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# An Introduction to Geophysical and Geochemical Methods in Digital Geoarchaeology

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## Abstract

Archaeological geophysics is a range of techniques for the minimally invasive, remote investigation of the physical parameters of the near-surface environment. This suite of methods is complementary to archaeological survey or excavation as it can provide information about the stratigraphy of the survey area, locate anthropogenic traces of the past, document their spatial dimensions and—under ideal conditions—explore the physical properties of subsurface materials. Both material culture items such as a building foundations and indirect indications of anthropogenic activity such as subsurface disturbance or evidence of burning are excellent direct targets for geophysical investigations since they can be differentiated on the basis of their material properties from the wider soil context. In addition to directly locating archaeological material, geophysical techniques can make an important contribution to geoarchaeological investigations by elucidating the site stratigraphy and mapping its lateral geometry. In some cases, such as when locating prehistoric material buried offshore or within open Palaeolithic sites, the reconstruction of past landscapes may make a more important contribution to archaeological investigations than the direct geophysical detection of archaeological materials.

Different material culture items have characteristic physical properties (such as electrical resistance or conductivity, magnetic susceptibility) and so require different instrumentation for effective detection. The main techniques for archaeological prospection include magnetometer, resistance meter, magnetic susceptibility meter, ground-penetrating radar and electromagnetic induction meter. Apart from that, seismic methods (reflection and refraction seismics), gamma spectroscopy and gravity techniques are also used in certain circumstances.

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Unfortunately, there is no standard approach for the application of one specific geophysical method for all archaeological materials in all geological environments. The success of geophysical prospection techniques depends on a combination of soil and sediment characteristics as well as depth below surface and preservation of archaeological findings. In order to achieve the most reliable results and enhance the chance of detecting archaeological material, an integrated, multi-method approach is suggested.

In addition to field surveying, the effective processing of measured geophysical data is a crucial part of the interpretation process. Data processing aims to enhance signals of interest in order to better delineate archaeological and geological features. It helps to produce more interpretable results and therefore facilitates and fosters collaboration between geophysicists and archaeologists.

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**Keywords**

Geophysics • Landscape archaeology • Palaeolandscape reconstruction • Soil stratigraphy

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## 14.1 Introduction

Geophysical methods are an important component of geoarchaeological investigations due to their ability to non-invasively image the subsurface of an archaeological landscape. New developments in multi-sensor and positioning technology have facilitated the use of these methods over large areas, allowing archaeological questions to be addressed on a landscape scale. They are particularly useful in geoarchaeological investigations for defining site stratigraphy, mapping site disturbance and reconstructing palaeolandscapes.

Geophysical methods also make a significant contribution to archaeological investigations beyond geoarchaeology. Excellent detailed introductions to the application of specific geophysical techniques to archaeology in general are available for ground-penetrating radar (Manataki et al. 2015; Conyers 2013, 2015b), magnetometry (Armstrong and Kalayci 2015; Aspinall et al. 2008), resistivity (Schmidt 2013) and electromagnetic techniques (Simon and Moffat 2015).

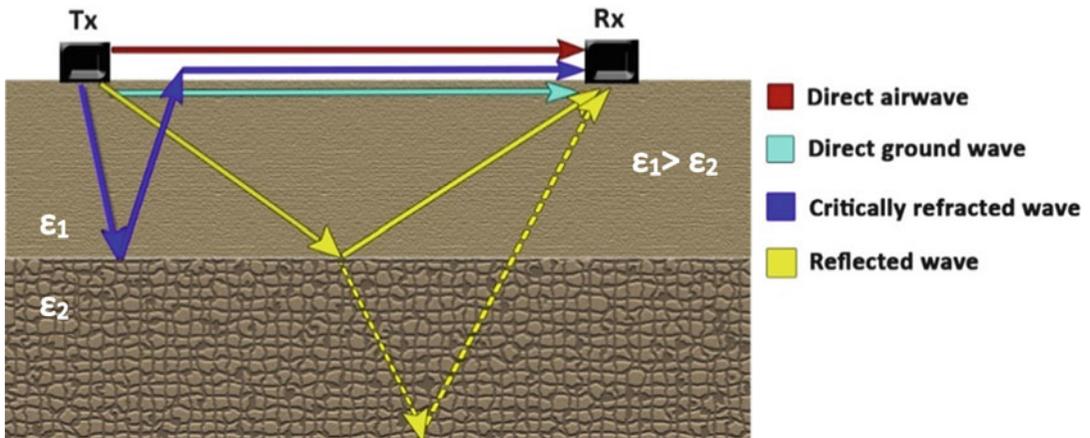
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## 14.2 An Overview of Geophysical Methods

### 14.2.1 Ground-Penetrating Radar

Ground-penetrating radar (GPR) is a widely used technique in geoarchaeology, which allows the detection of features in the subsurface that cause a change in the propagation of electromagnetic energy. A typical GPR includes a transmitting antenna (Tx) and a receiver antenna (Rx). The Tx transmits electromagnetic waves with a fixed frequency into the subsurface. The Rx receives the portion of the energy, which is reflected by variations in material properties of the subsurface and registers the amplitude of this response for mapping purposes (Fig. 14.1).

Electromagnetic wave propagation is complex as it includes reflections, refractions and diffractions caused by changes in relative dielectric permittivity ( $\epsilon$ ) and/or conductivity ( $\sigma$ ). Variations in these values reflect geological and/or geomorphologic features (e.g. changes in



**Fig. 14.1** Signal paths between the transmitter (Tx) and the receiver (Rx) for two layers with different electrical properties ( $\epsilon$  stands for the dielectric permittivity). The

*dashed yellow line* indicates that part of the signal's energy was refracted and then reflected (Annan 2009)

lithology, faults, strike and dip of beds, cavities, bedding features, loose sediments vs. bedrock etc.), changes in hydrological conditions (degree of fluid saturation and water chemistry) or the presence of archaeological materials. GPR can be deployed with a variety of antenna frequencies allowing features on a wide range of scales to be imaged. In general, antennas with a frequency range of approximately 200–500 MHz are appropriate for most archaeological studies as they provide a depth of investigation up to about 3 m and an acceptable resolution (Fig. 14.2a) (Jol 1995; Conyers 2015a, b, pp. 14–15). Lower-frequency antennas can be used for deeper investigations (such as the location of geomorphic features), and higher frequency antennas are suitable for shallower, higher resolution surveys such as investigation of mortar thickness. Recent developments in GPR technology include multi-channel systems (Fig. 14.2b) coupled with GPS navigation systems for fast surveys, ultra-wide-band antennas (Trinks et al. 2010) and stepped-frequency antennas (Linford et al. 2010). Drone-mounted GPR systems are also expected to become available within the coming years (Merz et al. 2015).

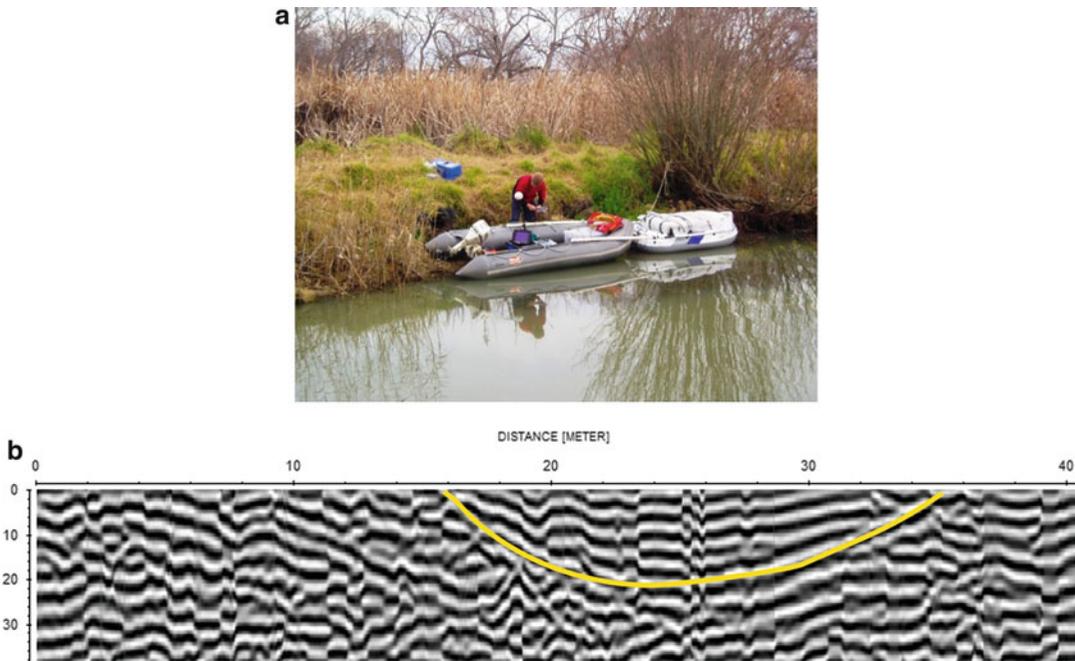
Usually, GPR surveys are undertaken on a grid of regularly spaced parallel lines, which are commonly post-processed together into a 3D volume. Radargrams represent the amplitude

of the reflected signals as a function of the time taken for the electromagnetic wave to travel from the Tx to the Rx via the subsurface. When the velocity of propagation of the electromagnetic radiation within the ground can be estimated, it is possible to convert the time of arrival to a depth estimate. GPR data can be viewed as 1D soundings (traces), 2D profiles (radargrams), amplitude 'slices' through the 3D volume, 3D cubes or 3D representation of the signal amplitude. In general, amplitude slicing is more effective for mapping archaeological features with obvious linear geometry and a high amplitude response than for stratigraphic features which are often more geometrically complex. For the investigation of geoarchaeological research questions, the combined analysis of individual traces, 2D profiles and slice maps is most likely to be more effective than the exclusive use of slice maps (Conyers 2015a, b).

GPR applications in geoarchaeology range from determination of the depth to bedrock, mapping of palaeolandscapes features (such as channels and shorelines, Fig. 14.3), locating of anthropogenic earthwork features like canals or moats and identification of soil disturbance due to habitation (Fig. 14.4). In addition, GPR allows mapping unmarked graves, which often can be identified through soil anomalies caused by excavation of tombs. Unfortunately, the high



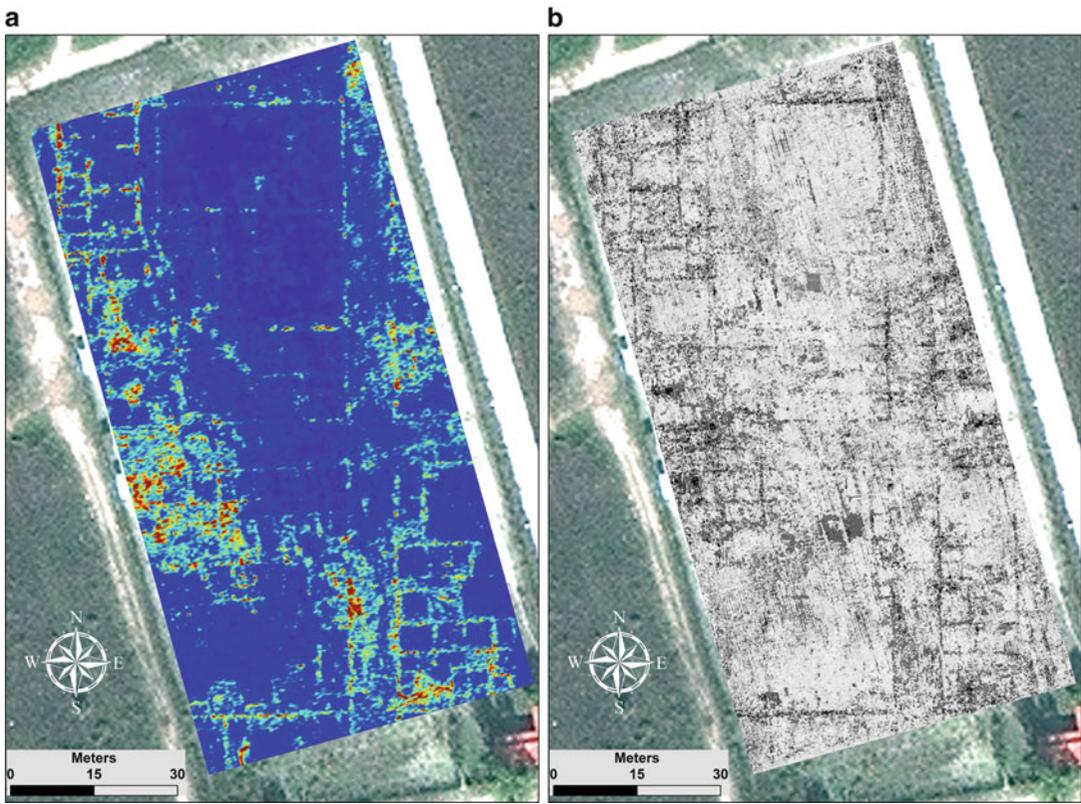
**Fig. 14.2** (a) Noggin Plus (Sensors & Software Ltd.) 250 MHz GPR system in a survey at the ancient theatre of Chersonessos in Crete. (b) MALA MIRA multi-antenna GPR configuration with eight 400 MHz antenna applied in a survey at Feres (Velestino), Central Greece



**Fig. 14.3** (a) Mala X3M 100 Mhz GPR system being used for mapping sedimentary environments within a lake. Lake Alexandrina, South Australia. (b) A palaeochannel (see the yellow line) imaged in a 2D profile using a Mala X3M 250 MHz ground-penetrating radar from the Umbum Creek, Central Australia

attenuation of radar energy in saltwater precludes the application of GPR in marine surveys, but it is suitable for use in limnic environments (Fig. 14.3).

A major advantage of GPR for geo-archaeological studies is that it can image sedimentary structures, such as cross bedding. Thus, it is an effective technique to be applied in areas



**Fig. 14.4** (a) Results of GPR slices at about 60–70 cm below the surface resulting from Noggin Plus and MALA. (b) GPR systems from Demetrias archaeological site,

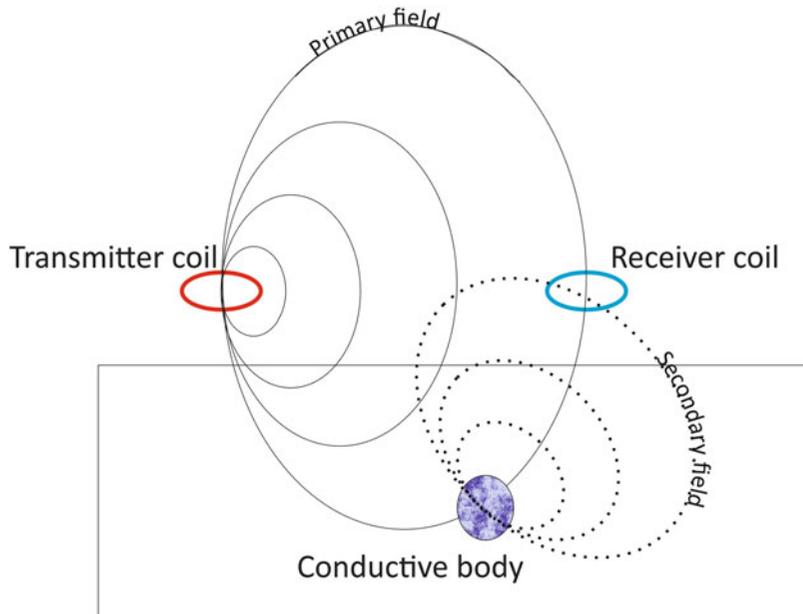
Central Greece. Measurements were taken along transects 0.5 m apart

characterized by changes in depositional facies that are not accompanied by lithological changes. Moreover, as the GPR antenna can be moved continuously during data acquisition, the method allows faster data acquisition and higher survey speed compared to methods such as resistivity tomography (see below) that require stakes to be inserted in the ground. GPR also benefits from the shielding commonly placed around antennas, which reduces the interference from features on the surface (particularly metal) as opposed to other methods, such as electromagnetic induction or magnetometry, making it suitable for use in urban settings (Sarris and Papadopoulos 2012; Papadopoulos et al. 2009).

### 14.2.2 Electromagnetic Induction Methods

Electromagnetic induction (EMI) can be used to calculate the apparent conductivity and magnetic susceptibility of the subsurface. In the most common type of EM instruments, a transmitter coil generates a primary electromagnetic field for a given frequency (~8–90 kHz) (Fig. 14.5). The interaction of the field with subsurface elements generates an electrical current. This electrical current, in return, generates a secondary electromagnetic field which is sensed by a receiver coil in the instrument alongside the primary field. The magnitude of secondary field is divided into two

**Fig. 14.5** Diagrammatic representation of the principle of operation of the electromagnetic induction methods



orthogonal components: the quadrature and the in-phase. The quadrature provides information on apparent conductivity (in mS/m), and the in-phase is related to the magnetic susceptibility (emu) of materials. The depth of investigation is mainly controlled by the separation between the transmitter and the receiver coils (Fig. 14.6; Simon et al. 2015a, b).

EM requires no direct contact with the ground surface allowing large areas to be surveyed relatively quickly (Fig. 14.6 and 14.7). Conductivity can be a good measure of changes in rock and soil units, because it is influenced by composition, the porosity, degree of water saturation and fluid chemistry. Magnetic susceptibility may provide information about erosion, pedogenesis and anthropogenic burning as all of these processes may form or concentrate magnetic minerals (French 2003).

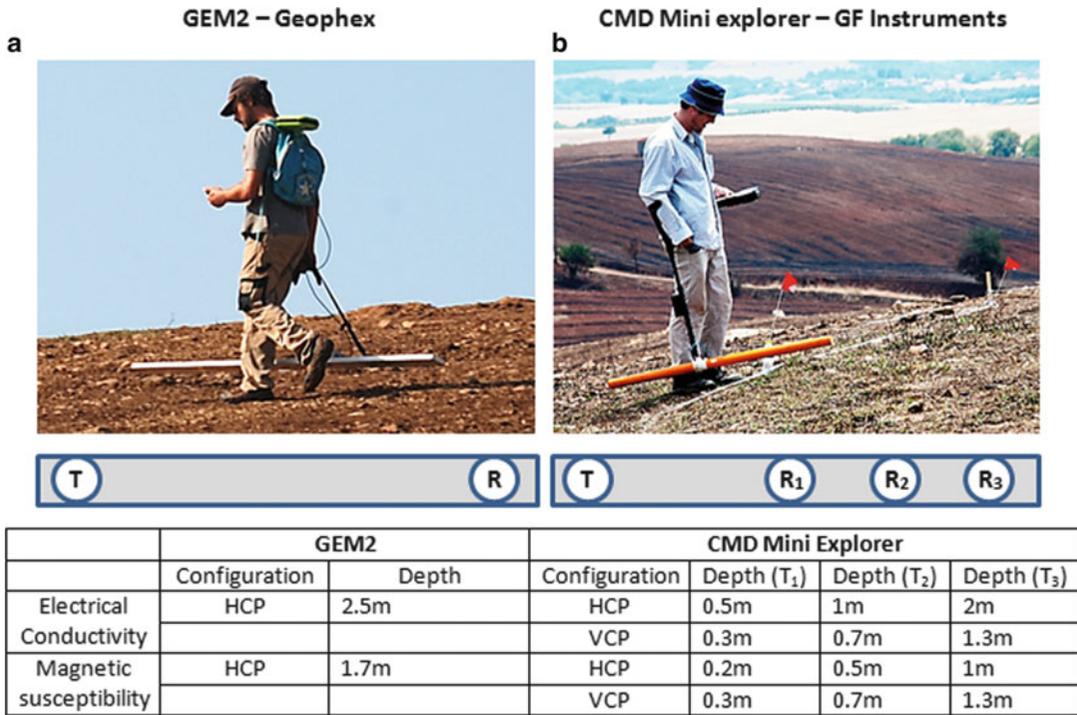
Another subfield of the use of electromagnetic induction in geoarchaeology is the specific investigation of magnetic susceptibility by dedicated instruments. Corresponding instruments are more sensitive to changes in magnetic susceptibility than general-purpose electromagnetic induction instruments and can be used to survey on the surface, on archaeological sites and

excavations and even down in drill holes (Dalan and Banerjee 1998). However, such applications are often complemented by more detailed magnetic measurements (Dalan 2007), as explained in the section on magnetic methods below.

### 14.2.3 Electrical Resistance Techniques

Electrical resistivity investigations work by measuring either the self-potential (passive) or the direct current resistivity or induced polarization (active) of the subsurface. The resistivity of geological and archaeological materials is controlled by their physical properties as well as their water chemistry and degree of saturation (Hecht and Fassbinder 2006).

Electrical resistivity surveys are undertaken between probes of a known separation. The larger the separation between the electrodes, the greater the penetration depth and the smaller the resolution. Various electrode configurations can be used, including the Twin, Wenner, Square, pole-dipole, dipole-dipole and Schlumberger arrays (Loke 2000; Fig. 14.8). Each configuration provides particular advantages for specific



**Fig. 14.6** GEM2 Geophex (a) and CMD Mini Explorer–CF Instruments (b) configurations and coil arrays for the investigation of the soil conductivity and soil magnetic

susceptibility with respect to the coil separation and orientation of coils (horizontal HCP and vertical VCP)

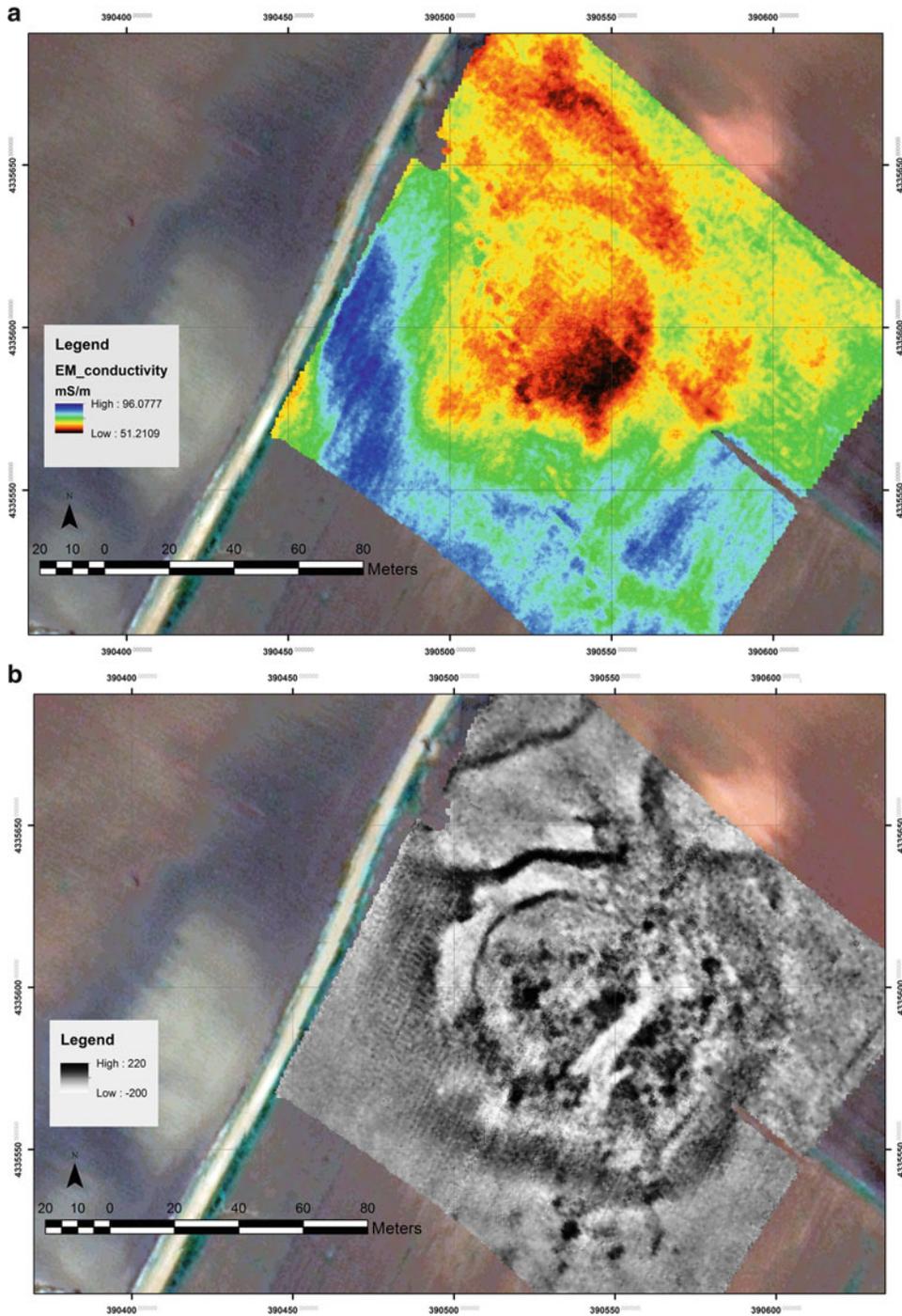
situations, depending on the size, geometry, orientation, depth and relative resistivity contrast between the target and background (Schmidt 2013). Multi-probe, wheeled and tractor-driven systems have also been developed for smooth and conductive landscapes.

Resistivity measurements can be carried out in various ways. Vertical electric soundings, in which the electrode separation is gradually increased at a fixed point, are used to obtain a model of the depth to bedrock at a fixed location. Resistivity mapping, the most common configuration for archaeological prospection, makes use of a fixed electrode separation which is moved as an array along parallel profiles within a grid. This approach produces a plan-view image of the distribution of the resistivity at a specific depth. Finally, multi-probe arrays [commonly referred to as electrical resistivity tomography (ERT)] use multiple equidistant electrodes that measure both the lateral and vertical variations of the subsurface resistivity as a 2D profile (Fig. 14.9). Having

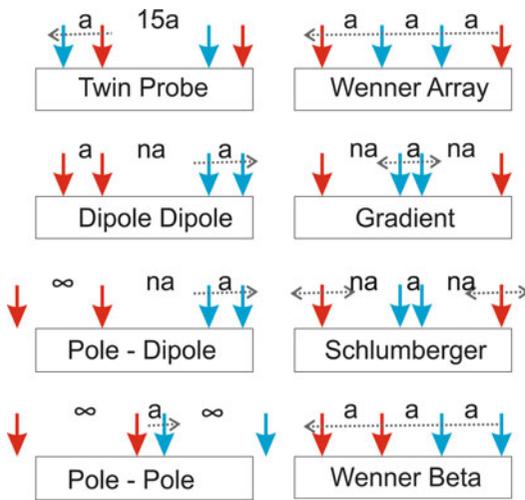
a number of parallel ERT transects, it is possible to generate 3D volumetric images of the resistivity. Resistivity, especially when used in the ERT configuration, together with seismic techniques, is excellent for imaging changes in lithology and geology (Laigre et al. 2012; Scapozza and Laigre 2014). ERT is also valuable when either deep depositional targets (e.g. ancient ports covered by alluvial deposits, ditches and palaeochannels) or offshore archaeological features are the target of investigations (Sarris et al. 2014; Tonkov 2014; Simyrdanis et al. 2015).

### 14.2.4 Magnetic Methods

Magnetic prospection (or magnetometry) works by measuring disturbances to the earth’s magnetic field caused by the presence of iron minerals. Magnetization of bodies consists of two components, namely, the induced and the remanent magnetization. While the former is



**Fig. 14.7** Indicative results from the EMI survey (GEM2) at the Neolithic site of Almyros 2 at Thessaly, Greece representing the soil conductivity (a), which suggests a higher conductivity to the southern side of the tell (indicative of the flooding zone) and the magnetic susceptibility (b) that outline the surrounding ditches and some of the details of the structural remains of the core of the settlement (Sarris et al. 2015a)



**Fig. 14.8** Indicative electrode configurations used in a soil resistance survey. Blue arrows represent potential electrodes, and red arrows represent current electrodes. The distance between them varies according to the electrode array. In the mapping mode, either all or some of the electrodes move within the area of interest

created by the modern magnetic field, the latter is a result from previous magnetic fields. Magnetic susceptibility is an additional important parameter, which measures the degree to which a material becomes magnetized when an external magnetic field is applied. Magnetic prospection depends on several parameters, such as the degree and orientation of induced and remanent magnetization of bodies, their magnetic susceptibility, their volume (or mass) and their distance from the sensor.

Magnetic measurements can be collected with single or multiple sensors configured to measure usually either the total magnetic field intensity or the total or vertical magnetic gradient (gradiometer mode). Recent equipment developments have introduced multiple sensor array carts to archaeology which, when combined with high-quality positioning and navigation systems, facilitate extremely high-sample density measurements over large areas extremely quickly (Fig. 14.10).

Contrary to its widespread application for archaeological prospection, field magnetometry plays a rather little role within geoarchaeological investigations. This is mainly because it is rather suited for the direct detection of ferrous or burnt

materials than for understanding the stratigraphic matrix that contains archaeological material. One promising application, though, is mapping the extent of pedogenic soil minerals, which is more effective using single sensor equipment instead of gradiometry equipment.

In contrast, laboratory magnetic measurements are very useful for understanding the depositional conditions at archaeological sites (Dalan and Banerjee 1998). Magnetic susceptibility, particularly the frequency dependant component, is increased by archaeological occupation both through heating and the addition of organic material to the soil. The surface distribution of magnetic susceptibility values provides a proxy for the spatial distribution of occupation, and, in combination with other magnetic properties [e.g. anhysteretic remanent magnetization (ARM) and saturation isothermal remanent magnetization (SIRM)], it is possible to infer the intensity of habitation or to determine the provenance of archaeological materials (Thompson and Oldfield 1986; Dearing 1994).

### 14.2.5 Acoustic Procedures

Acoustic measurements are undertaken by creating repeatable acoustical waves that enter the ground and are refracted or reflected by changes in density before returning to a series of geophones (Fig. 14.11). The study of the arrival times, amplitude and form of the returned wavefronts provides information about the stratigraphy of the subsurface and the presence of archaeological material.

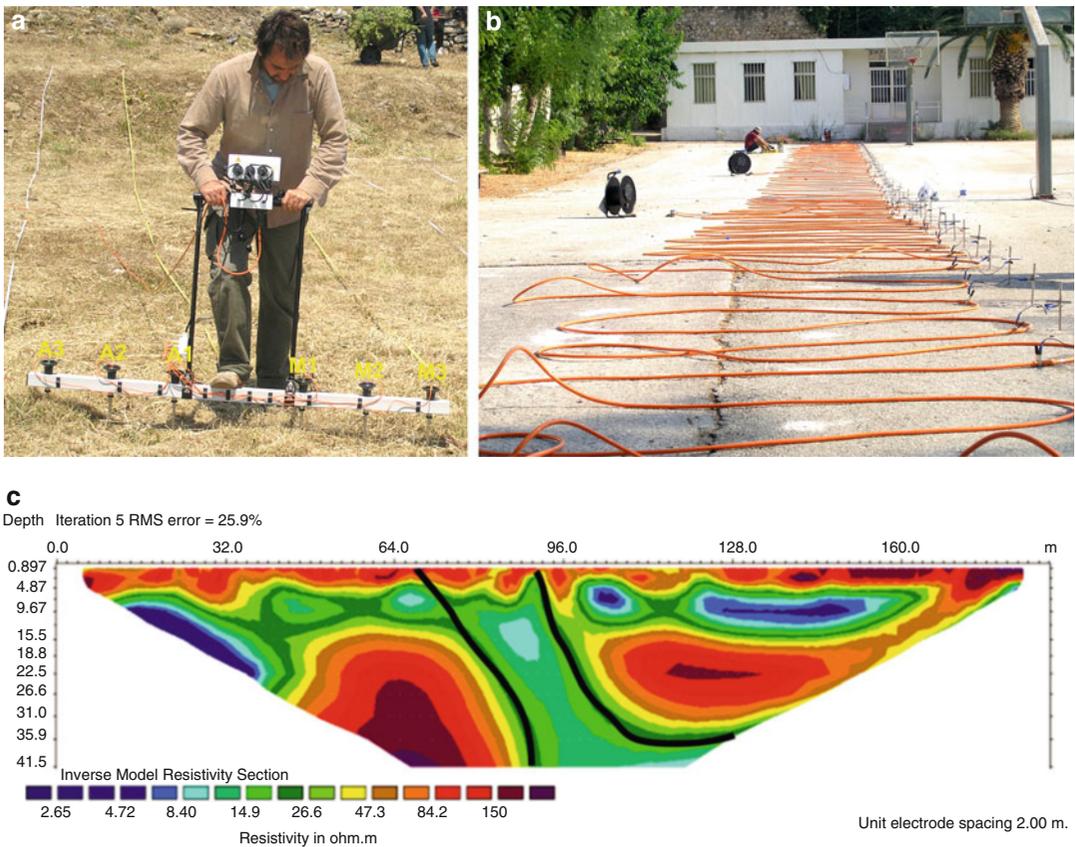
The most common acoustic techniques in archaeological research are seismic reflection and bathymetry, particularly for the reconstruction of underwater palaeolandscapes (i.e. Tizzard et al. 2015). The acoustic response of subsurface sediments measured by seismic reflection provides two- and three-dimensional representations of the geometry of sedimentary depositional units, their internal structures and their lithology. Seismic methods are particularly suited to aquatic surveys, as the acoustic properties of water allow the geophones to be used without direct coupling to

the seafloor which greatly enhances survey speed compared to terrestrial surveys.

On land, seismic methods are useful for geoarchaeological investigations as their relatively deep depth of penetration is well suited to mapping large monumental structures and mounds or reconstructing the palaeotopography. Seismic refraction is particularly useful for determining the depth to bedrock within archaeological sites (Fig. 14.12). In contrast, seismic reflection is very valuable in terrestrial archaeology to map site stratigraphy, with surface wave techniques in particular showing great potential for wider use.

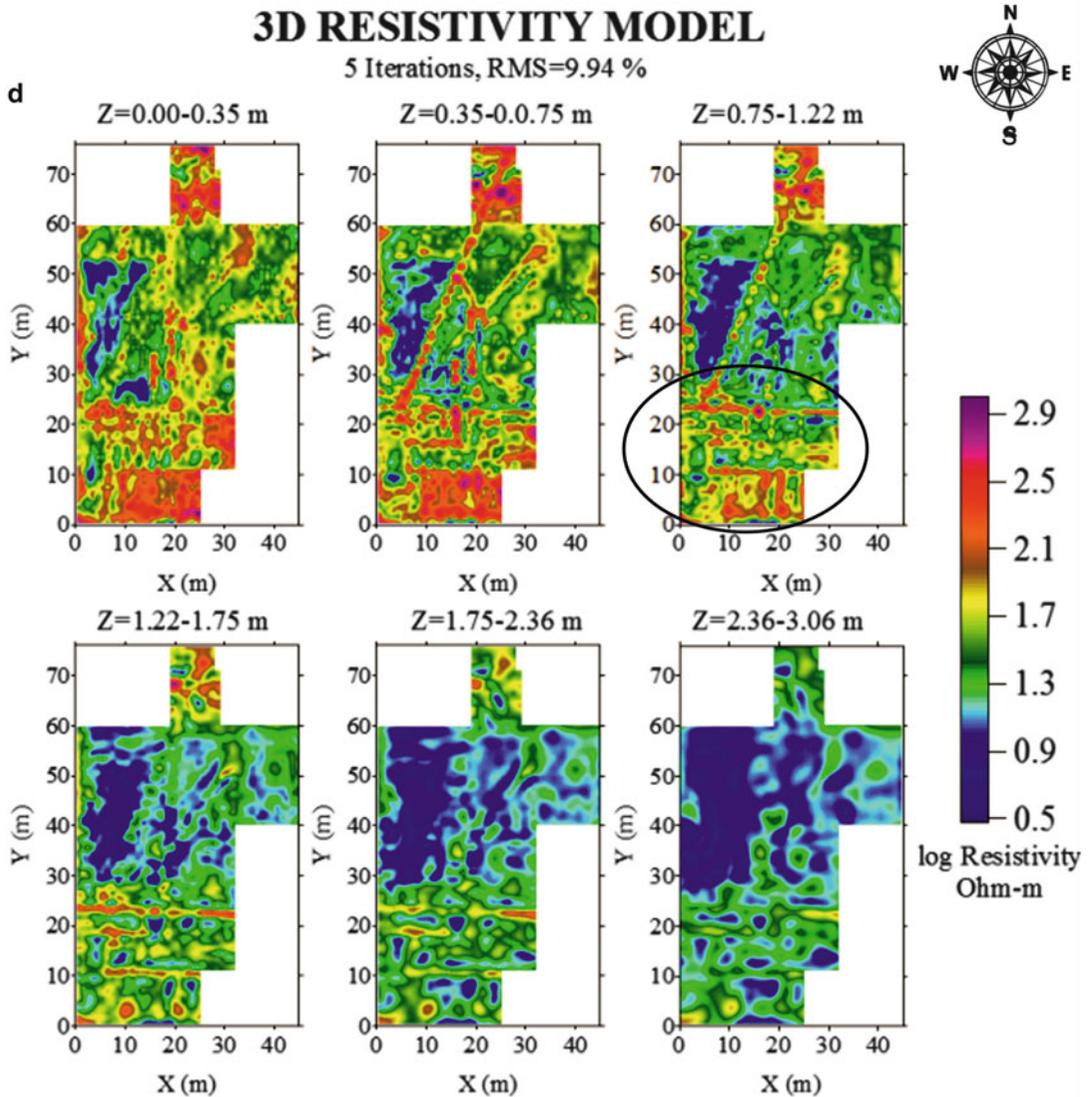
### 14.2.6 Other Geophysical and Geochemical Techniques

Microgravity measurements are carried out using sensitive devices that measure small variations in the Earth’s gravitational field. These alterations are usually caused by air-filled voids in the subsurface (e.g. tunnels, cavities, caves and architectural features; see Fig. 14.13). They show a significant contrast between mass density and the surrounding loose sediments or the parent rock.



**Fig. 14.9** (a) Geoscan Research Resistance meter (RM15) with multiplexer employing six electrodes (current electrodes As and potential electrodes Ms) at various configurations. (b) ERT extension of electrodes being used to map the area of the old Franciscan monastery of Rethymno (Mikrasiaton plaza) in Crete. (c) Stratigraphic results of an ERT transect measured above a fault (see the *black line*) within the suggested ancient port of

Priniatikos Pyrgos at Istron, Crete (Sarris et al. 2014). (d) 2D representation of the 3D resistivity model shown as horizontal slices with increasing depth in the area of Mikrasiaton Square at the centre of the old town of Rethymno in Crete. The architectural relics of a Franciscan monastery become obvious towards the southern part of the surveyed area (Papadopoulos et al. 2008)



approaches have the potential to assist geoarchaeological investigation by providing information about the sedimentary matrix of the archaeological site and determining if it has recently been disturbed by anthropogenic or natural processes.

Quite similar to isotope mapping is the chemical analysis of soils, which may indicate anthropogenic activity including agricultural and workshop activities, animal husbandry, construction of ditches, etc. Phosphate analysis, trace element analysis (Cu, Mn, Mo, Ca, Se, Sr, Zn, Cd, Cr, Cu, Ni, Pb) and assessment of chemical stability of organic chemical compounds are the most widely used approaches contributing to the recognition of former land-use practices and past human occupation in general. Calorimetric measurements, atomic absorption spectrometry, inductively coupled plasma mass spectrometry and gas chromatography-mass spectrometry are usually employed (Szostek et al. 2005; Price and Burton 2012; Manhita et al. 2014; Lauer et al. 2014)

### 14.3 Examples for Principal Applications

Geophysical methods have a wide range of application within archaeology in general, but their explicit use for solving geoarchaeological questions is principally related to three major aspects: the determination of sediment stratigraphy, the mapping of soil disturbance related to human occupation and the reconstruction of palaeolandscapes.

**Sediment Stratigraphy** Understanding the stratigraphy of an archaeological site is crucial for effective excavation planning, palaeoenvironmental reconstruction and putting excavation results into context, particularly with regard to geochronology. Yet geophysical methods are mostly currently used to simply locate and map archaeological sites and not to determine key stratigraphic features. The most important information that can be obtained using geophysics includes depth to bedrock, thickness and lateral extent of stratigraphic features and the location

of archaeological material with respect to the stratigraphy.

Depth to bedrock and geomorphology of the surface provide important information about past depositional conditions and are key for correctly locating archaeological excavations so as to resolve the most complete record of occupation. Besides GPR and ERT, which are the most suitable techniques for investigating the vertical stratigraphy of archaeological sites, on-site or down-hole magnetic susceptibility measurements also provide promising results. When it comes to horizontal mapping, EMI, GPR, soil resistivity, ERT and gamma spectroscopy are particularly suitable.



**Fig. 14.10** (a) A single fluxgate gradiometer sensor of Bartington G601. (b) An eight-sensor fluxgate gradiometer array of SENSYS surveying the Neolithic tell of Perdika 2 at Central Greece. (c) Indicative results from the single sensor magnetic survey of the Agora of Sikyon in Peloponnese (Sarris et al. 2008). (d) Multisensory survey of Almyriotiki Neolithic tell at Central Greece. Results have been superimposed on a WorldView-2-satellite image (2 June 2012) (Sarris et al. 2015a)



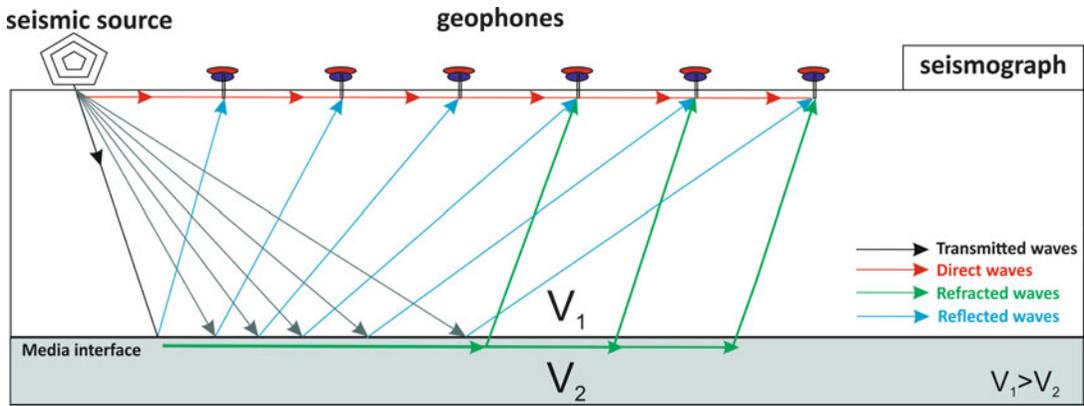
Fig. 14.10 (continued)



**Fig. 14.10** (continued)

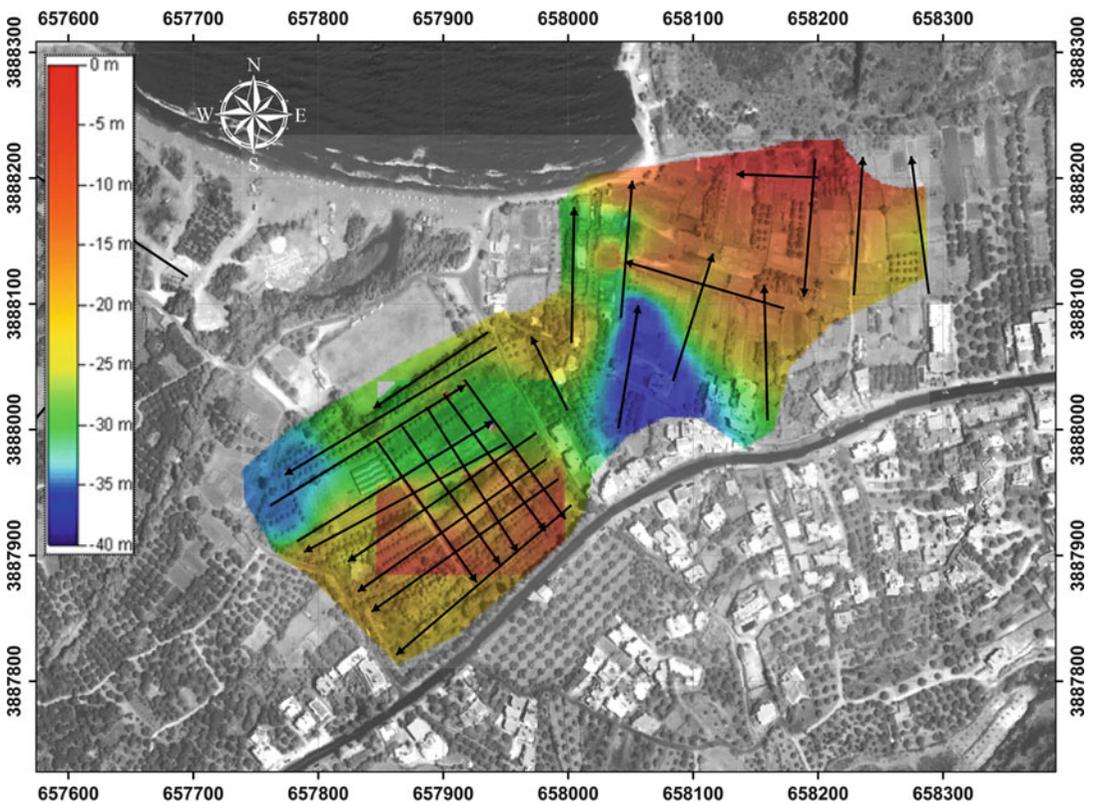
**Stratigraphic Disturbance of Sediments and Soils** Soil stratigraphy (i.e. the development of recognizable soil horizons) typically takes significant time to develop, and, as a result, its disturbance can provide crucial information about the historical record of an archaeological site. This perturbation can be mapped geophysically through a number of techniques. Among others, alteration of soil properties due to mixing of different components can be investigated by GPR, EMI, resistivity or gamma spectrometry, while changes of soil porosity are shown best by ERT and GPR. The latter approach is particularly appropriate for the detection of unmarked graves, as in the absence or following the decay of a coffin; soil perturbation caused by the dig is the most evident feature to be detected by geophysical methods (Moffat 2015; Conyers 2006).

**Reconstruction of Palaeolandscapes** Buried palaeolandscapes provide valuable information for the identification and the understanding of archaeological sites, particularly when surface features are absent. The reconstruction of palaeoenvironments allows an identification of areas with sediment accumulation (and, thus, prospective for preserving archaeological material) and areas characterized by landforms (such as rivers or shorelines) conducive to ancient land use. In addition, it can also provide information about past climatic conditions, which had an impact on human occupation history. Besides terrestrial palaeolandscape reconstructions, which are quite often based on multi-method approaches (e.g. by combining ERT, seismics, geochemical studies), aquatic palaeoenvironments that have been submerged due to



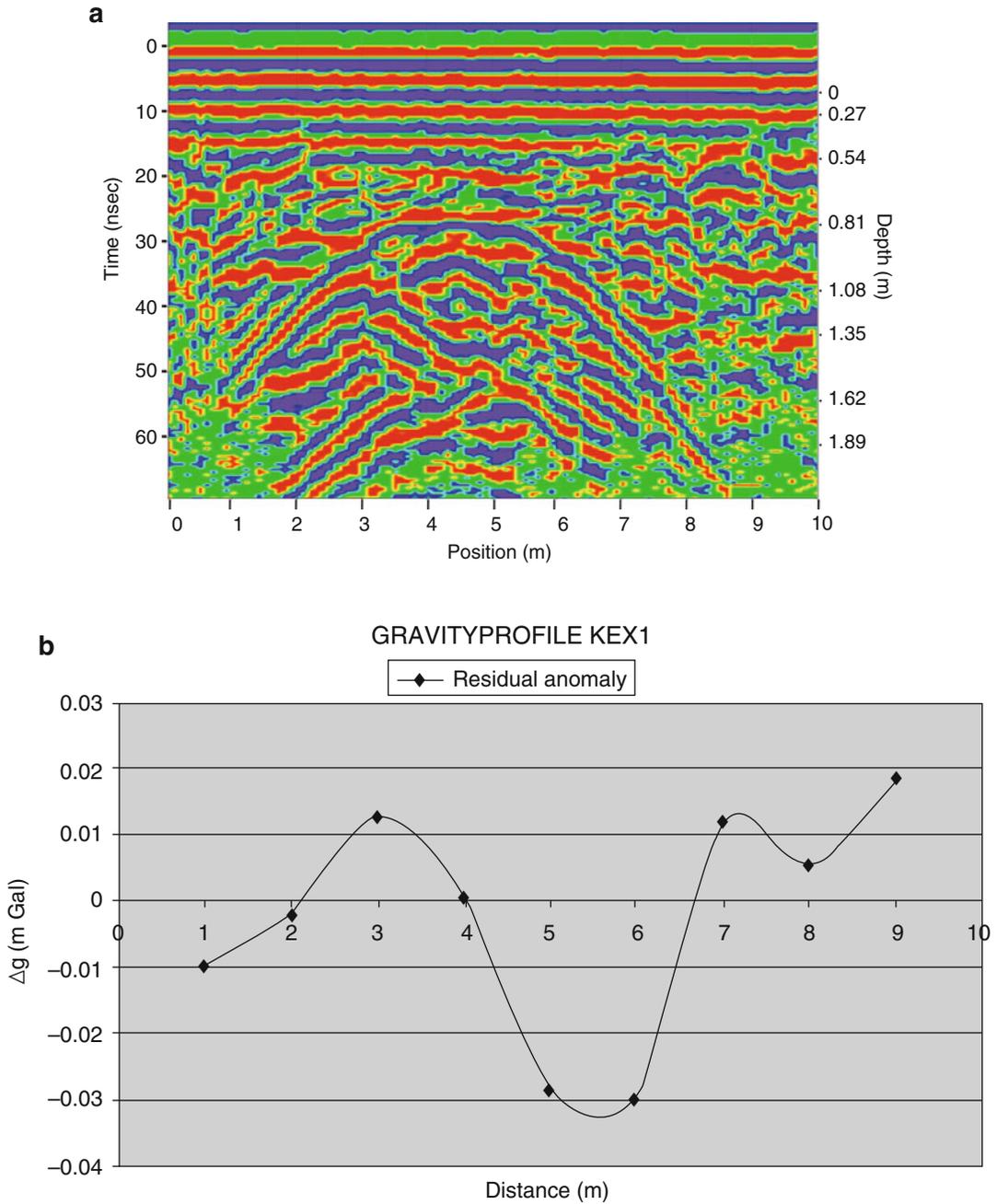
**Fig. 14.11** Typical setup in a seismic survey. The seismic source is needed to generate controlled acoustical waves that are either reflected or refracted at the different

media interfaces to be recorded by the geophones. Geophones convert the velocity of the registered waves into voltage



**Fig. 14.12** Results of a seismic refraction survey at the area of Priniatikos Pyrgos (Istron, E. Crete, Greece), where an assumed ancient port has been hypothesized. The area has been completely covered by alluvial deposits and conglomerates as a result of past landslides and tectonic activity. The image represents the depth to the

bedrock which reaches levels of about 40 m below surface, superimposed on a panchromatic Ikonos image (30 July 2001). The *arrows* represent the seismic transects along which the geophones were placed. The seismic results have also been verified through ERT measurements (Sarris et al. 2014)



**Fig. 14.13** (a) GPR radargram (taken with Noggin Plus GPR with 250 MHz antenna) above a Roman chamber tomb at the Kenchreai cemetery located at Koutsonglia Ridge, north of the harbour of Kenchreai in NW Peloponnese. The tomb has a diameter of 3.55 m and an interior height of about 2.5 m, located at a depth of 1.1 from the ground level. The amplitude of the GPR data is represented by *red* (positive reflection), *blue*

(negative reflection) and *green* (minor dielectric constant differences between the media creating almost no reflective interfaces) colours. (b) Gravity residual anomalies recorded at the same transect using the Lacoste and Romberg model D land microgravitometer. The centre of the tomb chamber is located approximately at the middle of the transect (Sarris et al. 2007)

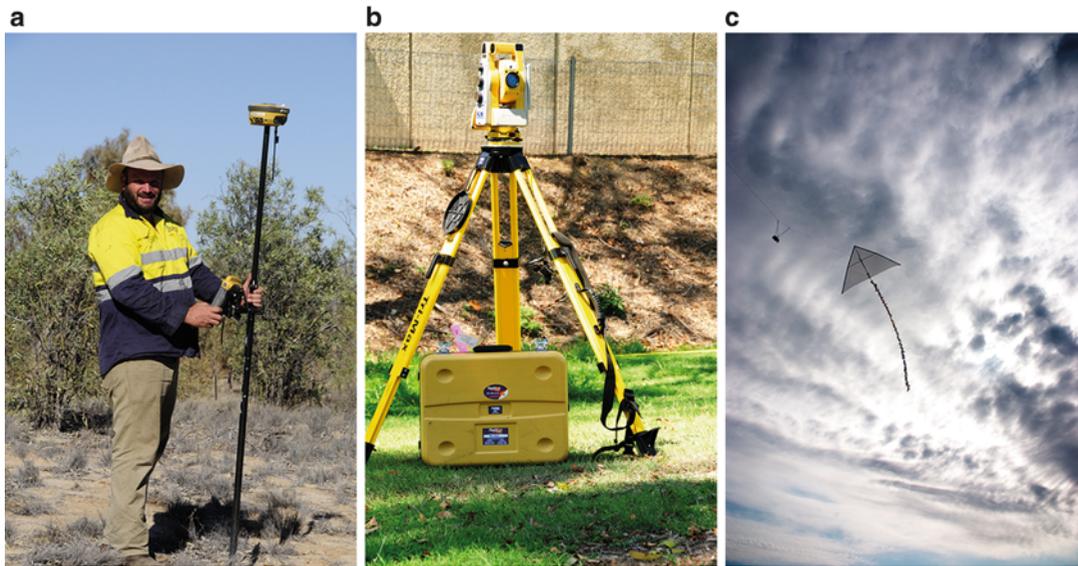
**Table 14.1** Strengths and weaknesses of geophysical methods in geoarchaeological surveys

Method	Strengths	Weaknesses
Ground-penetrating radar	<ul style="list-style-type: none"> <li>• Application in both shallow and medium depth investigations</li> <li>• Suitable for use in both rural and urban settings</li> <li>• Operation in limnic environments</li> <li>• Provision of high-resolution data</li> <li>• Fast data acquisition</li> <li>• Provision of stratigraphy and volumetric images of the subsurface</li> <li>• Ability to map geological and/or geomorphologic features</li> <li>• Determination of the depth to bedrock</li> <li>• Ability to detect voids, caves, tombs, wall structures</li> </ul>	<ul style="list-style-type: none"> <li>• Need of good contact with ground surface</li> <li>• Dependence on climatic conditions</li> <li>• Not possible to operate in marine investigations</li> <li>• Specialized way of data processing</li> <li>• Shielded antennas are required for surveying inside structures</li> <li>• Medium mobility and flexibility of instrumentation</li> </ul>
Electromagnetic induction methods	<ul style="list-style-type: none"> <li>• Application in both shallow and deep investigations</li> <li>• Suitable for use in rural settings</li> <li>• No need of contact with ground</li> <li>• Ideal for large-scale surveys</li> <li>• Large mobility of instrumentation</li> <li>• Provision of both soil conductivity and soil magnetic susceptibility</li> <li>• Provision of information about geology and lithology, stratigraphic changes and the depositional record of a landscape</li> <li>• Ability to detect ditches, pits, burnt architecture, palaeosoils, palaeochannels which may accumulate magnetic minerals through pedogenic or erosional processes (French 2003)</li> </ul>	<ul style="list-style-type: none"> <li>• Not suitable in urban environments</li> <li>• Easy to medium degree of data processing</li> <li>• Difficult to collect multi-sensor data as an array</li> </ul>
Electrical resistance techniques	<ul style="list-style-type: none"> <li>• Application in medium depth and deep investigations</li> <li>• Suitable for use in both rural and urban settings, limnic and sea investigations</li> <li>• Easy processing of the data</li> <li>• 2D and 3D modelling of the subsurface geological strata</li> <li>• Straightforward application in archaeological surveys</li> <li>• Ideal for the detection of deep depositional targets (e.g. ancient ports covered by alluvial deposits, ditches and palaeochannels)</li> </ul>	<ul style="list-style-type: none"> <li>• Need of contact with ground surface</li> <li>• Dependence on climatic conditions</li> <li>• ERT measurements need specialized data treatment</li> <li>• Expensive ERT instrumentation</li> <li>• ERT is relative bulky and slow for extensive mapping</li> <li>• Medium to hard mobility and flexibility of instrumentation</li> </ul>
Magnetic methods	<ul style="list-style-type: none"> <li>• Application in shallow depth investigations</li> <li>• Suitable for use in rural settings</li> <li>• No need of contact with ground</li> <li>• Ideal for extensive mapping surveys with high sampling resolution</li> <li>• Easy processing of the data</li> <li>• Large mobility of instrumentation</li> <li>• Detection of ferrous or burnt features, metal objects</li> <li>• Mapping the extent of pedogenic soil minerals</li> </ul>	<ul style="list-style-type: none"> <li>• Not suitable in urban environments</li> <li>• Dependence on terrain conditions</li> <li>• Very sensitive to metallic objects</li> <li>• Not appropriate for sediment stratigraphy studies</li> </ul>
Magnetic susceptibility methods	<ul style="list-style-type: none"> <li>• Application in shallow investigations</li> <li>• Suitable for use in rural settings</li> <li>• Ability to map the depositional conditions at archaeological sites and the occupation layers</li> <li>• Detection of extension and intensity of occupation</li> <li>• Provenance of archaeological materials</li> <li>• Proxy for the success of the magnetic survey</li> </ul>	<ul style="list-style-type: none"> <li>• Not suitable in urban environments</li> <li>• Need for Laboratory measurements</li> <li>• Not appropriate for high resolution or extensive surveys</li> </ul>

(continued)

**Table 14.1** (continued)

Method	Strengths	Weaknesses
Acoustic procedures	<ul style="list-style-type: none"> <li>• Application in medium depth and deep investigations</li> <li>• Suitable for use in both rural and urban settings, limnic and sea investigations</li> <li>• Ability to map the sediment stratigraphy and reconstruct the palaeotopography and the depth to bedrock</li> <li>• Ability to map large monumental structures and mounds</li> </ul>	<ul style="list-style-type: none"> <li>• Need of good contact with ground surface</li> <li>• Specialized way of data processing</li> <li>• Slow method for mapping surveys</li> <li>• Medium to hard mobility and flexibility of instrumentation</li> <li>• Expensive instrumentation</li> </ul>
Microgravity	<ul style="list-style-type: none"> <li>• Application in shallow and medium depth investigations</li> <li>• Ideal for detection of voids, caves and monumental structures</li> </ul>	<ul style="list-style-type: none"> <li>• Very expensive instrumentation</li> <li>• Not suitable in urban environments</li> <li>• Tedious data processing</li> <li>• Not appropriate for extensive mapping</li> </ul>
Chemical analysis	<ul style="list-style-type: none"> <li>• Provision of information regarding agricultural and workshop activities, animal husbandry, construction of ditches</li> <li>• Reconstruction of past land-use practices</li> </ul>	<ul style="list-style-type: none"> <li>• Need for Laboratory measurements</li> <li>• Not appropriate for high resolution or extensive surveys</li> </ul>
Gamma spectroscopy	<ul style="list-style-type: none"> <li>• Fast survey</li> <li>• Ability to map soil types</li> <li>• Appropriate for sediment stratigraphy studies</li> </ul>	<ul style="list-style-type: none"> <li>• Sensitivity and reliability issues</li> </ul>
Aerial and satellite remote sensing	<ul style="list-style-type: none"> <li>• Provision of multispectral information</li> <li>• Provision of a digital terrain model (DEM)</li> <li>• Ideal for regional landscape studies</li> </ul>	<ul style="list-style-type: none"> <li>• Limitation to shallow depth investigations</li> <li>• Dependence of the time of imagery, crop growth, spatial resolution of the satellite platform</li> <li>• Specialized software for data processing</li> </ul>



**Fig. 14.14** (a) Differential GPS being used to survey an archaeological site in NE South Australia. (b) Robotic total station being used for mapping a cemetery in Queensland, Australia. (c) Camera attached to a kite for acquiring aerial photos from the Neolithic site of Perdika 2 at Thessaly, Central Greece. (d) Satellite image of the urban plan of the ancient city of Ferai (Central Greece);

pansharpened IHS transformation of the 15 June 2009 Quickbird image showing linear features associated with roads to the northern fields. (e) Same image as in (d); modified simple ratio (MSR) transformation of the 4 May 2010 GeoEye-1 image indicating the projection of the above features to the southern field (Sarris et al. 2015b)



Fig. 14.14 (continued)

sea level rise are primarily investigated by acoustic methods (Tizzard et al. 2015).

## 14.4 Final Remarks

Geophysical techniques can make a significant contribution to geoarchaeological investigations. They allow non-invasive and rapid imaging of archaeological landscapes and help answer scientific questions by considering a site integrally along with its environmental surroundings. The methodological spectrum includes the investigation of the site stratigraphy, the mapping of remnants of past human occupation and the reconstruction of palaeolandscapes. Each method has its own merits and limitations, and it is through the combination of the various techniques that various aspects of the archaeolandscapes can be addressed (Sarris, 2013, 2015) (Table 14.1).

It has to be noted though that geophysical prospection techniques cannot and shall not independently address all questions arising from the archaeological research. Moreover, they are usually combined with other applications spanning from topographic mapping and geomorphometry of the landscape using LiDAR, DGPS units, robotic total stations and 3D laser scanners to aerial reconnaissance and satellite remote sensing (Fig. 14.14). Only the integration of the above-mentioned techniques with on-site excavations can provide a more holistic approach to the questions related to the interaction between human occupation and landscapes.

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