Romanian Reports in Physics, Vol. 64, No. 3, P. 878–890, 2012

PHYSICAL METHODS AND INSTRUMENTATION

CESIUM MAGNETOMETER SURVEY IN THE CUCUTENI SETTLEMENT OF FULGERIŞ - *LA TREI CIREŞI*, BACĂU COUNTY, ROMANIA*

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Received March 5, 2011

Abstract. The archaeological site of Fulgeriş – *La trei cireşi*, belonging to the A3 phase of the Cucuteni culture, is situated in the south-eastern part of Bacău county, on a part of a cuesta of the Tutova Hillocks, at a relative altitude of 75 m. It is an elevated settlement, enjoying natural protection on three of its sides, with an approximate surface area of one hectare, out of which were researched 393.5 m^2 (from 2003–2010). The main purpose of the geophysical prospections of the summer of 2009, when a cesium vapor magnetometer was used, was to identify the fortification elements specific to this type of settlement and to establish a new archaeological research strategy. This paper presents the interpretation of the large magnetic anomalies observed on the settlement's unprotected side, typical for a double excavated structure (ditches). Archaeological researches from 2010 have confirmed the results obtained using the geomagnetic prospection method, with two defense ditches, of different sizes, identified.

Key words: archaeological geophysics, cesium magnetometry, chalcolithic, Cucuteni culture.

1. INTRODUCTION

It is well known that archaeology has always had to work around the lack of substantial financial support, hence the efficient use of nonintrusive geophysical prospection methods can significantly reduce the overall costs associated with an archaeological research, by accurately localizing and mapping the buried material [11]. Despite these obvious advantages offered by this technology, its use in Romanian cultural resource management (CRM) is quite limited, in applications

* Paper presented at the *National Symposium of Archaeometry*, October 2010, Bucharest, Romania.

only tangentially touching upon the subject-matter, due to the lack of available funds for purchasing the equipment and for training. Nonetheless, a few such initiatives in Romania, particularly in the archaeological field of study [9, 20-21, 25-28], have successfully proven the effectiveness and productivity of these non-destructive techniques and methods (Fig. 1). Moreover, the storage, checking, integration, analysis and dissemination of the acquired information using GIS, CAD and 3D technologies can ensure their proper capitalization in various domains.

Chris Gaffney and John Gater designate the employment of these methods in archaeology with the term *archaeological geophysics*, defining it as „*the examination of the Earth's physical properties using non-invasive ground survey techniques to reveal buried archaeological features, sites and landscapes*" [12]. The main purpose of these non-destructive investigations is to identify archaeological anomalies, to determine their depth, planimetry, physical properties, etc. in preparation of the commencing of the excavations.

Although geophysical research methods have been in use in archaeology since the middle of the 20th century (late 40's to be precise), the method of magnetic surveying we make use in this paper has enjoyed a peak since the beginning of the 1980's, a moment when numerous researchers started to apply it to obtain high quality and accurate images of the archaeological bed/layers, in unprospected areas [3–4, 18, 24].

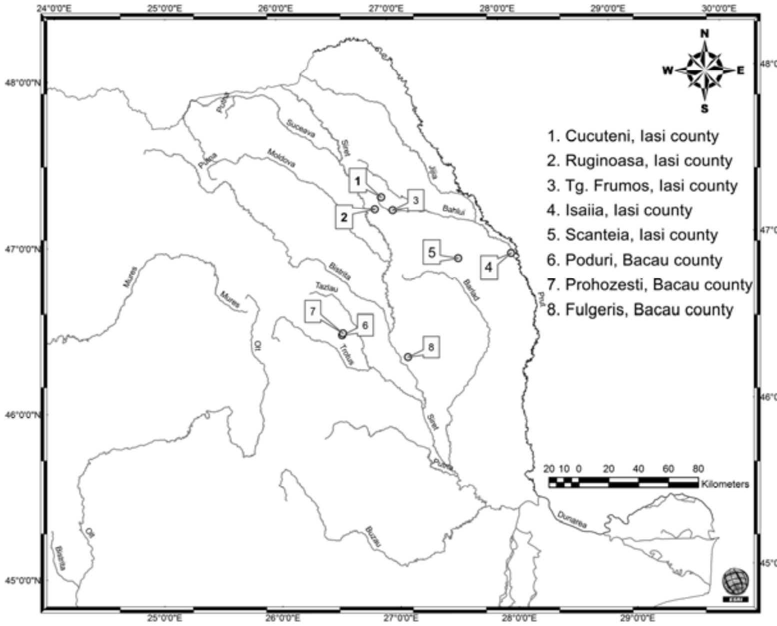

Fig. 1 – Precucuteni (3-4) and Cucuteni culture (1-2, 5-8) sites in Moldavia in which geophysical investigations took place.

Due to the wide surfaces which can be covered (up to 10 hectares in a single work-day), and of the quick data collecting and mapping process this method is currently the one most often employed in archaeological investigation. This paper will present a typical study case of a chalcolithic Cucuteni settlement (Fulgeriş – *La trei cireşi*, situated 50 km southwards of Bacău), with a surface area of approximately 2 hectares, and charted only using the ceramic material discovered during archaeological surveys, nonetheless insufficient for an accurate delimitation of the site's geographical limits and for the proper identification of any of its fortifications. The geophysical investigations sought to accurately delimit the main structures and to determine the new excavation strategy.

2. SITE DESCRIPTION AND BACKGROUND

The Fulgeriş – *La trei cireşi* settlement was discovered in 1982 by archaeologist Viorel Căpitanu [7], who carried the first systematic archaeological investigations between 1987 and 1988 [8]. Since 2003–2010 the research has been re-initiated by a collective from the "Iulian Antonescu" Museum Complex from Bacău, first led by Alexandru Artimon [1], and then by Lăcrămioara Istina [14], who discovered several archaeological complexes and artifacts belonging to the Cucuteni culture, Bronze Age and Latène period (1st BC and I AC centuries).

The site is situated in the western part of the Tutova Hillocks, towards the southern flank of the Fulgeriş Hill, a hilly interfluve with elevations ranging from 300 m to the north, towards Soci brook, and 200 m to the south, towards Fulgeriş brook. Typical for the morphology of the area is the relief conditioned by the monocline structure, with the Fulgeriş Hill belonging to the cuesta alignments specific to Tutova Hillocks [2]. The settlement from *La trei cireşi* occupy a part of a cuesta with a relative altitude of 75 m and confined to the south by Fulgeriş brook, by Valea Hurui brook to the east, and to the west by a seasonal torrent (Figs. 2, 3).

Archaeological research of this site carried out since the 1980's lead to the discovery of a sizeable settlement belonging to the A3 sub-phase of the Cucuteni culture [23], with five dwellings and over 25 garbage pits. Post-Cucuteni discoveries are to be found in the vegetal layer (with a thickness of cca. 0.40 m), the thin habitation levels having been destroyed by modern agricultural work.

Chronologically speaking, the Cucuteni settlement is dated approximately between 4450 and 3800 BC [5].

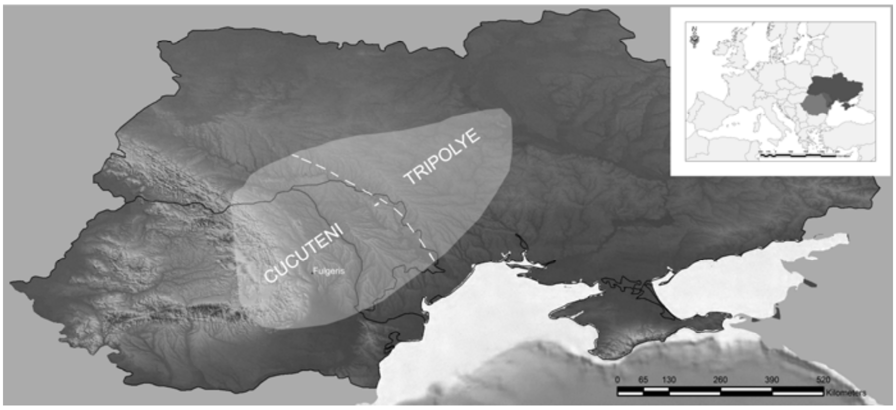

Fig. 2 – Approximate extent of the area covered by the Cucuteni-Trypillian archaeological complex.

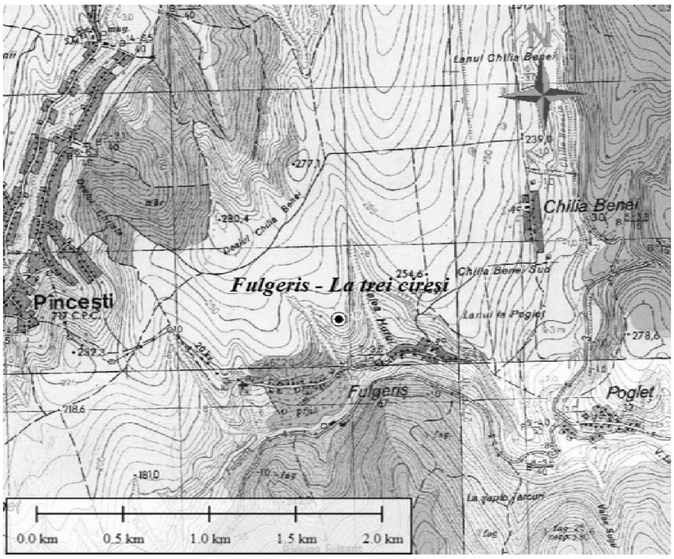

Fig. 3 – Fulgeriş – *La trei cireşi*. Topographical map.

3. METHODS

Magnetometry is a method of prospection dealing with the charting of the soil's local variations of the magnetic field. Since it is grounded in the interpretation of the Earth's magnetic field, magnetometry is labeled as a passive method, in contrast with active ones – such as GPR, electrical resistivity, seismic method, galvanic method, electromagnetic method – working under the principle of inserting a signal into the soil and subsequently registering and analyzing the feedback – the same signal, with more or less altered traits [15, 24].

Having been first applied by Martin Aitken in 1958, in England, (Aitken *et al.* 1958), the technique was further perfectioned through the contributions of J.C. Alldred (1964) from Oxford University, the German I. Scollar and F. Krückeber (1966), J. W. Weymouth (1976, 1986) from the U.S., quickly becoming the most employed method in archaeology (Table 1) [10, 15, 18].

Table 1

The most frequently used geophysical techniques for terrestrial investigation [10]

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

3.1. PRINCIPLES

The principle behind magnetic surveying revolves around the presence in the soil of weakly magnetized iron oxides. Most types of soil and rocks contain between 1 and 10% iron oxides which form tiny magnetic fields positioned in various dispositions, thus making magnetometric surveying possible. There are two distinct phenomena belonging to the behavior of these magnetic anomalies: thermoremanent magnetism and magnetic susceptibility.

1. The first of these concerns weakly magnetized materials which after having underwent heating, have acquired a permanent magnetic character. For this to happen, the material must be heated to a temperature not higher than a certain value known as the Curie Point, which may vary according to the soil's mineral composition. For example, for hematite we can speak of a Curie Point equal to 675°C, while for magnetite the value is 565°C. Above these temperatures the iron contents of the minerals is de-magnetized and the material loses all of its magnetic properties. After cooling, the material is re-magnetized, developing new permanent magnetic properties, in a manner specific to its position in respect to the Earth's magnetic field. To put it differently, the alignment of the materials possessing magnetic features with the Earth's whole magnetic field is called thermoremanent magnetism. Among the archaeological remains which have certainly underwent this process, we can list burned clay hearths, stoves and ovens for ceramic burning, ever-present in a settlement such as the one investigated by us [12, 15, 18–19, 24].

2. The ability of a body to magnetize while inside a magnetic field is a function of its magnetic susceptibility. This property can be negative (diamagnetism) or positive (paramagnetism), and most natural materials have trivial values of susceptibility. This means that the identification of magnetic anomalies can only be achieved if the soil contains certain magnetizable minerals, such as hematite, magnetite and maghemite. A major contribution in the description of the mechanism for increasing magnetic susceptibility came from E. Le Borgne who suggested the following schema [12]:

$$\text{Hematite} \xrightarrow[\text{Reduction}]{} \text{Magnetite} \xrightarrow[\text{Oxidation}]{} \text{Maghemite}$$

All soils are, to a larger or smaller degree, magnetically susceptible, but what is fundamental in producing anomalies is the contrast between a structure's magnetic susceptibility, generated by natural or anthropic phenomena, and the surrounding matrix. Among the anthropic causes which might generate anomalies we can cite pits containing organic fill, ditches, fireplaces, incinerated dwellings, invasive structures such as foundations, walls, etc. [6, 12, 15, 19, 24].

4. DATA ACQUISITION AND INTERPRETATION

The geophysical research campaign from Fulgeriş was made possible through the collaboration between the Interdisciplinary Research Platform in the Field of Archaeology – *ARHEOINVEST*, from the "Alexandru Ioan Cuza" University of Iași, and the "Iulian Antonescu" Museum Complex from Bacău. The main purpose of this investigation was to identify the fortification works of the cucutenian settlement from *La trei cireşi* site using a cesium vapor magnetometer, and to archaeologically confirm the registered data.

The delimitation of the 8700 m² area for the magnetometric scanning was made in accord to the presence of ceramic material on the surface, subsequently assigning, using a Leica 1201 total station, three grids of different sizes (grid I = = 28 × 70 m; grid II = 50 × 100 m; grid III = 20 × 80 m), aligned on a north-south direction, and traced respecting the geomorphological configuration and vegetation present on the site (Fig. 4).

The magnetometer used was the Geometrics G858 deployed as a horizontal gradiometer with a distance of 0.9 m between sensors and a height of 0.75 m above ground. The delimitated area was thus investigated in approximately eight hours distributed in two work-days.

The data was bidirectionally collected from a grid with a distance between the lines measuring 0.5 m, with 10 readings per meter.

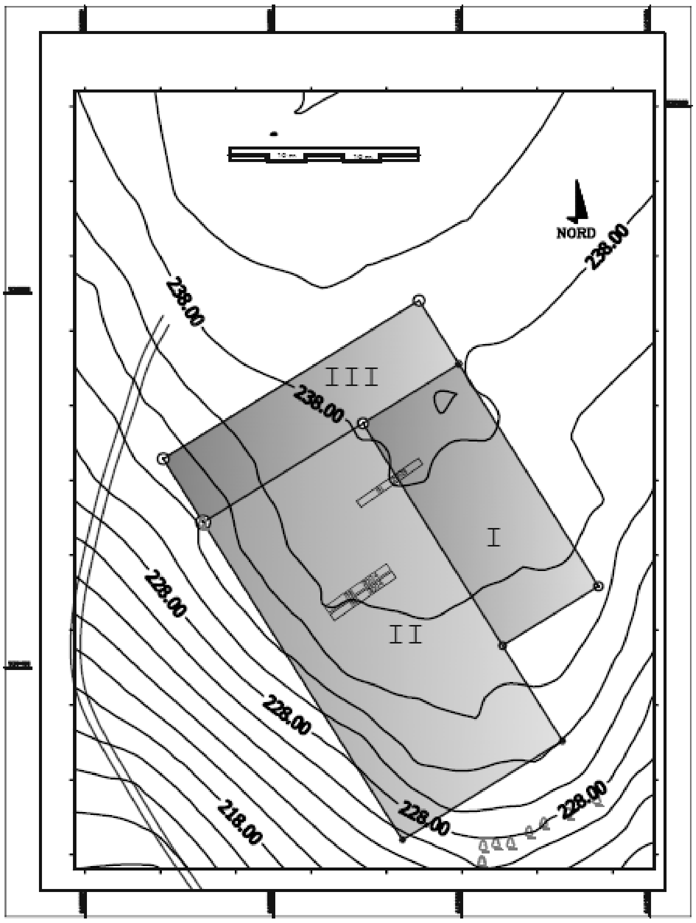

Fig. 4 – The general view of the magnetometric prospection.

The processing of the obtained data was made using the instrument's own software – MagMap2000 and MagPick [13]. After combining all profiles, a detailed gray scale map of the scanned area was produced, depicting in lighter shades anomalies with a strong magnetic signal, and weakly magnetic anomalies in darker shades, respectfully (Fig. 5).

The registered data was processed with *destripe*, *despike*, *remove drop outs* and *smooth readings* filters to remove the noise created during data collecting by metal objects and the bedrock. The problems which arose during the merger of the three grids were annulled by attaching to the original file of a set of diurnal corrections, while also adjusting the variations of the Earth's magnetic field caused by various disturbing factors. To prevent difficulties in locating the identified anomalies, the magnetometric map was georeferenced using a Leica GPS1200. The final stage in data processing was its export to MagPick to locate and map the main anomalies, and to Surfer, with which the tridimensional model was created based on the registered signal (Fig. 6).

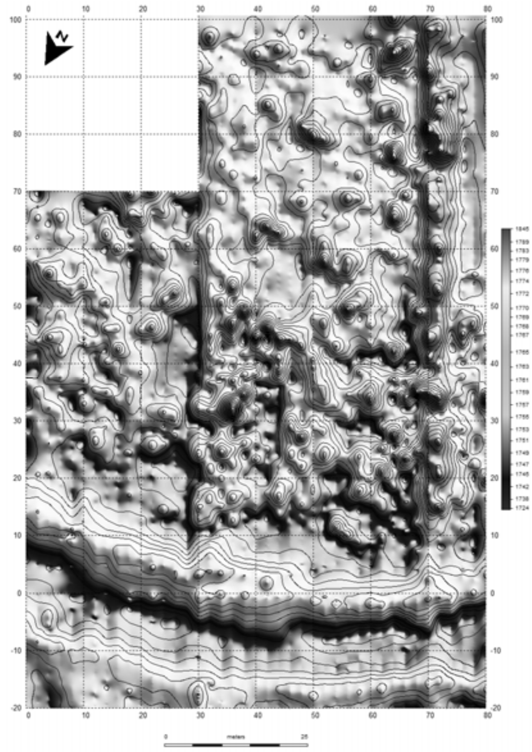

Fig. 5 – The map of the magnetometric scanning.

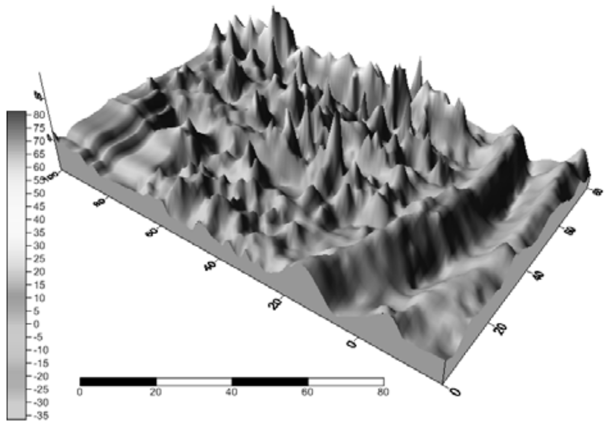

Fig. 6 – The tridimensional model based on the registered signal.

5. GEOPHYSICAL RESULTS AND DISCUSSION

As previously said, the effectiveness of a magnetic scanning with applications in archaeology is strongly dependent on the degree to which structures with altered magnetic properties are present in the ground. Archaeological remains usually exhibit local magnetic anomalies in the 1–20 nT range, ancient burned structures may range from 10 and 1000 nT, while ferrous objects have magnetic susceptibilities that range between 20 and 2000 nT.

Our main purpose was to locate and map the main magnetic anomalies, particularly of the fortification elements, characteristic of elevated Cucuteni settlements, naturally protected on three sides, with an accessible flank protected (Fig. 7) by anthropic defense structures [16-17, 22-23]. This consideration was the base for determining the area to be prospected, alongside other aspects such as property rights of the land and geomorphological features (landslides). A mention should be made of the fact that up until the moment of investigation the area was agriculturally exploited by mechanical means, meaning that the soil's natural configuration was affected, thus making the interpretation of the data much more difficult.

On the magnetometric map obtained, several anomalies of different sizes can be noticed in the southern part of the site, probably residues of burned dwellings or small metal objects. Some of these anomalies can be identified with older archaeological excavations (Fig. 8).

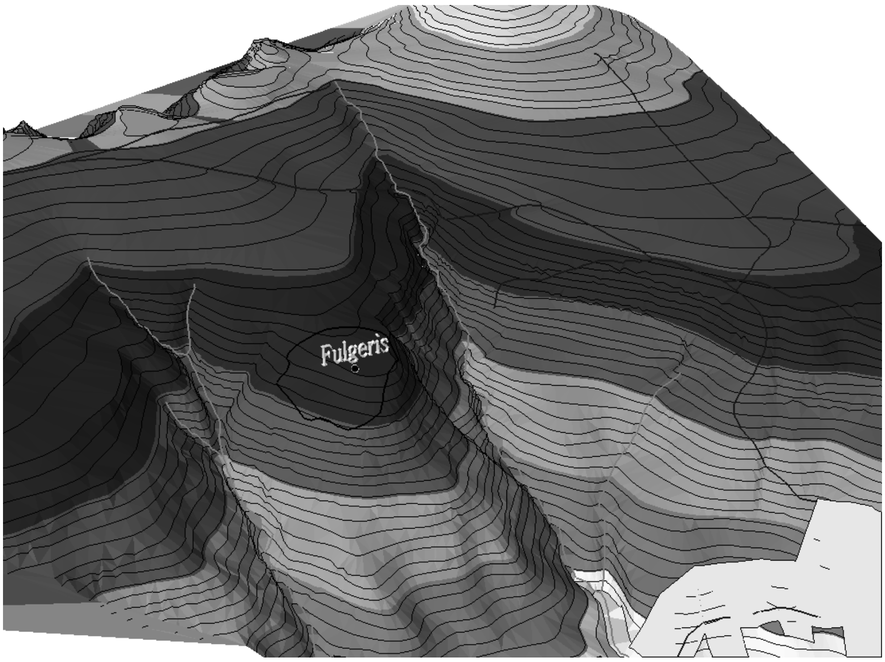

Fig. 7 – Tridimensional terrain modeling of the Fulgeriş site.

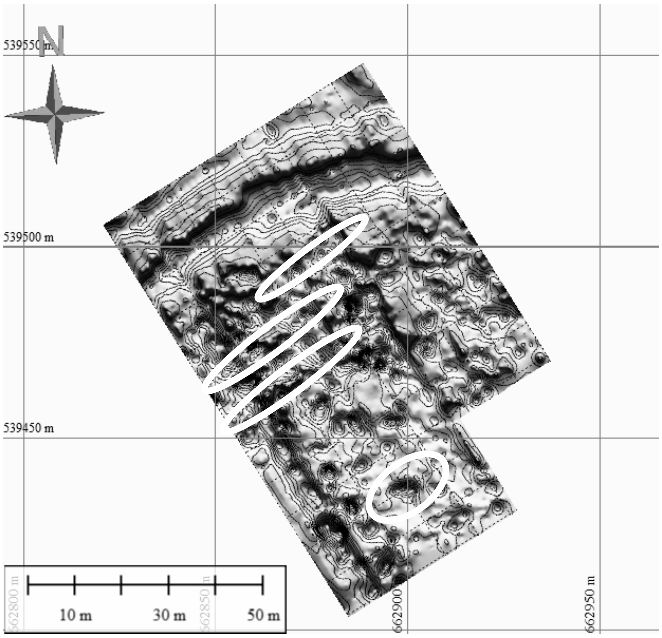

Fig. 8 – Secondary anomalies visible on the site's surface.

What is distinguishable on the settlement's accessible flank constitutes the research's primary objective. Our expectations were fulfilled when two apse-shaped anomalies, with magnetic signals in the range between 48720 and 48789 nT, fully enclosing the settlement's northern side. Their dimensions are considerable, with the southern one having a width of approximate 10 m, and the northern one deployed on a length of 8 m.

Following the excavation campaign of the 2010 summer the anomalies' presence was confirmed as two defense ditches. The distance between the two v-shaped fortification elements is 9.60 m, with an opening of 9.70 m for the southern one, and 9.70 m for the northern one. The depth for the first ditch was 2.50 and 2.12 m for the second. Based on the material found in the fills (exclusively of cucutenian origin), and considering the ditches' building technique, it was inferred that both date from the late Chalcolithic and that both were most likely fashioned simultaneously. Alongside painted and non-painted pottery typical for the Cucuteni A3 phase, found at –1.80 m and 2.10 m in depth, the southern ditch also witnessed the discovery of pieces of burned clay originating from hearths or walls, as well as of stone fragments and osteological material.

Other small anomalies were observed in addition to the two major ones; during the excavations they were identified as garbage pits dating from the Getae-Dacian period.

a.

b.

c.

d.

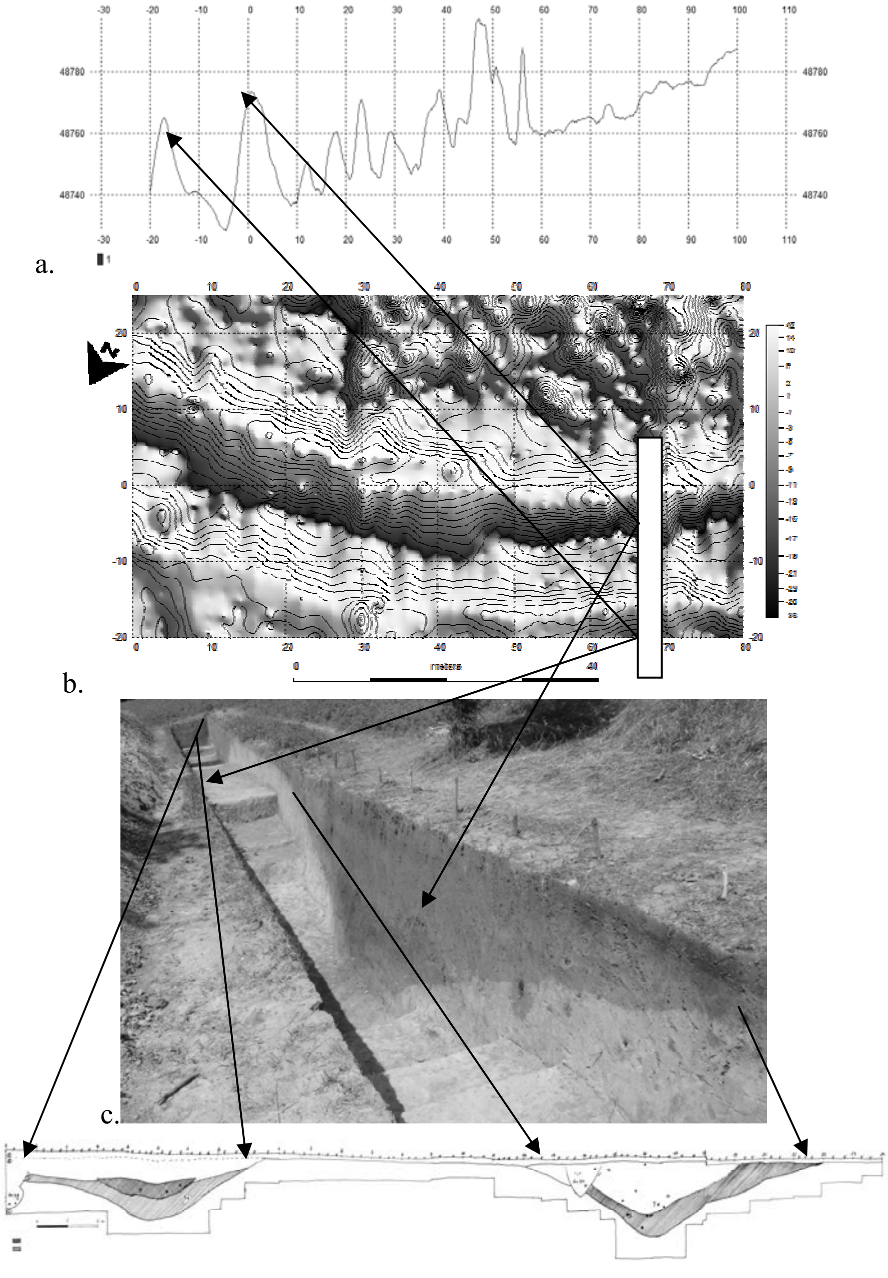

Fig. 9 – A comparison between the magneometrical and archaeological results: a) the magnetic profile obtained in the archaeologically researched area; b) observed magnetic anomalies representing the defense ditches; c) photo of the archaeological trench; d) graphical representation of the archaeological profile.

6. CONCLUSIONS

The employment of interdisciplinary research methods in archaeology has, once again, proven to be highly valuable and effective, as exemplified by the magnetometric prospection of the chalcolithic site from Fulgeriş. That the use non-invasive techniques and their correlation with topographical information can be used to pertinently elaborate an excavation strategy for the archaeologist, constitutes the main idea advanced in our paper. Furthermore, the magnetic method amply presented above proved to be adequate for identifying possible fortification elements of an archaeological site, may it even be from the Chalcolithic. Due to the lack of pre-existing researches of this type in the area, and moreover of a Cucuteni settlement, our mission was not a facile one. As the data was registered and processed, notable difficulties emerged particularly in respect to the risk of subjective approach and interpretation.

The lack of additional data for comparison can be a problem in such undertakings, but the confirmation of our interpretations by the archaeological excavation can be of support in drafting a model of interdisciplinary-sustained archaeological research model.

Acknowledgements. We thank the "Alexandru Ioan Cuza" University of Iaşi for its support of the *Cucuteni Universalis* research project.

This work was partially supported by the by the European Social Fund in Romania, under the responsibility of the Managing Authority for the Sectorial Operational Program for Human Resources Development 2007-2013 [grant POSDRU/88/1.5/S/47646].

This paper was prepared with the financial support of OIPOSDRU, through the project "Dezvoltarea capacităţii de inovare şi creşterea impactului cercetării prin programe post-doctorale" – POSDRU/89/1.5/S/49944.

This work was made possible also with the financial support of the Ministry of Education, Research, Youth and Sports of Romania (Exploratory Research Project PN-II-ID-PCE-2011-3-0825, The Ethnoarchaeology of Salt Springs and Salt Mountains from the extra-Carpathian areas of Romania, no. 219/2011 – http://ethnosalro.uaic.ro; grant director Marius Alexianu).

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