9.2 IMAGING ARCHAEOLOGICAL RUINS BY GPR AND ERT SURVEYS: THE CASE OF ANCIENT SELEUKEIA SIDERA IN PISIDIA

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ABSTRACT

Ancient Seleukeia Sidera in Pisidia, located northwest of the village of Bayat in the Atabey district of Isparta, was one of the most important colonies of the Seleucid period. Since there are few visible ruins today, as most parts of the architectural structures have been lost or hidden in the ground or moved to surrounding buildings, archaeo-geophysical investigations in the city play a crucial role. The surveys are mainly conducted using ground penetrating radar (GPR) to determine the archaeological structures' location, depth, and extent. The GPR surveys, conducted as part of the city's recent three-period excavation and surface investigation campaigns between 2020 and 2022, examined an area of approximately 5.5 ha. The results of the GPR surveys to date are also consistent with those of surveys conducted in previous research periods using magnetic prospecting. In particular, they help shed light on the urban residential areas and architecture southeast of Hisar Tepe. Identifying two roads about 5 m wide in the survey area in this region, running toward SW-NE and NW-SE, clearly indicates that Seleukeia Sidera had a regular urban plan. In some cases, ERT surveys are also conducted as a supporting method to verify GPR results. Therefore, this study focuses mainly on presenting the results of GPR and ERT surveys conducted south of the city's theater ruins. In the study, the GPR scans are performed using a shielded antenna system with a center frequency of 500 MHz, while the ERT surveys are performed using a dipole-dipole array. The results of the GPR survey detect the ruins of a hidden archaeological structure with high resolution, regular geometry, and extent in the shallow subsurface. Also, the two-dimensional (2D) inversion results of the collected apparent resistivity datasets are compatible with the results of the GPR survey in this area. According to them, the anomalies of the archaeological building ruins with relatively high resistivity (> 700 Ωm) and regular geometry are located within the cultural layer under the modern surface layer, which is about 30-40 cm thick. The relatively high contrasts in electrical conductivity and dielectric constant between the ground and the archaeological target allow the identification of hidden ruins to a depth of 2 m in the survey area with high resolution. According to the results of the GPR and ERT surveys, the ruins of the archaeological structures in the ancient city of Seleukeia Sidera are mainly located about 30 cm to 180 cm below the surface. Unfortunately, this indicates that agricultural activities can potentially damage the ancient city's near-surface archaeological remains when locals use tractors, rakes, and cultivators in production. As archaeo-geophysical research progresses, it will be possible to obtain more information about the residential structures, transportation routes, and architectural background of the city in this area.

KEY WORDS : Archaeogeophysics, GPR, ERT, Pisidia, Seleukeia Sidera

INTRODUCTION

An archaeo-geophysical survey efficiently determines the ruins of archaeological structures awaiting discovery beneath the surface of ancient cities at low cost, time, and effort. For this purpose, geophysical methods are often used during or prior to archaeological excavations and surveys. However, their success depends on the subsurface characteristics of an archaeological site and the degree of contrast between physical parameters such as magnetic susceptibility, dielectric constant, and electrical conductivity that these features form with the targeted archaeological structure. Since this condition is sufficiently fulfilled in the ancient city of Seleukeia Sidera in Pisidia, it is possible to identify hidden structures at a given site. The city is located on and around Hisar Tepe (1271 m), 800 m northwest of the village of Bayat (formerly Selef), which is 7 km south of the Atabey district in present-day Isparta province. It was the southern neighbor of Apollonia on the border between Phrygia and Pisidia and the northern neighbor of Sagalassos in central Pisidia. Seleukeia Sidera occupied a central position in the northern Pisidia region, as its territory borders the cities of Konane to the west and Prostanna to the east. The excavation and research work in the Seleukeia Sidera has been conducted since 2019 under the direction of Prof. Dr. Bilge Hürmüzlü Kortholt with a multidisciplinary and international team. The multidisciplinary research in Seleukeia Sidera through excavations, archaeological surface surveys, and geophysical prospecting provides essential information about the settlement plan and the settlement area's hierarchy (Hürmüzlü et al., 2023).

The sole or integrated use of magnetic prospecting, GPR, and ERT is widespread in archaeo-geophysical investigations and successful examples such as from Alacahöyük (Candansayar and Başokur, 2001), Zeugma (Drahor et al., 2008), Amorium (Ekinci et al., 2014), Pisidian Antioch (Balkaya et al., 2018), Side (Akca et al., 2019), and Doliche (Balkaya et al., 2021) can be found in the literature. In the city, the first geophysical explorations by GPR and magnetic prospecting were conducted between 2016 and 2019 by HTW (Berlin) under the direction of Thomas Schenk (2023). Since 2020, the Earthquake and Geotechnical Research Center of Süleyman Demirel University has been leading archaeo-geophysical investigations through GPR and ERT applications. The results of the GPR surveys, conducted mainly in the flat areas southeast of Hisar Tepe where agricultural activities are now taking place, are consistent with the results of the previous magnetic prospection (Balkaya et al., 2023). This study discusses the results of the GPR and ERT surveys of the archaeo-geophysical prospection near the theater ruins southwest of Hisar Tepe.

METHOD and APPLICATION

As a non-invasive method, GPR is a valuable tool in archaeological investigations. It provides high-resolution images of hidden ruins of archaeological structures without excavation using high-frequency electromagnetic waves. Seleukeia Sidera GPR surveys are conducted using a shielded antenna system (MALÅ™ ProEx) at a center frequency of 500 MHz on parallel profiles spaced 50 cm apart with 5 cm trace spacing. Depth slice maps through a three-dimensional (3D) volume of reflection data were created using the software GPR-SLICE (v7.MT, https://www.gpr-survey.com/) with appropriate basic data processing techniques such as dewow, time-zero correction, gain, bandpass filter, and migration. ERT is typically used in archaeological surveys to detect buried objects such as walls, trenches, or artifacts by measuring the differences in electrical resistivity between the target objects and the

surrounding materials. The ERT survey was performed with a dipole-dipole array using the ARES GF multi-electrode resistivity measurement system with 48 electrodes on 38 parallel profiles, mainly 70 cm apart with an electrode spacing of 50 cm. ERT profile data were inverted using ResIPy (v3.4.5), an intuitive open-source software for complex geo-electrical inversion/modeling, available on GitLab (https://gitlab.com/hkex/resipy/), and then visualized using ParaView (v5.11.0), an open-source post-processing visualization software (https://www.paraview.org/).

SURVEY RESULTS

The survey area is located southwest of the ruins of the ancient theater of Seleukeia Sidera and is shown in Figure 1a within the dashed line. During the investigation, the direction of the GPR survey was approximately SE-NW, while the direction of the ERT survey was approximately NE-SW. Figure 1b shows a depth slice map of 100 cm from the GPR data analysis. Based on the map, the results of the GPR survey show the ruins of a hidden anthropogenic structure with high resolution, regular geometry, and extent in the shallow subsurface. In addition, Figure 1c shows a tomogram of Profile 21 derived from the inversion of the ERT data. The tomogram is characterized by three observations in the interpretation, including modern topsoil (1), cultural layer (2), and promising resistivity anomalies. Accordingly, the thin modern subsoil above the cultural layer is about 30-40 cm thick and has a resistivity of < 120 Ωm (Balkaya et al., 2023). On the other hand, the cultural layer contains promising anomalies that can be attributed to the remains of archaeological structures characterized by relatively high resistivity values of more than 700 Ωm. These 2D inversion results from Profile 21 also agree well with the results of the GPR survey and identify the walls that form the foundation of this structure.

CONCLUSION

Overall, the results of the GPR and ERT surveys indicate that the remains of the buried archaeological structures are located at a depth of approximately 30 cm to 180 cm. Considering that agricultural activities are taking place in the ancient city's flat areas, it can be concluded that these activities pose the risk of damaging the near-surface archaeological remains when the local population uses power harrows and cultivators in production. The GPR and ERT investigations will be continued in future campaigns at Seleukeia Sidera in light of the results of the previous archaeo-geophysical surveys.

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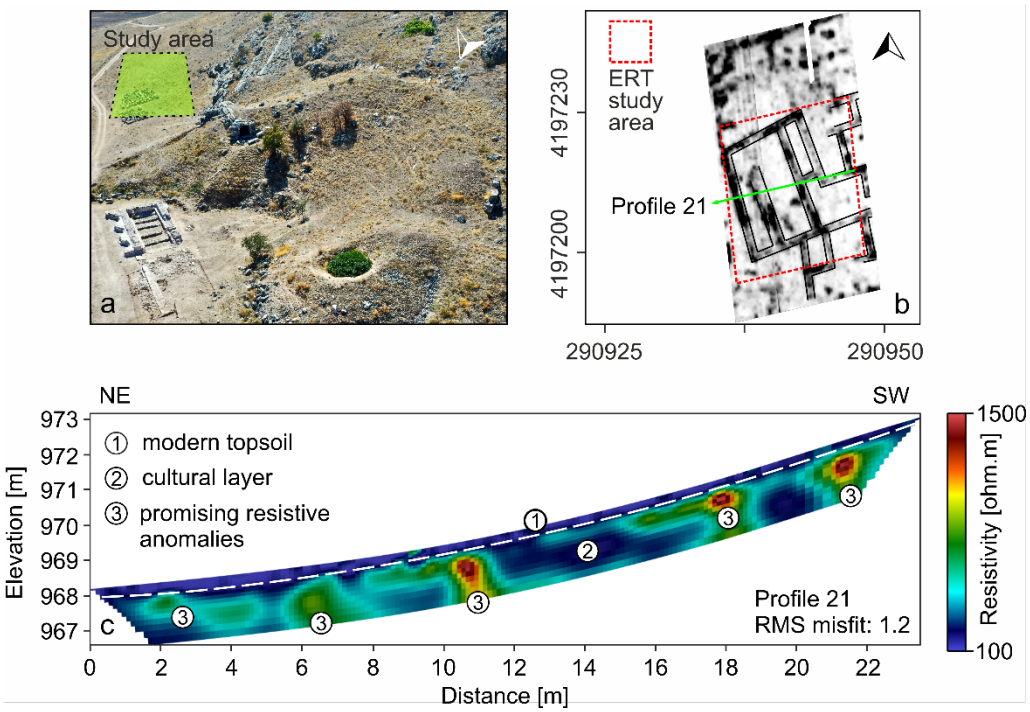

Figure1 (a) The study area southwest of the ruins of the ancient theater of Seleukeia Sidera, on an aerial photograph from the city project archive (b) A GPR depth slice map of 100 cm obtained from data analysis (c) Resistivity tomogram of Profile 21 obtained by 2D inversion (Balkaya et al., 2023)

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