JOURNAL OF THE BALKAN GEOPHYSICAL SOCIETY, Vol. 10, No. 2, December 2007, p. 1-8, 8 figs.

3D resistivity imaging of buried tombs at the Parion necropolis (NW Turkey)

Yunus L. Ekinci[1,+] and Mehmet A. Kaya[1]

[1]Çanakkale Onsekiz Mart University, Department of Geophysical Engineering, 17020, Çanakkale, Turkey

[+]Corresponding Author (ylekinci@comu.edu.tr)

(Received 04 November 2007; accepted 14 December 2007)

Abstract: *The first archaeogeophysical survey at the ancient site of Parion (Biga-Çanakakle) is presented in this paper. During the summer of 2006 we conducted an electrical resistivity tomography survey at the necropolis. Resistivity data were collected along parallel profiles using Wenner-Schlumberger array and electrode spacing of 1 m. A two-dimensional least squares algorithm based on the smoothness-constrained technique inverted the apparent resistivity data. MATLAB-based visualization tools displayed resistivity distribution of the subsurface in three-dimensional volume. These tools yield volumetric resistivity images by combining two-dimensional model resistivity sections. Thus, both the horizontal and vertical extent of the anomalous zones were displayed. This visualization technique revealed high resistivity zones at depths ranging from 0.25 to 2.5 m at the investigation area. Taking into account archaeological evidence, these higher resistivity zones are the most promising locations for archaeological excavation.*

Key words: *Parion, Archaeogeophysics, Resistivity, Two-dimensional Inversion, MATLAB, Three-dimensional Volume*

INTRODUCTION

Archaeological methods involve excavation, which is time consuming. Sometimes, this effort may not be very cost-effective since there are risks of damaging or missing the archaeological remains. On the other hand, information about the location, depth, size and extent of buried archaeological remains may be determined by means of geophysical investigation, which is carried out easily and quickly on the surface without disturbing or damaging the buried archaeological structures (Yiğit, 2005). Archaeological structures have certain physical properties which can be estimated from the surface. The geophysical methods can locate them by measuring their magnetic susceptibility, electrical resistivity or conductivity (Doğan and Papamarinopoulos, 2003).

The resistivity method is one of the most commonly applied technique for geophysical investigation in archaeological sites. This is due to the ability of detecting walls, voids, graves and other man-made structures. It is also an efficient tool because of the low cost of the investigation and the fact that there is resistivity contrast between these structures and the surrounding soil. Furthermore, the high technological development of computer controlled multi-electrode survey systems and the development of two- and three-dimensional resistivity inversion software packages, resulted to more effective surveys and reliable resistivity high resolution images (e.g. Griffiths and Barker, 1994; Candansayar and Başokur, 2001; Candansayar et al., 2001; Tohon et el., 2004; Papadopoulos et al., 2005; Drahor 2006; Drahor et al., 2007; Ekinci et al., 2007; Vafidis et al., 2007).

The aim of the electrical resistivity tomography (ERT) technique is to scan the subsurface along the survey line using a selected electrode array. An automatic electronic system collects data quickly in order to observe the pseudosection along the investigation line in the field (Drahor, 2006).

The present work was carried out to locate the buried archaeological structures at the necropolis area of Parion (Biga-Çanakkale). We also aimed to explore the extent of the man-made structures revealed in the nearby excavated area. Taking into account both existing archaeological information about the site and the advantages of the ERT technique, we decided to apply it at Parion necropolis. Apparent resistivities were inverted to true resistivities by a two-dimensional inversion algorithm (Loke and Barker, 1996) in order to obtain more accurate resistivity distribution of the subsurface. The geo-electrical sections, obtained

Partly presented at the 13th European Meeting of Environmental and Engineering Geophysics, Near Surface 2007, 3-5 September, Istanbul, Turkey

from the two-dimensional inversion of each profile, were combined in a three-dimensional volume, which is displayed by using MATLAB-based three-dimensional visualization tools. These tools can display horizontal slices, isosurfaces and patches. The high resistivity zones were easily depicted from the volumetric representation. These zones are attributed to man-made structures. Finally, iso-resistivity model sections were produced to view the depth and the extent of these zones.

DESCRIPTION OF THE SITE

The ancient site of Parion is located northeast of Ancient Troas (Fig. 1). The site is approximately 90 km to the northeast of the modern town of Çanakkale (Dardanelles). The village "*Kemer*", which belongs to the administrative district of Biga, partially covers the site. The modern name Kemer or Kamares derived from "*kamarai*" (ancient arc-shaped buildings). Remains of the walls from buildings, such as aqueduct, water reservoirs and the fallen architraves of a portico, are still visible.

This site was first investigated during rescue excavations, completed by the Çanakkale museum in 2004, and has been under systematic excavation since 2005. Archaeological works focused on the aqueduct and the well-preserved necropolis. The necropolis includes varying size sarcophagi, made from simple pithoi to sandstone and marble. Inhumation remains, found at the necropolis, point out that it dates back from the first half of the 4th century BC to the Roman period. The findings at the site are exceptionally well preserved (http://cat.une.edu.au/page/parion).

DATA ACQUISITION, PROCESSING AND INTERPRETATION

Taking into consideration the information obtained from the excavation at the necropolis, the penetration depth of the geo-electrical survey was set to approximately 4 m with electrode spacing of 1 m. The dipole-dipole array was initially applied because of its sensitivity to lateral changes in resistivity. However the very small signal strength for large values of the "n" factor is one of the possible disadvantages of this array. In addition, it is usually not advisable to use "n" values greater than 6 or 7 (Loke, 2000). Thus, in this investigation the dipole-dipole array did not provide adequate penetration depth. On the other hand, although the pole-dipole array has relatively better horizontal resolution and greater depth of investigation compared to dipole-dipole array, it wasn't suitable because the field conditions did not allow placing one current electrode sufficiently far from the survey line. Therefore, the Wenner-Schlumberger array was considered the most suitable array for this investigation (Fig. 2).

We conducted the ERT survey in a 23 m by 7.5 m grid next to the excavation area at necropolis. The measurements were collected along 6 parallel lines, each 23 m long, with line spacing 1.5 m (Fig. 3). There were 21 measuring stations along each survey line. A total of 720 apparent-resistivity measurements were collected (n=1 to n=10) using the Iris-Syscal R1 Plus resistivity meter. The vertical stack was set to four. The relative standard deviation for each stack is a good indicator of the quality of the data (Tohon et al., 2004). Therefore, it was checked during the measurements. When the relative standard deviation of the stacked data was greater than 3%, the vertical stack was increased to six. The standard deviation of the measurements was mostly below 1%. Measurements, stored in the data logger of the resistivity meter, were transferred to the computer using the RS232 port.

Although the pseudosection may give some information about the location of possible archaeological structures, their size, depth and extent can not be estimated. Thus, we applied a two-dimensional inversion method to obtain a more reliable image of the subsurface using the Res2Dinv software. This program iteratively calculates a resistivity model, trying to minimize the difference between the observed apparent resistivity values and those, calculated from the model. The maximum number of iteration was set to 4 or 5 for all profiles in order to avoid overfitting the data. The inversion process resulted a satisfactory fit with RMS error between 2.5-5.5 %. Due to low RMS error, the obtained results can be considered as a reliable representation of the true resistivity distribution of subsurface. Then, we jointly presented the geo-electrical sections using a visualization technique. This technique generates a three-dimensional volume and displays user-selected horizontal slices or sections. The 3D anomalous zones are easily displayed by selecting resistivity isosurfaces. The natural logarithm of the resistivity values was used in order to highlight the resistivity variations.

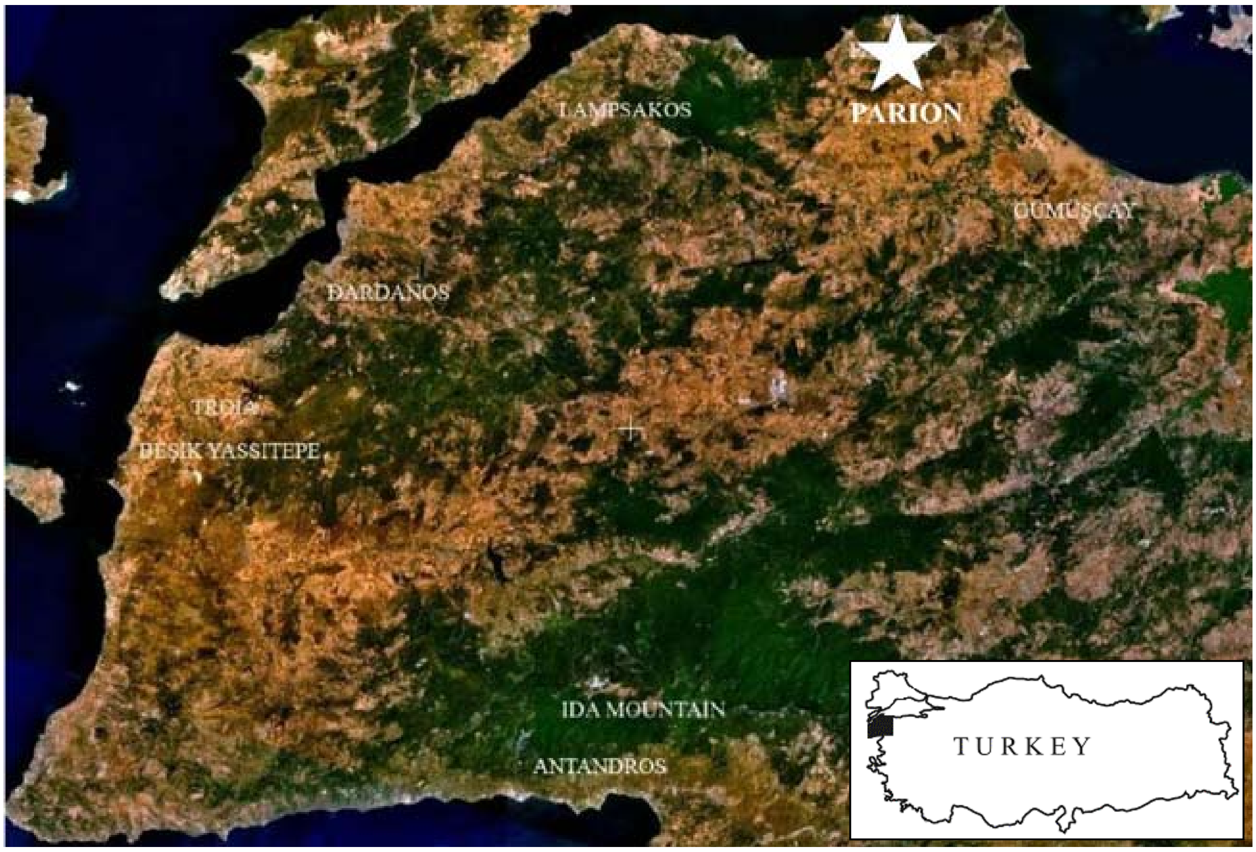

FIG. 1. Ancient Troas region and the location of the ancient site of Parion.

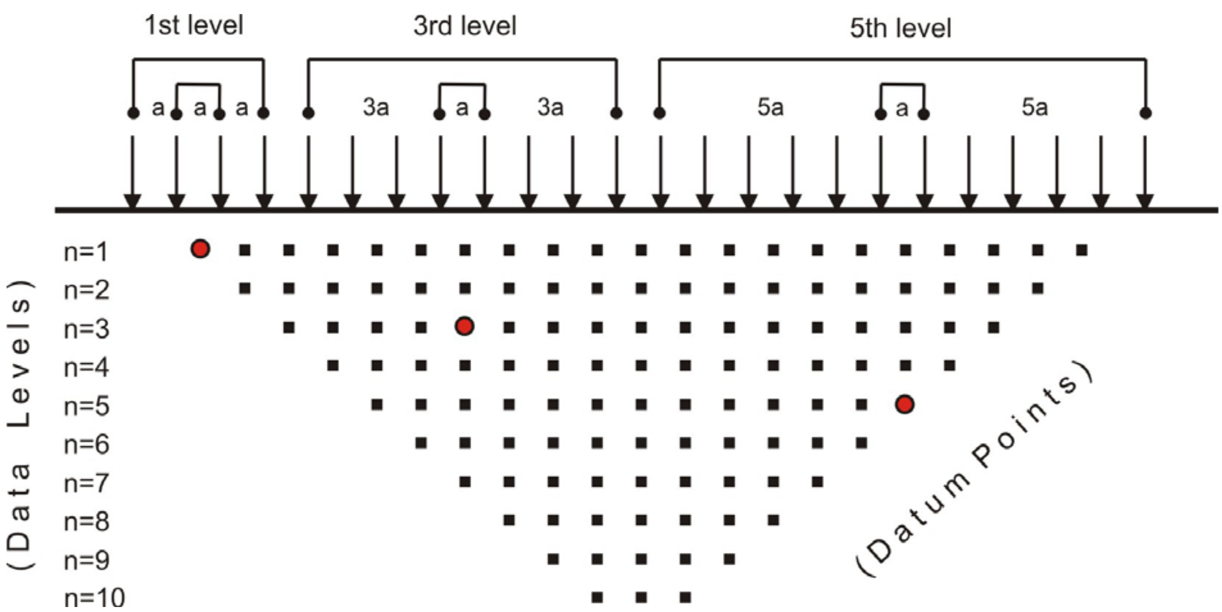

FIG. 2. Sequence of measurements to create a pseudosection using Wenner-Schlumberger array. The datum points and the data levels are displayed.

FIG. 3. The investigation area and the location of the ERT profiles. The black arrow shows the man-made structure extending from neighbour excavation area into the investigation area (not to scale).

The geoelectrical sections exhibit high resistivity zones (> ~2.7 log ohm.m) (Fig. 4). Since the necropolis is covered by alluvium, moderate resistivity values are expected (~1.8-2.5 log ohm.m). Therefore, lower resistivity values (green colour) indicate the cover material, while high resistivity zones (blue and magenta) trace the man-made structures.

In order to view the resistivity distribution of the whole surveyed area, the data from the parallel resistivity sections were linearly interpolated and displayed as a pseudo three-dimensional block (Fig. 5). The high resistivity zone (black rectangle – Fig. 5) is related to a man-made structure, revealed in the excavation (black arrow – Fig. 3).

From the data volume we extracted horizontal slices (Fig. 6) in order to display the lateral extent of the high resistivity zones. The anomaly, which is observed in the slices at depths ranging from 0.25 to 1.75 m (black rectangles – Fig. 6), is also related to the one observed in Fig. 5. The anomaly at the depths of 1.25-2.25 m (black arrows – Fig. 6) may indicate the location of a smaller man-made structure. High resistivities are not observed at the depths greater than 2.5 m as expected.

Alternately, in order to display the three-dimensional extent of high resistivity zones, an iso-resistivity surface was also produced, which corresponds to resistivities higher than 2.7 log ohm.m. This is derived from the data volume by specifying an isovalue. That is, the isosurface connects data points of equal resistivity values, yielding to the three-dimensional anomaly representation (Fig. 7). According to this figure, the high resistivity anomalies are located between 5-14 m along y direction, which may indicate archaeological remains, such us graves or sarcophagi. At the last step, a cross-section of the iso-resistivity surface was produced in order to view the depth extent of this anomaly (Fig. 8), which ranges between 0.25-2.5 m. Taking into account the distance of the first profile from the excavated area (Fig. 3), this structure may be attributed to a series of tombs under the investigation area. Taking into consideration the archaeological evidence and the structures, indicated by the high resistivity anomaly, shown in Fig. 7, this area is the most promising for the next excavation project.

CONCLUSIONS

The results of the first archaeogeophysical survey at the ancient site of Parion are presented in this paper. During the summer of 2006, a geo-electrical survey was conducted using Wenner-Schlumberger array along six parallel profiles. The detection of high resistivity anomalies indicated that this electrode array is suitable for searching tombs. Three-dimensional visualization techniques aid the interpretation of resistivity data sets, obtained from the parallel geo-electrical profiles. Depth slices and iso-resistivity sections display both the horizontal and vertical extent of the high resistivity zones.

The results are in accordance with the findings obtained from the neighbouring excavated area. Taking into account the archaeological evidence, these anomalies are attributed to man-made buried structures. The iso-resistivity surface indicated the most promising locations for the archaeological excavation. Accordingly, this strategy is very suitable for archaeogeophysical surveys performed by the ERT technique.

ACKNOWLEDGMENTS

We would like to express our gratitude to Dr. Emin U. Ulugergerli for his useful suggestions. We thank Prof. Dr. Cevat Başaran, Dr. Ali Tavukçu, Canan Albayrak and the Parion excavation team who supported us during the survey. Thanks are given to Can Ertekin and Alper Demirci for their helps in preparing the images. Many thanks to Cemal Durgut for his enormous effort during the geophysical survey at Parion. We are also grateful to the anonymous reviewers for their useful criticism.

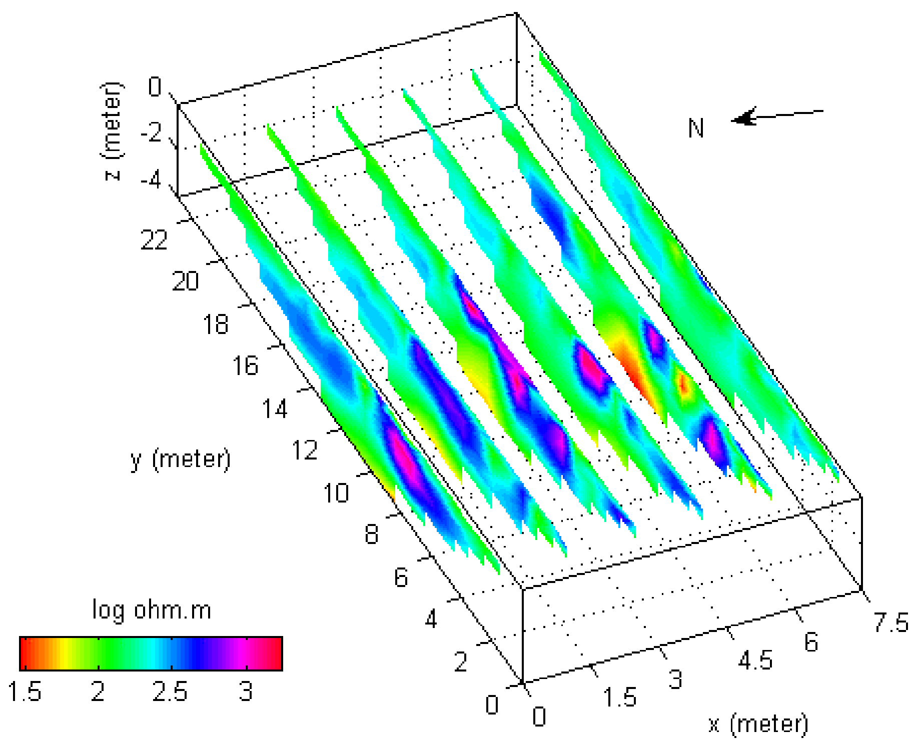

FIG. 4. Two-dimensional geo-electrical sections of the six profiles. Profiles 1 and 6 are located at 0 m and 7.5 m along x-axis, respectively.

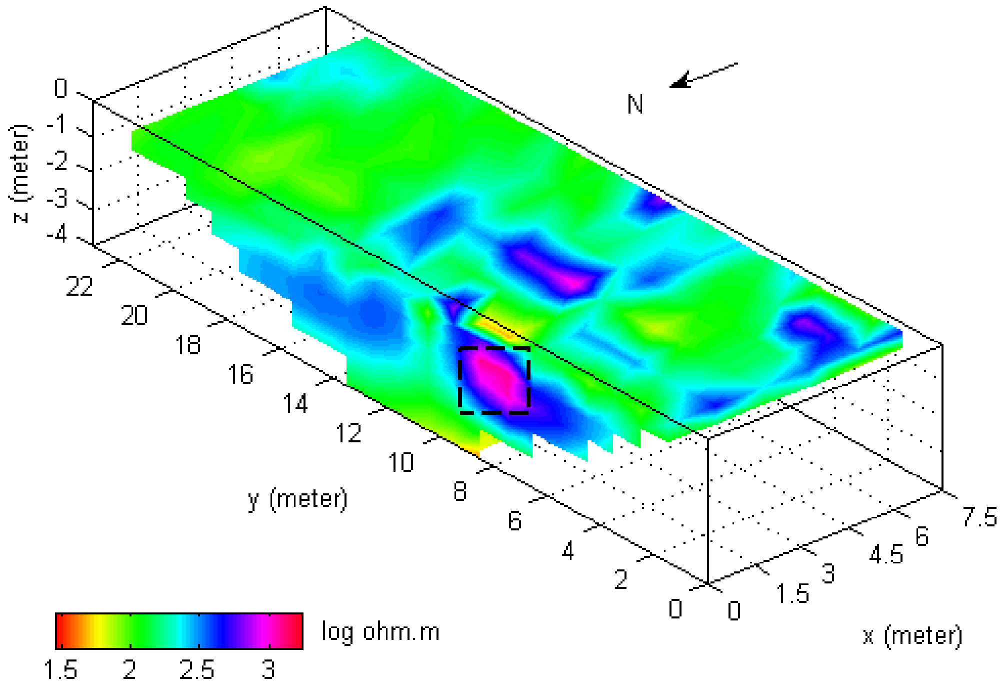

FIG. 5. Pseudo three-dimensional geo-electrical model of the investigation area. The high resistivity anomaly (black rectangle) is related to a man-made structure.

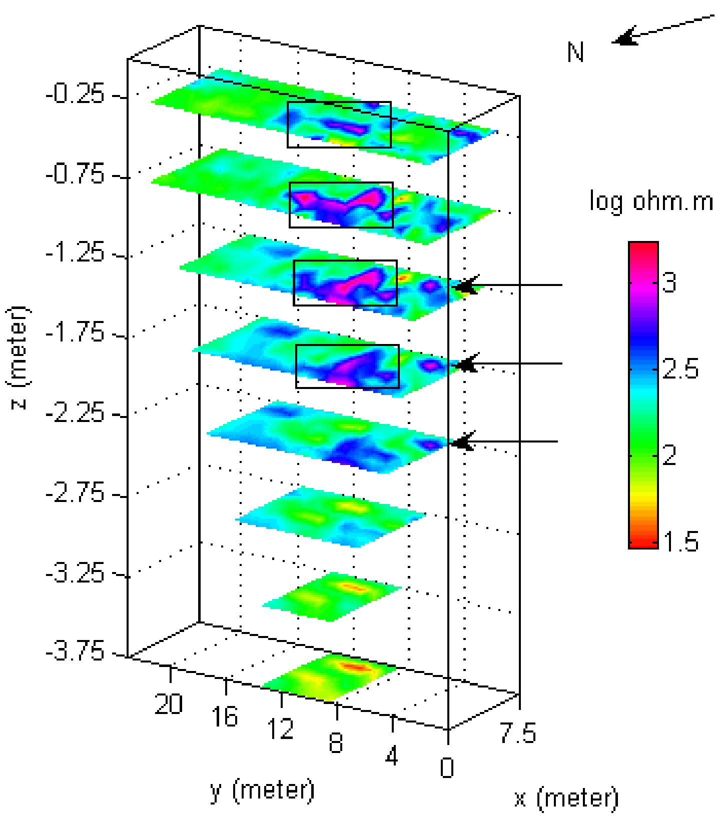

FIG. 6. Horizontal slices of the pseudo three-dimensional resistivity distribution with 0.5 m depth interval. The high resistivity anomalies, marked with rectangles and arrows, are related to man-made structures.

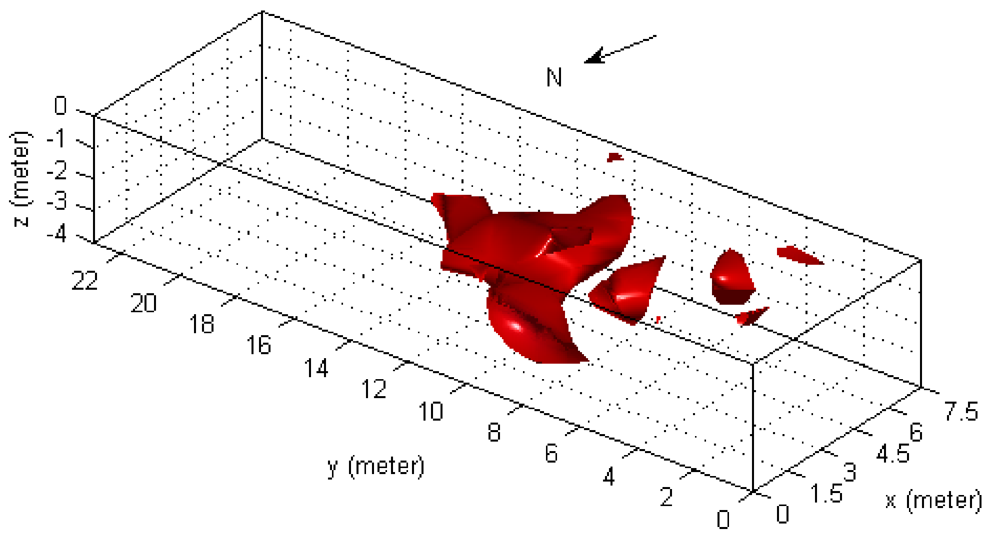

FIG. 7. Iso-resistivity surface of the highest resistivity zones (> 2.7 log ohm.m).

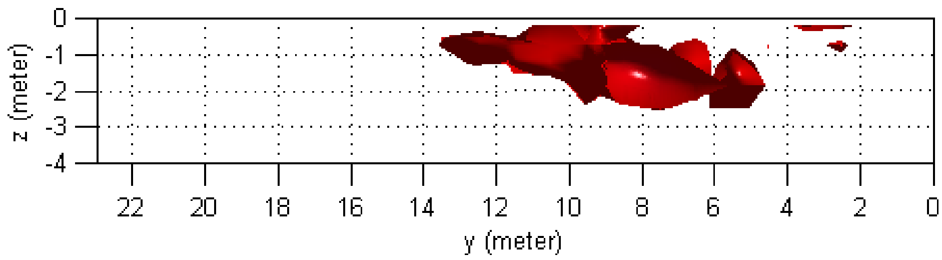

FIG. 8. The cross-section of the iso-resistivity surface (> 2.7 log ohm.m).

REFERENCES

Candansayar, M.E., and Basokur, A.T., 2001, Detecting small-scale targets by the 2D inversion of two-sided three-electrode data: application to an archaeological survey: Geophysical Prospecting, 49 (1), 13-25.

Candansayar, M.E., Ulugergerli, E.U., Batmunkh, D., Tosun, S., and Gündoğdu, B., 2001, An investigation of archaeological targets by using 2D inversion and two-sided gradient transformation of the direct current resistivity data: Geophysical survey around Turkish Monuments in Mongolia: Jeofizik, 15 (2), 105-123 (in Turkish).

Doğan, M., and Papamarinopoulus, S., 2003, Geoelectric prospection of a city wall by multi-electrode resistivity image survey at the prehistoric Site of Asea (Southern Greece): Archaeological Prospection, 10, 241-248.

Drahor, M.G., 2006, Integrated geophysical studies in the upper part of Sardis archaeological site, Turkey: Journal of Applied Geophysics, 59 (3), 205-223.

Drahor, M.G., Göktürkler, G., Berge, M.A., Kurtulmuş, T.Ö., and Tuna, N., 2007, 3D resistivity imaging from an archaeological site in south-western Anatolia: a case study: Near Surface Geophysics, 5 (3), 195-201.

Ekinci, Y.L., Kaya, M.A., and Demirci, A., 2007, Electric resitivity tomography investigation at the ancient site of Parion (Nortwest Turkey): 13th European Meeting of Environmental and Engineering Geophysics, İstanbul, Extended Abstract, P40.

Griffiths, D.H., and Barker, R.D., 1994, Electrical imaging in archaeology: Journal of Archaeological Science, 21, 153-158.

Loke, M.H., 2000, Electrical imaging surveys for environmental and engineering studies, a pratical guide to 2D and 3D surveys (http://www.terrajp.co.jp/lokenote.pdf).

Loke, M.H., and Barker, R.D., 1996, Rapid least-squares inversion of apparent resistivity pseudosections using a quasi-Newton method: Geophysical Prospecting, 44 (1), 131-152.

Papadopoulos, N.G., Tsourlos P., Tsokas, G.N., and Sarris, A., 2005, 2D and 3D inversion of electrical resistivity tomography data collected from archaeological sites: 6th International Conference on Archaeological Prospection, Rome, Extended Abstract, 116-120.

Tohon, D.S., Vannesta, K., Sintubin, M., Muchez, P., and Waelkens, M., 2004, Two-dimensional resistivity imaging: a tool in archaeoseismology: An example from Ancient Sagalassos (Southwest Turkey): Archaeological Prospection, 11, 1-18.

Vafidis, A., Economou, N., Spanoudakis, N.S., Hamdan, A.H., and Kindelli, V.N., 2007, Application of classification methods on geophysical data from the archaeological site of Aptera, Chania, Greece: 13th European Meeting of Environmental and Engineering Geophysics, İstanbul, Extended Abstract, P37.

Yiğit, P., 2005, Archaeological geophysics investigation of Amorium Ancient City: Master thesis, Institude of Science and Technology, Çanakkale Onsekiz Mart University (in Turkish).

INTERNET SOURCES

Current Archeology in Turkey, The Ancient Site of Parion (Kemer-Biga-Çanakkale), 2007 - http://cat.une.edu.au/page/parion