Archaeologia Polona, vol. 53: 2015, pp. 444-448

Integrated geophysical investigations at Šapinuva, a Hittite city in central Anatolia, Turkey

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KEY-WORDS: ERT, GPR, integrated approach, MASWT, magnetic gradiometry, SRT, Šapinuva

INTRODUCTION

This paper presents integrated geophysical investigations carried out at the Šapinuva archaeological site, which was one of the important cities in the Hittite Empire. The objective was to explore the buried structures with a multi-method geophysical approach, applying the techniques of magnetic gradiometry, ground penetrating radar (GPR), electrical resistivity tomography (ERT), seismic refraction tomography (SRT) and multichannel analysis of surface waves tomography (MASWT). In the last two decades, integrated geophysical investigations, which maximize information on subsurface features, have been applied in near-surface geophysics increasingly often, especially in archaeological studies (Diamanti *et al.* 2005; Drahor 2006; 2011; Kvamme 2006; Piro *et al.* 2000; Papadopoulos *et al.* 2012; Vafidis *et al.* 2005). The aim of this approach is to obtain more reliable results and interpretations of the subsurface characteristics of areas investigated at archaeological sites, where the soil conditions are often complex. Important archaeological remains have been discovered at the Šapinuva archaeological site using the results of these integrated geophysical surveys.

ŠAPINUVA ARCHAEOLOGICAL SITE

Šapinuva was a religious, military and governmental Hittite city that had a relationship with the capital of the Hittite empire (Hattuşa). Recently, archaeological excavations have been carried out in two different areas: the city itself (Tepelerarası) and the sacred district (Ağılönü) (Süel 1995). However, Šapinuva is a problematic archaeological site for geophysical prospection. The city was affected by major earthquakes during Hittite times, creating a complex soil stratigraphy that would not be without effect on the results of geophysical surveys. Moreover, subsurface structures within the city were affected by an intense and extensive fire that may have left remains giving rise to confusing magnetic anomalies. In addition, the archaeological structures are extremely close to the surface in an area of intensive modern agricultural activity. The archaeological context has been affected by this activity and this may cause spurious and undesirable anomalies to come up in the geophysical surveys.

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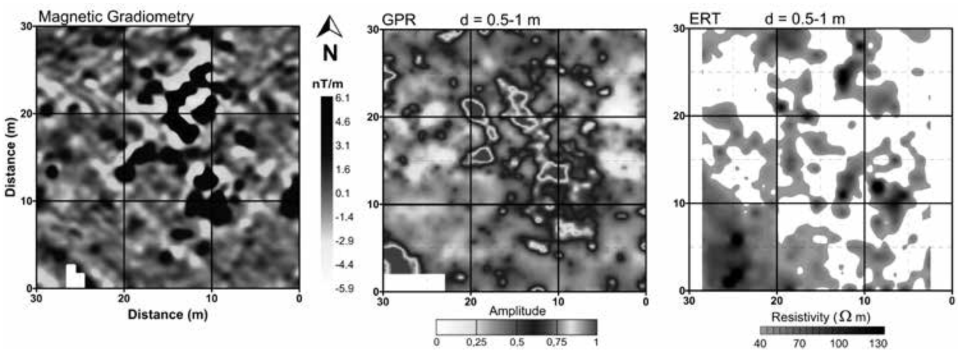

Fig. 1. Comparison of integrated geophysical results from the Tepelerarası area

RESULTS OF INTEGRATED SURVEYS

Ground-based integrated geophysical surveys at the Šapinuva archaeological site were carried out in two stages. Generally, data were processed with well-known data enhancement techniques. Gradiometric data were processed by standard correction and evaluation techniques, GPR data in conventional GPR processing stages; resistivity data were evaluated using a 2D inversion approach and the P wave tomographic velocity models were obtained by an iterative tomographic approach, using SeisImager/2D software. For the MASWT survey results, SeisImager/SW software was used for the processing in similar manner.

Geophysical surveys using magnetic, GPR and ERT techniques were performed in the Tepelerarası area of Šapinuva. Considering the comparative results of these techniques (shown in Fig. 1) one can see that the relationship between the results is very good in terms of anomaly localization. An important burnt archaeological structure is clearly seen in the magnetic image. Dark magnetic anomalies indicate the burnt mud-brick walls, while light anomalies are likely to indicate unfired archaeological structures and limestone material. Medium anomalies describe the soil covering the archaeological ruins. The magnetic image reveals important archaeological structures buried in the near-surface, oriented NE–SW and NW–SE, which is typical of Hittite layers excavated in the area. The GPR and ERT anomalies are of similar character and coincide for the most part with the magnetic anomalies. The high-reflection GPR anomalies in the depth slice between 0.5 and 1 m correlate with dark magnetic anomalies. These structures are likely to indicate shallow archaeological structures affected by agricultural activities. ERT results show that highly resistive anomalies are focused in a similar location. The ERT depth slice from 0.5 to 1 m reveals anomaly groups that are well correlated with the magnetic and GPR anomalies.

The magnetic image from the Ağılönü district was overlain with photographs from archaeological excavations (Fig. 2). It shows structures located at shallow depths, approximately 0.5 m below the surface. Important traces of burning were found in the archaeological context, together with earthquake 'footprints'. It was determined based on the archaeological results that the burnt zones corresponded to highly magnetic anomalies, while the unfired structures did not give distinguishable magnetic anomalies

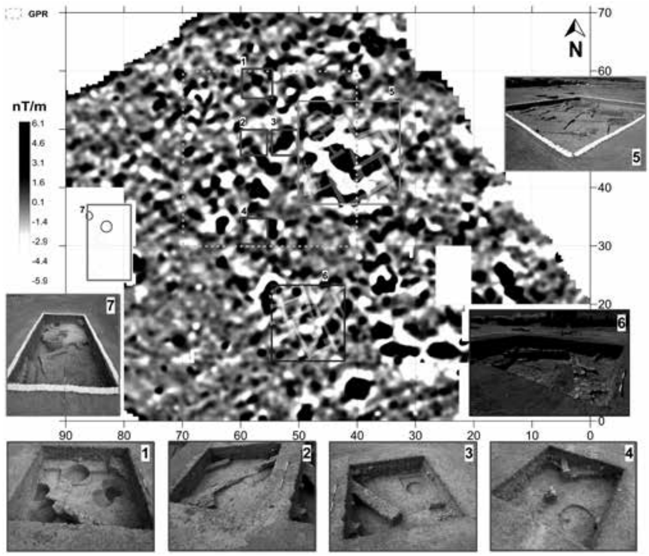

Fig. 2. Archaeological excavation results superimposed on a magnetic image of the Ağılönü area; 1–7 – views of archaeological structures excavated in 2013

Seismic refraction tomography (SRT) and multichannel analysis of surface wave tomography (MASWT) methods were applied alongside GPR, ERT and magnetometry in the Taşdöşem area of the Ağılönü site. In the magnetic data image of the Taşdöşem, three important anomalies are marked with ellipses (Fig. 3): 1 – negative anomalies aligned NW–SE, 2 – distinct anomalous zone oriented almost E–W, 3 – positive-to-negative transition zone due to surface variations, as revealed by recent agricultural activities. Moreover, the GPR, ERT, SRT and MASWT slices between 0.5 and 1.78 m depth, compared with the magnetic image, revealed the anomalies in the first zone to be oriented NW–SE in all cases. The second anomalous zone (2) indicated a loess medium in the GPR depth-slice and a conductive character in the ERT slice. At the same time, this zone demonstrated low Vp and Vs velocity distribution in the SRT and MASWT slices. The third anomaly was arc-shaped and it showed up clearly in the same location in both the magnetic image and the GPR results. Furthermore, the changes were also partly observable in the ERT, SRT and MASWT slices.

CONCLUSIONS

Integrated geophysical investigations carried out at the Šapinuva archaeological site revealed that such an approach based on different geophysical methods will be very useful to interpret the various physical properties, true locations and dimensions of the buried archaeological structures. Magnetic gradiometry provides valuable knowledge about the shallow archaeological remains and the covering soil through the magnetic properties of the deposits. ERT enables

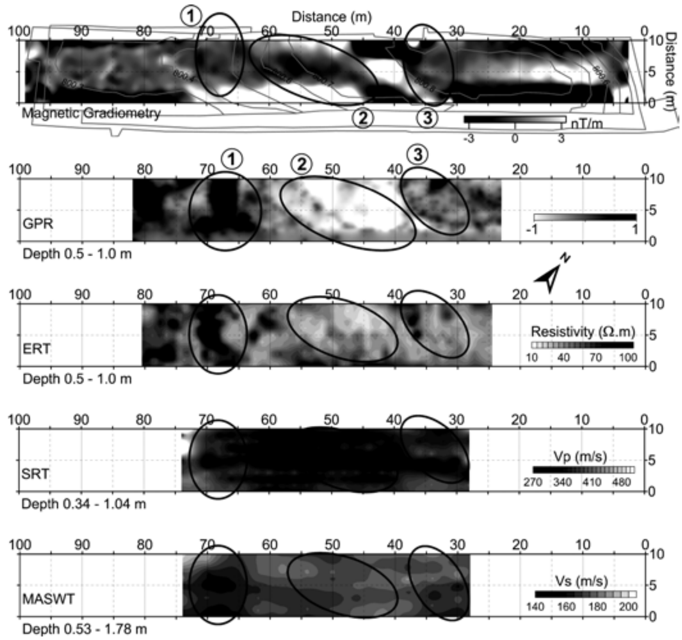

Fig. 3. Combined interpretation results of the near-surface features of the Taşdöşem ditrict of the Ağılönü area

determination of the location, extension, depth, thickness and electrical characteristics of subsurface features including geological units. GPR highlights the overall spatial distribution of archaeological remains and subsoil layers. Seismic refraction tomography supplies additional information about the buried archaeological structures and geological units, particularly with respect to their depths. MASWT detects the lateral Vs velocity changes of any anomalous body and the archaeological context within the geological environment.

This study showed that an integrated approach using different geophysical techniques enabled better definition of position, localisation, depth, thickness, extension and the physical characteristics of buried archaeological structures and their geological context at the archaeological site of Šapinuva. The methods applied provided very useful and informative data on the internal characteristics of this monumental city in the Hittite Empire. The approach provides an important tool for archaeologists to inform their detailed and extensive excavations.

ACKNOWLEDGEMENTS

The authors are grateful to Prof. Dr. Aygül Süel and Dr. Mustafa Süel who are the Director and Co-director, respectively, of the Šapinuva archaeological site. Thanks are also due the entire excavation team, who supported us during the survey. In addition, we are thankful to the Geoim Company for help during on-site investigations and for financial support.

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