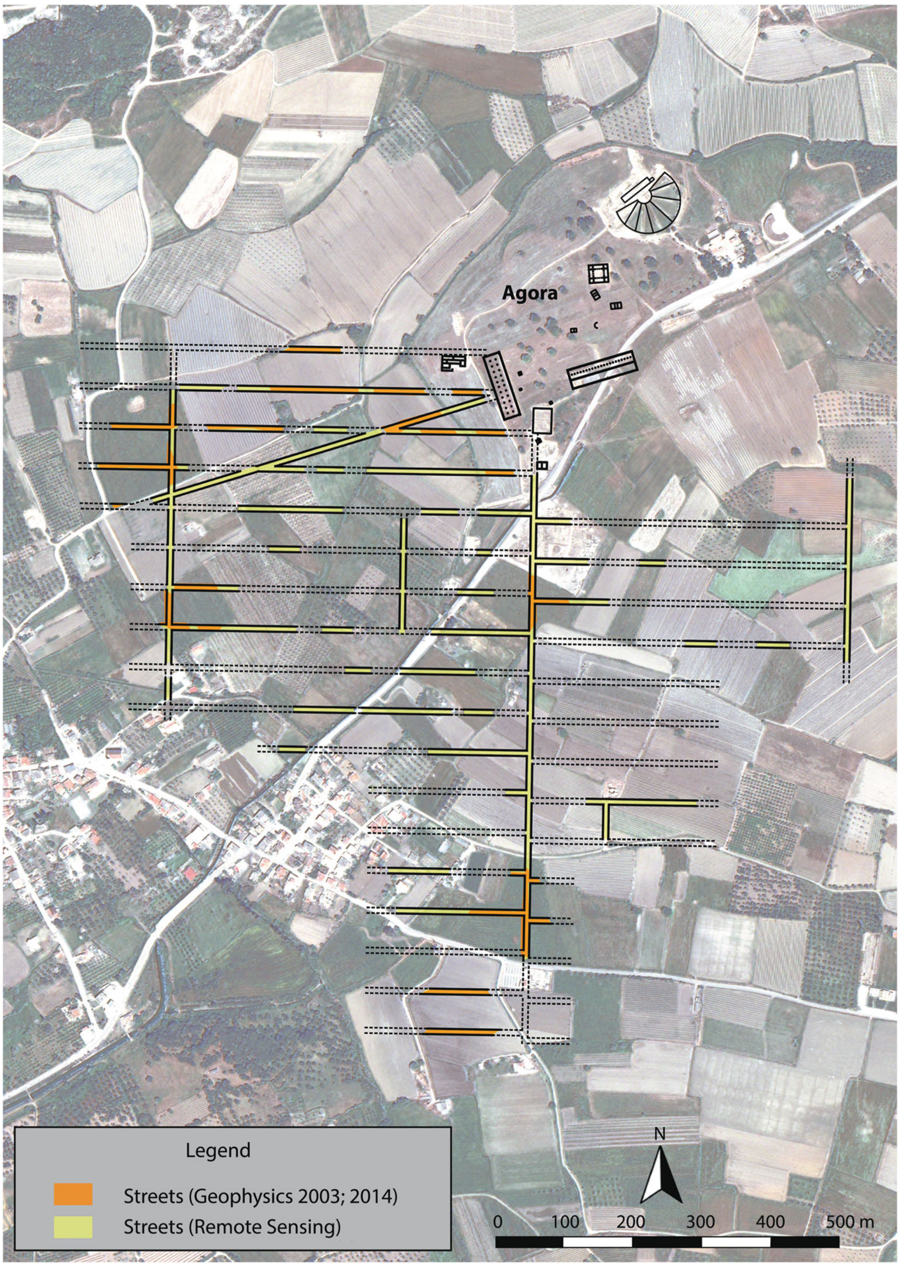

Figure 14. Elis. A partial reconstruction of the orthogonal street system based on the results from geophysics and satellite and aerial remote sensing.

the latest phase of occupation, it can be challenging to distinguish between layers of habitation and to assess the diachronic use of urban space. This can be partly alleviated by monitoring the depth horizons and responses (e.g., magnetic susceptibility) of anthropogenic features and noting their spatial correlations to one another. At Mantinea, for example, GPR mapped several structures along a north-south street in a region southwest of the agora. One building has a room or courtyard with four columns along the street and several adjacent smaller rooms in the back. A multi-roomed structure further south may be an associated or separate structure. The strength of the reflectors from walls in the GPR data is most intense at depths of 0.6–0.7 m. Immediately behind and below these buildings to the west are the remains of an east-west street with strong reflectors at depths of 0.9–1.0 m. A comparison of the different depth horizons of these features indicates that some walls were built over the road and intruded upon its original path. In an example at Elis, a rectilinear structure with internal divisions from the magnetics survey is in the same location as an east-west road. However, in the absence of depth horizons, one cannot be certain that the building lies on top of the road, even though this would seem to be the most likely scenario.

More widespread signs of urban modifications were noted at Halos. In considering the evidence, differences in building orientations, wall thicknesses, and depths of construction favor identifying a minimum of two major phases. The large building appears to have wiped away previous architecture at its location. Walls from other buildings to the west abruptly stop at the large building, and, based on this evidence, the structure is likely a later addition. An earlier phase includes the rectilinear yet smaller structures of the main part of the settlement, and the secondary phase is noted by the large building; the other large construction may be from either phase. Considering the history of the settlement, its destruction and abandonment in the 4th century B.C.E., and apparent reoccupation after New Halos was itself abandoned in the 3rd century B.C.E., a tentative suggestion places the earlier phase in the 4th century B.C.E. or earlier

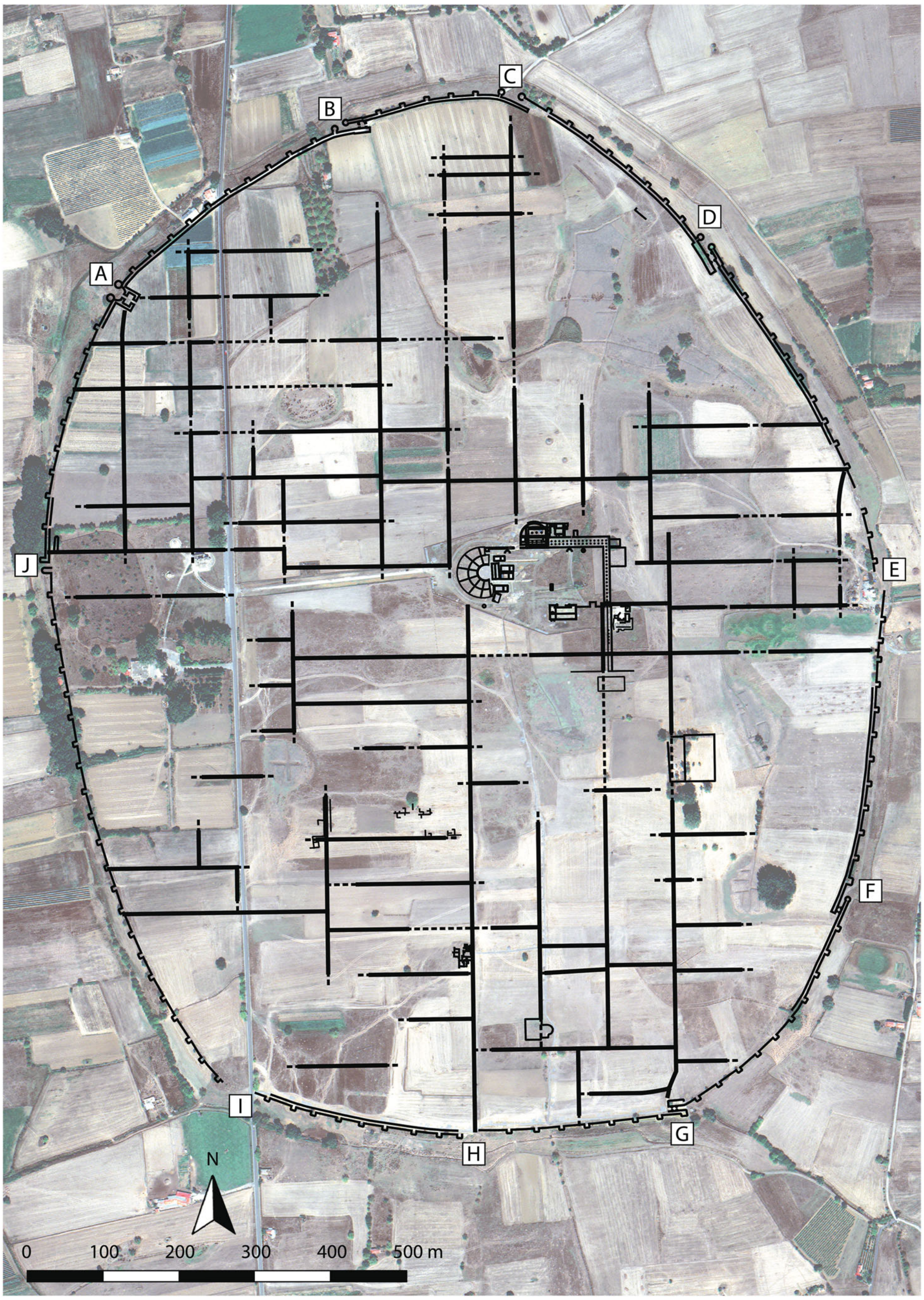

Figure 15. Mantinea. A partial reconstruction of the orthogonal street system. Solid black lines indicate evidence from geophysics and satellite remote sensing. Dotted black lines indicate hypothetical extensions of the streets.

and the secondary phase after the abandonment of New Halos.

Conclusions

Geophysics can successfully be used as a methodological tool for conducting regional archaeological surveys. The high density of data, the rapid execution in the field if push- and towed-systems integrated with GPS are available, and the ability to map multiple physical properties are significant advantages to understanding the wider spatial assemblages of archaeological contexts and their correlations and variations. The extensive surveying at ancient cities in Greece reveals urban morphologies on a unique scale. It also exposes the inherent contrasts in built environments, which could be contingent upon social, cultural, and political dynamics of local and regional proportions. The 31 ha scanned to date at Mantinea exposes a large portion of the city, but most interpretations of ancient Greek cities rely on a much smaller sampling of the subsurface. A limited scale of site exploration severely impedes a wide-ranging awareness of urban life and its surroundings. One wonders whether the conception of town planning in the ancient Greek world and human interaction with the city is only partly true, while a fuller examination would expose irregularities and complexities. The combination of bridging macro-scale and micro-scale perspectives of the subsurface is an asset that should be exploited in archaeological research, more so than at present. As this paper demonstrates, archaeological geophysics can be used effectively and efficiently in regional surveys as the primary method of data acquisition. An ideal approach combines geophysics with other comprehensive non-invasive remote sensing methodologies, particularly satellite or airborne image processing, aerial laser scanning, and photogrammetry. In the approach undertaken here, satellite remote sensing was a critical first step towards identifying organized street systems, and, in fact, it directed the survey team to target case studies with geophysics. If resources are available, pedestrian surveying, environmental coring, and targeted excavations can complete the total interpretation by offering contextual material with distinct diachronic horizons.

Acknowledgments

Fieldwork was supported by the ARISTEIA II Action of the Ministry of Education and Religious Affairs under the "Ancient City project" (Code: 2013SE01380048), co-financed by Greece and the European Union (European Social Fund) as a part of the NSRF 2007–2013 and the operational program "Education and Lifelong Learning"; KRIPIS Action of the General Secretariat for Research and Technology, Ministry of Education, Greece and the European Regional Development Fund (Sectoral Operational Program: Competitiveness and Entrepreneurship, NSRF 2007–2013)/European Commission under the "POLITEIA project" (Code: 2013SE01380035). Research for publication was supported by the National Endowment of the Humanities through a Summer Stipend and American School of Classical Studies fellowship awarded to Jamieson C. Donati. Financial support for the open-access publication fees of this article was generously provided by the Alexander S. Onassis Public Benefit Foundation.

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