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ARCHAEOLOGY IN GREECE 2015–2016

Geophysical survey in Greece: recent developments, discoveries and future prospects

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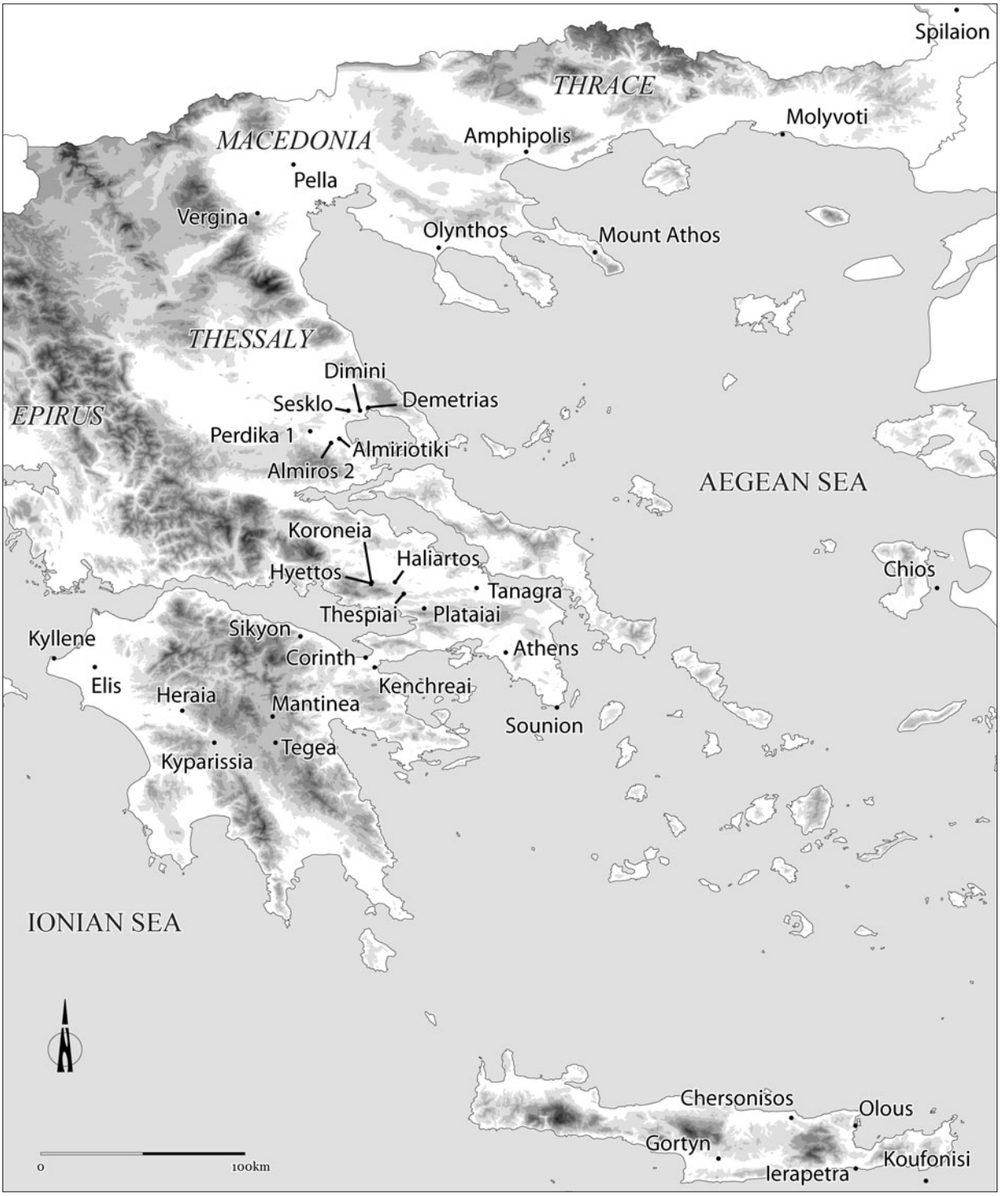
Introduction

Geophysics has emerged as a significant and primary tool of archaeological research in Greece. It is no longer marginalized to a supporting role for excavations and pedestrian surveying, but has developed into a fundamental method of investigating layers of cultural heritage in its own right. This can be explained varyingly, from the increasingly holistic nature of archaeological fieldwork, to a broader appreciation of the diverse applications of geophysics to characterize historical contexts, the unique range of site assessment offered by geophysics and the capacity of geophysics to explore the subsurface in challenging conditions. Technology too plays a vital role. New generations of equipment have the ability to map archaeological features in high resolution, in rapid sequence and oftentimes in 3D. Geophysics along with other non-invasive methods, like satellite and airborne remote sensing, has also gained wider traction because of concerns about the costs, impacts and time horizons of traditional fieldwork practices. This brief report highlights some of the recent developments and applications of geophysical survey in Greece. It is not meant to be an inclusive account or an evaluation of each geophysical technique; instead, it emphasizes current trends in this important and expanding field of research and touches upon its future prospects in the country.

Much has changed in archaeological geophysics since the 2000 review published by Apostolos Sarris and Richard Jones in the *Journal of Mediterranean Archaeology*: 'Geophysical and related techniques applied to archaeological survey in the Mediterranean: a review' (Sarris and Jones 2000). The report was the first extensive assessment of the state of the field in Greece, and only a handful of commentaries of smaller scope have appeared in the meantime (Papadopoulos *et al.* 2014). One of the biggest transformations in archaeological geophysics has been a movement away from limited single-site oriented studies, even if this still continues, towards more extensive surveys of multi-site and regional proportions. Geophysics has particular advantages for characterizing the spatial attributes of large and diachronically diverse contexts, providing a range and level of detail otherwise unavailable with conventional methods. It is not surprising then that urban archaeology has been a principal area of research for geophysical surveying in Greece. Another development has been the wider adoption of a manifold or integrated approach to surveying. The most widely used techniques today include, in no particular order, magnetic gradiometry, electrical ground resistance, ground-penetrating radar (GPR), electromagnetic induction (EMI) and electrical resistivity tomography (ERT). Rather than rely on one technique, integrated geophysics assimilates several techniques together to enhance the archaeological interpretation (Drahor 2006; Keay *et al.* 2009). Since each method collects information about a different physical property, a manifold approach usually provides more detailed information about the nature of subsurface material. A final trend noted here is the introduction of rapid data-acquisition approaches. New generation multi-sensor systems connected to GPS positioning equipment can cover several hectares of surface area per day if ground conditions permit. The relative speed of data acquisition has a substantial impact on the dimensions of archaeological investigations, because a wider corpus of data can be gathered in a shorter amount of time. A positive outcome of this condition is that geophysics can be used for conducting large-scale archaeological surveys, either independently or in tandem with other methodologies.

doi:10.1017/S0570608416000065 Archaeological Reports 62 (2015–2016) 63–76

https://doi.org/10.1017/S0570608416000065 Published online by Cambridge University Press



Map 4. Locations of sites mentioned in the text. © BSA.

Ancient urban studies

In recent years, geophysics has played a prominent role in documenting the spatial parameters of ancient settlements and cities in Greece, which on account of their large size are often challenging to investigate with conventional archaeological methods. The results have been effective in highlighting major urban features, such as streets, venues and building plans, but also broad characteristics of settlement size, density

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and organization. The emphasis on extensive surveys at single sites or multiple sites within a regional framework is a welcome trend in the field, making it now possible to appreciate the evolution and morphological attributes of human settlements on a greater scale. The *Ancient Cities of Boeotia Project* is a pioneer in the application of geophysics as a method for conducting regional surveys of ancient urban sites. For more than a decade, the project has used a multitude of geophysical techniques to survey large areas at Haliartos (**ID2065**), Hyettos (**ID2631**, **ID2064**), Koroneia (**ID166**, **ID2063**, **ID2008**, **ID2630**, **ID4228**), Tanagra (**ID2632**, **ID164**, **ID799**) and Thespiai (**ID2066**, **ID802**, **ID165**). The magnetics survey at **Tanagra** stands out because the extent of explorations (+40ha) has revealed much of the city plan in good detail (Bintliff *et al.* 2013). The city was planned according to a regular arrangement of streets and city-blocks (**Fig. 66**). Interestingly, the town plan extends beyond the Late Roman fortification walls, and there is indication that the street grid may even go beyond the presumed line of the classical walls. Modifications in the alignments and internal arrangements of buildings and venues at Tanagra point to diachronic layers of habitation. One structure that appears to be a church was inserted at a later time into the open area of the agora.



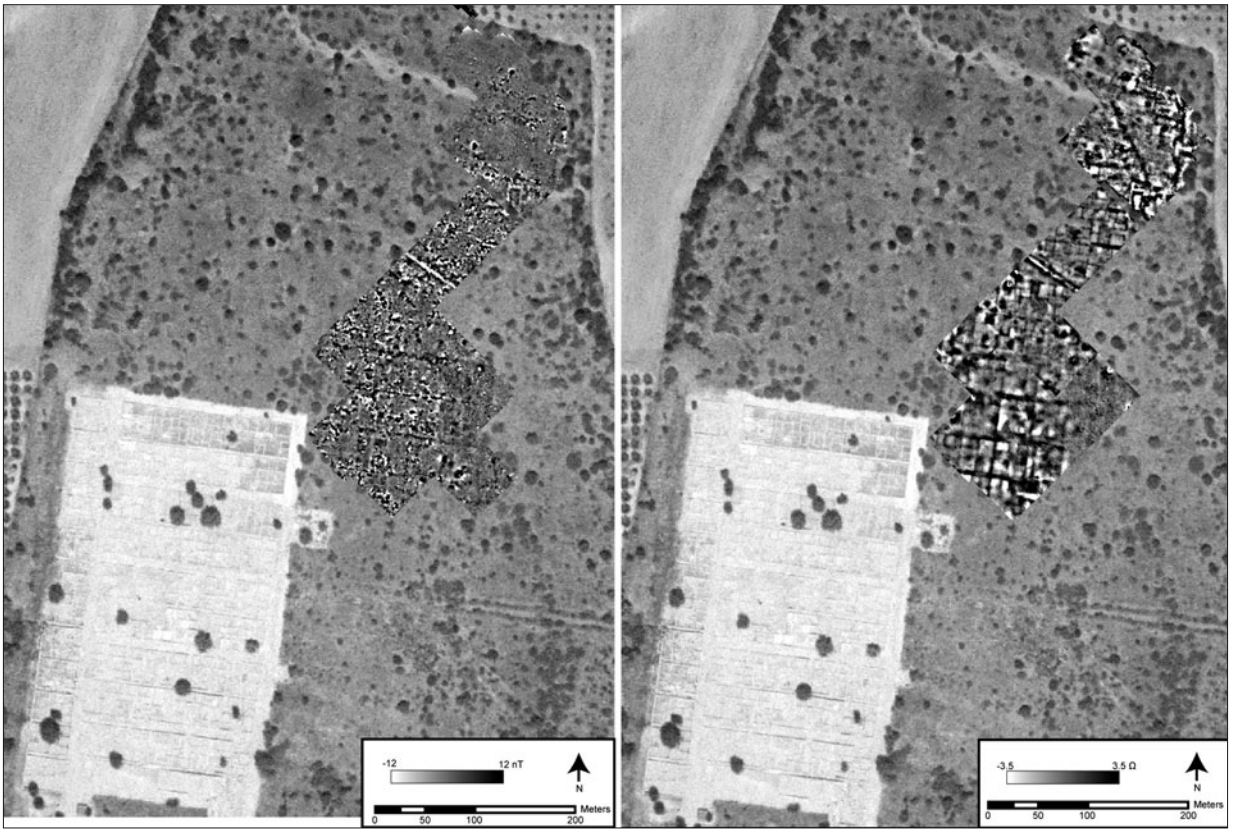
66. Tanagra: results of the magnetics survey. The city walls (black line) are Late Roman. © Ancient Cities of Boeotia Project, B. Slapšak, B. Mušič, R. Plesničar and J. Bintliff.

Other large-scale surveys at Sikyon (**ID107**, **ID289**, **ID1422**) (*ca*. 40ha) and Plataiai (**ID3030**) (27ha) further showcase the advantages of geophysics to map big urban contexts and their built environments. Fieldwork at **Sikyon** using magnetics has mapped a considerable portion of the Hellenistic city (Lolos and Gourley 2012). Despite the site's uneven topography, streets are strictly organized along the cardinal points in the lower plateau and in some cases even extend without interruption to the steeper upper plateau. City-blocks take the form of squares with variable dimensions of 60–65m per side, and there is evidence that some are bisected by smaller streets or alleyways and have regular housing units. The agora at Sikyon and its boundaries are carefully inserted within the Hellenistic urban grid. An integrated geophysical approach using magnetics, electrical ground resistance and GPR helped identify several new architectural features in the agora to complete the picture gained by Anastasios Orlandos' excavations early in the 20th century (Lolos and Sarris 2011). A small temple surrounded by a π-shaped stoa was found immediately north of the palaestra, and a basilica whose orientation deviates from the urban grid was identified in the agora's central region southeast of the Temple of Apollo. At **Plataiai**, electrical ground resistance and magnetics have delivered a remarkable representation of the internal plan of the Hellenistic city after its refoundation in the decade after 338 BC (Konecny *et al.* 2012). Foremost of the results was the identification of an extensive network of organized streets and rectangular city-blocks spanning the upper plateau ('acropolis') and the town's lower valley. The geophysical data from Plataiai present some of the most comprehensive evidence to date concerning the configuration and metrology of a planned ancient Greek settlement in Greece. Streets do not follow the cardinal points but instead have alignments that slant 9.1° to the east. Divergences in street alignments have been noted, and in certain cases streets deviate a few metres before returning to their normal projections. Rather than measurement errors, these variances are attributed to efforts by the town planners to lay out the urban grid within an uneven terrain. Fluctuations in street widths (4.2–6.7m) and the dimensions of city-blocks (widths: 36.3–48.5m; lengths: 96.5–99.1m)

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illustrate irregularities in the application of the town plan. The system at Plataiai is noticeably distinct from a strict 'Hippodamian' grid plan. In fact, the evidence from other geophysical surveys (for example Tanagra, Elis and Mantinea; see below for the latter two examples) suggests that irregularities in the placement and metrology of streets and city-blocks are common in planned Greek settlements. They likely represent the variable nature of town planning in classical antiquity. A probable location for the agora was mapped north of the Temple of Hera as a large open area flanked on at least three sides by structures. The form of the eastern structure, *ca*. 11m wide and 160m long with an internal line of column bases, is almost certainly a stoa. Another line of column bases within the southern structure might indicate the location of a second stoa, although the properties of this building are not as clear in the data.

Several geophysical surveys inaugurated in the past few years at urban sites are ongoing, and they are expected to provide substantial evidence on the same scale as the examples above. A new multidisciplinary programme of fieldwork at **Olynthos** (**ID4883**, **ID5566**; http://sites.lsa.umich.edu/olynthos-project/) includes the application of geophysics in order to understand the wider dimensions and internal makeup of the classical city plan beyond what was revealed by David Moore Robinson's excavations in the early 20th century. So far the results have been promising. Magnetics and electrical ground resistance have mapped an extension of the classical urban grid to the northeast of the excavated zone and have found sections of the eastern fortification walls (**Fig. 67**). At **Molyvoti** (**ID4213**, **ID5057**, **ID5452**), satellite remote sensing and geophysics using electrical ground resistance have been used to identify a regular street system organized on a diagonal axis along the eastern side of the city (Arrington *et al.* 2016). The dimensions of the urban grid, where measurements are possible, are 37m × 74m and road widths are approximately 6m. Inside one insula, the survey mapped a regular division of eight building units that measure 18.5m per side; partial excavations indicate that these are likely domestic residences. Therefore, the total ground area of houses in the surveyed region of the city is *ca.* 342m^2 per unit. The preliminary



67. Olynthos: magnetometer survey, after interpolation (left); earth resistance survey (0.5m twin probe) (right), after applying a High Pass filter and interpolation. © Horsley Archaeological Prospection and the Olynthos Project.

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results from Molyvoti shed important new insights on systems of ancient town planning and processes of urban life in Thrace, a region largely ignored in discussions on Mediterranean urbanism. Another project at **Sikyon** (diathens.gr/en/aktiviteter/enaktivitetersikyon) is unique in that wide-scale geophysics are being used along with pedestrian surveying and excavations to locate the still undiscovered Classical city in the plain below the Hellenistic plateau. It is an ambitious undertaking that emphasizes the exploratory capacity of geophysics. Fieldwork to date has identified several subsurface features from buildings and possibly streets below the eastern ravine of the Hellenistic plateau.

A regional approach to ancient urban studies using integrated geophysics in combination with satellite and airborne remote sensing has been adopted by the *Politeia Project* (http://politeia.ims.forth.gr/) and the *Ancient City Project* (http://ancientcity.ims.forth.gr/). These initiatives, along with the *IGEAN Project* (see below), are the first in Greece to use multi-sensor push-systems that communicate with a base station GPS for the rapid assessment of archaeological sites (**Fig. 68**). Such an approach is distinct from conventional geophysical surveys that use survey grids, requiring additional personnel and time which greatly reduces the speed and efficiency of data acquisition. Although the speed of data acquisition is not comparable to that which can be achieved in the flat cultivation planes of central Europe, the spatially extensive sampling methods and rapid execution of multi-sensor systems guide the emphasis of research towards city-scale and regional investigations. The *Politeia Project* and the *Ancient City Project* have focused on urban contexts in the Peloponnese and Thessaly, and a significant outcome has been the identification of town planning at cities where this kind of information was not previously known.



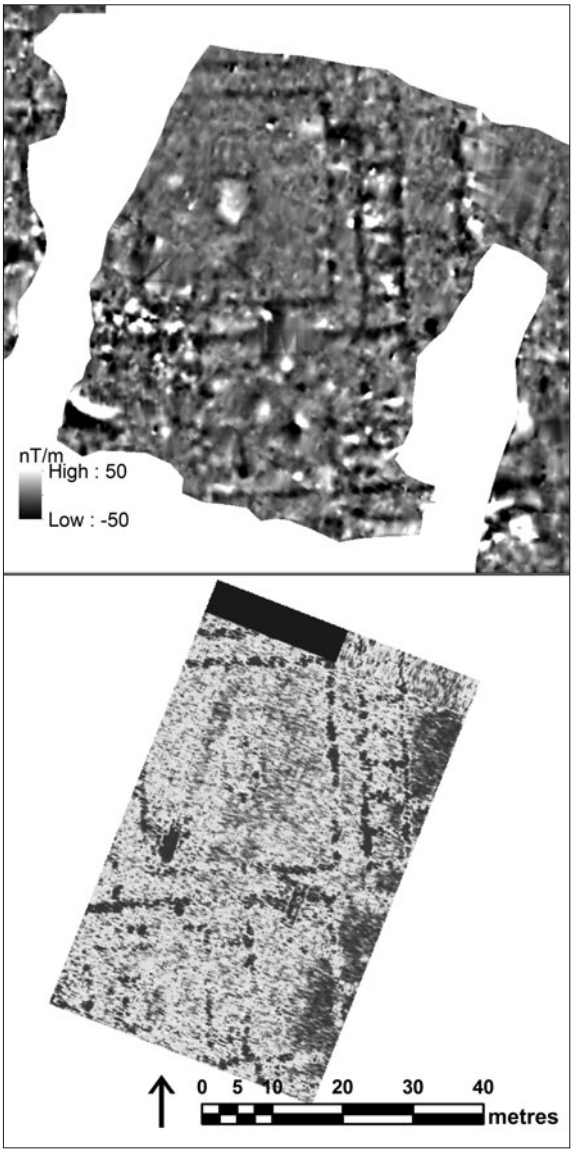
68. Mantinea: SENSYS magnetometer MX with an array of eight fluxgate gradiometers spaced 0.5m apart in use. The device is equipped with a GPS 1 JAVAD Triumph rover station that communicates with a base station in Real Time Kinematic (RTK). © Ancient City Project.



69. Mantinea: results of the magnetics survey at the southern end of the city near Gate G. © Politeia Project and Ancient City Project.

The approach outlined above has managed to provide a detailed image of an extensive urban street system at **Mantinea** that appears to date to the refoundation of the city in the fourth century BC, if not earlier (Donati and Sarris 2016). Streets are oriented along the cardinal points and define rectangular city-blocks (**Fig. 69**). There is great diversity in the metrology of city-blocks at Mantinea. While the general dimensions are approximately 60m × 90m, a ratio of 2:3 as measured from the street

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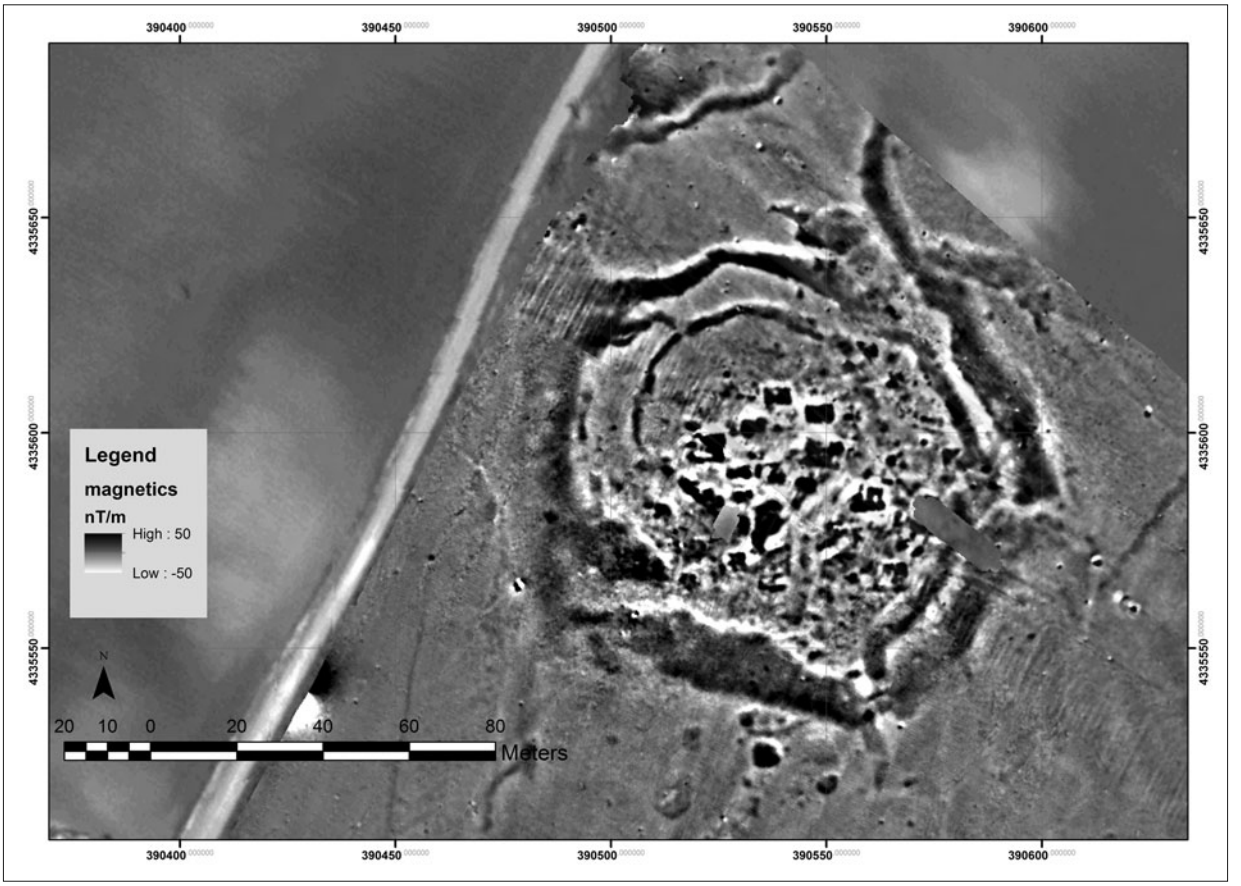


70. Heraia: results of the magnetics survey (top) and GPR survey (bottom), showing a large courtyard building. Depth slice of GPR 0.9–1m. © Ancient City Project.

centres, the widths and lengths of blocks vary greatly. Some, for example, are as short as 80m or as long as 160m. Streets do not continue uninterrupted from one side of the city to the other, but are broken up into smaller trajectories giving the urban grid a tiered or stepped arrangement. A similar urban grid has been discovered at **Elis**. Streets here are aligned to the cardinal points and form rectangular city-blocks around 58m wide as measured from the street centres. There is not enough evidence yet to gain accurate measurements of block lengths; however, there are instances where streets adopt the same tiered arrangement as at Mantinea. Excavations south of the agora at Elis date some road surfaces to the fifth century BC, which might suggest a similar chronology for the urban grid mapped by geophysics. **Heraia** has also been identified as a planned settlement with streets organized along the cardinal points and a spacing sequence of 85m for north-south streets and 54m for east-west streets. Although more of the city must be surveyed to target possible variations in the urban grid, the confirmation of Heraia as a planned settlement is significant in light of the complete lack of archaeological research before geophysical surveying. Many of the buildings at Heraia conform to the alignments of the urban grid. In one striking example, magnetics and GPR have mapped a large building almost square in shape (35m × 38m) with an internal courtyard (27m × 30m) surrounded on all four sides by what would appear to be porticos (width: 4.5m) (**Fig. 70**). A rectangular anomaly (4.5m × 6.5m) stands in the centre of the courtyard; the high magnetic values of this feature are distinct from the low magnetic values of the building's walls, and might suggest burning activity here or organic materials such as mudbrick. Abutting the eastern side of the building, there are at least seven rooms with dimensions of 5m × 6m that form a façade along a north-south street. It would be premature to determine the function of this large complex without ground truthing. Its shape and central anomaly could be correlated with one of the many sanctuaries reported by Pausanias (8.26.1–4); however, it could also be some other public complex like a palaestra or even part of an elaborate urban villa. The results from Heraia, Mantinea and other Arcadian cities where urban grids have previously been identified – for example **Tegea** (**ID120**; *AR* 53 [2006–2007]: 23–24) with geophysics and a classical town near the village of **Kyparissia** (Karapanagiotou 2005) with excavations – draw attention to Arcadia as a place where rational town planning proliferated on the Greek mainland.

The emphasis of geophysical surveys at urban sites dating primarily to classical Greek and Roman antiquity is obvious. There are fewer projects whose principal objectives centre on other periods predating or post-dating the Greek and Roman (Tsokas *et al*. 2012). A key exception is the *IGEAN Project* (http://igean.ims.forth.gr/), which has implemented a systematic and extensive programme of geophysical prospection at over 20 Neolithic settlements in and around the Almiros plain of eastern Thessaly (Simon *et*

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71. Almiros 2: results of the magnetics survey. © IGEAN Project.

al. 2015). Until now, only a limited number of these Neolithic tell and flat settlements have been extensively studied in the region. **Sesklo** (**ID1065**, **ID4032**–**ID4034**) and **Dimini** (**ID1043**, **ID1066**, **ID1989**, **ID4023**, **ID4019**, **ID4020**, **ID5094**) are the most well-known, but even these sites have only been partially exposed through archaeological excavations. The survey data from the *IGEAN Project* provide an unprecedented range and level of detail concerning the spatial organization of entire Neolithic communities. At the ***magoula*** **Almiros 2**, magnetics and EMI mapped a core habitation zone on the tell with 15–20 rectilinear structures built in a concentric circle (**Fig. 71**). Their high magnetic values indicate building materials exposed to burning, such as clay or mudbrick. Similar structures are just below the summit to the southeast. The *magoula* is surrounded by two circular enclosures: a smaller internal one about 50m in diameter and a larger exterior one about 100m in diameter. The faded signature of the exterior enclosure in places is probably an indication of flooding episodes. Intriguingly, there is potential evidence that a few structures are outside the final enclosure to the south, an indication of peripheral occupation beyond the core habitation zone.

The nearby ***magoula*** **Almiriotiki** is an exceptional case study (**Fig. 72**). The settlement is built atop a large mound with different projecting parts and extensions. The tell expands some distance to the west and east, but the northern side seems to have been impacted by hydrological activity. Approximately 35 high magnetic (most probably burnt) features of rectilinear dimensions are at the top of the *magoula*. They are mainly distributed in a concentric formation on the top part with some scattered elsewhere. Below the summit, geophysics mapped more than 50 rectilinear anomalies that are distributed in a concentric pattern until they reach several large anomalies corresponding to enclosure ditches. The structures are consistently encountered all around the site and most have internal divisions with two or three rooms. Magnetics and EMI identify the anomalies as low magnetic structures, a probable indication of the use of stone material. Around the buildings, several ditches enclose the habitation mound. At the eastern side, geophysics revealed a double ditch.

https://doi.org/10.1017/S0570608416000065 Published online by Cambridge University Press



72. Almiriotiki: results of the magnetics survey. © IGEAN Project.

A different kind of settlement structure appears at **Perdika 1**, about 20km inland from Almiriotiki. Here, there is evidence for a core habitation zone on the summit with a circular formation of at least ten rectilinear structures of burnt clay and mudbrick. This is the same kind of organization noted at Almiros 2 and Almiriotiki, although here the structures appear to be fewer and more compact. Beyond the summit, more than 50 structures extend 200m to the south in a distinct orthogonal formation unlike the circular formations previously observed. There is also an intermingling of structures of high and low magnetic values. Some of the buildings with low magnetic values are subdivided into two or three rooms. Finally, there is faint evidence of enclosures at the northwest and at the south. Flooding activity seems to have damaged the remaining traces.

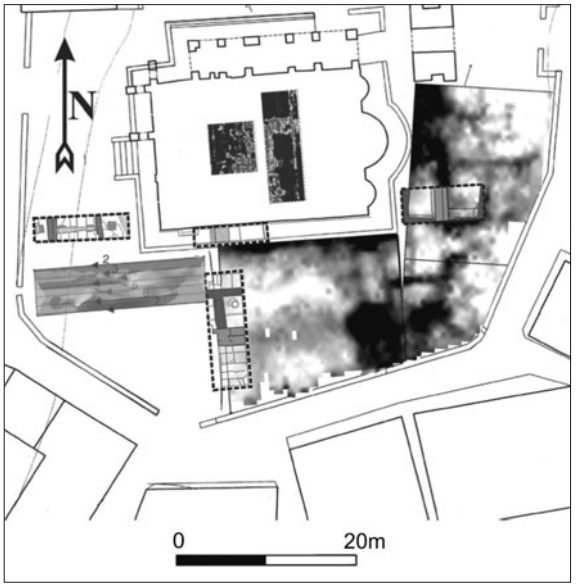
Monuments

The study of individual monuments through geophysical methods is another important field. Depending on the degree of monument preservation, its construction material and the impact of its local context (for example a modern urban setting), specific geophysical approaches can be applied to characterize geological and historical features otherwise inaccessible with conventional archaeological methods. An excellent case in point is the ERT survey carried out on the **Acropolis of Athens** to investigate the structural integrity of the Acropolis' southern walls and the nature of the infill material behind the walls (Tsourlos and Tsokas 2011). Since dark discolourations had been noted on the wall's exterior, there were suspicions that drainage water was causing damage. In normal ERT survey conditions, electrode spikes are inserted into the target area to establish galvanic contact. However, in places where surveying must be entirely non-destructive, other solutions are required. On the Athenian Acropolis, special copper-plated probes were attached to the exterior face of the walls and inside the Acropolis. Climbers had to scale the vertical faces of the walls

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to attach the plates in horizontal and vertical lines at regular intervals. The resulting data pinpointed the locations of low resistive soil conditions, which are indicative of high moisture content. The largest area of moisture accumulation was found towards the east. While some of these areas can be attributed to natural depositions from rainwater, the drainage and sewage system of the old Acropolis Museum, which is partially submerged below the ground on the hill's eastern side, clearly has had an impact on the eastern portion of the southern walls. Now that problem areas have been identified, a specific programme of conservation can commence.

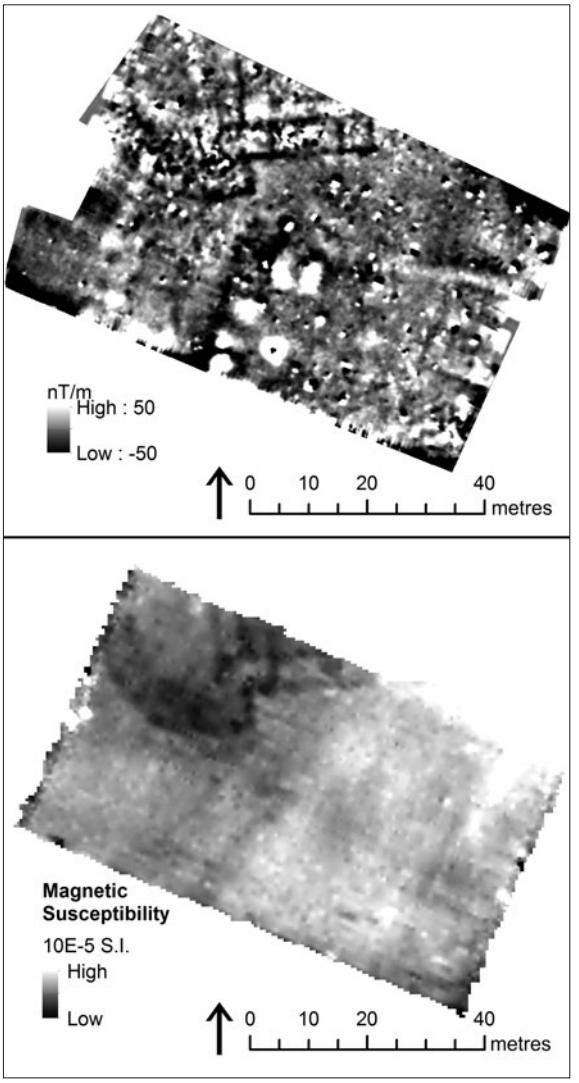
Byzantine churches have been a particular target of geophysical research in recent years. Like the Acropolis walls, this circumstance can be attributed to the unique capacity of geophysics to explore the subsurface at otherwise unsurveyable monuments. The **Kapnikarea Church in Athens** was explored by ERT using copper-plated probes that were attached to the stone flooring with a special gel to avoid damaging the monument (Tsokas *et al.* 2008). The stability of the church had been in question, since the Athenian metro runs directly below at a depth of 17m and noises had been resonating up through a well inside the sanctuary. The aim of the geophysics was to gain an understanding of the stability of the church and to identify the presence of earlier walls. Through the flooring of the church's interior and immediate exterior, several near-surface resistive features and voids were discovered. Some of the voids are likely from unknown wells or natural geological formations. Fortunately, none was deemed an immediate threat to the monument as a consequence of vibrations from the metro nor any other activity. An integrated survey at the **Church of Protaton at Karyes on Mount Athos** was implemented to identify earlier phases of the tenth-century sanctuary (Tsokas *et al.* 2007). In areas outside the church, electrical ground resistance and ERT mapped a series of near-surface foundation walls sharing the same alignment as the main church complex (**Fig. 73**). These features are possibly associated with structures that appear in 16th- and 17th-century drawings, but have long been destroyed. The interior of the church was investigated using GPR. Because of the non-destructive nature of data acquisition (antennae and the receiver are pushed over the surface with wheels), GPR is often the preferred method of surveying the interior of buildings, despite the backscattered reflections originating from the side walls of the monuments. No such problems were encountered inside the Church of Protaton, and a relatively clear plan of rectilinear walls beneath the sanctuary was identified.



73. Church of Protaton at Karyes on Mount Athos: results of electrical ground resistance (outside church) and GPR (inside church) in relation to excavation trenches (dotted boxes). Reproduced from Tsokas et al. 2007: 84, fig. 14; © G. Tsokas.

The ubiquity of **theatres** in classical antiquity and an interest in studying, preserving and utilizing these structures in recent decades has resulted in several fieldwork projects that use geophysics for investigating these monuments. Some surveys turn to geophysics in order to understand better the architectural details of known theatres. At **Demetrias** (http://www.theatreofdemetrias.gr/), the *skene* of the large theatre was mapped in greater detail than had previously been possible via excavations and above-surface material (Sarris 2011a). A similar approach has been adopted on **Crete**, where geophysical surveys at **Chersonisos** (**ID4534**), **Gortyn** (**ID1915**, **ID2859**, **ID2818**) and the small island of **Koufonisi** revealed additional evidence of the theatre's architectural makeup (Sarris 2011b). An interesting survey on Crete was performed to track down the small theatre and amphitheatre at **Ierapetra** (Papadopoulos *et al.* 2012). These monuments, along with a larger theatre, were mentioned in the 16th-century travelogue of Onorio

https://doi.org/10.1017/S0570608416000065 Published online by Cambridge University Press



74. Demetrias: results of the magnetics survey (top) and EMI survey (bottom), showing a possible theatre or odeion near the harbour. © Politeia Project.

Belli (1550–1604), who also drew a plan of the monuments he saw. After georectifying Belli's plan over satellite imagery of Ierapetra, geophysics targeted the likely locations of the theatres and amphitheatre. The large theatre now seems to lie beneath modern housing blocks; however, evidence for the *cavea* of the small theatre was identified with several geophysical methods. More limited confirmation was found for the amphitheatre, the location of which appears to be negatively impacted by a (now demolished) 20th-century industrial factory. At **Demetrias**, the chance discovery of what is likely to be a small theatre or odeion emerged from the magnetics and EMI survey of the *Politeia Project* (http://politeia.ims.forth.gr/). Adjacent to the modern shoreline northwest of the Hellenistic palace, the partial remains of a large buried structure were found (**Fig. 74**). It consists of a semicircular western half that is joined to a rectilinear complex with individual rooms. The radius of the semicircular feature is almost 25m, while the length of the building as a whole is at least 45m. The rectilinear complex is subdivided into four rooms at the south, and one of these rooms has an apsidal end. A large square area, perhaps a courtyard, appears to the north.

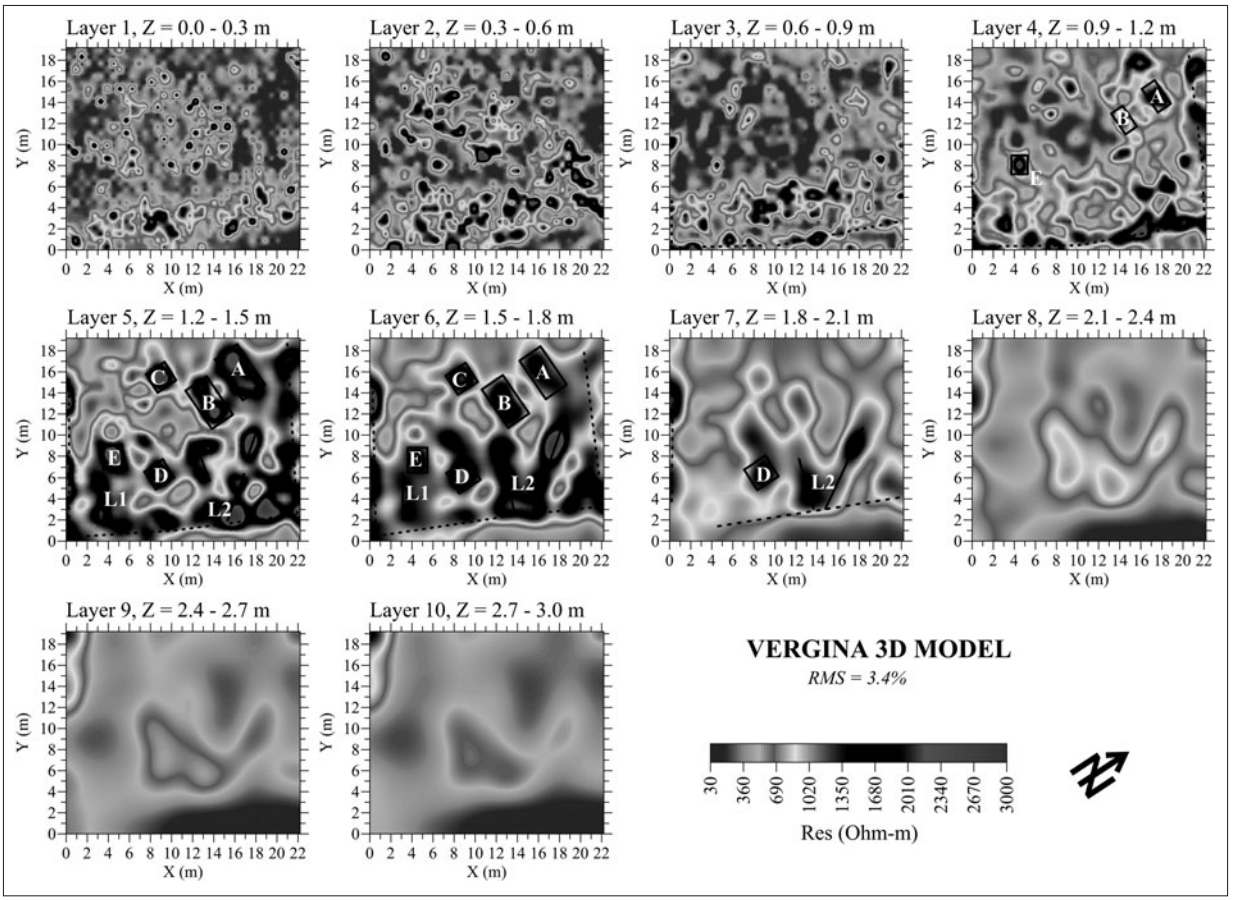
Cemeteries and tumuli

Geophysics is regularly used to study the archaeology of the dead, specifically in the detection of tombs and burials in cemeteries, and, even more challenging, in the recording of the internal structures of burial mounds or tumuli. At **Kenchreai** (**ID105**, **ID276**, **ID742**, **ID1417**, **ID2490**), one of the harbours of Corinth, an integrated geophysical survey using magnetics, EMI, GPR and micro-gravitometry was carried out on the Koutsongila Hill along the coast, where a Roman cemetery with chamber tombs and cist graves had been exposed by illicit digging (Sarris *et al.* 2007). The purpose of the survey was to gain a better picture of the extent and density of burials and other features in the cemetery ahead of excavations. Several methods mapped anomalies that mark the locations of cist graves and chamber tombs. More unexpected was the discovery of a large rectangular building (17m × 25–30m) above the southern cliff of the hill. Its location corresponds to large ashlar blocks still visible on the surface. Rather than a tomb, the rectangular feature is thought to be part of a sanctuary or similar kind of structure that required massive walls. The presence of ashlar masonry may indicate an earlier date preceding the hill's use as a cemetery in the Roman period. At the southern side of the Koutsongila Hill, magnetics identified a circular feature measuring 4–5m in diameter. Its high magnetic values suggest the presence of burning, and a probable explanation is that the feature is a kiln.

Exploring burial mounds or **tumuli** with geophysical methods has gained traction in recent years thanks to improvements in the methods of data acquisition. This has led to a number of high-profile surveys at tumuli in Macedonia and Thrace, such as the burial mound thought to be associated with the Macedonian royal family or a Macedonian general at **Amphipolis**. Geophysicists must adapt more to the unique challenges of studying tumuli than in other contexts. The uneven topography, depth of features and hetero-

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geneous accumulation of fill material often strewn about in different layers, limit the effectiveness of standard survey methods. Refraction seismic surveys have been successful in identifying the entryways and pits used to build tombs. This method does not map the tombs and related tumuli features themselves; instead, it simply suggests their locations based on the delayed arrivals of the surface measurements. In this way, the internal arrangements of tumuli at **Pella** and **Amphipolis** have been studied (Tsokas *et al.* 2015). More recently, 3D ERT methodologies have been devised to model the individual chambers inside tumuli. A survey at a prehistoric tumulus at **Vergina** using this method achieved good definition of the details of several tombs (Papadopoulos et al. 2010) (**Fig. 75**), as has another survey at a tumulus near the village of **Spilaion** in the Evros region of Thrace (Tsokas *et al*. 2015).



75. Vergina: ERT inversion model of a prehistoric tumulus with the interpretation of likely features of archaeological interest. Reproduced from Papadopoulos et al. 2010: 204, fig. 12; © N. Papadopoulos.

Underwater geophysics

Underwater archaeology has a long and rich tradition of activity in Greece, where the sea and maritime activity have been prominent features of daily life for millennia. Geophysics, along with other remote-sensing techniques, have played a critical role in expanding the ways in which archaeologists confront and analyse material cultural in submerged contexts and in reconstructing the palaeoenvironments of coastal sites. The primary issue at hand in underwater archaeology is meeting the challenges of collecting and interpreting data beneath the water, often in deep environments. The most widely used methods today include side-scan sonars, sub-bottom profilers, marine magnetometers and echosounders. Two shipwrecks off the coast of **Chios** (**ID649**, **ID827**), one dating to the fourth century BC and the other to the Hellenistic period, were investigated with an autonomous underwater vehicle (AUV) equipped with optical and sonar

https://doi.org/10.1017/S0570608416000065 Published online by Cambridge University Press

sensors, as well as a chemical sensor (Foley *et al.* 2009). The depth of the fourth-century shipwreck was 70m and around 350 transport amphorae (both Chian and of unknown origin) were identified. Molecular samples taken from some of the Chian amphorae show that olives and oregano were being transported in these vessels, while mastic was found in the amphorae of unknown provenance. The evidence from the Chian amphorae, in particular, appears to contradict previous attempts to associate the same type of Chian amphora with the wine trade.

Besides shipwrecks, there is great interest of late in studying the palaeoenvironments of coastal settlements and their **harbour installations**. A recent underwater survey at **Sounion** using a sub-bottom profiler and side-scan sonar mapped the coastal palaeogeographic changes around the classical fortified harbour settlement, showing that the coastline has receded considerably since 10,000 BP (Papatheodorou *et al.* 2014). Harbour installations were also mapped in the shallow waters near the settlement. Elsewhere, the *Kyllene Harbor Project* at **Kyllene** (**ID338**, **ID894**; http://www.finninstitute.gr/en/kyllene) – the harbour of Elis and later an important Frankish site – is using geophysics in combination with a topographical survey to record the classical and medieval port installations. Another recent project at the ancient coastal city of **Olous** on Crete has developed a method of applying 3D ERT to map submerged remains in shallow contexts (Papadopoulos *et al*. 2016). The placement of electrodes 1m beneath the water, rather than positioning them on top, has provided a clear picture of two phases of construction. The most visible is associated with salt pans in use during the 19th century, while the other phase is thought to date to the ancient settlement. What is unique in this study is the use of ERT to monitor features on the seafloor as well as those below the seafloor.

Future prospects

One advantage of geophysics is its capacity to examine the subsurface on macro- and micro-scale levels. If used in combination with excavations, pedestrian surveying and satellite or airborne remote sensing, geophysics contributes to the creation of a holistic perspective of cultural landscapes. Moreover, if used in tandem with GIS analysis, geophysics can reveal other facets such as movement, accessibility and visibility (Benech 2007). The plan of an entire community, for example, and its component parts, as identified with geophysics, could potentially be very enlightening about its sociopolitical organization and its cultural connections with other communities. Despite the potential, this is an aspect of geophysics that has not been exploited to the same degree as traditional fieldwork, perhaps due to uncertainties of interpretation and chronology that can arise in isolation from contextual material. However, the growing trend of applying geophysics to regional surveys could propel archaeology in Greece into new and surprising directions in the years to come. As an example, high-resolution plans of Greek and Roman domestic structures gathered from large surveys could provide substantial new data for spatial syntax studies. Another area where progress could be made is expanding the chronological and cultural focus of geophysical surveys. In urban studies in Greece, settlements and towns of the Byzantine, Ottoman and Early Modern periods are diminished or completely lacking compared to those of the Greek and Roman periods. At least for the Byzantine period, there is a focus on studying churches or other monuments using geophysics, rather than the morphologies of Byzantine settlements. Since many modern towns and villages in Greece are built on top of earlier phases, sometimes centuries or millennia old, surveying methods must adapt to these surroundings. Geophysics could also be used to investigate battlefields and war cemeteries in Greece dating to the First and Second World Wars. This is an area of research that is completely undeveloped despite plenty of areas of interest (for example northern Greece and Crete).

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