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DIPLOMA THESIS

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"Geophysical Mapping Methods: the case study of Veria in Chalkidiki"

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Abstract

This diploma thesis is divided into four chapters.In the first chapter, there is a referring to the history, progress of the geophysical methods over the years and their adaptation in archaeology. The chapter concludes with the presentation of various applications of these methods within the Greek territory, for archaeological purposes. The second chapter reports the main geophysical methods, are applied for detecting antiquities, focusing on the Magnetic and Electrical resistivity methods. In the third chapter, the archaeological excavations combined with the geophysical surveys applied in Vergina are presented, as an innovative, for our country, teamwork, in a very important archaeological site of Greece. Finally, in the fourth chapter is presented the archaeological site of the Toumba of Veria, N. Syllaton, previous excavations and a geophysical survey of 2017, by the magnetic method.

Contents

INTRODUCTION

As it is known, classical archaeological methods require an enormous expenditure of human energy. Today, archaeology has the need for fast and accurate mapping of the preferable sites of archaeological/cultural interest to dig, with sophisticated ways and methods (Tabbagh 1986). Archaeologists prefer to avoid unnecessary excavations,to limit the manpower and, usually, the size of the excavated area, mainly for planning purposes(i.e. accessibilityor legal issues, timelines). It must be mentioned that in some parts widely, the excavation survey requires permits that are difficult or practically impossible to obtain (Gaffney 2008). Moreover, an extended excavation has become an increasingly expensive processand the archaeologists prefer to choose methods with rapid and more focused results, to avoid costly techniques when it is possible.

Expect of that, it is known that during an excavation a lot of the existing archaeological information is destroyed by the procedure itself and its destructive invasive. Geophysical techniques have also partly filled this gap, due to the increasing reliability of the instruments and the explosion in computing technologies. Thus, bychoosing one of them or a combination of them lots of information are preserved. These properties have led to increased utilization of these methods in archaeological investigations. In nowadays,the most common form of geophysical investigation tool used for archaeological purposes is magnetometry(Gaffney 2008).

The great success of this method is based on the fact that almost all soils exhibit an enhancement of magnetic susceptibility in the topsoil. In our geophysical survey in Vergia Chalcidice we applied that method, using a fluxgate magnetometer. It was chosen due to lack of humidity during our survey period (in early July).

After the magnetometric survey, another method was applied there, the electrical resistivity method, that provided very important results. That survey took place during the winter, under damp conditions.The electrical resistivity method is equally useful in archaeological research and is perfectly related to the presence of moisture in the soil.These two methods are the most popular in Archaeology, usually combinedtogether for more completed results (for example, for direct detection of wall footings resistivity methods provide better results) (fig. 12) (Schmidt e.al. 2015). Of course, there is an abundance of other methods, based on different principles, alsoapplied for archaeological purposes, such as electromagnetic or gravitational methods.

A.1. A BRIEF HISTORY OF GEOPHYSICAL METHODS AND THEIR APPEARANCE IN ARCHAELOGY

From the 2nd century BC, it was known that the magnetic rod is orientated in the Earth's magnetic field. After almost two millennia, in 1600, the English physician and scientistW.Gilbert wrote a book in which he claimed that Earth can be regarded as a giant magnet. Seven decades later, J.Richer proceeded deeper, demonstrating that the gravitational field on the Earth's surface varies from place to place(Γιαννόπουλος 2014). The first who made accurate measurements of the geomagnetic field elements was Gauss, in 1834 (Daveport 2001).In modern times, with the use of all these

previous knowledgeas a basis, there is rapidly increasing the sophistication of geophysical methods and instrumentations. That has been mainly driven by the need for detection of oil fields(petroleum) and minerals and also by the necessity of developments for military purposes. To serve these modern needs, new approaches for the characterization of the earth's structure and composition at greater depths were required.

Very soon, it became perceptible the serviceablenessof applied geophysical methods in the service of Archaeology. Nevertheless, while natural principles were the same, the relatively small size of the archaeological evidence in combination with the lower depth of research led to the search of more targeted ways for investigation. As a result, a new, more specific sub-category of geophysics arose, currently referred as "archaeological geophysics" (Γιαννόπουλος 2014).

Already since the mid 1940s, archaeologist have been using classical geophysical methods for the completion of their archaeological researches(Daveport 2001).The first use of modern methodology was held in 1938, over the site of a suspected buried vault, in Virginia,USA, without the desired results. But, the utilization of geophysics to Archaeology was originally established in Europe, with the UK as the pioneer(Linford 2006)! In 1946, that Richard Atkinson successfully launched electrical resistance measurements at archaeological sites and the things were changed. Until the late 1960s his technique was further reinforced by the use of a transistor and of the Bradphys automatic electrical resistance meter, efficient to the detection of shallow archaeological features(Daveport 2001). Subsequently, archaeologists became familiar also with the magnetic surveys, as the development of another successful technique was initiated by Martin Aitken in 1958 (Γιαννόπουλος 2014).Because in archaeological research magnetic anomalies are not so intense, he realized that high sensitivity equipment was necessary and thus, he started to develop proton free precession magnetometers(Aitken 1974).Initially, this technique was rapidly developed due to the discovery of kilns in a site called Peterborough, in United Kingdom (Linford 2006). The next years, he proved that the method could also recordother soil features, such as ditches.

During the 1960s, new achievements widened the abilities of magnetometry. Some of them are mentioned beyond;I.Schollar properly adjust a new sensor configuration for conducting of large-scale surveys, digital recording of measurements was feasible, J.Alldred and F.Philpot introduced the fluxgate magnetometers, for large coverage of an area, with measurements of high speed and also Ralph introduced types of magnetometers of high sensitivity, the alkali vapour magnetometers (Linford 2006).With the passing of time, various geophysical methods were available for use in Archaeology;high-resolution seismic, ground radar, self-potential methods are some of them (Wynn 1986).

A.1.i. Application of geophysical methods in archaeological sites of Greece

In our country, geophysical methods have been widely applied for archaeological purposes. From Sarris and Jones (2000) we have an overview of the most of the geophysical survey sites in Greece up to the end of the millennium.

Fig. 1. Geophysical surveyed sites in Greece up to the end of the millennium, presented by Sarris and Jones(2000)

The case studies will be briefly presented, grouped by method, such as it is suggested by Sarris and Jones(2000).

The area of Europos in N.Greece (publication of Tsokaset.el. 1994; Tsourlos e.al. 1996), has been surveyed, among others, with the use of electrical resistivity prospecting, detecting town plans. Similar case studies have been carried out in Mantineia in S.Greece (publ. of Papamarinopoulos et.al. 1993; Sarris 1992: 193-280) and in Stymphalos in S.Greece (publ. of Williams 1985; Papamarinopoulos, Jones et.al. 1988).

With the same method have been investigated Dion in Eretria, Evia (publ. ofTsokas and Kyriakidis 1988; Rocca 1992), Knossos (publ. of Shell 1997) and Mallia, in Crete (publ. of Rudant and Thalmann 1976), identifying remains of towns and settlements.

Walls and fortifications have been detected in Louloudies in Pydna (publ. of Poulter 1996), in Limori/Epanomi in Thessaloniki (publ. of Tsokas et.al 1996), in the island of Mytilene (publ. of Papamarinopoulos et.al. 1985; 1986; Williams 1984) and in the

site Vrondas in Crete (publ. ofPapamarinopoulos and Tsokas 1988). Finally, in Poliochni of Lemnos (publ. of Bozzo et. al 1995) resistance mapping were applied at the environs, revealing their stratigraphy.

Magnetic techniques have been used for the localization of thermoremanent structures and more specific kilns. The three sites are mentioned are Louloudia in Pydna (publ. ofAedona et.al 1998), Panakton, Boeotia (publ. of Papamarinopoulos, Munn et.al 1996) and the island of Thasos (publ. Jones 1986).

Moreover, town plans have been reported in Dimini, Volos (publ. of Sarris 1998; Johnson et al 1999), in Elis in S.Greece (publ. of Ralph 1968), in Europos (publ.ofTsokas et al 1994; Sarris 1992: 281-361), in Knossos(publ. of Shell 1997), in Mantineia, S.Greece (publ. of Papamarinopouos et al 1993; Sarris 1992: 185-190, 193-280; 1993) and in Palaikastro in Crete (publ. of Lyness and Hobbs 1984).

In Pierria, in the site where is located the Castle of Platamon, building remains have been detected (publ. of Katsampalos and Tsiounis 1991). Furthermore, a series of building structures and features have been localized in other places, too. A port and other sites were reported in NikopolisEpiros (publ. of Sarris, Weymouth et al 1996) and fortress, structures and a hippodrome in Istmia of Korinthia (publ.of Gregory and Kardulias 1990). In Lefkas, a castle was investigated (publ. of Savvaidis et al 1999), in Makrygialos in Crete a Neolithic settlement (publ. of Tsokas et al 1997) and also in Theologos in Rhodes (publ. of Sarris, Marangou et al. 1996) while in Vronda/Kavousi tombs (publ.of Papamarinopoulos and Tsokas 1988).

Electromagnetic techniques were used in Delos have discovered coins (publ.of Foster and Hackens 1969), in Europos tombs and metallic objects(publ. of Tsokas et al 1994) and in Isthmia have been surveyed the hippodrome (publ. of Sarris 1998). In Makrygialos (publ. of Tsokas 1997), in Poliochni (publ. of Bozzo et al. 1995), in Pylos, in the site of the Palace of Nestor (publ. of Zangget et al 1997) and also in Stymphalos (publ. of Cross, in Williams et al. 1997: 69-73), buildings have been revealed. Finally, these techniques have been applied on the roman port ofNikopolis (publ. of Sarris, Weymouth et al. 1996) and on a road in Mantineia (publ. of Papamarinopoulos and Sarris 1992).

In a survey at Akrotiri in Thera (publ. of Papamarinopoulos e al.1996) two-storey houses have been investigated by using a ground penetrating radar. In Athens (publ. of Papamarinopoulos and Papaioannou 1994)and in Chalasmenos (publ. of Sarris 1998) the measurements have localized river beds and Minoan tombs,correspondingly. Tombs have also been scanned at Europos area (publ. of Tsokas et al. 1994).

Use of GPR have also been made in Lefkas in W.Greece (publ. of Savvidis et al. 1999) to castle reservoirs and galleries and in the coastline of Palaikastros (publ. of McCoy 1997). Moreover, on subfloor voids at the Peristeri I cave (publ. of Bartsiokas 1996) and on strata of pumice in Thera (publ. of McCoy 1997),too.

Some seismic techniques have been appliedin a Macedonian monumental tomb of Pella(publ. of Vafidis et al. 1995). This method, in Falasarna in Crete (publ. of Papamarinopoulos and Stamou 1988) revealedthe ancient shore and also defensive

and other types of structures. Seismic techniques have been combined with GPR during surveys inItanos in E.Greece (publ. of Sarris et al. 1998) and Xerxes Canal in Chalcidiki (publ. of Karastathis and Papamarinopoulos 1997: Jones et al. in press). In Itanos, the ancient port and other archaeological features were revealed, while in the location of Xerxes Canal parts of the canal structure.

Due to the fact that Sarris and Jones(2000) have collected and presented case studies of the previous decades it should be proper a reference in more modern case studies have been made.

Indicatively, resistance tomography have been carried out inHelike, Diakopto(S.Greece)(Tsokas et.al. 2009) where a roman road was scanned. With tomography and GPR has been made an estimation about the present condition of the south walls of Acropolis, Athens (Tsourlos and Tsokas 2011). Electrical resistance method were applied in Ag. Vassileios, Sparta (Tsokas et.al. 2012) and revealed buildings and graves and town plans in the area of the theatre of Campania, Maronia (Τσόκαςκ.α. 2011); this survey was combined with a magnetic prospecting survey. Finally, a recent case study is that of Torone, Chalkidiki (Beness et.al 2015) Surveying with an electrical resistance technique were detected Classical houses and remains of terraces walls.

B. A PRESENTATION OF THE MAIN GEOPHYSICAL METHODS

A GENERAL CLASSIFICATION

In a brief description, magnetic methods are used to detect magnetic subsoil deformations/anomalies. Electrical and electromagnetic methods define the geoelectric structure of the surface layers of the Earth's crust, while seismic are the most accurate to determine the structure of the layers of the crust. Finally, the gravitational methods are used for the determination of the density distribution of rocks.

To begin with, there are two categories in which the geophysical methods are separated in, depending on their principles and function (Gaffney 2008). In the first category are included measurements of physical fields or properties of the earth. Because in these fields simply measures of spatial changes are carried out and from them come out the conclusions about the sub-geological geology, they are called passive geophysical surveys. These passive methods include magnetic and gravitometric fields (Daveport 2001).

On the other hand, the other category, in which the active geophysical surveys are part of, follows different principles. In these cases signals are input into the earth and the measurements are carried out of the ways the earth responds to these. A variety of forms of signals can be used such as electrical current (Daveport 2001). In these active geophysical searches belong methods such as the electrical resistivity and the magnetic susceptibility.

Method	*Active or passive*	*Frequency of use*
Magnetometry	Passive	High
Electrical resistance/resistivity	Active	High
Ground penetrating radar	Active	High–middle
Electromagnetic	Active	Middle
Magnetic susceptibility	Active	Middle
Metal detectors	Active	Low
Seismic	Active	Low
Microgravity	Passive	Low
Induced polarization	Active	Low
Self-potential	Passive	Low
Thermal	Passive	Low

Table 1. Presentation tablet of the methods separated in active and passive and their frequency of use (Daveport 2001).

It is obvious from above (Table1) that some of them are more frequently used than others. This is because every method has different dynamic, advantages and disadvantages and there are various factors that affect their efficacy.

In general, data arising from a geophysical survey can be affected and sometimes misinterpreted due to four main factors: resolution, signal/noise ratio, contrast, and size/depth relationship(Daveport 2001). Thus, from the very beginning should be selected the most suitable prospecting tools to be used, depending on the environmental conditions and the aims of the survey. Furthermore, the acquired data must be processed and interpreted properly.To become more specific, the aforementioned factors will be briefly presented.

Resolution

With the term “resolution” is referred the ability to differentiate objects and structures that are in proximity. There are two types of closeness, the physical one (the physical proximity of structures/objects) and that is related to similarities in physical properties. To avoid false results, the right choice of capable instruments, with suitable settings, must be gotten.

Signal/Noise Ratio

Background noise is a factor that, if it is strong enough, limits the high quality of data. Thus, it is necessary the strength of the signal being measured to be more than the strength of randomly generated background signals. These signals are of two different origins. The first category, the natural noise-random signals, is emanated from naturally occurring conditions and events; for example, solar flares, telluric currents and rainfalls. The problem is that natural noise is not always evident until an actual survey is being performed, and thus, the data are examined in the field. The other category, the cultural noise-spurious signals, is obviously produced by man-made activities; metal fences, electricity cables, traffic, underground utilities are some of them. Unlike the natural noise, the sources of cultural noise are often easily visible or detectable during the planning phase of a survey.

Contrast

The archaeological remains present contrasts compared with their surrounding earth's materials, due to theirdifferent magnetic susceptibility. During a geophysical survey contrasts can be detected only if they are not very weak; and, of course, the sensitivity limitations of the measuring instrumentation plays a major role. To become more specific, to have a strong resulting signal and thus, more chances of detection, the contrast in the properties of the target with the corresponding properties of the host material it is desirable to be of high scale.

Size/Depth Relationship

An instrumentation with abilities that allow high penetration can take measurements in high depths, but, at the same time, the resolution is reduced; the deeper the signal penetration, the less the resolution! Exceptthe noise and the contrasts between the targets and the environment, as they are mentioned before, the size of the target and the frequency of input signalsare two very important factorsaffecting the measurements. First of all, an object or structure of big size can be detected in higher depths than a smaller one. Moreover, in geophysical methods that relatively low-frequency signals are input into the ground, deep penetration results are also provided; this because signals of low-frequency are not weakened by the earth as much these of higher frequency.On the other hand, although the high-frequency signals are not so capable concerning the depth, they give measurements of better resolution.

Except of these factors, anomalies presented in data should be investigated and understood based on the capabilities and limitations of each method, as well as its instrumentation and interpretation of the data, always figuring out parameters, such as types of soils, geology or climatic conditions of the surveyed site.

B.1. MAGNETIC PROSPECTING METHOD

Magnetometry is among the most developed geophysical methods for the detection and mapping of archaeological sites. Itoffers the most rapid ground coverage of the various survey techniques and responds to a wide variety of archaeological features (Schmidt et.al.2015).

The magnetic prospecting method has the property to detect strongly magnetized structures as well to outline soil features, such as pits and ditches (Piro et.al.2001). It is based on the detection of variations in surface magnetism through the detection and recording of local changes in magnetisation on Earth's cortical materials (Τσόκαςκ.ά.2011). The fundamental parameter that controls the changes is the magnetic susceptibility of the rocks, which does not change only between different rocks;also esoteric changes can occur in a rock (Γιαννόπουλος 2014).

The remains of past human activity usually have different magnetic properties than those of the hosted environment. Therefore, the local magnetic field is generally changed. This small deformation of the magnetic field is seen as anomalies, i.e. as relative contrasts between the subsoil and magnetically enhanced topsoil (Schidt 2009). Thus, the aim in archaeology is to interpret such kind of anomalies in terms of possible archaeological resources. The field of anomalies, together with the earth's magnetic field (i.e. the total field) can be measured by a magnetometerin Tesla or in nano Tesla and mapped combined with its identified anomalies. Something must be underlying is that the anomalies' shapes change depending on the interaction between the earth's and the localized magnetic field(Piro 2009).Except of that, when the magnetometers detect magnetic anomalies it is very important to become clear the discrimination between induced and remanent based anomalies (Fassbinder 2015), to understand the nature of the target.After the magnetometer survey, data plots can be produced, as conventional displays of the buried archaeological structures. For the calculation of the magnetic field of each localized feature is very useful to represent it as a 'magnetic dipole'.

Induced magnetism (the magnetization of a sample in the presence of the magnetic field)(Fassbinder 2015)

Topsoil carries a much higher magnetic susceptibility, due to the enhancement of ferromagnetic minerals, in addition to the underlying substratum (Aiken 1974). This phenomenon can be observed even on soils with high susceptibility of volcanic origin and background. Although these heavy ferromagnetic minerals are produced in the topsoil, they end up in ditches, pits and postholes, creating a magnetic irregularity above the ground. Induced magnetization would be disappeared if the earth's magnetic field ceased, following any changes in the direction of earth's field.

In brief, this deposition, enrichment and separation of them can be mainly the result of soil heating by intensive use of fire by human activity, wood fires and natural fires. Furthermore, there are other culpable factors, such as mechanical procedures (by waterpaths or winds) and pedogenic processes in soils.

To become more specific, first of all, through heating, in reduction conditions and under the presence of organic matter, weakly magnetic iron oxides contained into soil can be transformed to other forms, of higher magnetization (Schmidt 2009) (i.e. haematite to magnetite or maghaemite).

Secondly, the phenomenon of fermentation plays major role for the reforming of weakly magnetic iron oxides to more magnetic; this is caused by microbes that thrive

in rich organic deposits, during dry weather periodsand have the capability to change soil conditions and trigger this conversion (Fassbinder 2015).

Expect of microbes, the act of some specific bacteria can also increase soil magnetic susceptibility. The magnetotactic bacteria create intra-cellular crystalline magnetite that navigates in Earth's magnetic field. These crystals remain in the soil even after the death of the bacteria and enhance the soil susceptibility.

Magnetic materials of human action, such as fragments of pottery or broken bricks that are often found as discard or rubbish, can also produce magnetic enhancement of topsoils.Finally, mechanical and pedogenic processes can cause similar results in the soil; for example, during soil formation processes, caused by human influence or naturally.

Remanent magnetization (the permanent magnetization of a sample in the absence of an external magnetic field)(Fassbinder 2015)

Remanent magnetization is created once and it is permanent on a material (Aitken 1974). It is produced due to the mineral composition of the material and/or previous heating/s.The difference with induced magnetism is that, even if the earth's magnetic field alters its direction, remanentmagnetization will be always stable. From the comparisonof the remanentmagnetizationof a material with calibration curves for ancient directions of the earth's field the exact date for the last heating event can be detected. Thus, it is used as the basis for 'archaeomagnetic dating' (Schmidt 2009).Most soil features that have been exposed to high temperatures during heating (e.g. kilns, kilnfired bricks) or burning (e.g. burnt walls or houses) acquired remanentmagnetization and exhibit a detectable magnetic contrast.

Magnetic susceptibility and Archaeology

Anthropogenic activity oftenlocalize concentration of soils and sediments with an increased magnetic susceptibility, producing detectable anomalies, even in the absence of the heating mechanism of enhancement (Gaffney 2002). In general, magnetic susceptibility is a measure of the degree to which a substance can be magnetizedby an external (weak) magnetic field. It is defined as the ratio of the enhanced magnetization to the inducing field, i.e., it quantifies the response of each material to the external field. A magnetic field may be applied at various positive and negative strengths and it is possible to be calculatedboth the induced and the remanent magnetization (Dalan 1998). The magnetic susceptibility of soil is not stable or common across an area, even over a short distance. Due to that fact, the estimation of values for areas between actual measurements should be avoided. 'Symbol plots' is often the most appropriate display formatof arising data (Schmidt 2009).

There are two ways for the conduction of the research. First of all, the laboratory determination of susceptibility for a standard volume or mass, by collecting indicative soil samples(Gaffney 2002). This way provides accurate data but requires much time. On the other hand, more flexible is to take measurements from the field's surface directly. In that caseappropriate field instruments are necessary. The most commonly used instrument for that purpose is the "MS2 Field Coil"(Schmidt 2009). Although ithas a penetration depth of no more than 0.1 m, allows the rapid assessment of topsoil

magnetic susceptibility. The investigated area can either be mapped in detail, if the aim of the process is the revealing of individual archaeological features (e.g. charcoal burning areas), or with sparser sampling (e.g. 5-20 m);that provides an overview of the magnetic susceptibility variation of the area and can also identify ‘hotspots’,that are underlined and can be used for further investigation with higher spatial resolution (Schmidt 2009).

B.1.i<u>Magnetometers</u>

Magnetometers have been used for archaeological purposes for more than fifty years and the instrument of primary choice seemed to be the scalar proton magnetometer, but it quickly fell out of fashion(Aitken 1974).In a concise description, the sensor of a proton magnetometer contained liquid rich in protons and coil of polarization and collecting. Their slow rate of readings producedsensitivity of about 0.1nT, absolute accuracy, but also, noise in nT range (Hrvoic 2010).Nowadays, the types with frequent use in Archaeology are two (Scollar 1990). The first are thefluxgates, which are vector magnetometers. Proton magnetometers are sometimes used for calibration of fluxgates. The second type is the scalar alkali-vapour magnetometers, equipped with more efficient systems for ground coverage than their precursor (the proton magnetometer)(Gaffney 2008).

The first ones are usually required when conditions of high magnetic or electromagnetic noise predominate in the under examination field (i.e. gradiometers can survey in closer proximity to modern ferrous objects such as pylons, wire fencesetc). They have fast paces of readings, sensitivity of the order of 0.1nT and lightweight design (Fassbinder 2015). In our country, such as in UK, the fluxgate magnetometers are the most commonly used instruments in Archaeology.

In other European countries, the second type,the alkali-vapour magnetometers, also known as optically pumped or caesium magnetometers, has become more popular, though it is of very high cost!(Fassbinder 2015)The optically pumped sensors are very significant during measurements at places with very weak soil susceptibility contrast or surveys that fast results are of high importance (Scollar 1990). They can make maesurements at similar rates to fluxgate system and their sensitivity is in order of 0.05 nT to 0.01 nT (Fassbinder 2015). Although, to avoid or limit possible random error measurements the operator should mount them on some form of mobile platform or cart (Schmidt 2015)!

These two types of magnetometers have a basicdifference.The optically pumped magnetometers measure the total absolute magnitude of the local magnetic field. (Fassbinder 2015) Inaddition, the quantity measured by the fluxgates is a component of the earth’s field intensity, usually the vertical one(Aitken 1974).

Furthermore, their sensors’ arrangements are quite different and respond to the solution of different problems to the data collection. Because the earth’s field varies slightly throughout the day, suitable sensor’ arrangement is required (Schmidt 2009). Sometimes, it also shows very strong and rapid changes. During intense changes like them, i.e. “magnetic storms”, it is preferable to avoid to take measurements. The diurnal variations are a result of the greater proximity to the sun during daytime,

while the “storms” are caused by the ‘solar wind’ that emits charged particles, interfering with the earth’s magnetic field (Τσόκας 2004).

A fluxgate magnetometer can be operated as gradiometer, with two instead of one sensors (one above the other) for the subtraction of the part of the magnetic field (the temporal variations of the Earth’s field) that is common to both sensors and for thereduction of the directional errors.On the other hand, optically-pumped magnetometers can also be used in gradiometer configuration,but for different purposes; they are capable to expunge the diurnal variation of the earth’s field (Fassbinder 2015).

Of course, there are also other types of instruments, with lower frequency of use; for example, the vector SQUID is a magnetometer of very high sensitivity range. The magnetic field resolution of the SQUID is approximately 0.00002 nT (Schmidt et al 2015). It operates at cryogenic temperatures and it is used for tensor calculations or short base gradiometers (Hrvoic 2010). Its advanced sensors allow much higher samplings rates than conventional magnetometers; hence, operating as a vehicle-towed array, they are ideal for rapid data acquisition over surveys of large areas (Schmidt et al.2015).Although it is so sophisticated, its use is rare. The main reason is theneedforcryogenicsupplies,which reduces the mobility of SQUID magnetometers (Nabighian et al 2005).

Fig.2/ 3.Handheld signal fluxgate magnetometers (Jones 2008); (Gaffney 2002).

Fig.4(left)Handheld magnetometer in dual sensor configuration (Jones 2008)

Fig.5 (right)Dual channel fluxgate system (Jones 2008)

Fig.6Acaesium magnetometer (Jones 2008)

Fig.7A4-channel fluxgate system (Jones 2008)

Fig.8 (left)Cart mounted magnetometer systems: four caesium sensors mounted at 0.5m intervals(Jones 2008)

Fig.9 (right) Two sets of SQUID gradiometers mounted at a 0.5m interval(Jones 2008)

B.1.ii THE FLUXGATE GRADIOMETER. IMPLEMENTATION ON THE FIELD

Configuration, capabilities and limitations of the device

If the use of a fluxgate gradiometer is the most proper choice for the field conditions under investigation, must be taken into account the abilities and the weaknesses of the instrument.

It consists of two matched cores of highly permeable material. In each core primary and secondary windings are wrapped around. The primary windings are connected in series but with opposite orientations, driven by current of 50-100Hz. This causes saturating to the cores in opposite directions, twice per cycle. The difference between the magnetic field produced in the two cores is measured by a differential amplifier connected to the secondary coils (Nabighian et.al.2005).

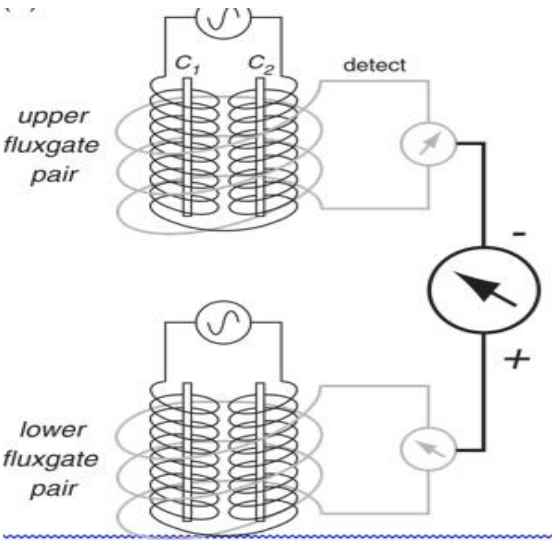

Fig.10The construction of a practical field gradiometer (Linford 2006)

The first potentiality of a sophisticated magnetometer as a fluxgate gradiometer is its double usage (www.geoscan-research.co.uk). First of all, it has the capability to be operated as a signal stand-alone gradiometer or either in dual mode. When dual mode is used, two instruments are combined together, to double the speed of the survey. Moreover, by modifying their traverse pattern, the instruments can increase the survey density up to four times.

The second usage of this magnetometer configuration is the scanning mode, if the aim is rapid search for disturbed areas (www.geoscan-research.co.uk). A modern device is equipped with an LCD display that permits the direct display of readings in digital or analogue bar-graph form. This property is very useful for the scanning process.

Other benefit of the fluxgate magnetometer is that it has a huge memory and excellent stability. When Geoplot software has been integrated to the device the drift correction logging is unnecessary.

The biggest advantage is that gradiometer can survey in closer proximity to modern ferrous objects and thus, it is very usual to be chosen for magnetometer survey near roads e.tc. Transient magnetic anomalies caused, for example, by passing vehicles and affect the measurements can be reduced by the instrument itself. That is very important because some of these anomalies cannot be easily filtered out by post-processing (Schmidt 2015).

On the other hand, although this configuration excels at the discrimination of anomalies in close proximity to the sensors, it shows some weaknesses. This property affects its detection limits about the maximum depth at which it is capable to detect buried remains. Thus, for the detection of deeply buried features (e.g. in alluviums),total field systems are more suited (Schmidt 2015).

B.1.iii Implementation

Preliminary preparation of the field.

First of all, before the direct contact of the survey team with the field, a “view from above” is always very helpful for the overall planning of the survey.Aerial photos is a common method, with huge benefits (e.g. in very large areas) and of low cost. It is used intensively at the last decades.Today, satellites are also used to provide pictures of high quality. Google Map, for example, is an application, widely spread in our time, with open access to the public.

At the next stage, the preparation is becoming more practical and active. The area under investigation must be “cleaned up”, at least, of the majority of mobile modern ferrous objects; therefore, the acquired data will be almost uninfluenced. After that, the entire area must be divided into sections. That division is carried out with several ways; typically, into a series of sub-grids, regular square or rectangular blocks (Schmidt 2015). There are, although, cases that some more sophisticated

magnetometer systems integrate with a GPS system and log the position of each measurement directly, eliminating the need for pre-established grid.

At the beginning of the survey the device must be correctly prepared. The fluxgate gradiometer requires about twenty minutes to adapt to the site conditions, because it is of high sensitivity to variations in temperature. After that, the operator must complete the preparation, firstly, by 'balancing' the gradiometer, by aligning the two sensors along the vertical axis. Secondly, in an area of uniform magnetic field and preferable the same during the survey process, the operator must adjust to zero the device (calibration of the measurement scale of the local conditions)(Schmidt 2015).

During the preparation and before every measurement, all the team of the survey and especially the operator, must be sure that all sources of magnetic inference have been removed from their clothes, shoes and accessories (e.g. sun glasses or hat with metal details). Of course, there is a possibility, during the survey, magnetic material to cling on footwear or/and even to the instrument itself (e.g. accumulation of soil). Consequently, that can have effects on data quality!

Every grid section must methodically surveyed by conducting a series of equally spaced parallel traverses across it with the instrument. Measurements are recorded at regular, closely spaced, intervals along each traverse. This is usually achieved by tuning the device to take readings at fixed time intervals, in combination with an audible time signal to ensure an even pace. Another way is by recording fiducial markers at regular distances so that variations in pace can be subsequently corrected for.

Afterthe measurements being completed and saved on a computer device, follows the data processing. It is necessary the processing and the final interpretation of data to be as diligent and accurate as possible, to avoid erroneous results (Schmidt 2015). Although, there are possibilities some anomalies to have more than one explanation and the interpretations are always uncertain in a variable degree!

B.1.ivData arising of a survey with magnetometer

Almost always, structures that have enhanced magnetic susceptibility, such as cooked clay or stone, from pyrogenic or metamorphic rocks (ovens, domestic hotplates, trenches, etc.) cause positive anomalies. On the contrary, paved roads, underground gaps, walls andstructures of sedimentary rocks exhibit negative anomalies. There are, of course, and particular cases where reverse results have been observed. For example, there have been very large positive anomalies that produced by a wall and strong negative magnetic anomalies due to trench (Μελλέ 2011).

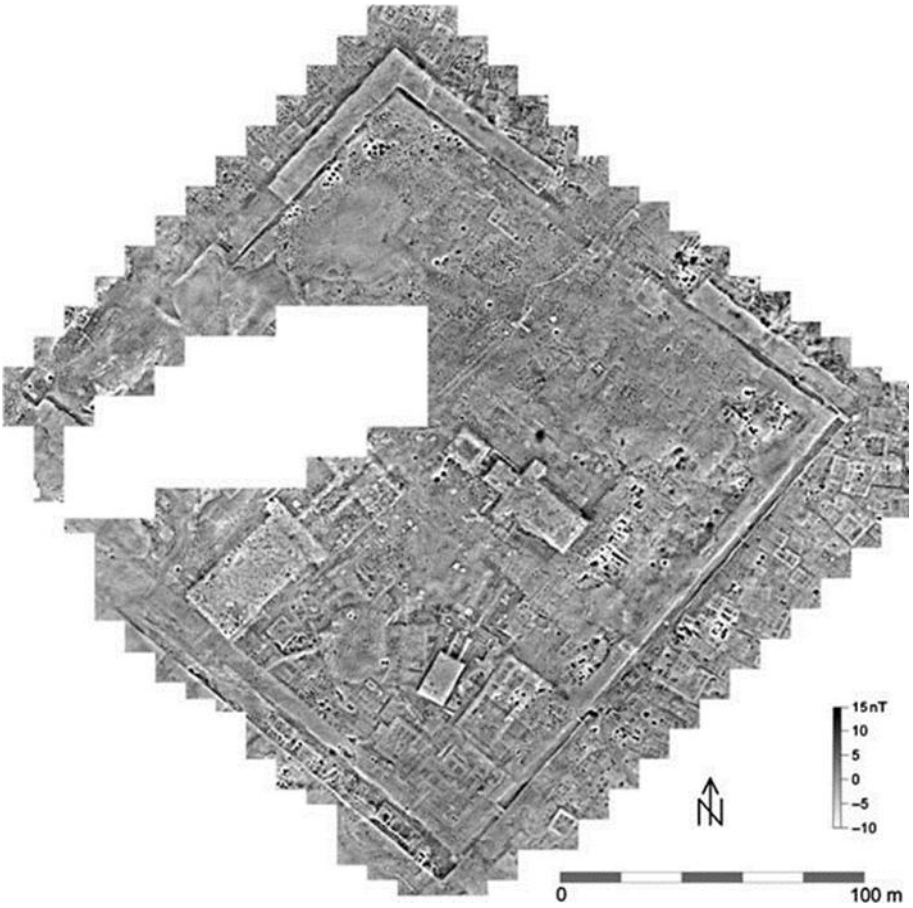

Fig.11A fluxgate gradiometer survey from Tell el-Balamun, using a Geoscan Research FM36 fluxgate gradiometer. Prior to the survey, large parts of the Temple enclosure were 'blank'. Additional buildings and even a previously unknown temple have been identified in the magnetometer data.

B.2 RESISTIVITY METHOD

The electrical methods rely in the fact that electrical current can be transferred through the earth, although most rockforming minerals are insulators, by interstitial water held in the rock/soil structure (Gaffney et.al.2002). Water is needed to dissolve the salts into their constituent ions and also to facilitate their transport. Soil moisture levels are depended on the sizes of individual soil particles (grains), their porosity (ie. the space between them) and the availability of water, as it has already been referred. In addition, resistivity also depends on the mobility of ions in the water, which decreases with temperature and ceases when the water is frozen to ice(Scollar et al. 1990).

In particular, the detection of earth resistance to injection of electrical current into the ground operates as follow; if electrical current has been inserted into a homogeneous ground and does not spread evenly, but it changes its course, that indicates the existence of obstacles in the form of archaeological remains. These changes cause electrical effects at the surface that can be measured in ohms(Gaffney et.al.2002). Accordingly, an acquired map of the lateral surface variations will be representative of the buried archaeological features of the surveyed area.

B.2.i. Data arising of a resistivity survey

Resistivity is linked to moisture content and porosity, as it is mentioned before. Thus, clay and fine soils, which retain humidity, it is expected to exhibit a relatively low specific resistance (for example, pits and ditches) (Gaffney et.al.2002); on the contrary, compact formations, such as wall foundations, coarse and drained soils will give a relatively high resistivity response (Γιαννόπουλος 2014). The greater depth in which a resistivity survey can arise data is related to the length of the probes' expanding.Furthermore, archaeological layers can be revealed using two methods, two-dimensional pseudo-sections or the two or three-dimensional tomography (ie. the real tomography of the ground) (Gaffney 2002).

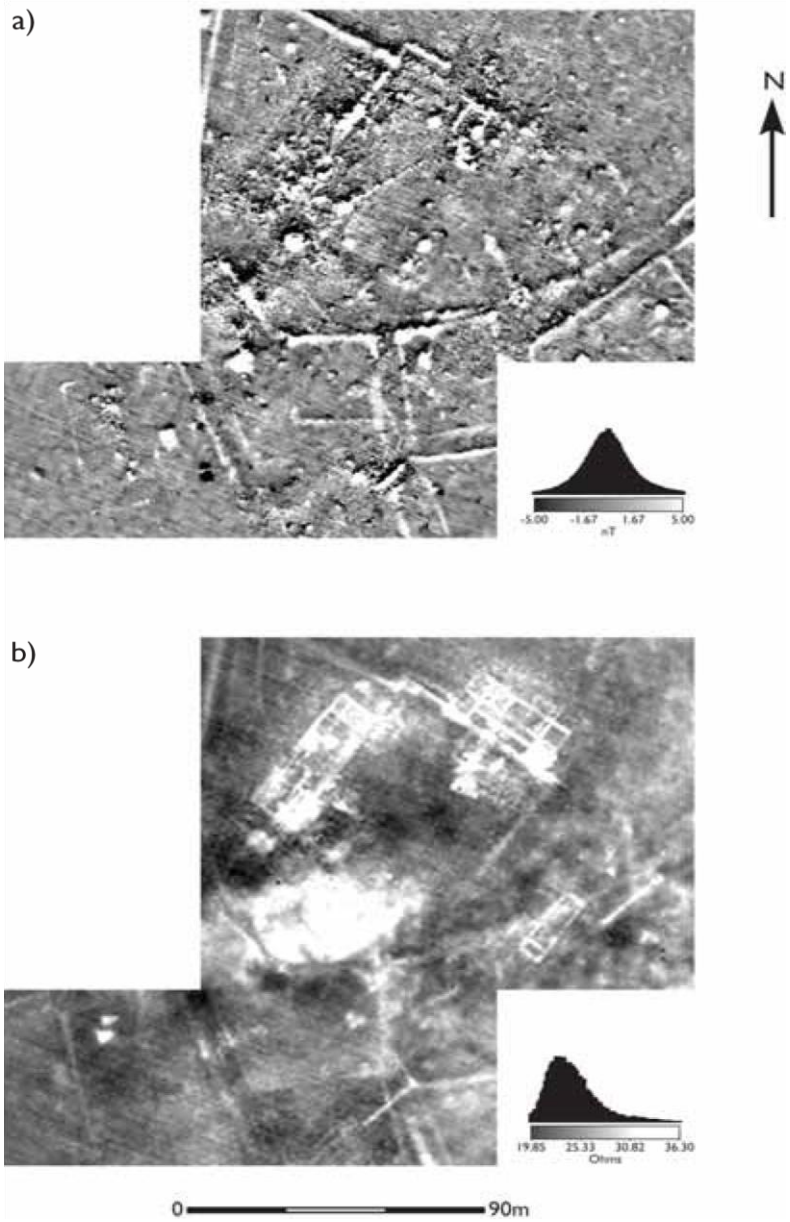

Fig.12Caesium magnetometer (a) and earth resistance (b) survey of the same area of a Roman site in Hampshire. Both detect ditches but the earth resistance survey reveals wall footings in clear plan, not as magnetic 'noise' (Jones 2008).

B.2.ii. Methodology

Two electrodes inject source of low frequency continuous or altering electrical current into the ground, at two different points,away from the area under survey(Tsokas, Van de Moortel et.al 2012)/(Γιαννόπουλος 2014). Each of them is connected with a probe for the measurement of the potential difference, indicating hence the apparent resistance; this quantity is not stable, but is changing depending on the geometry of the measurement configuration (due to earth'sheterogeneity and anisotropy)(Τσόκαςκ.ά.2011). Every measurement hence involves four electrodes arranged on the ground (Tsokas, Van de Moortel et.al 2012). Their possible configurations are a lot. The most widely used in archaeological survey are the twin probe array, suggested by Aspinall and Lynam and the pole-pole array, by Clark.

The common point between these configurations is that the two electrodes remain stable on the ground, in a fixed position away from the grid and the others are carried from point to point on the predefine frame. The small spacing of the mobile electrodes on the grid leads to good spatial resolution and the arrangement is compact enough to make detailed mapping possible. The systematically acquired data is later used for the creation of an earth's resistance map. Thus, the buried archaeological features are depicted as resistivity contrasts (Schmidt 2009).

Fig.13/14Geoscan RM15 earth resistance meter in use (left) in standard twin electrode configuration; (right) with a multi-electrode array addressed via an MPX15 multiplexer (Jones 2008)

B.3. ELECTROMAGNETIC METHODS

Electromagnetic methods are based on the response of the ground to the propagation of electromagnetic (EM) waves (Gaffney 2002). Compared to the magnetic methods, have the advantage of allowing a direct measurement of the absolute value of the soils magnetic susceptibility and, in parallel, of the electrical component of the soil (Gaffney 2002). The different methodologies may be distinguished through the frequency and duration of the EM source that they utilize and, furthermore, by the nature of the received signals. Their systems have a transmitter, which is the producer of the signal, and a tuned receiver. Depending on the technique, they can be co-located or in a large distance.

Because EM instruments do not require contact with the ground and, therefore, they can be applied for surveys in drier climate and on sites of a dry surface. They perform

better than electrical resistance techniques and thus they are more preferable in survey areas under conditions like them (for example, during summer)(Gaffney 2002).

Fig.15 Electromagnetic (EM) instrument with one meter separation between the transmitting and receiving coils (Davenport 2001).

B.4. THE GROUND PENETRATING RADAR (GPR)

GPR is an active electromagnetic method. It has the ability to provide subsurface profiles grounded in vertical radar section and three dimensional view of a buried site, whenis carried out a parallel investigation of more than one section(Gaffney 2002). In an archaeological survey it is a useful tool for the mapping of the remnants of mounds, detecting of in-filled fortifications, tracing of metallic artifacts etc.

The Radar's operation is the following: the instrument emits a pulse of electromagnetic radiation in the ground(Gaffney 2002),with nominal frequency value in the range 1–2500 MHz(Piro et.al 2009). This pulse echoes reflections from interfaces with differing dielectric constants, either by changes at the interface between strata or between materials; this is expressed in decibels/meter (dB/m).

To become clear,the strength of reflections of pulses depends primarily on the magnitude of change in the dielectric coefficient or conductivity at a discontinuity, unlike other methods, directly affected by the bulk magnetic susceptibility or of the resistivity contrast. These two parameters play a secondary role(Piro et.al 2009). Afterwards, by recording the time that need the transmitted signals to travel to the tuned receiver and converting them into depth measurements, the estimation of a geoelectric depth can be achieved(Gaffney 2002).

Ground penetrating radar can obtain very valuable results in small scale evaluations over deeply stratified areas. By collecting data from parallel lines into a common block it is possible to produce a series of time-slice, or amplitude, maps. These can sum the data of every traverse between a selected time or depth range and they can save it as an XYZ file. This file can be further edited for the production of a plan of anomalies at these particular ranges.

A limiting factor for the GPR survey can be consideredits possible attenuation (ie. its signal power loss) and diffusion. That is sometimes happened due to the media resistance and their heterogeneity(Piro et.al 2009).

Fig.16 A ground penetrating radar (GPR) (Gaffney 2002).

B.5. LESS COMMONLY USED METHODS

B.5.i. SEISMIC METHOD

During a seismic survey artificially generated seismic waves propagate through the subsurface. The waves are reflected to the surface and are refracted at boundaries with differing reflection coefficients. The travel times of these waves are recorded and provide a vertical section, converted into depth values. Seismic reflection has been used in archaeology for the detection of tombs, although refraction surveys are more proper to archaeological prospecting, as they are very efficient in restricted areas, providing detailed data through relativelysimple processing. The method can be used as an alternative to Ground penetrating radar, as it is more efficient for surveys in conductive soils than GPR instrumentation (Gaffney 2002).

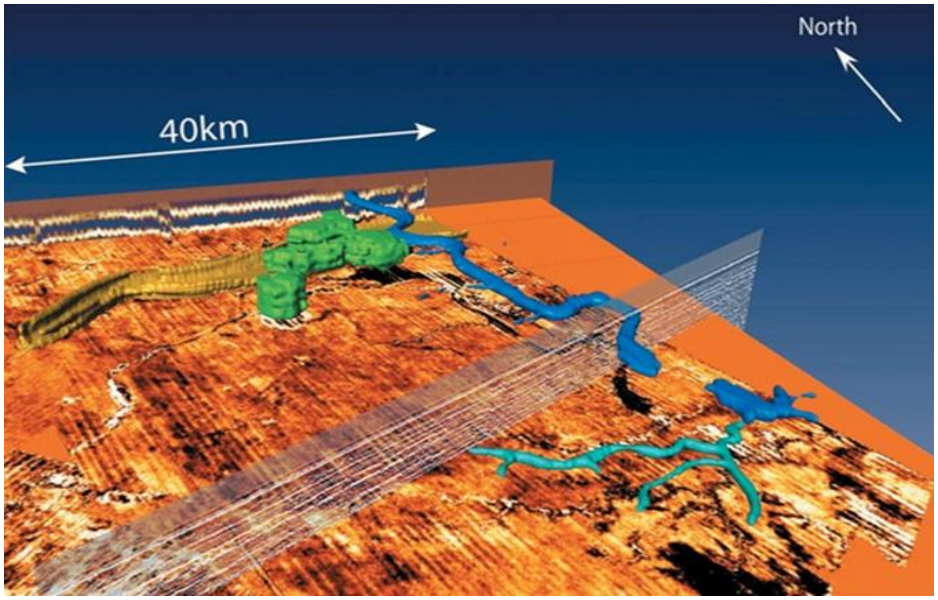

Fig.17An analysis and visualization of seismic data originally collected for oil and gas exploration. The analysis is capable to reveal archaeological landscapes on a big scale (Gaffney 2008).

B.5.ii MICROGRAVITY

This method it measures gravity anomalies. These anomalies are arisen from the density contrasts between masses of buried materials or cavities and their surrounding environment. In archaeology there are only few case studies that this technique has been used, mainly because it is time consuming and the processing of its data is quite lengthy (Gaffney 2002).

B.5.iii METAL DETECTORS

Metal detectors are one of the most frequently used tools in searching for artefacts. In a survey of archaeological interest their role is mainly complementary. The detectors, depending on their instrumentation, emit a pulsed or continuous EM signal into the subsoil. These signals produce characteristic eddy currents (ie. electric current induced in a conductor by a varying magnetic field) in targets of conducing metals. The detectors can be sensitive to a large scale of signals, in different depths, depending on their capabilities; from coins to large structures buried in great depths. A big advantage is their easy tuning for the detection of only metals subject to interest (Schmidt 2015).

Fig.18Systematic metal detector survey of an area that has been divided into 10m grids (Jones 2008).

B.5.iv SELF POTENTIAL METHOD

The Self Potential (SP) method, also known as Spontaneous Polarisation. It takes surface measurement of natural potential differences which are produced from electrochemical reactions in the subsurface. The methodology is quite simple, with two nonpolarising electrodes connected via a high impedance millivolt meter. This method is capable for the detection of metallic artefacts, building foundations, pits and underground chambers(Gaffney 2002).

B.5.v INDUCED POLARISATION

The Induced Polarisation (IP) method has a lot similarities with resistivity, as it also makes use of the passage of electrical current through the pore fluids by means of ionic conduction. This induced polarisation can be measured by studying the variation of resistivity with the frequency of the transmitted current, while the earth acts as a capacitor. It is useful for the detection of in-filled ditches, and variations in the topsoil (especially in the clay content)(Gaffney 2002).

B.5.vi THERMAL DETECTION METHOD

Thermal detection method is based on the fact that buried features usually create temperature variations at the earth surface. Thus, its data is of high interest for the survey evaluation. These temperature variations can be measured using suitable ground probes or airborne detectors(Gaffney 2002).

C. THE EXAMPLE OF VERGINA. Application of geophysical methods, from 1984 to 2004, for archaeological purposes.

C.i.Historical context of the site and the archaeological surveys.

Vergina is one of the most important archaeological sites in Greece. In 1996 was designated as a World Heritage Site, by UNESCO.The ancient city of Aigai was founded by the descendants of Hercules of Argos, around the middle of the 7th century BC. The case of Verginais of high importance as it is an integrated example of a combination of an archaeological and geophysical survey; it is the first and only, in Greece, developed to such an extent and lasted twenty years.

The archaeological site of the ancient Aigai extends eastwards from the modern Vergina to Palatista, westwards.Fortunately, inside the fortified settlement no later building activity was permitted except mild agricultural activity.On the contrary, the cemetery of the tombs, which extends to the north, east and west of the ancient settlement, was largely altered due to the long-term agricultural activityand the existence of current buildings in one part of it (Τσόκαςκ.ά.2006).

The application of geophysical methods along with the archaeological excavations was considered appropriate, to speed up the excavations and also to locate antiquities without substantial intervention in the landscape. During the surveys, these methods encountered difficulties and through them evolved.Geophysical investigations began in 1984, at a point within the fortified settlement, where remnants of a small Hellenistic temple and a dedicated inscription of early classical times had already

been revealed.The inscription belonged to Queen Evridiki, mother of Philip II indicating the royal presence in this area, which could be identified with the ancient ‘agora’ of the Aigai.The first years of these investigations were conducted by professor M. Andronikos. But, first localization of the area was made by the French archaeologist L. Heuzey, since the middle of the 19th century and the professor of Aristotle University of Thessaloniki K. Romaios started the university excavation in 1938.

During the archaeological excavations had been revealed the cemetery of tombs and the ancient settlement. M. Andronikos, in the 1950s and 1960s, brought to light the early phase of the settlement (1000-700 BC). Then, the tombs of the 5th and, later, of the 6th century BC were revealed.It is worth mentioning that the tombs of the 5th century presented impressive artworks of metal and clay, as well as a lot of other findings. Particularly impressive were the tombs of the Filipino and Alexandrian period, their monumental size and the plurality of inscribed tombstones. The unlooted Macedonian tombs have impressed the world because of their sophisticated grave goods and their monumental architecture and painting decoration.

Regarding the ancient city, initially, the research had focused on the palace area of about 11 acres.But in the early ‘80s, it expanded, revealing the fortification walls and the town plan.Close to the castle was found the ancient theater. To the north, the sanctuary of Eukleia was located and also a part of the ancient ‘agora’. In addition, another public building was found at the northwest end, while in the eastern part of the city was discovered the sanctuary of the Mother of Gods (i.e. the sanctuary of Cybele).Finally, a large private residence was found to the south.

C.ii. Achievements of the geophysical methods in the region.

Fig.19Imprinting of the archaeological area(Τσόκαςκ.ά. 2006).

Several geophysical methods were applied locally to the archaeological site.During the applying of the measurements there were cases that a lot of experience was necessary to avoid erroneous conclusions. That mainly because of the geomorphology of the site.

In an area from the north of the palaceto the ‘tomb of Romaios’ was carried out the resistance mapping method; also, near the excavation of the sanctuary of the Mother of Gods (Τσόκαςκ.ά. 2005). Their data were processed properly and were presented in a resistivity map of the values of the apparent resistances (ie. not the real resistance values, as in tomography), of grey scale, similarand very close toa real ground plan.

This displaygave the ability to the archaeologists to understand the underground conditions and structures, without consuming so much time and digging “blindfold”, destroying the landscape and may some antiquities too.Wherever had been detected field anomalies during the measurements, these were imprinted on the map. There were not few the spots wherethe high resistances were appeared with a clear geometric shape, easily identified as buried structures.After that, these maps were combined and were attached to the excavations-floor plans. Thus, their reading became even more understandable and realistic, even if for someone that was not a specialist.

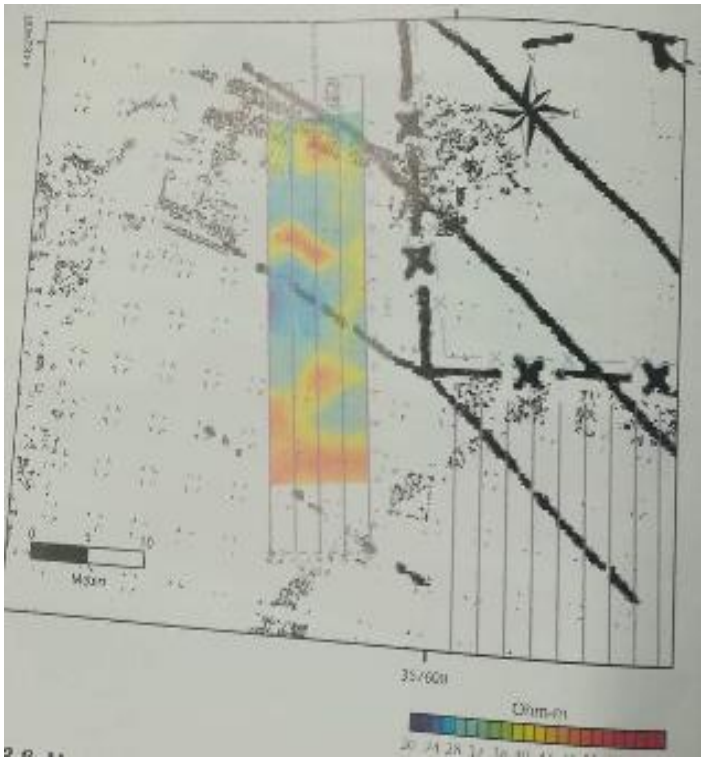

Fig.20Conversion of apparent resistantvalues into horizontal section, in the spot near the tomb of Romaios, above plan view of the excavation.The abnormal positive valuesare identified with previously revealed antiquities and to the south indicate the existence of others(Τσόκαςκ.ά. 2006).

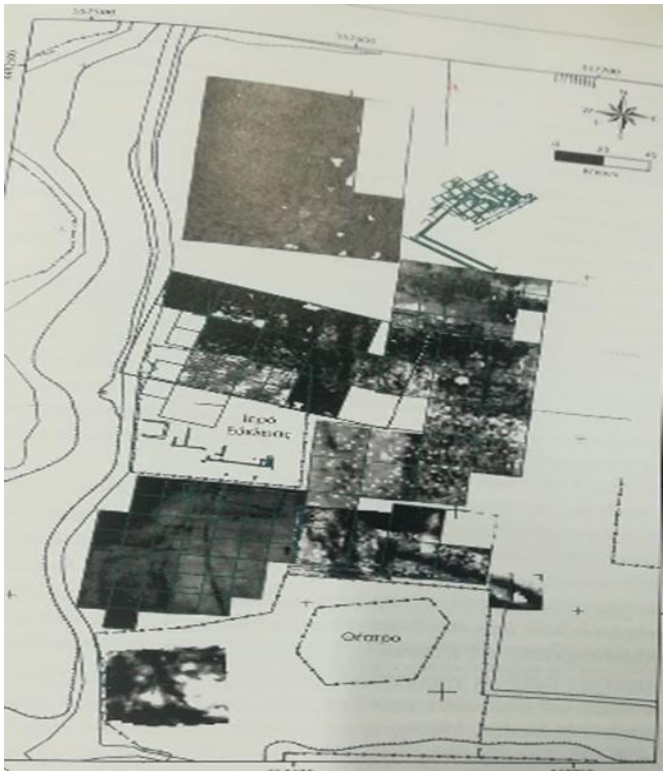

Fig.21 Combinatory presentation of the distribution of the electrical resistance of the ground various in parts of the archaeological area; were not used different rating scales of values in all parts. High values correspond to dark tones of ash. (Τσόκαςκ.ά. 2006).

As it was mentioned before, the geological substratum was very close to the surface, presentingfield anomalies that were misleading for the existence of large structures. However, due to these difficulties that were arisen from time to time, all methods had been corrected, evolved and made more adaptable for antiquities' detection (Τσόκαςκ.ά. 2006).

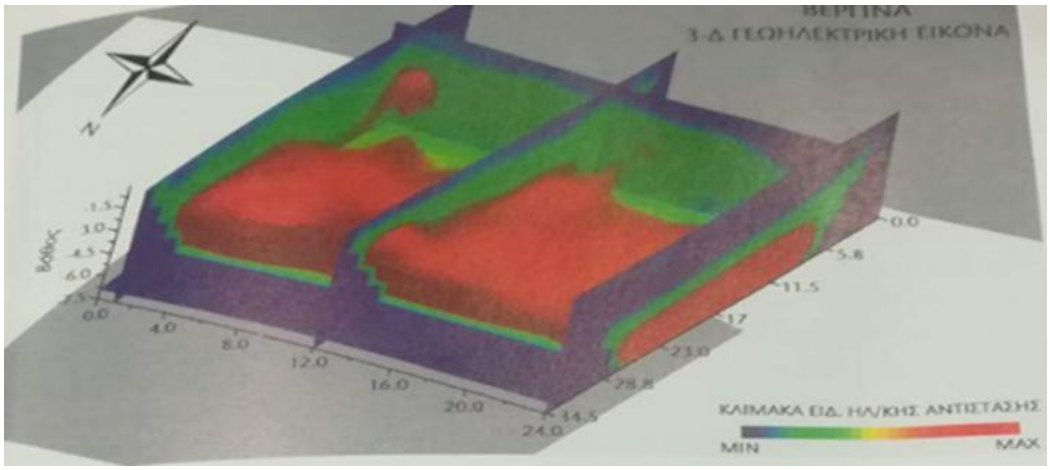

Fig.22Conversion of apparent resistant values in a 3D model. The higher the values are rendered to the warmer colors. With the blue color is rendered the surface layer which is presented homogeneous, using appropriate settings. The layers of interest were the lower. That one, of green color, is the layer of the riverbanks deposits. In this case are not recorded there inhomogeneities that could possibly be identified with archaeological structures. It appears to be an anti-static formation that corresponds to the background of the area (rendered in a deep orange color)(Τσόκαςκ.άλ. 2006).

By that reasoning, were performed geoelectrical tomographies, in order not only to identify antiquities but also to record their quantity characteristics (i.e. size, depth etc.) and these to be rendered in two-dimensional and three-dimensional models, testing the abilities of the method and also theinstrumentation.Thus, that method applied in two ways, in a long range of an area of high archaeological interest, into the fortification. The first one aimed at the detection of remains in a low depth (not over than 2m from the surface) and the other at remains of large buildings located deeper.

Magnetic prospecting was another method applied into the fortified area. Though it was particularly affected by soil geology, it gave some data. Although, it mainly confirmed past data rather than gave new information. An exception was the site of thesanctuary of Eukleia, where all the other methods also identified and confirmed the existence of a complex of buildings.

Moreover, ground penetrating radar was also started to be used in the surveys; firstly, very limited and in an experimental level and, during the years, with more sophisticated function. It was applied in specific and small areas; in the sanctuary of Eukleia, the area near close the tomb of Romaios and the area near the ancient theater. Its results were useful and were also displayed. On the other hand, comparing them with the arisen data of tomography were more week.

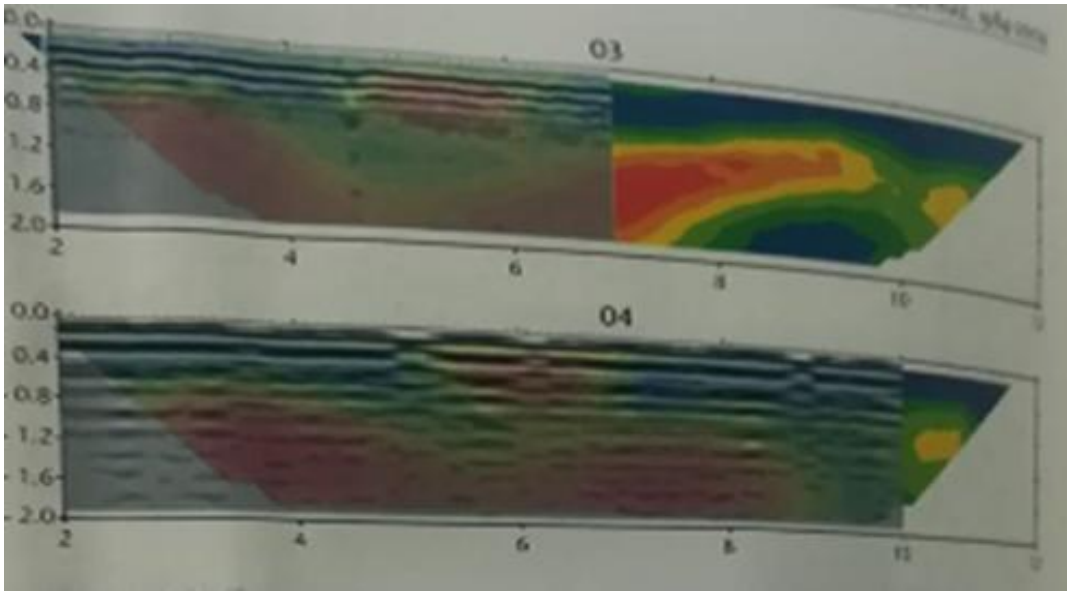

Fig.23Results from two same traverses (03 and 04) of radar sections (tones of ash) above the corresponding results of tomographies. The anomaly of a structure that is presented between 5 and 6.5 m. along the traverse of the tomography corresponds to the signals of the traverse with GPR(Τσόκαςκ.ά. 2006).

Furthermore, for a total overview of data, geophysics again gave the solution, proving that their ways to interpret data were the most proper and useful for the archaeologists. They created a complex of geophysical maps, each of them with imprinted the measurements of every method that was applied in every specific area,

comping all consecutively on layers, above the ground plan; by collecting and putting together the combinatorial maps of every surveyed spot on the general ground plan, immediately, were created some valuable tools for the archaeological survey. These maps were accurate, easily used and could always be added with new data.

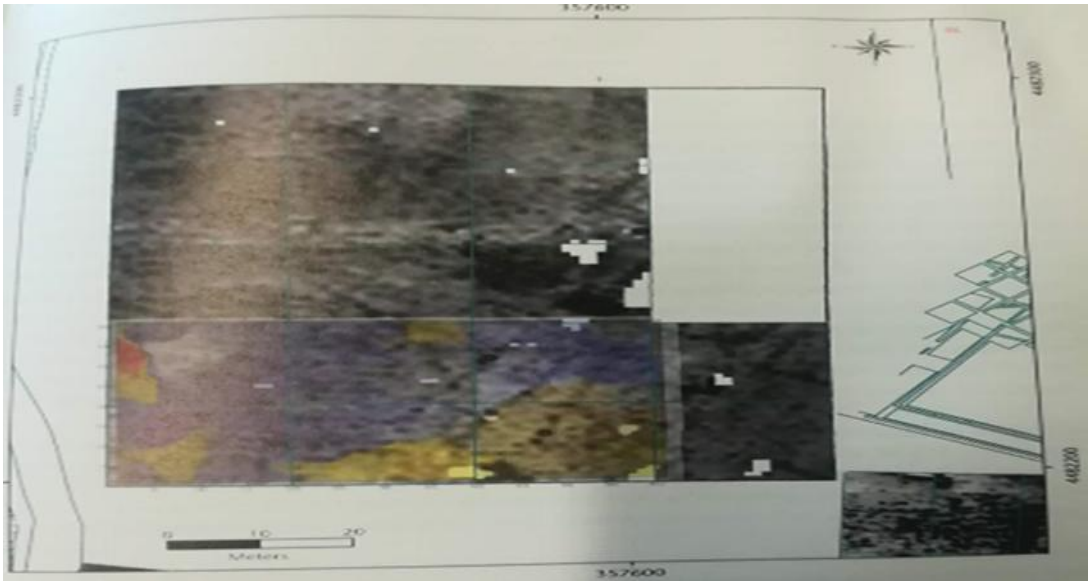

Fig.24After sophisticated processing of the magnetic results, the distribution of the total magnetic field was placed over the general results of the resistivity mapping (the tones of ash) of the same area, giving complementary information for the ground. (Τσόκαςκ.άλ. 2006).

In general, all the methods were useful for the detection of new buried remains or for parts of others, partly discovered. But, the most important was that the cooperation of all these scientists for many years built bridges, becoming an example and leading the surveys in a different way from that one of the typical excavation, in Greece.

D.1.CASE STUDY VERGIA, CHALCIDIKI

D.1.i General features

(Tsanana, Pazaras1990)The Toumba of Vergia is located on the coast of N. Syllates beach, between the communities of N. Kallikratia and Sozopolis, on the western shore of Chalcidiki. The hill shows a steep topographyon its eastern and northern side and a large plateau on the upper surface of the Toumba (approximately 27 acre), which rises to the south and ends abruptly at sea. Contrariwise, the western slope exhibits a smootherformation.

D.1.ii Historical context and archaeological data of the area from previous surveys

The Toumba of Veria is inhabited by prehistoric times, as evidenced by surface surveys, and is abandoned in the second half of the 13th century (ΠαζαράςκαιΤσανανά 1990).From ancient and historical sources, there are references about cities existed in different periods, with similar names, that probably can be identified with Veria.

Already since the period of the Athenians' campaign against Potidea (in 432 B.C.), during the Peloponnesian war, an area called Veroia is mentioned from Thucydides. Pelekidiswas the first thatconsidered a possible correlation betweenthe thucydideVeroia and the area of Veria, Chalcidiki. A relative theory, expressed by J.A. Alexander, argues that a city on the east coast of Thermaikos called Veroiawas the port of Kassandria, where in 429 BC. colonists of Vrea settled there; although,there are other scholars that have rejected these scenarios and the excavations have revealed finds until the 4th century BC and not earlier.Other important references about alater city calledVrea, localized in western Chalkidiki, have been made in‘Philippica’ of Theophrastus, as well as in medieval lists containing denominations of cities.

On the other hand, the area of the Toumba can be confidently identified with the medievalCastle of Vrya, fromsome visible traces of fortification that presents andfrom the finds of a series of excavations. The importance of this naturally fortified castle has been recorded in many sources of the byzantine period. Moreover, the excavations have proventhat the city thrived particularly in the mid-Byzantine period, since there is evidence that became the seat of the bishopduring the 1070s, with an extension outside the fortification walls.

The area was declared “archaeological” in 1973, consisted of the mound and large areas on both the east and west side,along the coast.On the mound, there had already been visible some antiquities; a rectangular tower at the southeastern corner of the hill, a small portion of the wall on the south side and one other on the west. Additional,on top of the Toumba was clearly visible a reservoir and to the west of the hill, to the sea, a well(ΠαζαράςκαιΤσανανά1995).

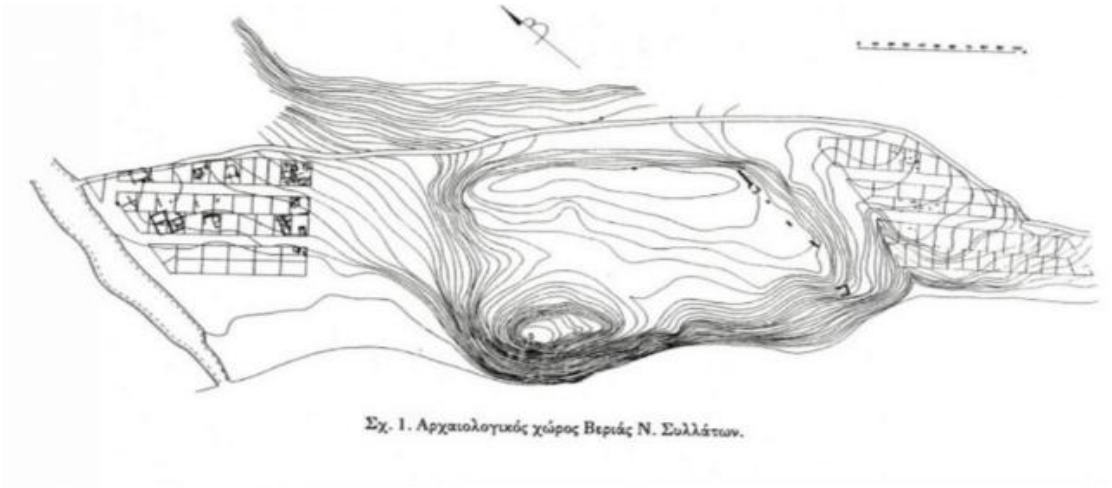

Fig.25The archaeological site of Veria (ΠαζαράςκαιΤσανανά 1995).

Unfortunately, except of the Toumba, eventually, the east and west sides were distributed to landless locals. These areas were used for the erection of apartment buildings. As a result of the intensive building constructions, in 1976,there was an immediate need for life-saving excavations. Due to this priority, there was no time for a systematic excavation in the Toumba.(ΠαζαράςκαιΤσανανά1995)At the place, a limited research had already been carried out in 1981 by J.Tavlakis, revealing a part of a large buildingeastward, which is believed to be a paleochristian temple. In the eastern coastal side it was also recovered a cemetery. From the style and morphology of the tombs and the arisen grave goods, it was dated to Late Roman and Early Christian years. Moreover, a second cemetery was detected, at a distance of about 300 meters northwest of Toumba(ΠαζαράςκαιΤσανανά 1990).

In western areamost life-saving excavations have taken place and have provided an overview of the out-of-the-wall parts of the city,from the late Roman to the Byzantine period. In brief, in northern and western plots were discovered buildings of large dimensions and meticulous masonry. In addition, two ceramic kilns, cisterns and wells were identified. All structures belong to the late antiquity and, as it appeared from the pottery and coins, were in use until the 10th century.From the spatial planning and dimensions of the structures it was probable that storehouses and workshops were functioned there.

Fig.26 The west area outside the castle (ΠαζαράςκαιΤσανανά 1992).

Approaching from the edges towards Toumba, the building phases have been revealed are consecutive and dense, mainly belonging the byzantine period, as it was confirmed by the ceramics and coins of the 10th-13th century. The buildings have been identified as residences and auxiliary spaces, except of one that was a small bath. At the area,were also presentedvery few traces of foundation of earlier buildings, because most of them were destroyed by the byzantine building phases.

In 1990, the northwest plots 11 and 12 were excavated by A.Tsanana. It turned out that, the earliest buildings were found in the west side, were dated back from the 11th to the end of the 12thcentury and were the following: two consecutive, small-sized spaces, another adjacent space, open to the north, and a fourth near them, to the east. On the last one, a furnace was found.

In the same plots was found a group of structures,built on the top of the earlier. These were of the 13th century, as it was considered by the ceramics, and were the following: consecutive spaces located on the south side andparts of building revealed in the west, with gravel yard. Expect of them, parts of spaces were found on the northeast and northwest corner of the plots, respectively.Furthermore, walls were saved at a very small height. From their style, the materials from which they are made, as well as the types of ceramics, it was realized that these structures were identified as residences.Other building remains were discovered in north and south corner, but it was impossible to be dated or to be estimated their use, because of their destruction from the newest building phases. But on the northeastern side the foundations of the oldest building of the excavation appeared. It was consisted of adjacent spaces of small dimensions. From some coins were found there, the building was estimated to be used until the 2nd century BC.

During the same year, sections were opened on the northeastern slopes of the Toumba, with the purpose to reveal the fortification around thecastle. After the completion of the excavation, six parts of the fortification were revealed, from the middle of the north side of the mound to the visible tower, southeast (a distance of approximately 150 m.). The excavation also revealed parts of a second rectangular tower (3*5m.), at the north side of the fortification walls.

In parallel, the surveying of the west side of Veria begun in 1990 and continued in 1991.The excavation of 1990, was completed with the shortly examination of plot 32. As it was mentioned, the survey was not completed the same year, for various reasons,Thus, in 1991, archaeological research brought to lighta building block. The buildings have been distinguished in four major building blocks; from the first, only remains of small walls were saved, to the southwest corner. Due to the minimal information they provided, their age could not be detected (ΠαζαράςκαιΤσανανά1991).

In the second and most important phase the foundation of a main, elongated space communicating with a second, almost square space, of smaller dimensions, belonged.Inside the main structure were found two pairs of cisterns; in each of them one cistern was surface, with low walls and contacted with hydrants with the other, which was underground. From the presence of marble sanctuary pillars in second use, as taps, these facilities were dated after the 7th century. Their use ceased at the end of

the 10th century or at the beginning of the 11th century, as arose from the coins found on the destructive layer.From their layout as well as their absolute tightness (very good quality coating and careful manufacture, particularly the underground cisterns), it was concluded by the archaeologists that it wasa sophisticatedgrape press. Moreover, the fact that there were two pairs of cisternsled them to a second conclusion; that each one was intended for two different wine varieties.As Tsanana and Pazaras(1991) have reported, similar constructions had been recovered earlier in other plots of the area.

The third phase of use begins in the 11th century, immediately after the second. Then, the space was used as a ceramic kiln. The continued use of the site was certified by the existence of baked and broken vessels within the winepresses. In the middle of the 11th century it was abandoned, as burials were found in the area. Evidences of abandonment of the residential area outside the walls, during this period, have also been found at other sites of the excavation, with the existence of similar burials.

During the 12th century, as it arose from ceramics and coins of that layer, the fourth and final phase began, with the construction of two elongated buildings, separated from each other by corridor. The western building consisted of two large and unified spaces, while the east was divided into three rooms. Due to the layer where the last was found, it was chronologically associated with the adjacent bath was arisen during the excavation of the year 1990. The use of both buildings was not identified, but from their masonry, their size and layout, these were probably storehouses and workshops.

After the plot 31 the excavated was extended to the plot 197,in the eastern part of the archaeological site. There, a cluster of nine tombs was revealed. From them, only within of one were detected grave goods. Between them were recorded a beaded necklace, a bronze earring and a Diocletian's coin, dated around in 296 AD. The coin, in combination with the morphology of the tombs, determined their chronology in the later Roman years.

The plot 25 was beginning to be excavated in 1991, but its examination was completed in 1992.Already in the first year, a part of a large building complex was founded, thatwas a continuation of a second building complex, located in contiguous plots whichhad previously been discovered by the archaeologists I. Papaggelos and J. Tavlakis. In the lower layers of the section, on the southeast corner of the plot, were found remains of constructions whose use was not identified. These constructions, together with a double substrate of mosaic floor on the same layer, belong to the earlier construction phase. Above them was built a pretty large building which covered almost half the area of the plot.This building continued in adjacent plots, to the north, south and east, andit consisted of two contiguous spaces(ΠαζαράςκαιΤσανανά1992).

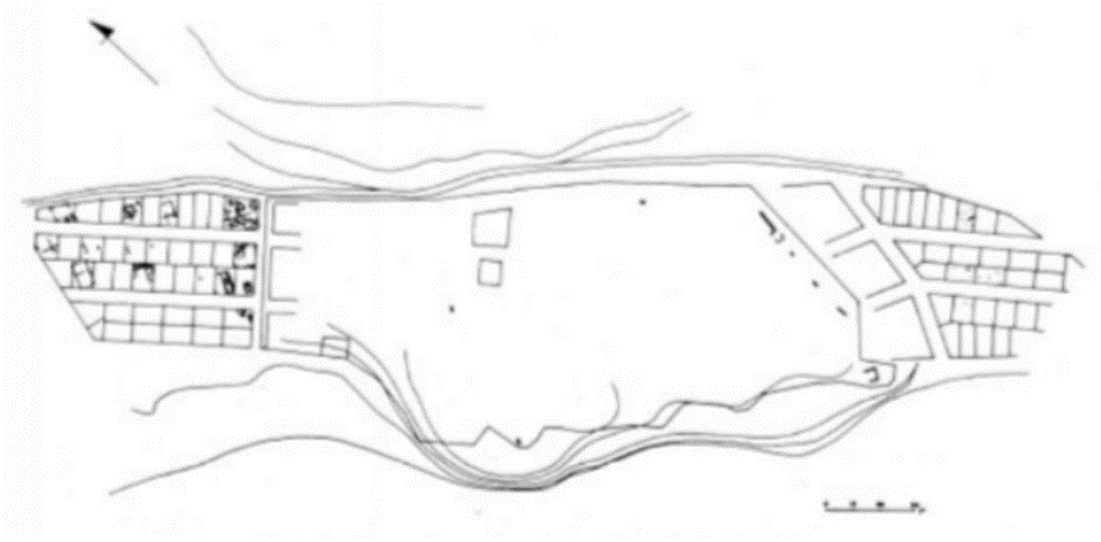

Fig.27Imprinting of the archaeological area (ΠαζαράςκαιΤσανανά, 1992).

In the southern one, there was a thick-walled mosaic floor and on its western wall there were two water run-offs at the level of the floor. The researches considered that this was open-air orsemi-outdoor space, from its masonry and because the completion of parts of the mosaic was not meticulous, a well from other architectural features.

The northern room presented a complex layout,with its eastern wall being arranged stepwise with a rectangular opening and the west ending on a rabbet, which protruded.The floor had a coating and the eastern wall was connected, to the north, with the western one by three arched openings made of plinths.Inside the ground were also clay air ducts (tubulo),reused as building material of the floor but also dispersed. Hence, the place was characterized as a largebath.

The exact interpretation of the use of the spaces could not be done, as no hydraulic systems were found.This probably happened due to their partly excavation, the intermediate changes of use and the subsequent foundation of another building of large dimensions above them. Consequently, it was not possible the accurate distinguish between the construction phases. According tothe ceramics and the coins of the same layer andalso the technique with which the mosaic floor was made, the bath was dated back to the 2nd century A.D. Its spaces were used until the 4th or 5th century AD, but not necessarily with a relative function.

On top of ita huge building was built, directly after the abandonment of the bath (in the early Christian period). This building was of such a size that it was extended, beyond plot 25,to plots of its east and north side. Moreover, it occupied a plot of land already excavated by Tavlakis and Papaggelos, towards the west. It was made by massive walls and careful construction. Based on these characteristics Tsanana and Pazaras concluded that it was a public building with storerooms or shops. In the middle byzantine period, it underwent an alteration;it subdivided in smaller rooms that probably were used as residences.At the beginning of the 10th century the building was destroyed and abandoned, as confirmed by a hoard with coins of Leo VI(ΠαζαράςκαιΤσανανά, 1992).

During 1992 and 1993, the plot 9, to the northwest of the western sectorof the excavation, outside the castle, was surveyed. There, were found remains of rectangular buildings of the middle byzantine period. They were directed from east to west, sharing the same axis with all the other buildings of that sector. As it was assumed from their architectural characteristics they were probably storehouse, workshops or stables.

The excavation also revealed that, after their destruction, the area lost its previous character and, from then on and until the early 13th century, was functioned as a cemetery. After that period, the area was abandoned. By combining that case with other cases of the same section, the desolation of the settlement of the western side was confirmed. Its inhabitants were considered to have moved within the fortified castle to protect themselves from various enemies.

Until 1995, a more extensive survey was carried out to complete that of 1990, revealing the entire fortification area. It was focusing mainly on the west side of the hill, because there was a reference in a document of 1104 AD., about the existence of a portal. The excavation began from the middle of the western side, where remains of the wall were visible and the portal was finally revealed; the thick fortification wall was extended from north to south and, along with the other arisen parts of the fortification, was subjected to three main structural phases(ΠαζαράςκαιΤσανανά, 1995).

The first building phase is the part of the wall that was beginning at the portal, with direction to north. Only the foundations and its underpinning were preserved. In addition, along the inner side of the wall, a solid mass was found, which was extended toward the interior of the castle. Some possible interpretations were its function as a basis for a scale or as a backing of the wall.

The second phase includes the castellated portal and part of the walls the southern. The portal was open inward, ending to two columns of plinths. From the opening only the underpinning was found, not the threshold. All the floor inside was made of a substrate of stones in mortar, covered with soil with small gravel and broken tiles.

Moreover, within the portal, to the northern cheek, an auxiliary terrace was detected and at a distance of about 5 meters southern to the portal, a rectangular opening at the base of the wall, approximately 0.50 * 0.50 m., with a relieving arc above it, was also detected. Probably, through the passage a drainage pipe would pass.

As for the part of the wall,initially, it was aligned and then formed an angle toward the southwest.The whole part was covering a distance of 22 meters and elsewhere was preserved in the foundations and elsewhere at a great height.

In the third building phase the completion of the wall at the destroyed southern end, as well the enlargement of the portal to the west were included. On the outer side of its northern section was constructed a triangular structure of large volume, built up in a heap of soil and tiles, indicating a rough and fast construction. That structure had an oblique direction to the northwest, demonstrating that the portal's axis was shifted slightly, so as to make it more accessible, following the steep slope of the ground.

This scenario was also confirmed by the existence of a retaining wall,adjacent to the south cheek, of the same direction.

Apart from these main phases, a series of other complementary repairs took place during the years,mainly in the north and south parts of the wall.Finally, it should be noted that, at the northern end of the fortification, wall remains were discovered, belonged to adjacent buildings. From the arisen evidences (i.e. keen burning layer, molten ferrous metals etc.)the archaeologists concluded that they were workshops and mainly facilities for metalworking.

Due to the absence of a more extensive excavation of the area within the walls, it was considered necessary to survey the site by geophysical methods.Other factors in this decision were the indications of a second portal or tower in the middle of the northern fortification line, the absence of building remnants, synchronous with other buildings of the Hellenistic era found in the wider area andthe sloping landscape. Except of them, thestratigraphywas disturbed by the opening of defensivetrenches during the Second World War, earlier excavations of the site and also modern digging, to find materials proper for building use(ΠαζαράςκαιΤσανανά, 1995).

D.2Geophysical methods applied at the Toumb of Vergia

Magnetic and resistivity geophysical surveys were conducted over theToumba ofVergiaN.Syllaton, inChalcidiki. The aim of the survey was the detection and identification of possible buried structures,enlighteningtheprevious archaeological excavations in the area.Taking part only in the measurements of the first method I will present the process of them on the field. Hence, only a brief reference will be presented about the next stages of the magnetic survey, before the final interpretation of the data.

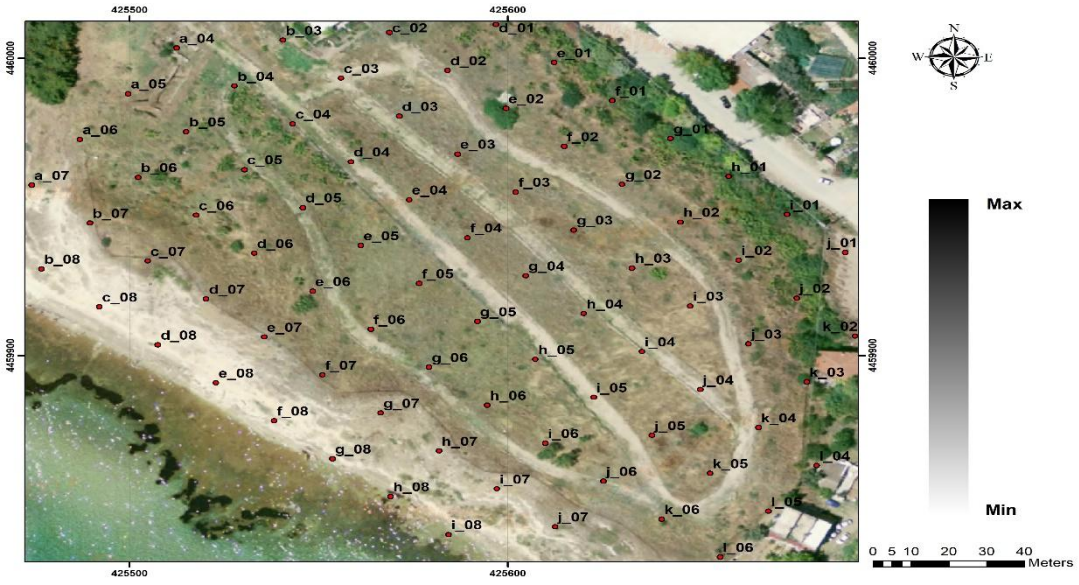

Fig.28Points on the area of the Toumba, in Veria.

The magnetic prospecting method took place on July 4 and 5 of 2007, under dry soil conditions. In the area of ten acres we placed measuring tapes at 0.5 m intervals to form a subsidiary grid within each of the twenty grid squares. The intersections of the tapes indicated where the measurements should be performed. In each 20 x 20 m grid square, we took 1,600 readings, with the use of a fluxgate gradiometer, manufactured by Geoscan Research.

Fig.29The grid of the area of the Toumba, in Veria.

Data were saved onto a laptop computer in the field at the end of each day of fieldwork, for a quick check on data quality in situ. Additional data checks as well as initial data processing were performed at the end of the last day. After the completion of the survey, data processing continued at the Laboratory of Exploration Geophysics at the Aristotelian University of Thessaloniki.

The processing sequence was the following(Τσόκαςκ.αλ.2011):

- Statistical analysis of the data.
- Despiking by median filter (3X3 windows).
- Transfer of the mean of each traverse to zero (Zero Mean Traverse).
- Interpolation both in the X and Y (cubic splines of the form sinX/X).
- Smoothing by low pass Gaussian filter.
- Clipping of the dynamic range to relatively low values (-5 to 5 nT/m) to enhance the effect of weak anomalies caused by the antiquities at the expense of the strong ones caused by ferrous near surface objects.
- Creation of gray scale images.
- Georeferencing the mesh of the geophysical cells.

D.2.i.Results of the magnetic survey and discussion

After the completion of the data processing important results arisen. It must be mentioned that the quality of the measurements was reduced, affected by the background noise of the area; modern metal garbage and piles.

As it is obvious (fig.30a), in the grid squares D 04, D 05, E 06 and I 05 were detected some anomalies of circular shape. Moreover, in the squaresF 04 and G 04 two square structures were formed, nearby to the visible path in the squares E 05, F 05, G 05 and H 05. Finally, an elongated structure resides along the central path, in the E 05 grid square.The last one was presented more clearlyat the second image (fig.30b).

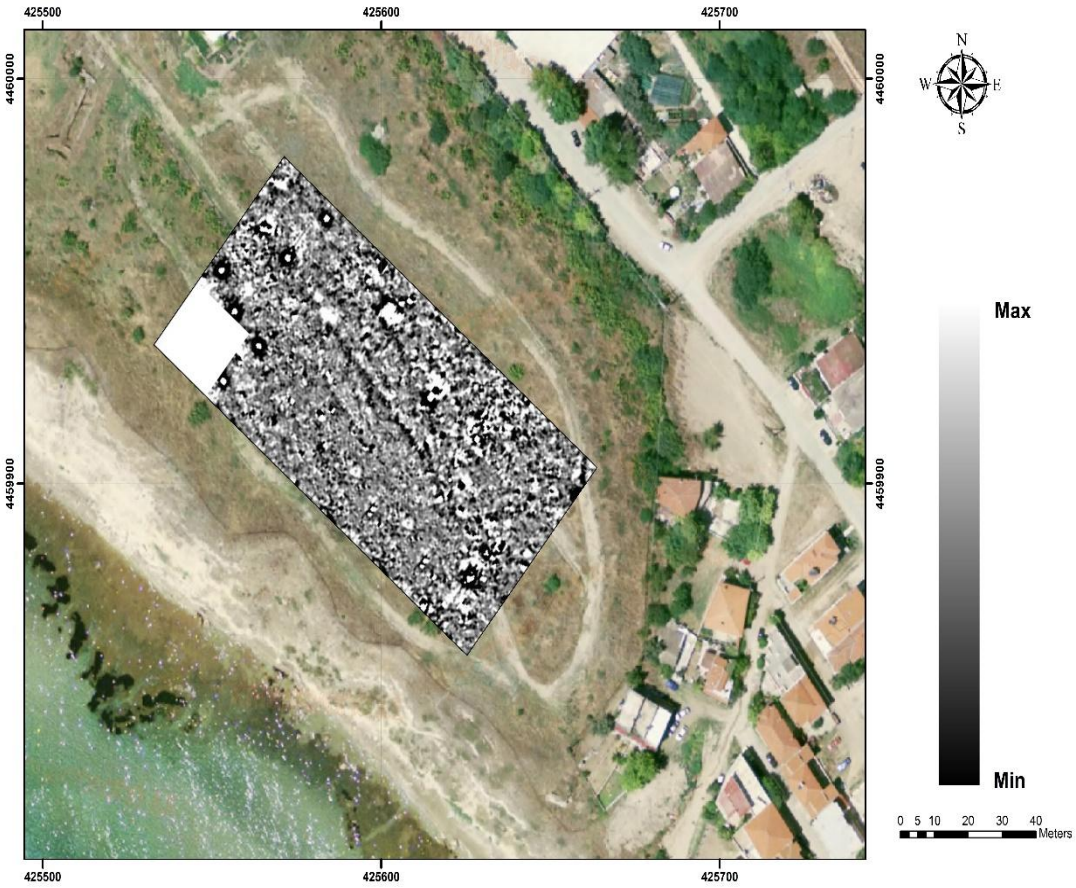

Fig.30a,b The gray scale images of the area. The positive anomalies are rendered with dark tones (due to their enhancing susceptibility), while the negative with lighter tones.

In early December electrical resistance measurements were made at the same area, under humid conditions. The data of the resistivity survey were of higher quality than that of the magnetic. After proper processing was carried out the data were displayed in a gray scale image. Under the surveyed grid was revealed the existence of urbanplanning.

Fig.31 The urban planning of the Toumba, revealed by the electrical resistivity survey.

Further investigation and future excavation must be carry out to reveal the dating and function of each of these architectural remains.

Conclusion

Geophysical surveys have today been placed next to the archaeology. In the content of this essay the main methods and their value and necessity in the archaeological research were underlying. Their advantages are many, but the two most important of them on an excavation are the combination of speed in ratio with acquired data and their non-invasive or partially invasive techniques.

The example of Vergina was mentioned because it was decisive for the current evolution and acceptance of these methods in the archaeological study. Through the collaboration of archaeologists with geophysics both the two disciplines evolved, providing comprehensive and valuable data for the site.

Thus, the usefulness of geophysics, therefore, was evident in our case. They revealed the existence of urban planning at a site of great importance, with inhabitation from the prehistoric times and thriving particularly in the mid-Byzantine period, in which archaeological excavations had not been completed. The data of the geophysical study and especially its visualization, will now help researchers for future surveys in the Toumba of Veria.

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