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Integrated usage of geophysical prospection techniques in Höyük (tepe, tell)-type archaeological settlements

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Key words: Magnetic, Electrical resistivity tomography, Ground penetrating radar, Electromagnetic VLF, Self-potential, Seismic refraction tomography.

The integrated use of geophysical methods has developed rapidly in the last fifteen years in archaeological prospection (Brizzolari *et al.*, 1992; Gaffney *et al.*, 2004; Drahor, 2006; Casana *et al.*, 2008). The combined application of different geophysical techniques supplies useful information about buried archaeological contexts, particularly höyük(tell, tepe)-type archaeological settlements. The aim of such studies is to help archaeologists conduct fast, effective and economical excavations by providing probable architectural plans, structural characteristics and locations of archaeological settlements.

Höyük-type settlements are formed when the mud-based building in circum-nucleated settlements with complex archaeological contexts erodes for natural reasons and over time, turning into mounds covering the settlement (Drahor & Kaya, 2000). Höyük-type sites include various archaeological structures from different archaeological periods – Neolithic, Chalcolithic and Bronze Age – all over the Near East, the Balkans and in territories as far away as India.

The aim of the present work was to demonstrate the advantages of integrating results obtained from various geophysical methods for höyük-type sites. Therefore, six different methods were applied to a test site of 30 x 30 m in size, located in Bayraklı Höyük, close to the city of Izmir, Turkey. This site is one of the important höyük-type settlements in Western Anatolia. The six geophysical methods applied comprised electrical resistivity tomography (ERT), magnetic, ground penetrating radar (GPR), seismic refraction tomography, electromagnetic VLF and self-potential (SP).

The magnetic method is very sensitive to magnetic susceptibility changes within the soil and to strongly magnetic features like all kinds of burnt archaeological structures, kilns, pottery deposits, etc., which are characterized by thermoremanent magnetization and which are very common in archaeological sites (Drahor, 2006). Magnetic studies were carried out using a practicable fluxgate gradiometer. The effects of different spacing of measuring points and lines were tested during these investigations.

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In an archaeological study, resistivity variations between soil types and stones are important, whereas in geological studies these variations are generally important between the different rock types. The electrical imaging technique has recently become an efficient tool in investigating shallow archaeological structures (Drahor, 2006). The ERT method was applied using five different arrays (Wenner, Wenner-Schlumberger, dipole-dipole, pole pole and pole-dipole) to display buried archaeological structures for various measuring and line intervals (0.5, 1 and 2 m). Also, the orientation problem was studied using two perpendicular directions during the investigations.

The VLF electromagnetic method used widely to map shallow structural features takes advantage of signals transmitted by powerful radio stations in frequency bands varying between 15 and 30 kHz. The VLF and VLF-R measurements were performed using Scintrex ENVI-VLF equipment. The data were collected by a three-point array with 1 m measuring and profiling intervals. Furthermore, the intervals of dipoles measured were 5 m, and they were perpendicular to one another. In the measurement process, two effective frequencies, 20.3 and 26.7 kHz, transmitted from Tavolara, Italy and Bafa, Turkey respectively, were used. Also, VLF data were processed using the Karous-Hjelt and Fraser filters (Pirttijarvi, 2004).

The SP method investigates the different SP phenomena responsible for anomalies on archaeological sites, such as electrokinetic, electrochemical and other SP effects (Drahor, 2004). Thus, the other aim of this study was to evaluate appropriate survey procedures important to obtaining good quality data in SP surveys. The orientation problem, measuring and line interval effects were investigated for total and gradient SP data.

The GPR method has been extensively used in archaeological prospection. However, the usage of this method is very limited on höyük-type sites. In order to test method performance, experimental GPR studies were carried out on the test site using three different antennas (500, 100 and 25 Mhz). The measuring and line interval effects and orientation problem were also investigated during the measuring process. Also, a seismic refraction study was carried out in test lines, and this data were interpreted using the refraction tomography method.

The interpretation of geophysical measurements, both qualitative and quantitative, proved that the final interpretation is further enhanced after integrated usage. Figure 1 shows some results of integrated studies obtained for line GK6. The different ERT sections are given in Figure 1a, and their results are comparable. Resistive bodies are clearly displayed in the VLF-R graphic, and this result is consistent with ERT results. The VLF section and gradient SP graphic give the contact zones and variations in the subsoil. Magnetic changes are generally observed in the southern and northern part of the line. The GPR radargram also detected fundamental variations in the subsoil (Fig. 1b). Physical changes are mostly observed in similar locations

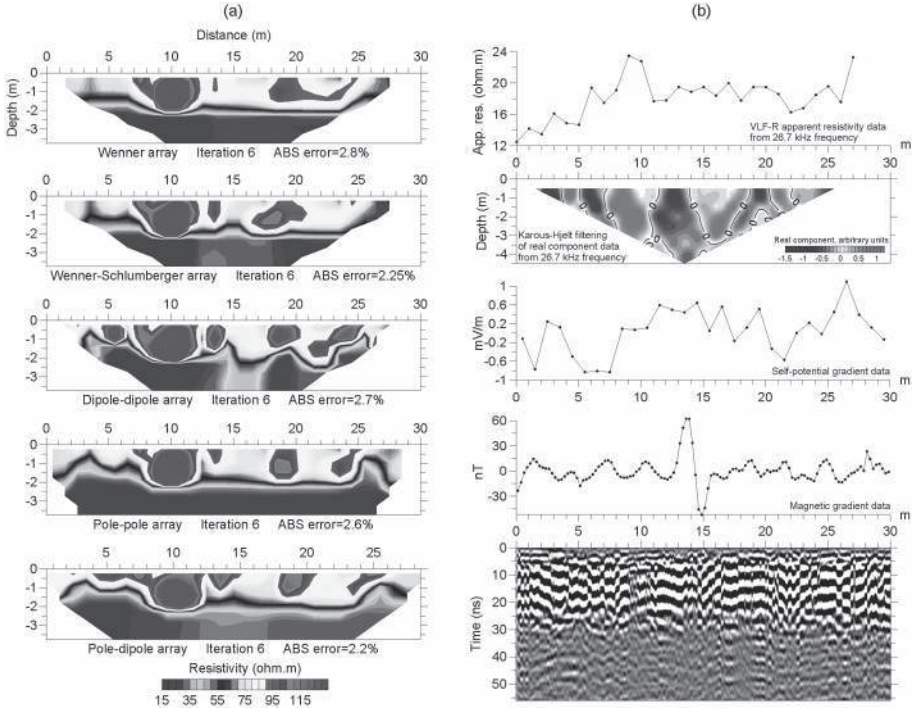

Figure 1 (see color plate): a) ERT and b) VLF-R, IP, SP gradient, magnetic gradient and GPR results for line GK6.

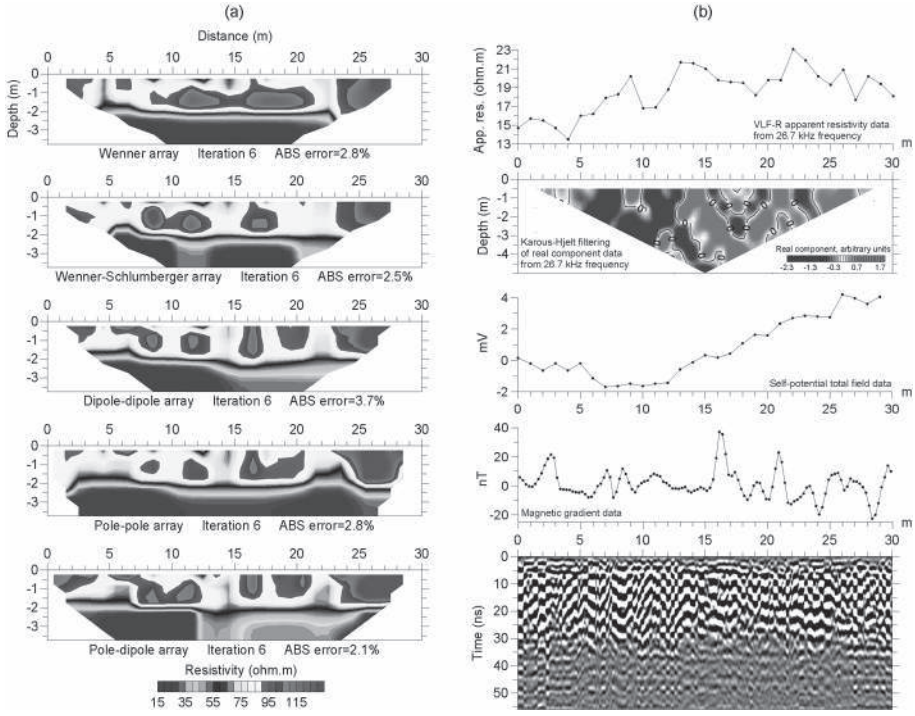

Figure 2 (see color plate): a) ERT and b) VLF-R, IP, SP total field, magnetic gradient and GPR results for line GK16.

of the integrated results for line GK6. Similar results are also observed in Figure 2 which shows the integrated results obtained from line GK16. The ERT sections are slightly different from each other (Fig. 2a). The VLF-R result is similar to the ERT sections, particularly the Wenner-Schlumberger array. In addition, an important variation appeared between the 13th and 27th meter of the line in both total field SP graphic and VLF section. Typical magnetic anomalies were also displayed in anomalous zones which were observed in other geophysical sections and graphics (Fig. 2b). Many changes in the GPR radargram of line GK16 were observed, corresponding to resistive structures in the resistivity model sections (Fig. 2).

The conclusion is that the integrated use of six different geophysical techniques has provided matching results. It means that each method has successfully detected archaeological features in the surveyed area and a correlation between them has been confirmed. Consequently, the integrated usage of geophysics allows for more detailed information and less invasive examination of archaeological structures at höyük-type sites.

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