Australian Journal of Forensic Sciences
Publication details, including instructions for authors and subscription information:
http://www.tandfonline.com/loi/tajf20

Geophysical investigations at Agadere Cemetery, Gallipoli Peninsular, NW Turkey

Aydın Büyüksaraç[a], Cahit Çağlar Yalçıner[b], Yunus Levent Ekinci[a], Alper Demirci[a] & Mehmet Ali Yücel[c]

[a] Department of Geophysical Engineering, Canakkale Onsekiz Mart University, Canakkale, Turkey.

[b] Can Vocational Collage, Canakkale Onsekiz Mart University, Can, Canakkale, Turkey.

[c] Department of Geomatics Engineering, Canakkale Onsekiz Mart University, Canakkale, Turkey.

Published online: 14 Jun 2013.

To cite this article: Aydın Büyüksaraç, Cahit Çağlar Yalçıner, Yunus Levent Ekinci, Alper Demirci & Mehmet Ali Yücel (2014) Geophysical investigations at Agadere Cemetery, Gallipoli Peninsular, NW Turkey, Australian Journal of Forensic Sciences, 46:1, 111-123, DOI: 10.1080/00450618.2013.804948

To link to this article: http://dx.doi.org/10.1080/00450618.2013.804948

Australian Journal of Forensic Sciences, 2014
Vol. 46, No. 1, 111–123, http://dx.doi.org/10.1080/00450618.2013.804948

Geophysical investigations at Agadere Cemetery, Gallipoli Peninsular, NW Turkey

Aydın Büyüksaraç[a*], Cahit Çağlar Yalçıner[b], Yunus Levent Ekinci[a], Alper Demirci[a] and Mehmet Ali Yücel[c]

[a]*Department of Geophysical Engineering, Canakkale Onsekiz Mart University, Canakkale, Turkey;* [b]*Can Vocational Collage, Canakkale Onsekiz Mart University, Can, Canakkale, Turkey;* [c]*Department of Geomatics Engineering, Canakkale Onsekiz Mart University, Canakkale, Turkey*

(*Received 12 March 2013; final version received 7 May 2013*)

Historical cemeteries are challenging targets for geophysical prospection but some non-destructive imaging techniques may be successful for mapping buried cemeteries if applied appropriately. Ground-Penetrating-Radar (GPR) has generally been considered to be the only geophysical method for determining cemeteries; however, Electrical-Resistivity-Tomography (ERT) and Magnetic-Imaging (MI), may determine geophysical traces of such cemeteries. Thus, as a first attempt at applying geophysical methods in the cemetery area of the Gallipoli Peninsula, these techniques were used to explore the buried graves at Agadere Cemetery. In this study, measured apparent resistivity data were processed using a two-dimensional (2D) tomographic inversion scheme. Resultant resistivity depth slices and volumetric resistivity images clearly showed the anomaly zone, which may be attributed to anthropogenic burials. Additionally, three-dimensional (3D) visualization of GPR results indicated some anomalies, much like the resistivity anomalies in terms of location. MI data were processed using linear transformations and an analytic signal image map presented anomaly zones located in some parts of the area, which are in agreement with those obtained by ERT and GPR surveys. Results derived from data processing techniques showed that these methods are suitable for bordering the locations of other buried historical graves in areas that have the same geological environment in the Peninsula.

Keywords: Gallipoli; Martyr Cemetery; Agadere; ERT; GPR; MI

Introduction

The Battle of Gallipoli took place on the Gallipoli Peninsula of the Ottoman Empire (modern day Turkey) during the First World War, between 25 April 1915 and 9 January 1916 (Figures 1(a), (b)). A joint British and French attack was mounted to capture the Ottoman capital of Istanbul and secure a sea route to Russia. The attempt failed with heavy casualties on both sides. The campaign was considered one of the greatest victories of the Turks and was thought of as a major failure by the Allies[1].

There were nearly half a million casualties during the campaign. In addition to these battle casualties, many soldiers fell ill and suffered from diseases such as enteric fever, dysentery, and diarrhea because of the unhygienic conditions. It is estimated that more than 145,000 British soldiers fell ill during the campaign. By the time the Gallipoli Campaign had ended, over 130,000 men (more than 80,000 Turkish soldiers and 44,000 British and French soldiers, including more than 8,500 Australians) had died[2].

*Corresponding author. Email: absarac@comu.edu.tr

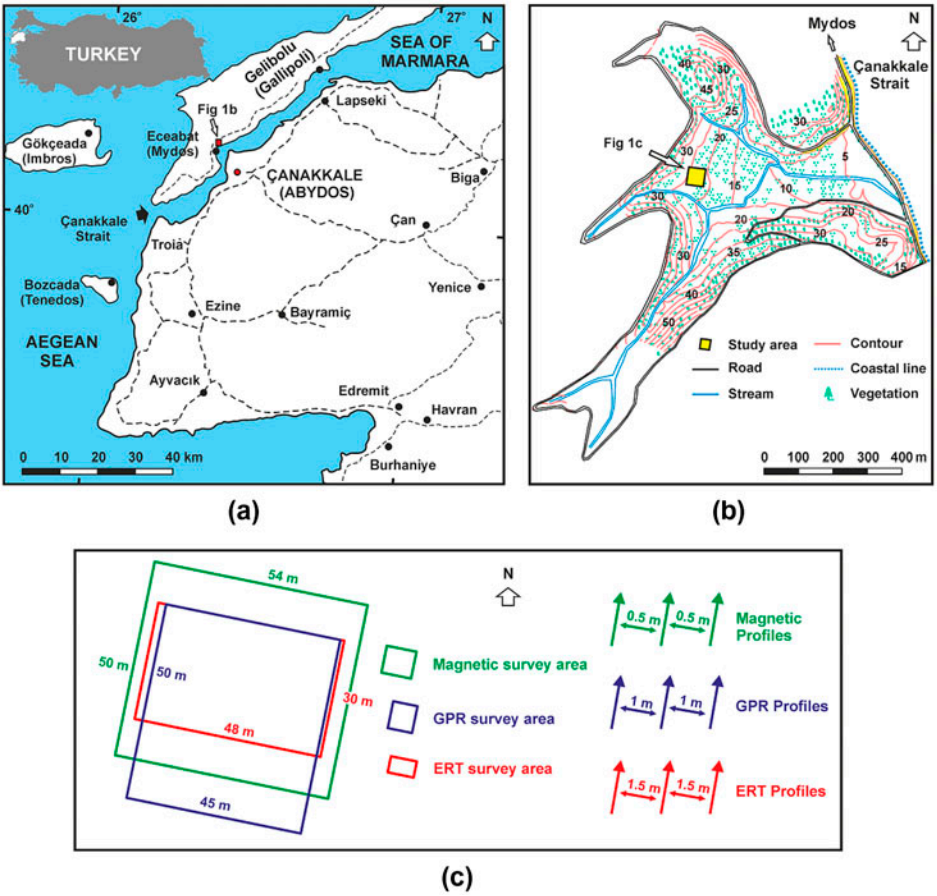

Figure 1. (a) Location map of the study area. (b) Topographic map of the Agadere Martyr Cemetery. The filled box shows the study area. (c) Positions of the geophysical surveys in the filled box in (b).

In July 1915, there were 25 Ottoman hospitals, with a total of 10,700 beds, and three hospital ships in the area[2]. Allegations had been made that Allied forces had attacked or bombarded Ottoman hospitals and hospital ships on several occasions between the start of the campaign and September 1915. As hospitals were destroyed, temporary hospitals were established in tents behind the battlefront to safeguard them from allied forces and bombs. One of these was established in Agadere, and seriously wounded soldiers were transferred by boat from the Dardanelles to the tent hospitals. Most of these soldiers died there, and approximately 3000 soldiers were buried in the Agadere Martyr Cemetery. The graves were generally not marked with stones. The cemetery was placed on a slope in order to avoid water infiltration due to precipitation, where the bedrocks are shallow. The geology of the Peninsula is represented by various kinds of sedimentary rocks[3] and Upper-Miocene aged Neritic limestone is dominant on the Agadere area (Figure 2). However, the cemetery in the Agadere area was dug into the covering that was overlying the bedrock.

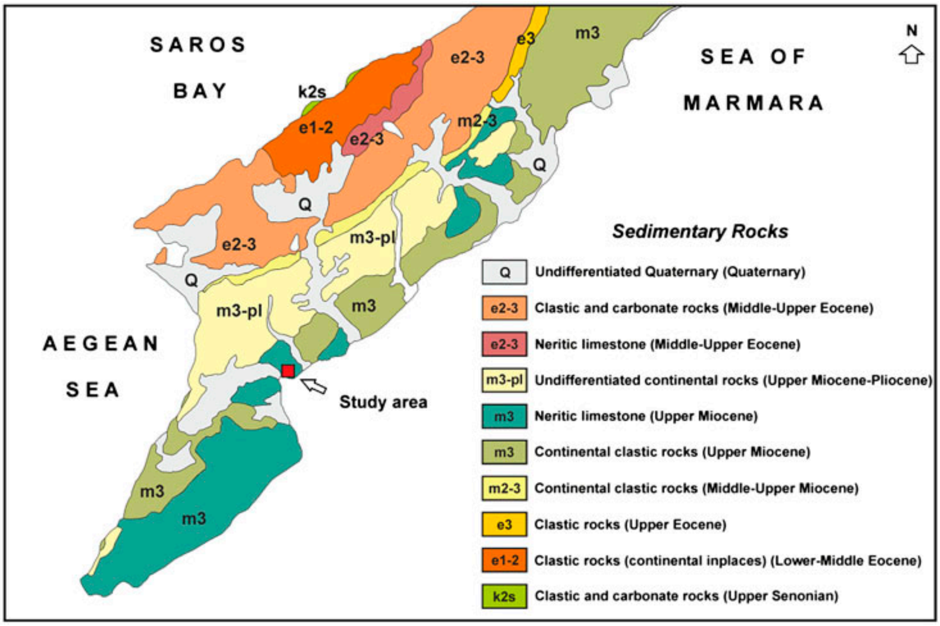

Figure 2. Geology map of the Gallipoli Peninsula[3].

Cemeteries, in many ways, are unique subjects of study in archaeology. Whether archaeological investigation is undertaken for preservation, cemetery management, or research, respect for the dead and for descendant communities is of paramount importance. Related ethical and legal considerations affect every aspect of archaeological practice. On a methodological level, this generally means that disturbance to the site must be minimized, if not avoided entirely.

Because the ground-based physical sensing nature of geophysical surveys are non-invasive, they seem to be an obvious choice for the investigation of cemeteries, and several geophysical methods have been used successfully to map the physical anomalies (e.g. resistivity) related to historical graves[4,5]. Very often, however, geophysical surveys of cemeteries have failed to yield useful results. Many lessons about applying geophysics in this challenging context have come from the intermittent successes and failures, as has an acceptance that the conditions at some cemeteries may not be suitable for any geophysical method.

One of the pioneering investigations on buried graves using a non-destructive geophysical method was the Ground-Penetrating-Radar (GPR) survey performed at a historical house in Annapolis and at three other sites in Maryland, near Washington, DC[6]. Other geophysical surveys for unknown grave sites have had mixed success. Evidence sometimes suggested that there was a grave where there was none. At other times, known graves were not obvious in the surveys. However, some surveys have been successful. Thus, the initial purpose of this study was to determine whether it was possible to locate unmarked graves using geophysical imaging methods. Image maps of the subsurface were obtained by using Electrical-Resistivity-Tomography (ERT), GPR and Magnetic-Imaging (MI) surveys and they pointed out some anomaly zones that are compatible with each other in terms of location and depth. Based on the evidence obtained from geophysical imaging surveys, we attempted to locate markers on the maps.

Measurements by geophysical methods in a historical Martyr Cemetery

The principal aim of cemetery investigations is to determine the existence of graves and the extent of the cemetery. Missing or misplaced grave markers are very common in historical cemeteries, and records may sometimes be absent or inexact. The boundaries of the cemetery are often unknown. Some specific uses of geophysical imaging surveys include locating unmarked burials, finding the extent of a cemetery, fitting historical cemetery plans to their physical locations, determining used and unused areas for cemetery management, making cost assessments and planning for exhumations, and targeting exhumations and minimizing exploratory excavation. Geophysical surveys are most often used in conjunction with other complementary methods of investigation, both archaeological and historical[7]. Additionally, using the information about the geology of the survey area also facilitates the geophysical interpretation. In this study, some evidence, such as old photographs[8],[9] showing the historical situation of the area (Figures 3 (a), (b)), rock piles marking a grave boundary (Figures 3(c), (d)), and a type of pine tree named the cypress – an evergreen coniferous tree with flattened shoots bearing a small scale-like leaf – helped us establish the position in the geophysical surveys. Traditionally, cypresses have been used as arbors near graves in Turkey. Due to the

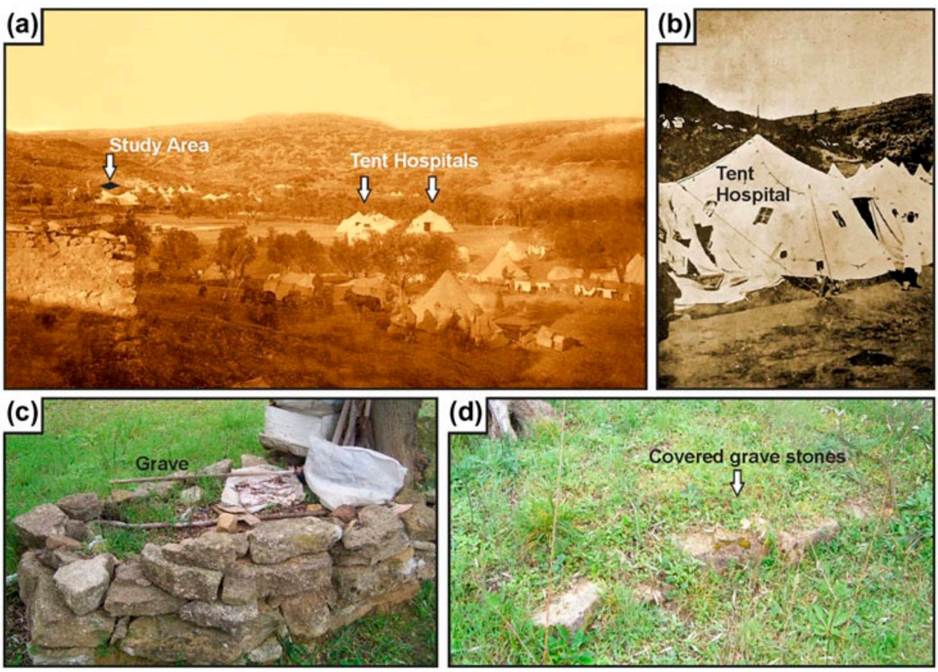

Figure 3. Some photographic presentations of the study area. (a) A historical photograph showing the study area in 1916[8]. (b) Some of the tent hospitals[9]. (c) A grave appearance, probably belong a grade officer. (d) A different grave buried in soil, and rock piles marking the grave boundary.

field conditions in terms of vegetation cover, the aforementioned surveys were carried out along traverses at various intervals (Figure 1(c)).

The ERT technique, an advanced form of the conventional vertical electrical sounding, is a commonly-used tool to study the shallow subsurface materials. It is also known that rapid data acquisitions via multi-electrode systems, efficient modeling algorithms (forward and inverse) and the resulting reliable resistivity images lead to a sound interpretation. A high-resolution resistivity imaging survey was conducted using a two-dimensional (2D) ERT technique via a GF Instruments ARES multi-electrode resistivity-meter system. A total of 4158 apparent resistivity data were gathered along 33 parallel traverses of length 30 m with 21 electrodes spaced every 1.5 m. The interval between the parallel traverses was set at 1.5 m. The dipole–dipole electrode configuration was used with electrode spacing of 1.5 and 3 m for nine different depth levels along each measuring line. Quality enhancement (increased signal-to-noise ratio) of the measured apparent resistivity data was attained by initially setting the number of repeat measurements (stacks) for each data point to 4. The number of stacks was increased to 8 when the relative standard deviation of the stacked data was greater than 5%. After the data acquisition stage, a 2D tomographic inversion algorithm was used to build up a real resistivity distribution of the study area. The algorithm used is based on a smoothness-constrained least-squares inversion implemented by a quasi-Newton optimization technique[10]. The forward modeling procedure was performed by using a finite-element method. For a more accurate process, four nodes per unit electrode spacing were used for the calculation of apparent resistivity data. The inversion process produced inverse model resistivity tomograms after five iterations with root mean square (RMS) errors of less than 2.51%. Owing to these low RMS errors and to avoid over-fitting of the data, the maximum number of iterations was not increased beyond 5.

GPR is probably the most widely applied geophysical method for cemetery investigations. Its success depends on the specific site conditions. High-frequency electromagnetic waves are sent into the ground from a transmitter antenna. These waves are reflected back to the surface as they encounter changes in the dielectric permittivity of the matrix through which they travel and are then detected by a receiver antenna. The study area, 44×50 m^2 in size, was scanned with a Mala RAMAC ProEX GPR unit with a 250 MHz shielded antenna. Forty-five GPR profiles were taken in a NE-SW direction. The aperture of the profiles was 1 m. It is known that slicing the processed data parallel to the axes or along arbitrary directions and presenting the data by three-dimensional (3D) images provide a more complete understanding of the subsurface with clear views[11]. Thus, these visualization techniques were used for a better interpretation of the GPR data in this study.

The MI technique is a very fast and effective tool for mapping cemeteries. Coffins containing any steel or iron fixings, buried grave markers, and other monuments of stone or brick can be easily detected. Multiple burials and burials without grave marks may be mapped and may provide indirect evidence of grave patterning. Historical burials often appear as a lower magnetic intensity in the absence of highly magnetic components. The lower magnetic intensity may result from the replacement of topsoil with subsoil or from mixed soils in the filled grave cut[7] and it is known that the martyrs were buried collectively without coffins in Agadere Cemetery due to the insufficient war conditions. The total field magnetic data set of the study area was acquired using a Geometrics-G858 Caesium Magnetometer with 0.01 nT sensitivity. The data were collected sequentially in the discrete mode with a 0.25 m sample interval along parallel profiles with a profile interval of 0.5 m. The height of the sensor from the ground surface was set at 0.5 m. We used the base-station method for removing the effects of magnetic diurnal variations from the measured total field magnetic data.

Results and discussion

Figure 4 shows the resistivity tomograms, which have a depth range of about 3.3 m, obtained after the 2D inversion process. Note that horizontal axes (east–west) were exaggerated for a better demonstration. Resistivity values are in the range of about 10 to 30 ohm.m and generally the survey area is dominated by relatively lower resistivity values (< 15 ohm.m). Although the resistivity values in the survey site do not vary in a wide range, a relatively high resistivity zone is clearly seen in the image (Figure 4). These high resistivity anomalies are located between the horizontal distances of about 27 and 47 m (highlighted with black dashed ellipses) and they may be attributed to an anthropogenic burial place since they possess similar features in terms of shape and alignment (Figure 4). Leveling of the resistivity anomalies produced a deep areal change of anomalies belonging to buried structures or materials. Resistivity variations in 3D volume are illustrated by depth slices with an exaggerated vertical axis (Figure 5). The resistivity anomalies are clearly seen at the depth range of about 0.8 to 2.4 m and these anomalies (highlighted with black dashed ellipses) may be the trace of buried structures. Additionally, another anomaly zone located on the western side of the survey area is clearly seen from the resistivity depth slices (Figure 5). The trace of this high anomaly zone continues downward to more than about 3.5 m and, based on the information obtained from the other known cemeteries in the Peninsula, this depth is not expected for target graves. Additionally, this high anomaly zone shows an

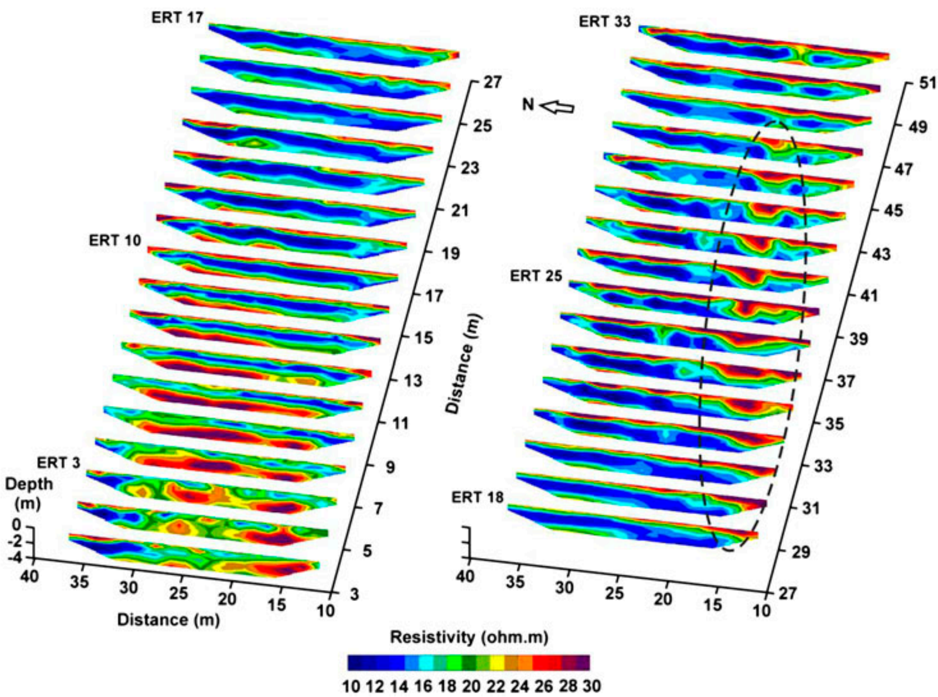

Figure 4. Electrical resistivity tomograms obtained by 2D inversion process.

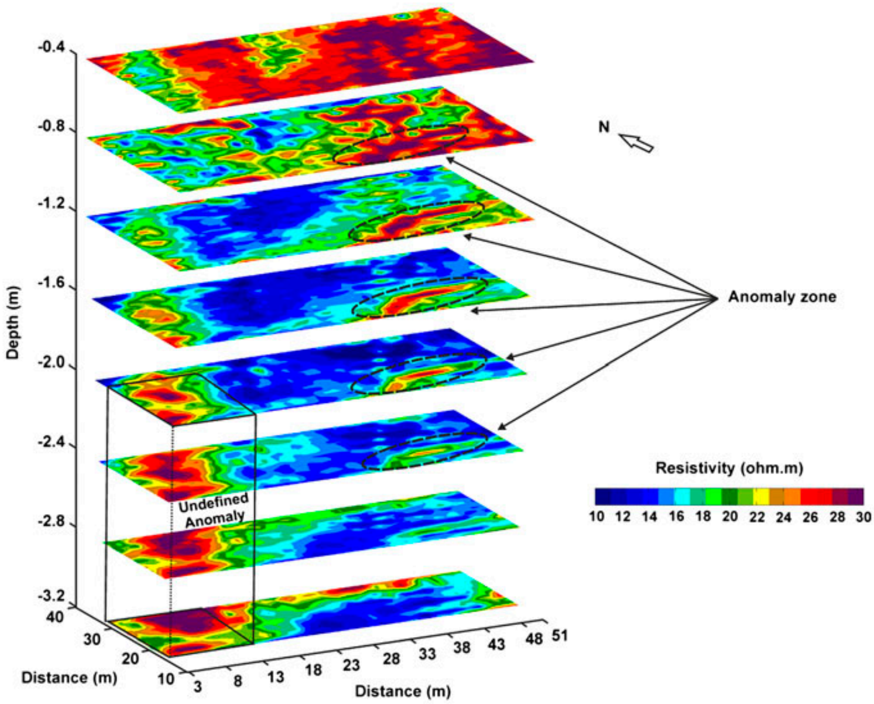

Figure 5. Electrical resistivity depth slices produced by using 2D tomograms.

expansion in size with depth. Thus, the anomaly zone located on the western side of the survey area is considered to be a lithological anomaly that is not related to the buried cemeteries. Figure 6 shows an iso-resistivity anomaly map (> 24 ohm.m) produced by using a multi-dimensional gridding technique. Relatively high resistivity zones are clearly seen in the volumetric illustration. The anomaly highlighted with

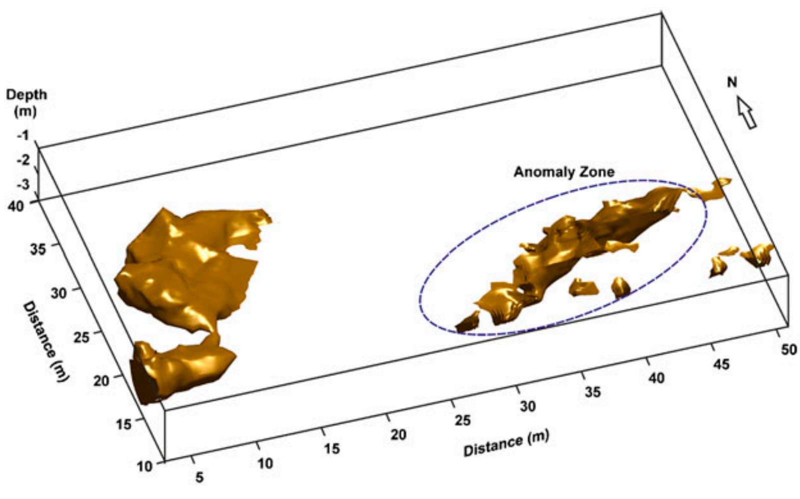

Figure 6. Iso-resistivity surface map of higher resistivity zones (> 24 ohm.m).

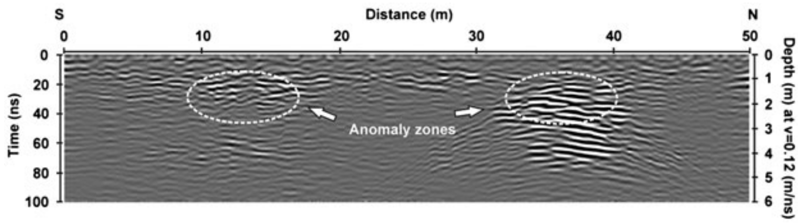

Figure 7. An example processed 2D GPR profile, showing the anomaly zones.

black dashed lines is characterized by high resistivity and probably represents an organic material-filled cavity. It is interpreted as a cemetery in which several soldiers were buried side by side.

A 2D plot of horizontal distance versus travel time was constructed from the two-way travel times of the reflections (Figure 7). Reflections in the image may be caused by material-filled voids. It has also been suggested that the decomposition of bones may result in calcium salts being leached into the surrounding soil, which over many years can change the physical properties of the soil, making it visible to the GPR[12]. The most widely used method for displaying GPR data is as 'time slice' maps[13]. Time slices are the easiest and most rapid way to provide a synthetic plan of the anomaly pattern. The time slicing technique constructs plan-view maps of an area at specific

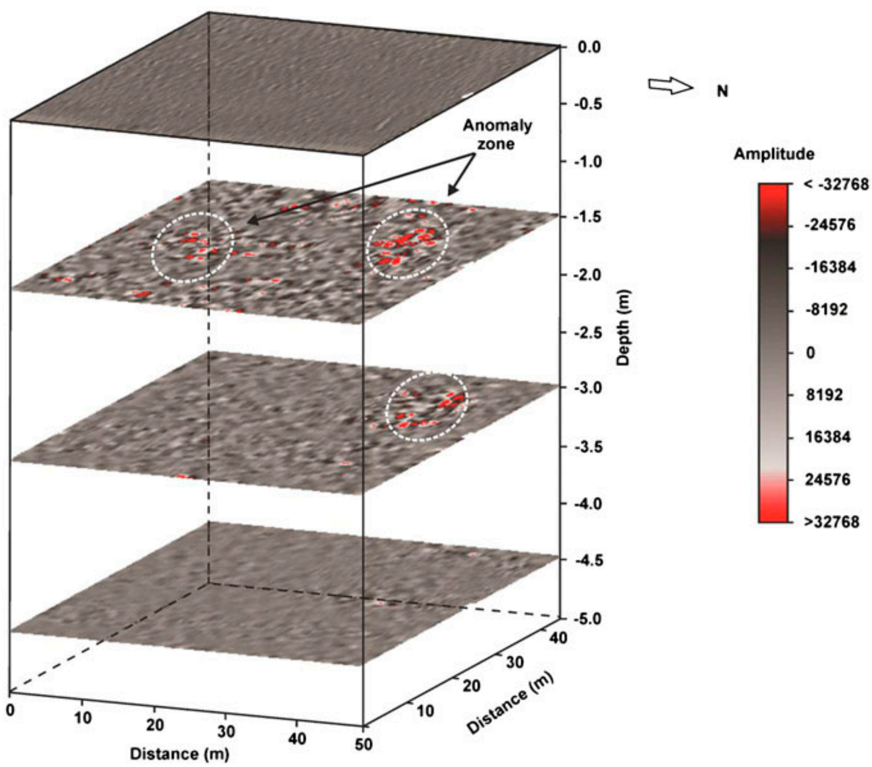

Figure 8. Time slices of 3D presentation. The high amplitude areas are probably related to a buried grave.

isolated depth ranges (Figure 8). The data for time-slice analysis must be collected systematically at closely spaced (generally $\leq$ 1 m) transect intervals. In this way one may detect the disturbed soil of the grave cut or breaks in the natural stratigraphy or soil profile[6]. In light of the information mentioned above, the anomaly zones, shown in Figures 7 and 8, may be considered to be the traces of organic material-filled cavities. These zones are highlighted with white dashed ellipses in the image and the anomaly located at the northern part can be followed in the deeper zone of the soil (Figure 8). The GPR anomaly located at the southern part of the survey area is supported by the existence of the anomaly zone in the ERT image shown in Figure 5. This anomaly is not observed at the depth of 3 m in Figure 8, which is in close agreement with ERT survey result, which indicates that the anomaly zone is located between the depths of 0.8–2.4 m (Figure 5). Additionally, the backfilled soils and organic material-filled cavities can be identified in a more detailed manner by GPR surveys in several ways; the same data set was demonstrated by iso-amplitude surfaces using four different threshold values: 20%, 30%, 40% and 50% of the maximum complex trace amplitude (Figure 9). The threshold value seems to be the most delicate parameter[11], and the values of 30% and 40% appear to be the best choice, because they underlined better the remnants of archaeological interest.

The recorded total field magnetic dataset was split into a grid using the Kriging gridding method with a grid size of 0.25 m (Figure 10(a)). To reduce possible noise and the effects of very near surface causative sources, a linear transform, named the upward continuation process (0.5 m), was performed on the data set and the planar horizontal trend was then removed from the upwarded total field magnetic data (Figure 10 (b)). The continuation level was not increased by more than double the data sampling interval so that the objective anomalies were not masked. At the next stage of the data

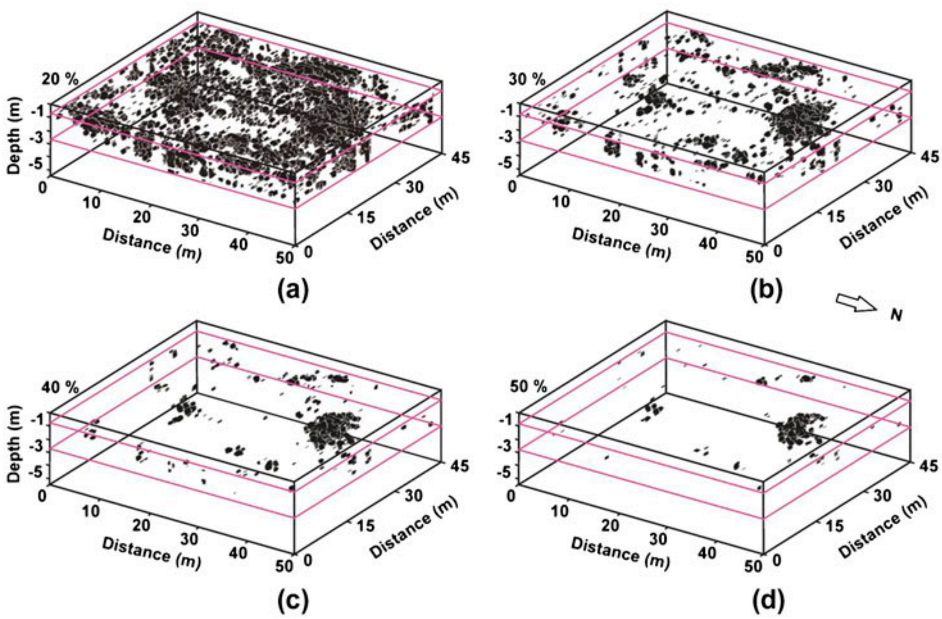

Figure 9. Three-dimensional visualization of iso-amplitude surfaces by using different thresholds: (a) 20%, (b) 30%, (c) 40%, (d) 50%.

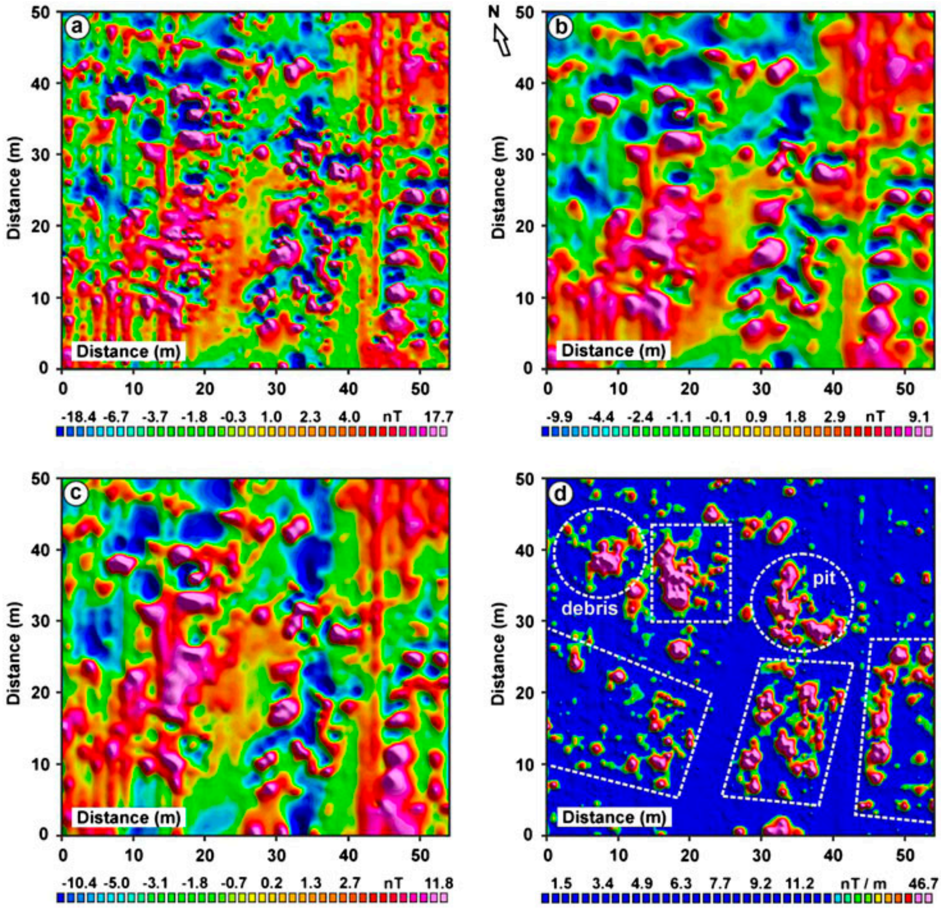

Figure 10. (a) Total field magnetic anomaly map. (b) Trend-removed anomaly map produced after an upward continuation process (0.5 m). (c) Reduced to the pole anomaly map (Earth's magnetic inclination angle, *I*=55° and declination angle, *d*=4°). (d) Analytic signal anomaly map.

processing, the reduction to the pole transformation was carried out by assuming 55° and 4° for the Earth's magnetic inclination and declination, respectively. We assumed that the magnetic anomalies were centered on their respective sources using this linear transformation[14]. The reduced-to-pole image map is illustrated in Figure 10(c) and amplitude variations in the survey area clearly show the high and low amplitude magnetic anomalies. Finally, since directional derivative-based filters may successfully determine the source body edges[15,16], the analytic signal (total derivatives) method[17] formed through a combination of the total horizontal (both diagonal directions) and vertical gradients of the potential field data was used to locate the locations of source maxima on the grid plane. Total horizontal gradients were computed using some simple finite-difference relationships while vertical derivatives were computed in the wavenumber domain using fast Fourier transform[14]. The analytic signal method is an efficient tool for enhancing abstruse details in potential field data and may aid interpretation[18,19]. The resulting analytic signal image map is illustrated in Figure 10(d). It can be clearly seen that the analytic signal enhanced the anomalous zones. The anomalies of the debris and

Figure 11. Some evidence belong to martyr cemeteries in Agadere.

pit are highlighted with white ellipses, which is in agreement with field observations. Other anomaly zones showing high amplitude responses are highlighted with white rectangles, and they may be attributed to man-made buried cemeteries located at the southern and northern part of the survey area.

To draw correct conclusions about the existence and placement of possible graves, the geophysical data obtained from three different methods were examined point by point and compared with each other. Significant anomalies were evaluated and marked on maps. High resistivity anomalies located at the southern part of the area begin at 0.8 m and ended at 2.4 m. This finding was confirmed by the GPR results (Figure 8). The analytic signal image map (Figure 10) also supported this anomaly zone in terms of location. This anomaly may indicate organic–material filled cavities and we interpret them as graves. Additionally, this zone presented a geometric shape similar to a thin rectangle in resistivity depth slices (Figure 5). Under Islamic rules, bodies are placed into their graves aligned in the direction of Kaaba (a holly stone building in Mecca, Saudi Arabia, which is shaped like a cube). Of course, these anomalies do not represent a grave but rather a graveyard in which bodies were placed side by side. On the other hand, the other high resistivity anomaly zone, which occurred in the western parts of the area, continues deeper, which means that the anomalies belong to in situ rocks. Figure 8 indicates an anomaly zone located in the northern part of the survey area, which can be followed to a depth of between about 1 and 3 m. The analytic signal image map (Figure 10) also supported the existence of this significant anomaly zone in the southern part of the area.

Conclusions

Geophysical imaging techniques are effective tools for mapping subsurface materials. Historical cemeteries can be very challenging subjects for geophysical prospecting, but some of the geophysical methods may easily detect the physical traces of human burials in several ways. They may detect the disturbed soil of the graves or breaks in the natural stratigraphy or soil profile. In this study, ERT, GPR and MI surveys were applied with success to the historical Agadere Cemetery. Ground-truth of the geophysical results by excavation is impossible in Turkey in view of the respect given to martyrdom. However, some supporting evidence appeared in the survey area after a rainy period (Figure 11). Based on shallow geophysical surveys (Figures 5, 8 and 10) and existing field evidence (Figures 3 and 11), the anomaly zones in the study area are attributed to traces of the graves. In brief, it is concluded that the results of this study showed the effectiveness of geophysical methods in bordering the locations of historical graves. Thus, it is thought that these methods and the applied data processing techniques should be suitable for investigations of the other buried historical cemeteries in the Gallipoli Peninsula.

Acknowledgements

This research was financially supported by the Directory of Historical National Park in Gallipoli Peninsula, Turkey. We also thank to Dr. Ebru Sengul and our students for their help in collecting the magnetic data. We are also indebted to two journal referees for constructive comments that have greatly improved our paper.

References

1. Chisholm H. 'George V'. Encyclopedia Britannica (11th ed.). Cambridge University Press; 1911.
2. Wikipedia. http://en.wikipedia.org/wiki/Gallipoli_Campaign 2012.
3. MTA (General Directorate of Mineral Research and Exploration of Turkey) 2002; Geological map of Turkey, MTA Publications scale: 1/500000 Ankara, Turkey.
4. Ellwood BB. Electrical resistivity surveys in two historical cemeteries in northeast Texas: A method for delineating unidentified burial shafts. Histo Archaeo 1990;24(3):91–98.
5. Ekinci YL, Kaya MA, Başaran C, Kasapoğlu H, Demirci A, Durgut C. Geophysical imaging survey in the south necropolis at the ancient city of Parion (Kemer-Biga), Northwestern Anatolia, Turkey: Preliminary results. Mediterr Archaeol Ar. 2012;12(2):145–157.
6. Bevan BW. 1991. The search for graves. Geophysics 1991;56(9):1310–1319.
7. Jones G. Geophysical mapping of historic cemeteries. Technical Briefs in Historical Archaeology 2008;3:25–38.
8. Sayılır B. Çanakkale iline bağlı Eceabat ilçesinin Kilitbahir Köyü sınırları içersinde yer alan ve Ağadere Mevkii olarak bilinen bölgenin Çanakkale Savaşı'ndaki tarihî özel konumu ile öneriler (An internal report); 2010.
9. Arslan O, Bilkan AF, Çakır Ö, Bilkan ÖF, Ceyhan N. Çanakkale Savaşları Albümü, Çevre ve Orman Bakanlığı 2005: 121 (In Turkish).
10. Loke MH, Barker RD. Rapid least-squares inversion of apparent resistivity pseudosections using a quasi-Newton method. Geophys Prospect 1996;44:131–152.
11. Leucci G, Negri S. Use of ground penetrating radar to map subsurface archaeological features in an urban area. J Archaeol Sci 2006;33:502–512.
12. Mellet JS. Location of human remains with ground penetrating radar. Proceedings the Fourth International Conference on Ground Penetrating Radar. Geol Soc Fin, Special Paper 1992;16:359–365.
13. Conyers LB. Ground-penetrating radar for archaeology. Walnut Creek (California): Altamira Press; 2004.
14. Blakely RJ. Potential theory in gravity and magnetic applications. Cambridge University Press; 1995: 441 pp
15. Büyüksaraç A, Arısoy MÖ, Bektaş Ö, Koçak O, Çay T. Determination of grave locations in Dedemezari Necropolis (Western Turkey) using magnetic field derivatives. Archaeol Prospect 2008;15:267–283.
16. Balkaya Ç, Göktürkler G, Erhan Z, Ekinci YL. Exploration for a cave by magnetic and electrical resistivity surveys: Ayvacık sinkhole example, Bozdağ, İzmir (western Turkey). Geophysics 2012;77(3):B135–B146.

17. Roest WR, Verhoef J, Pilkington M. Magnetic interpretation using the 3-D analytic signal. Geophysics 1992;57:116–125.
18. Tsokas GN, Hansen RO. On the use of complex attributes and the inferred source parameter estimates in the exploration of archaeological sites. Archaeol Prospect 2000;7:17–30.
19. Büyüksaraç A, Bilim F, Ateş A, Bektaş O. Investigation of magnetic surveying data of buried grave jars in Harmanoren Necropolis (Turkey) using linear transformations and analytic signal. J Archaeol Sci 2006;33:910–920.