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Using Integrated Geophysical Techniques to Prospect an Unexcavated Archaeological Site at Sungai Batu, Kedah, Malaysia

[1]S.Y.M. Alashloo, [1]R. Saad, [1]M.N.M. Nawawi, [2]M. Saidin, [1]M. Ali Dakhel and [1]M.M. Alashloo
[1]School of Physics, Universiti Sains Malaysia, 11800 Penang, Malaysia
[2]Global Center for Archaeological Research, Universiti Sains Malaysia, 11800 Penang, Malaysia

Abstract: None-invasive geophysical methods are nowadays commonly used in archaeological studies. In this study, an integrated geophysical investigation utilizing both the electrical resistivity tomography and magnetic techniques was performed at one of the unexplored sites of Sungai Batu archaeological complex, Kedah, Malaysia. The main purposes of this survey were locating buried archaeological artifacts and determining the shallow subsurface geology. The geophysical study proceeded in two steps. First, the magnetometry survey was performed employing a G-856 proton precession magnetometer over 13 lines. Then, the Electrical Resistivity Tomography (ERT) survey was designed in 5 lines utilizing a pole-dipole array. The ERT data was processed by using the smoothness constrained least-squares inversion. The magnetometry results displayed two main anomalies which had a high magnetic value, indicating buried structures. The ERT results demonstrated three main layers of alluvium soil mixed with sand and clay, saturated zone and the bedrock layer. The correlation of two methods indicated a good agreement between magnetic and resistivity results. An excavation test, conducted by archaeologists, confirmed the geophysical results. Consequently, the survey results revealed that integrated geophysical techniques are useful tools to obtain more detailed information about underground for designing a fast and cost-effective archaeological excavation.

Key words: Magnetic, electrical resistivity tomography, geophysical methods, Sungai Batu, archaeology

INTRODUCTION

A rapid growth of using Geophysical methods in archaeological prospecting can be observed in recent years. The correlation of these non-invasive methods acquires high resolution images of the subsurface to decrease the destruction, time and cost of archaeological excavations. These methods include magnetic, geoelectric, Ground Penetrating Radar (GPR) and seismic (Bavusi *et al*., 2009; Cardarelli *et al*., 2010; De Domenico *et al*., 2006; Gaffney, 2008). The magnetic and Electrical Resistivity Tomography (ERT) are commonly used in geophysical survey because of acquiring large amounts of data, quickly and providing a high-quality image of subsurface structures (Aspinall *et al*., 2008; Clark and de Biran, 2007; Taha *et al*., 2011; Urbini *et al*., 2007). These methods represent a wide range of non-invasive applications for the archaeological purpose (Chianese *et al*., 2010). However, employing the magnetic method is restricted due to the existence of high magnetic noise in the urban area (Drahor, 2011).

In this study, an unexcavated archaeological site was investigated to obtain the principal objectives of finding the location of archaeological remains and characterizing the shallow geological structure.

Data were collected using two geophysical methods, magnetic and ERT from the Sungai Batu archaeological area. Sungai Batu is considered by archaeologists as a high-potential archaeological area where scientists search signs of civilization. In the first step of geophysical investigation, magnetic survey was carried out to detect the location of archaeological targets. Consequently with guidance from magnetic results, the resistivity survey was designed to define the subsurface stratigraphy, also to act as a complementary tool to improve the magnetic results. The processing and joint interpretation of the data certified the successful application of magnetic and ERT methods for planning the archaeological excavation survey.

STUDY AREA

The Sungai Batu archaeological area demonstrates that civilization in Malaysia had begun much earlier and was the oldest in southeast Asia (Fig. 1). This area might have been a remnant of an ancient jetty applied for

Corresponding Author: S.Y.M. Alashloo, School of Physics, Universiti Sains Malaysia, 11800 Penang, Malaysia
Tel: + 60174391603 Fax: + 6046579150

Fig. 1: The location of investigation site at the Sungai Batu area, Kedah. The states of Malaysia are shown with different colors. (modified from Google Maps)

exchange traded goods that may have involved iron ores (Sabtu, 2002). Sungai Batu is located in Bujang Valley at geographical coordinates 5°41′ 40″ N and 100°26′ 59″ E along the road from Sungai Petani to Merbok in northwestern Malaysia. Bujang Valley extends from Kedah Peak in the North, to Muda River in the South and involves two main rivers of Muda and Merbok. Studies of the Bujang Valley civilization began more than a century ago. During this period, over 80 sites were found which most of them were the site of temple and entrepot. Bujang Valley is believed to be the earliest entrepot and religious center in the country. Its role can be confirmed by the discovery of archaeological evidence such as the discovery site of the Hindu-Buddhist temple, statues, porcelain, beads and many other artifacts (Rahman, 2008; Wales, 1970). The significance of this area has resulted in traders landing at Bujang Valley while waiting for a change of monsoon (Allen, 1997).

The study area is part of Jerai formation in Kedah and its elevation is about 12 m above sea level. The drainage pattern on the Kedah Peak massif is radial (Nawawi *et al*., 2004). Away from the peak area, however, the pattern becomes more complicated. This area is covered by Jerai Formation which consists of two distinct facies. One of the facies is clay comprised of schist, semi-schist and mudstone. Another one is metamorphosed sand including quartzite, granulite and grit (Bradford, 1972). Distribution of the two facies cannot be sharply delineated, due to complex interbedding and the gradational character of contacts between them throughout the formation. Generally however, the sediments are very poorly sorted and the sand and clay strata are frequently interbedded (Willbourn, 1926).

METHODS OF INVESTIGATION

The geophysical survey includes the utilization of magnetic and ERT techniques. These techniques are described as fast data acquisition rate, high resolution, non-destructive and cost-effective methods (Chianese *et al*., 2010). Moreover, they can obtain valuable information from shallow subsurface for planning the future archaeological prospection. The present survey was performed through these steps, first a magnetic prospecting was carried out followed by ERT survey.

Magnetic survey: The magnetic survey is a passive geophysical technique depends on the contrasts in a magnetic property between the feature of interest and its surrounding environment (Schmidt, 2007). The most significant magnetic properties for archaeological prospection are magnetic susceptibility and magnetization. As most archaeological materials contain magnetic particles, they will have magnetic properties and cause magnetic anomalies that can be applied in different ways (Tarling, 1983). Magnetometry is one of the magnetic survey methods which record the magnetic fields produced by a contrast in magnetization, whether it is produced due to a magnetic susceptibility contrast, or remanent, for instance from thermoremanent magnetization (Schmidt, 2007).

In the present study, the magnetic survey was performed in 13 lines using a G-856AX proton precession magnetometer with 4 m sampling interval. The length of each line was 160 m with 10 m distance between each two adjacent parallel lines (Fig. 2). The coordinates of the beginning and end points of each line were recorded by the Global Positioning System (GPS) for applying in the Surfer software to create a plot of the survey area. A base station was set up around 250 m away from the survey area which a G-856 magnetometer recorded magnetic readings at a time interval of one min. These data were used to remove the diurnal variation effects of the earth's magnetic field from survey measurements. The data acquisition procedures were conducted well. Nevertheless, the readings still need to be processed to become useable. First step in magnetic processing was inspecting raw data for gaps, spikes, instrument noise or any other irregularities in the data. The next step involved diurnal variation correction and the International Geomagnetic Reference Field (IGRF) correction. Once corrections were done, the data were exported into a grid file to the program Surfer 8. After calculating a grid in Surfer, residual was carried out to compute the difference between a grid value and the raw data at any XY location.

2D RESISTIVITY TOMOGRAPHY

The ERT technique, as an active method, enables geophysicists to achieve high resolution images of subsurface electrical properties. This method is widely applied in the archaeological prospecting to detect buried

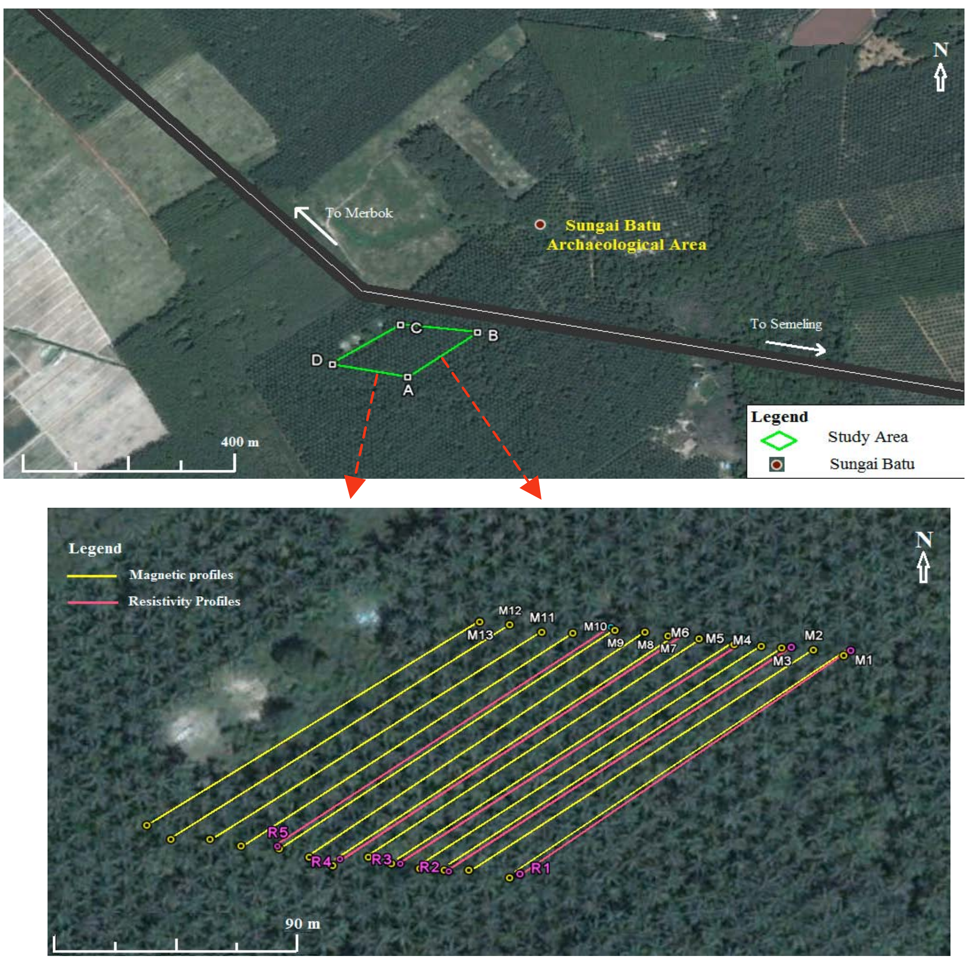

Fig. 2: Survey plan of geophysical investigation (modified from Google Earth)

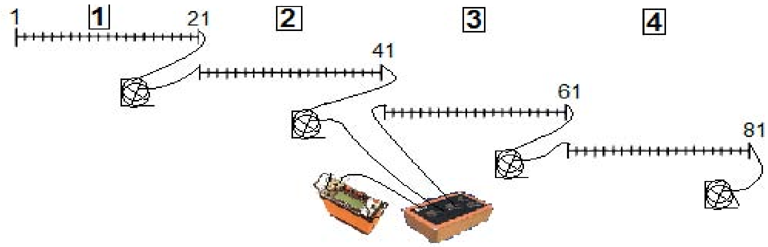

Fig. 3: The electrode arrangement of ERT survey with 2 m interval between electrodes in 4 spread

structures (Drahor *et al*., 2008). Basically, in resistivity method, two potential electrodes measure the potential difference caused by injecting the current into the ground through two current electrodes. The acquired data, in this way, are affected by two main factors: Technical factors such as electrode spacing, electrode configuration, measuring interval and orientation of arrays (Drahor, 2011) and underground factors such as porosity, temperature, salinity, pressure and composition of materials. The development of modern computer-controlled multielectrode systems (Griffiths *et al*., 1990) and 2D and 3D inversion models (Loke, 2001) allows scientists to obtain a detailed picture of the subsurface (Ekinci *et al*., 2008).

The ERT survey was conducted over 5 resistivity lines using a pole-dipole array with 2 m electrode spacing along 20 m spaced parallel survey lines (Fig. 2). Each line, involved 4 spreads, had 160 m length and each spread contained 21 electrodes (Fig. 3). The pole-dipole configuration was employed because of relatively good horizontal coverage. In this array, a remote electrode was set adequately far from the survey line to acquire deeper penetration. A Terrameter ABEM SAS 4000 system with an electrode selector ABEM ES 10-64C were used in data acquisition. The acquired 2D resistivity data were processed by utilizing the RES2DINV software which was based on the smoothness constrained least-squares inversion implemented by a quasi-Newton optimization technique (Loke and Barker, 1996). This technique which consists of a number of 2D blocks, is automatic and it does not need the user to provide a starting model. Ultimately, three sections, measured and calculated apparent resistivity pseudo sections and the inverse model resistivity section were yielded from the RES2DINV software.

RESULTS

Magnetic survey results: To produce contour maps, magnetic data were input into the program Surfer 8. A residual map was produced from the magnetic data to provide more visible results and highlight the main anomalies. Figure 4 displays the total magnetic field map and the residual magnetic map in which magnetic survey lines are indicated by yellow symbols in the first one and in the other one the most distinct anomalies are rounded for further discussion.

The residual magnetic map gives magnetic values which vary from about -24 nT to 18 nT. The residual map shows that there are no considerable anomalies in middle part of the site and around the borders; only four main anomalies can be seen. Magnetic anomaly 1 has a magnetic value of 12 nT in the positive pole and -10 nT in the negative pole. Magnetic anomaly 2 is a dipole anomaly in which the positive pole is 6 nT and the negative pole is -10 nT. A large dipole anomaly with a positive value of 16 nT and a negative value of -12 nT is found at the north end of lines 6 and 7, marked by No. 3. Finally, lines of 1 to 3 show the dipole anomaly of No. 4 with a value of 12 nT and -10 nT for positive and negative poles, respectively.

Electrical resistivity tomography results: The ERT data were inverted using the RES2DINV software (Loke and Barker, 1996) to obtain a more detailed image of the subsurface. The overall depth covered by the ERT survey is 31.4 m. Figure 5 illustrates the images of 5 ERT lines. These images basically display a clear stratigraphy involving three main layers. The upper layer, with a resistivity value of 150-1000 Ω.m, is interpreted as an alluvium soil consisting of sand and clay with high resistivity bodies distributed in isolated form, the depth of which changes from 2 to 15 m. The second layer, with low resistivity value (<150 Ω.m), is consistent with a water-saturated zone. The thickness of this layer is from 5 to 20 m in different parts of the site. The third layer has a high resistivity value (>1000 Ω.m) which is most probably related to quartzite bedrock. The subsurface characteristics are sorted in the image of line 1 as an example to express the principal features (Fig. 5).

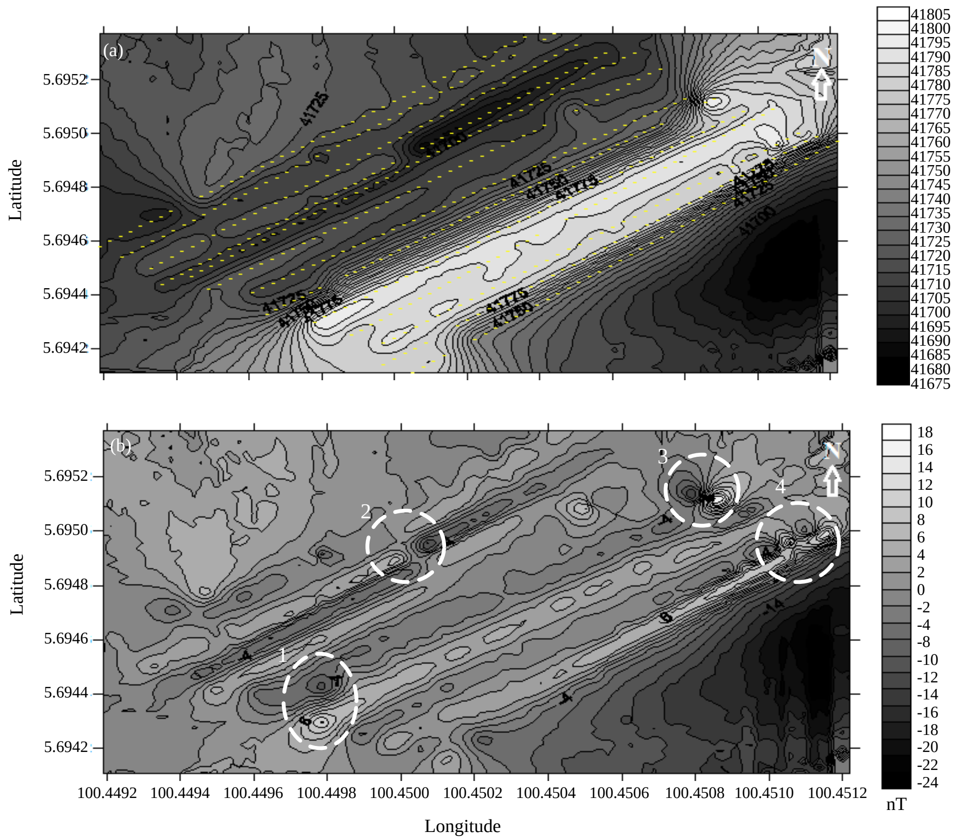

Fig. 4: Magnetometry survey results, a) Total magnetic field contour map with the contour interval of 5 nT, b) Residual magnetic map with anomalies labeled and the contour interval of 2 nT

DISCUSSION

The results of magnetic and ERT surveys were correlated and compared to reduce the inherent ambiguity in data interpretation of each method. From residual magnetic map, it can be found out that anomaly 2 and a few low anomalies in the central part of the site have low magnetic values (Fig. 4). These anomalies can be produced by a change in soil material properties. Therefore, they are not able to provide enough information to make any convincing conclusion about the archaeological targets. This can be confirmed by ERT results which show the change in subsurface geology near these anomalies. The presence of boulders near the surface, at a depth of 1 m, could be the main reason of these low anomalies (Iouane *et al.*, 2010). It is improbable to detect magnetic effects of boulders at the depth more than one to two meters because of the fast decrease of a magnetic field through space (Kvamme, 2006). In an earlier study, Leopold *et al.* (2010) reported the results of a multi-methodological geophysical survey in archaeological prospection. Archaeological remains such as kilns, ditch, buildings, walls and pits were found in which magnetic and ERT methods could detect 60 and 30% of the findings, respectively. This overlapping percentage of findings in magnetic and ERT methods can support using of ERT results to interpret the magnetic data. Three anomalies 1, 3 and 4 are large dipoles with higher magnetic values which can be related to ruins of old buildings made of mud bricks. There is evidence for this idea in the archaeological excavation in some part of anomaly 4, where mud brick collapses have been found. Another evidence is that the anomaly value, produced by mud bricks, could not be high such as fired bricks and pottery because they dried in the sun (Herbich, 2003; Moussavi Alashloo *et al.*, 2011). Becker and Fassbinder (1999) also performed magnetic surveys over mud brick structures which showed a negative magnetic contrast of these targets versus the surrounding soil.

With regard to ERT results, some anomalies with high resistivity can clearly be seen in the first layer, caused by boulders (Fig. 5). The depth of these anomalies also

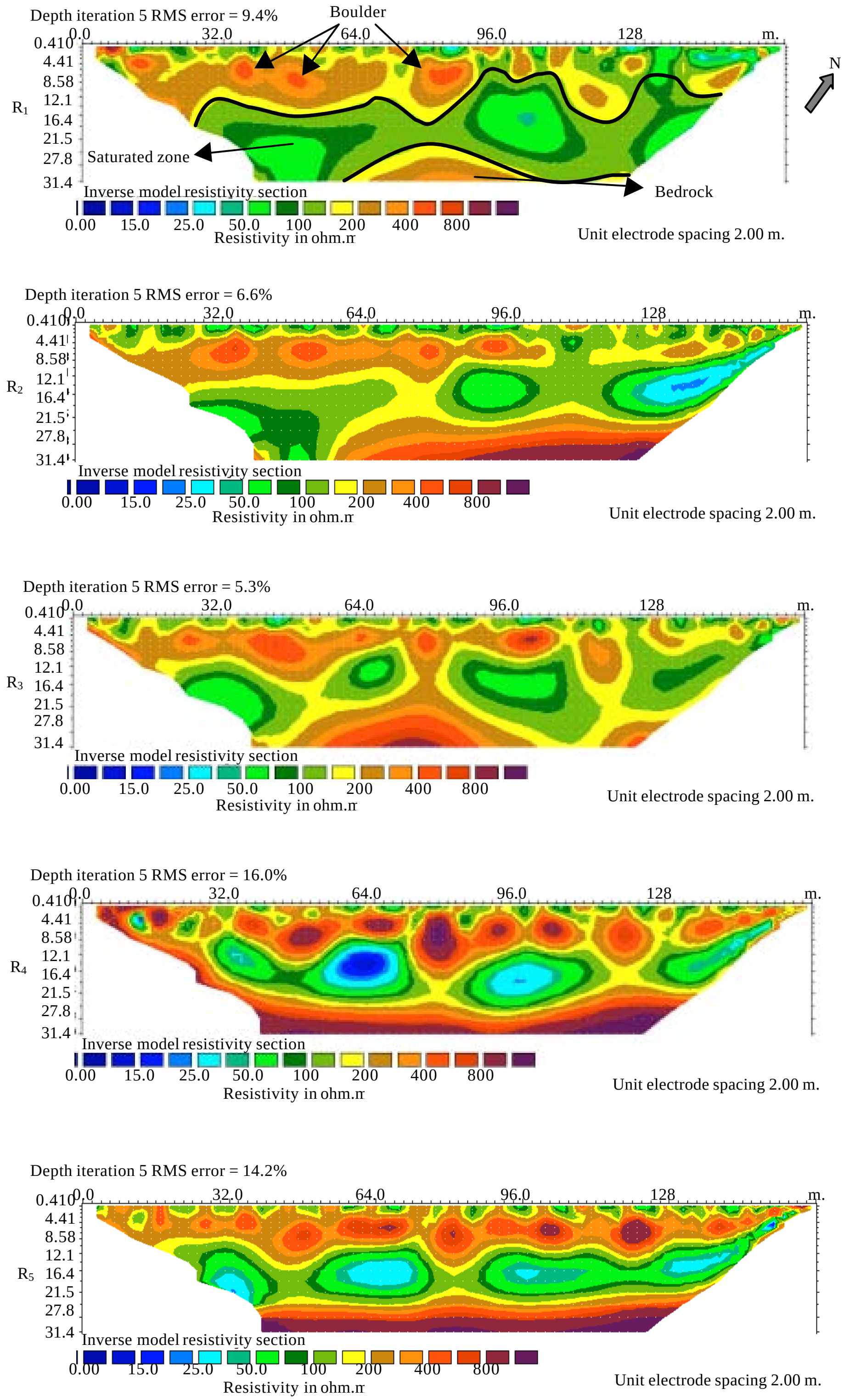

Fig. 5: 2D resistivity inverted model correspond to the lines of R_1 to R_5

demonstrates that they cannot be related to archaeological materials, since the usual depth of artifacts which were found at the Sungai Batu area, is from 0.5 to 1.5 m. The results of a geophysical study at the Saqqara archaeological area, Egypt, affirm our interpretation. The 2D resistivity survey at this area revealed high resistivity anomalies in shallow subsurface due to gravel layer followed by a thick conductive body (El-Qady *et al*., 1999). According to Di-Fiore and Chianese (2008) magnetic anomalies cannot be seen in the ERT image because maybe the magnetic sources are small in compare with the ERT resolution or they are buried in very shallow depths. The saturated zone could be referred to the fluvial system and this evidence can assist archaeologists for tracing the ancient river which may affirm the significance of the Sungai Batu area not only as a center for religious and production activities but also for the exchange of goods.

CONCLUSIONS

In this study, the magnetic evidenced the presence of three principal anomalies, due to buried collapses. Furthermore, the results of ERT survey revealed three main layers of alluvium soil mixed with sand and clay, saturated zone and the bedrock layer. The joint interpretation of the geophysical results demonstrated that the small anomalies on the magnetic map have been caused by the geological changes of the subsurface and they cannot be related to archaeological remains. In conclusion, this survey and its results confirmed that the application of magnetic and ERT as non-invasive methods in archaeological prospecting yields useful information upon which archaeologists can base further investigations of the site, thereby decreasing the time and cost of unnecessary excavations.

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