Taylor & Francis
Taylor & Francis Group

Australian Journal of Forensic Sciences

ISSN: (Print) (Online) Journal homepage: https://www.tandfonline.com/loi/tajf20

Determination of historical graves by ground penetrating radar method: Sakarya Field Battle (August 23 – September 13, 1921, Turkey)

Sinan Koşaroğlu, Züheyr Kamacı, Selim Erdoğan, Özcan Bektaş & Aydın Büyüksaraç

AUSTRALIAN JOURNAL OF FORENSIC SCIENCES
2022, VOL. 54, NO. 6, 842–860
https://doi.org/10.1080/00450618.2021.1921270

Determination of historical graves by ground penetrating radar method: Sakarya Field Battle (August 23 – September 13, 1921, Turkey)

Sinan Koşaroğlu[a,b], Züheyr Kamacı[b], Selim Erdoğan[c], Özcan Bektaş[a] and Aydın Büyüksaraç[d]

[a]Engineering Faculty, Geophysical Engineering Department, Sivas Cumhuriyet University, Sivas, Turkey; [b]Engineering Faculty, Geophysical Engineering Department, Süleyman Demirel University, Isparta, Turkey; [c]Republic of Turkey Ministry of Agriculture and Forestry, General Directorate of Nature Conservation and National Parks, Ankara, Turkey; [d]Çan Vocational College, Çanakkale Onsekiz Mart University, Çanakkale, Turkey

ABSTRACT

The Sakarya Field Battle was the last phase of the forward operation of the Greek Asia Minor Army, which started at the end of March 1921. Although there are contradictory numbers regarding the losses of the parties in the Sakarya Field Battle in the literature, it is generally accepted that the Turkish Army lost 5,713 martyrs. The Ground Penetrating Radar (GPR) method was applied to determine the accuracy of findings observed on the surface and to determine burial sites. Geophysical anomalies were detected in 2D profiles from the obtained results. It was determined that the Turkish side buried the martyrs in east-west direction, depending on their religious traditions. The detected anomalies were evaluated in two and three dimensions and the boundaries of the burial areas and the approximate depths of the burials were obtained. The results obtained from data processing techniques showed that the GPR method is suitable for determining the locations of historical graves on battlefields. The new martyrs found as a result of the studies are thought to be soldiers whose fate was unknown, recorded as 'missing' in the records.

ARTICLE HISTORY
Received 10 February 2021
Accepted 6 April 2021

KEYWORDS
Sakarya Field Battle; ground penetrating radar; grave; martyrdom; forensic investigation

Introduction

Determination of burial sites is very important as a study subject in terms of old and recent studies. Researches in cemeteries are carried out in order to respect the dead and other communities that descend from them, to protect burial sites, to make these places visible, for criminological researches, and to shed light on the archaeological or historical past. Searching for unclear or hidden graves created during periods of abnormal life, such as wars or epidemics, is time consuming and poses a significant challenge for national and local organizations in charge of their management[1]. This is because in cemeteries created under these conditions, there are usually graves without headstones or with a simple headstone. In addition, the situation becomes quite complicated if there are missing maps or historical documents. These areas are increasingly threatened with destruction due to

CONTACT Özcan Bektaş obektas@cumhuriyet.edu.tr

meteorological conditions, agricultural activities or construction. Search methods used to find graves may include collecting and examining historical records, aerial photographs and eyewitnesses, on-site surface observations, searching for biological remains by examining samples taken from boreholes, searches with shovels or simple construction equipment[2–5]. When the human body is considered in terms of physical and chemical conditions, it is extremely difficult to leave permanent traces under the ground and some clues can be reached with very detailed analysis. However, the most permanent remains are skeletal bones. Since there is no bone fixing device, the detection of the graves is only revealed by excavations. In this case, the detection of unidentified graves without excavation may be possible depending on secondary indicators such as determining the difference between the excavated soil and the unexcavated soil around or detecting objects outside the body itself. Metal parts of uniforms such as buttons and belt buckles can cause anomalies, especially related to soldiers who lost their lives in wars and were buried in battlefields. Geophysical surveys are highly preferred for cemetery research, as they can be applied without damage[6]. Geophysical methods are successfully applied especially for the mapping of historical graves. Often, however, geophysical surveys of cemeteries have failed to yield useful results. Mostly spatial differences such as electrical conductivity, water content, porosity, chemical content, and depth should be obtained, in other words, measurable differences should be obtained in measurements made by geophysical methods. Applications have also increased with the existence of geophysical methods and devices developed in the last 30 years[2,6–17]. Trying to find the best discriminatory method by applying different geophysical methods in the same area or using methods that are compatible with each other were applied quite frequently. Buyuksarac et al.[14] applied magnetics, resistivity and GPR methods together to determine the burial sites of martyrs during the land wars in Çanakkale during World War I. They decided that among these methods, the fastest and most accurate result in wide area scans was obtained with GPR. GPR, the most successful geophysical method in forensic research, offers a fast and effective solution for the detection of buried objects, pollutants, shelters, weapons and buried objects with a clear difference compare to the natural geological background[18]. Studies in recent years show that the analysis of physical evidence obtained from concealed single and mass graves has important evidential and/or investigative value for both forensic purposes and humanitarian research[19]. It is known that those who lost their lives during the Spanish Civil War between 1936 and 1939 were buried in more than 2000 mass graves and their locations are not determined. GPR research was conducted on a suspected mass grave and a mass grave was found after a large anomaly was detected and excavated in the area where the anomaly was located[20,21]. Molina et al.[21] compared magnetic susceptibility, earth conductivity, electrical resistance and terrestrial results in order to investigate human bodies secretly buried in South America, especially with the GPR method. Research is being carried out with the GPR method in order to reach the bodies of people who lost their lives due to being buried by natural disasters. For example, many people are buried due to frequent earthquakes and landslides that occur in Indonesia. A detailed GPR investigation was conducted in Bandung Cikutra cemetery in order to examine the signal response for dead bodies found under the ground in GPR measurements, and it was observed that the radar profiles showed contrast anomalies caused by the corpses. It was also observed that new graves give stronger amplitude contrasts than the older ones[22]. Some researchers carried out time-dependent monitoring by burying animal cadavers at certain depths and published their results in order to model the geophysical response created by organic origin burials in the soil. While most of these results do not show much variation in anomalies over time, they stated that cadavers, especially in sandy soils, gave better results than those in clay soils[16,23–28].

GPR research was carried out to determine the burial sites in the oldest part of the cemetery, where non-Catholic foreigners were buried in Rome and which has been the main burial place for these people for the last three centuries. There is extensive information about even the oldest burials in this cemetery. However, many of them are only recorded in literary sources and their exact locations are unknown. Moreover, gravestones and markers have disappeared or been placed haphazardly over time. Using a specially designed GPR system for forensic medicine, an attempt was made to determine whether the grave records of the oldest part of the cemetery were consistent[29].

The variety of geophysical methods is increasing. Among these geophysical methods, electromagnetic induction, ground radar, magnetometers, metal detectors and electrical resistance predominantly stand out. However, GPR is considered almost unrivalled for grave exploration[13]. The Sakarya Field Battle is one of the major wars that enabled the establishment of the Republic of Turkey after rescue from enemy occupation in Anatolia. The main purpose of this study is to find the graves of Turkish soldiers who were martyred in this war and whose burial places are not known, using the GPR method. An estimated 18,650 people died during the Sakarya Field Battle between August 23 and 13 September 1921. In the last six years, more than 150 burial points were identified in the battlefield between Haymana and Polatlı. However, many more are not known. This study gives partial results of a successful search for many unmarked graves in the steppe between Polatlı and Haymana.

Historical background

The Turkish Army, whose front was breached in the Kütahya Eskişehir Battles and was in danger of being encircled, successfully retreated to the east of the Sakarya River and regained defensive order. The Greeks started the pursuit operation on 10 August 1921 in order to achieve their original goal of 'destroying the Turkish Army'. The Greeks, who reached the west coast of the Sakarya River with a 12- day walk, started to attack the Mangal Mountain and Türbetepe poles, which sealed the entrance to Demirözü Valley, south of Haymana on the morning of 23 August 1921. The Turkish forces used the Sakarya River and its southern branches, the Ilıcaözü Stream, and the range of hills to the east of both valleys as a natural embankment (Figure 1(a-c)). The main advantage of the Greeks was their high number in terms of soldiers and war equipment. The Greek Army headquarters were particularly careful about the dominance of the siege component of the operation; therefore, they sent two corps (72,000 soldiers in total) an additional 30 km to the south. This last march provided Mustafa Kemal Pasha's offensive centre to the south, in the Haymana section. The defence strategy of the Turkish Army against the numerically superior Greeks can be summarized as fighting, wearing down the enemy and retreating to the east. Meanwhile, the Greeks moved away from their logistics bases and their ranges, and the Turkish cavalry would hit the enemy supply arms in the steppe. Even if the enemy, without ammunition, food and water, gained a few tens of kilometres of land,

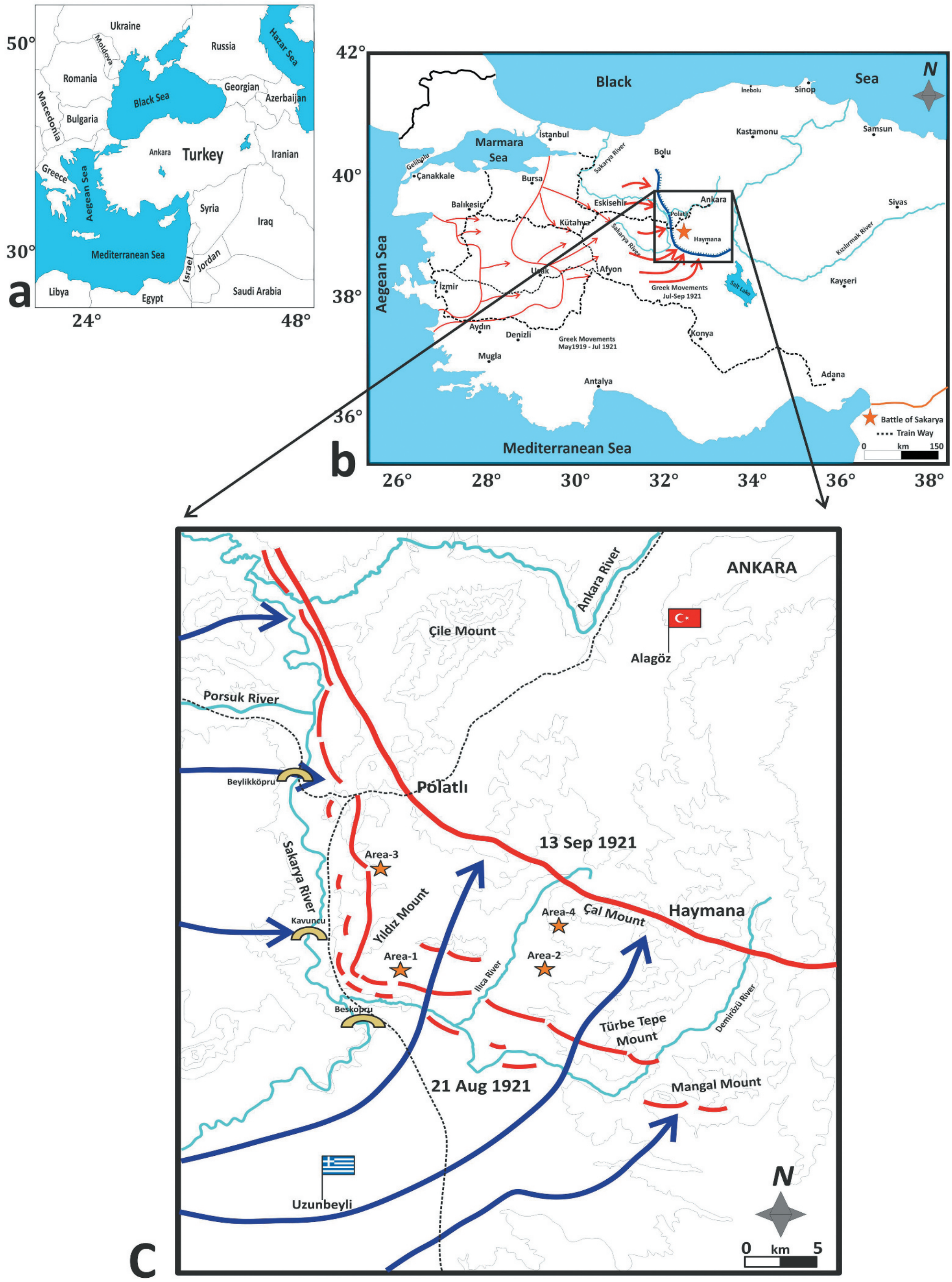


Figure 1. (a) Location map (b) The starting map of the war with the Greek forward operation (c) The areas where the war took place Turkish Defence lines (It is simplified from[30]).

they would be exhausted by the heavy casualties and lose their offensive quality. The Greeks advanced ten kilometres at the beginning of the battle with numerical superiority, but the defence strategy gained a concrete character with the order of Mustafa Kemal Pasha, which was summarized as 'There is no line of defence, there is surface defence, that

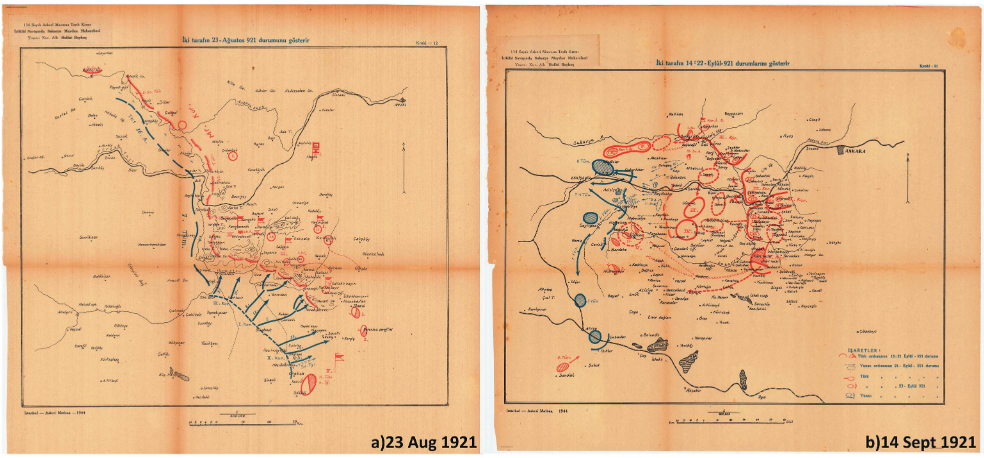


Figure 2. Sketches of the Sakarya Field Battle on (a) 23 August 1921 and (b) 13 September 1921 showing the process of the war between Turkish and Greek forces .[32]

surface is the whole country', and the whole army understood and defended bravely. The result of this sacrifice is that thousands of Turkish soldiers were buried scattered in the steppe. The Turkish counter-offensive, which started on 11 September 1921, lasted for 3 days, and at noon on 13 September 1921, not a single Greek soldier remained in the east of the Sakarya River and the Greek side claims there were 4,312 dead from their side[30,31].

Postwar mapping of burial sites is very important for future research. These maps can be used as a source for identifying lost burial sites. Maps created after the Gallipoli Wars have been very useful in defining burial sites and the war route approximately 100 years later[14]. In addition, vegetation can provide information about lost graves due to decaying corpses in old burial sites[4].

However, the Sakarya Field Battle maps were made long after the war, and the scale is insufficient. Since it is not possible to determine the location of burial sites by using old maps, the maps seen in Figure 2(a,b) were re-evaluated[32]. From these maps, a new map was created by determining the regions where the war took place, from satellite observations, information obtained from older people and military records. On these maps, the positions of the troops were investigated when the war first started and throughout the war. Since there was no time during the war, the dead were buried with very simple and primitive methods[33]. Researched areas are marked on the map (Figure 3).

Method

Geophysics is a remote sensing method and a way of detecting anomalies without physically disturbing the underground. Geophysical methods have been used in archaeological research for many years as they are a precise and fast way to investigate subsurface features without the time-consuming, expensive and destructive excavation process. They are increasingly used in forensic cases because data can be evaluated and interpreted in a short time. Determining which methods might be appropriate to search for a target requires knowledge of it. For example, information such as target or grave and its

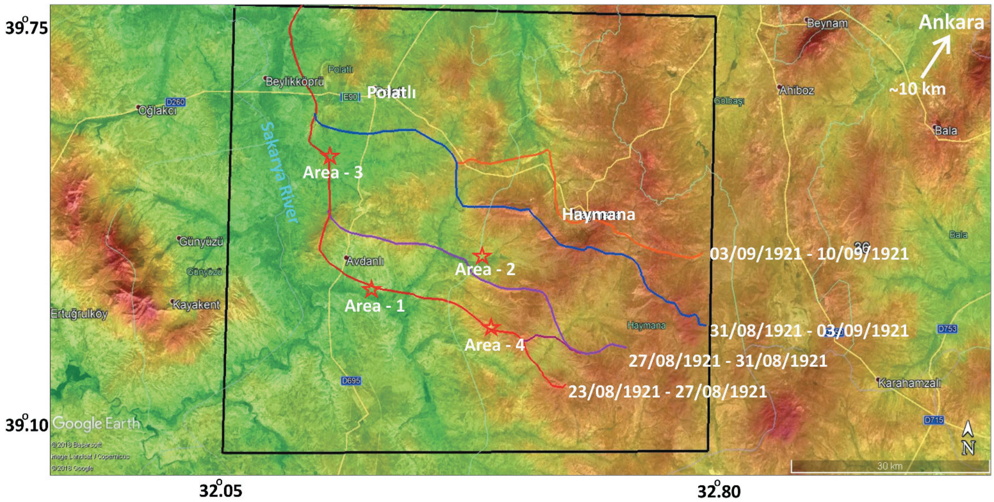


Figure 3. Map showing the locations of the main defence lines and measurement sites of the Turkish side in the battlefield of the Sakarya Field Battle.

content, site conditions, topography, vegetation, land use, and geological units should be well known. The method by which electromagnetic reflections caused by contrasts in dielectric permeability are measured and recorded for detecting unmarked and hidden burial locations and buried materials is known as Ground Penetrating Radar (GPR)[3]. Graphical representation of GPR data is an essential step in understanding and interpreting results. These results report greyscale reflections or stratigraphy, and software such as Reflexw V6.0[34] allows identification of images with very high visual resolution. Also, if measurements are taken with parallel profiles with a uniform geometry, it is possible to obtain maps of the area under investigation and therefore display the results. This represents not only geometries of buried objects of various depths, but also dimensions using an average envelope algorithm normally known as the average envelope amplitude[18]. In order to create two dimensional sections, electromagnetic reflection signals are collected sequentially and rapidly in one dimension with very high resolution. For this purpose, fixed frequency transmitter and receiver antennas are used. Because of these features, it is used in many studies[35]. There are many studies using GPR for unknown grave studies, which are the subject of this study[7,24,28,36–61]. GPR measurement and the operations applied to the data are shown in the generalized flow chart in Figure 4. In similar studies, researchers stated that 250 MHz antenna would obtain sufficient quality data, while 500 MHz and higher frequency antennas collected better quality data[62].

In this study, the survey plan was created with a profile interval of 1 m and the GPR measurements were taken. Raw data was collected with Mala Geoscience CU-II (Control Unit) 250 MHz (Shielded) antenna set by adjusting 2620.7 MHz sampling frequency, 512 samples, 195.4 ns time window, 0.05 m trace interval and 0.36 m antenna separation (Figure 5(a)). The raw data collected with these parameters was in rd3 format and evaluated with Reflexw V6.0 programme[34]. Move Start Time (−15ns) was applied to the raw data to eliminate air and earth reflections. At this stage, the aim was to eliminate strong reflections caused by the surface effects on the radargram manually. The data

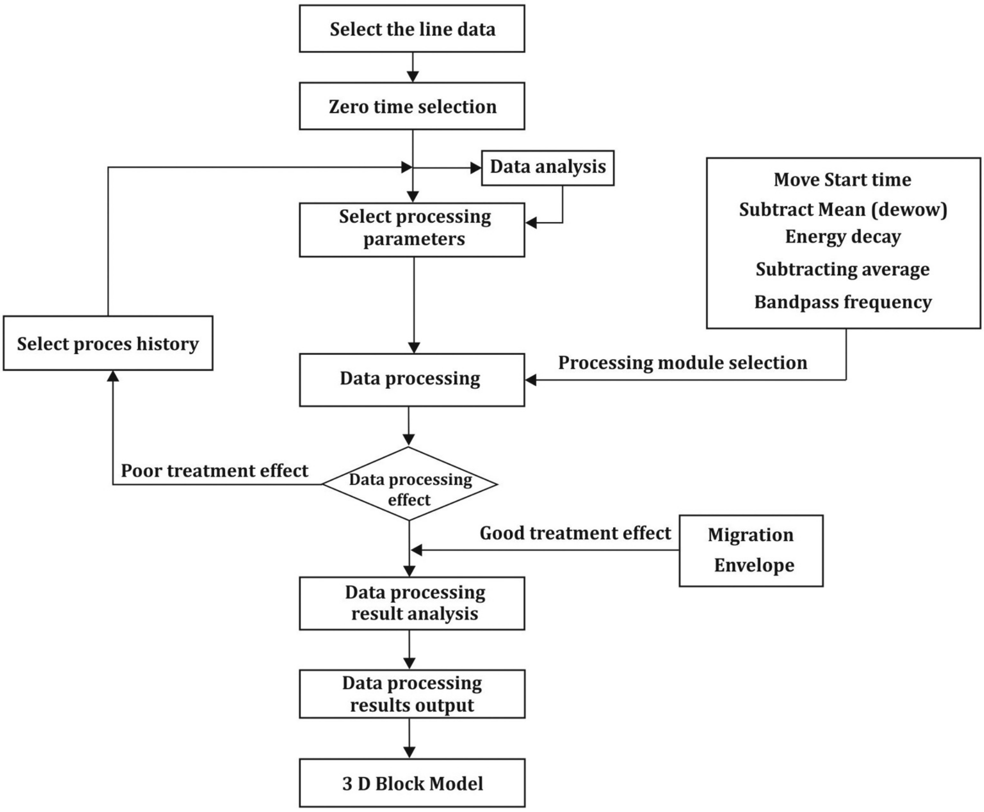


Figure 4. Evaluation flow chart of Ground Penetrating Radar (GPR) data (converted from[63]).

obtained were evaluated in 195.4 ns window size. Time cut wasn't applied to the data (Figure 5(b)). Subtract mean (dewow) was applied to the data in order to remove the values below the average frequency of the low frequency reflections originating from the batteries on the GPR system from the data set (Figure 5(c)). In the data obtained, the aim was to eliminate the amplitude losses due to the loss of energy, while strong EM reflections are moving deeper in the areas close to the surface. At this stage, the amplitude values calculated for each amplitude in the selected window intervals were added to the signal in proportion to all the amplitudes and differences in the cross section, and Energy Decay was applied to enhance the signals coming from depth (Figure 5(d)). The aim was to arrange the amplitudes in an average value range on the radargram by minimizing the energy differences especially in the horizontal direction with the subtracting average process. The data sets were reduced to an average value range with the 31/6 ns for window interval specified in this data processing step (Figure 5 (e)). In the data set, a bandpass filter was to applied to each GPR trace to pass the frequency values at specified intervals (100/200/300/400 MHz) (Figure 5(f)). Velocity readings were made from the reflection hyperbolas in the bandpass filtered data to be used in the migration process (Figure 5(g)). Finally, the data was migrated (Figure 5(h)).

In the evaluation, the data sets were checked in 2 dimensions and different reflection areas were determined in the measurements. Migration procedures were applied to the

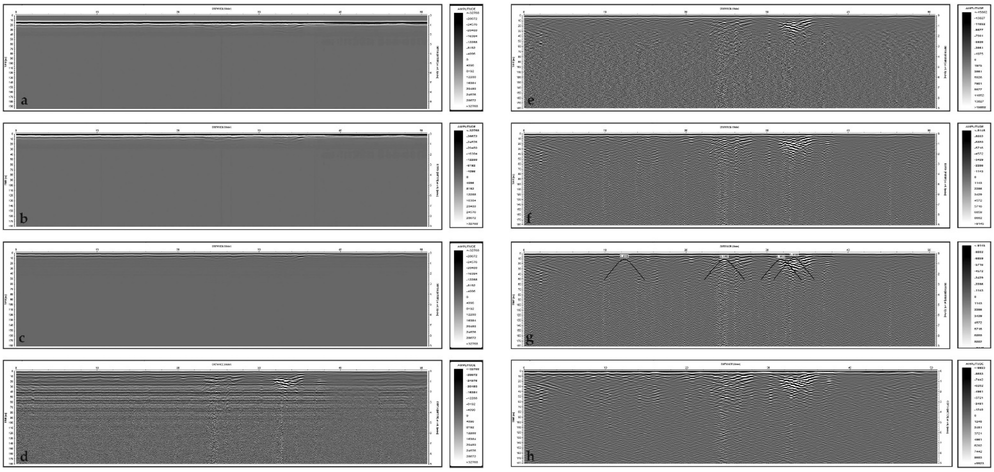
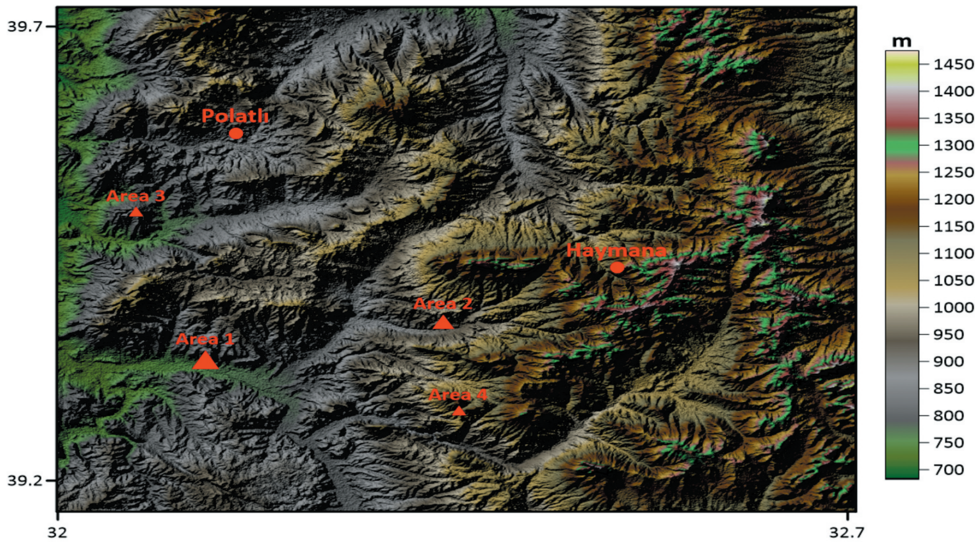


Figure 5. Example processing procedure of Ground Penetrating Radar (GPR) data. a) Raw GPR data. b) GPR data after applied move start time. c) GPR data after applied subtract mean (dewow). d) GPR data after applied energy decay. e) GPR data after applied subtracting average. f) GPR data after applied bandpass filter. g) Determination of velocities for migration process. h) GPR data after applied migration process.

data in areas where graves are possible. In the evaluated data, especially in migration processes, velocity readings were completed and interpretations were made after this process. The anomalies in the data obtained after these steps with burial direction in the direction of Qibla according to Islamic traditions, were modelled as 3-dimensional blocks. It was observed that the data gives better results when the migration process is applied in 3D block models.

Application of GPR method

Four regions were chosen as the study area (Figure 6). When determining the regions, old maps, local narratives, old photographs and irregularities in the field were used. Records are often incomplete for historical burial sites. Gravestones are demolished due to deterioration that occurs over time and their location becomes uncertain. However, old photos can give information about old graves. In Figure 7(a), the current and old photographs of the cemetery area measured as Area-1 can be seen. The deterioration that occurred over time in the cemetery can be seen in these photographs. In the new photograph in Figure 7(b), the cemetery borders are not completely clear. The burial area seen in the photographs in Figure 7(b) are the graves of the soldiers of the 5th Caucasus Division who were martyred while defending the Kocaderetepe region[31]. Most of the gravestones were toppled and the grave levels were lost. In GPR measurements, the Mala Geoscience CU-II 250 MHz protected antenna set was used. GPR measurements were made along parallel profiles with 1-m intervals in this region. In the section designated as Area – 1, measurements were made in 6 areas of 50 × 50 m to include areas with undefined borders. However, positive results were obtained in only one of these areas. For the GPR measurements made in the study area, anomalies in the burial area were determined in two-



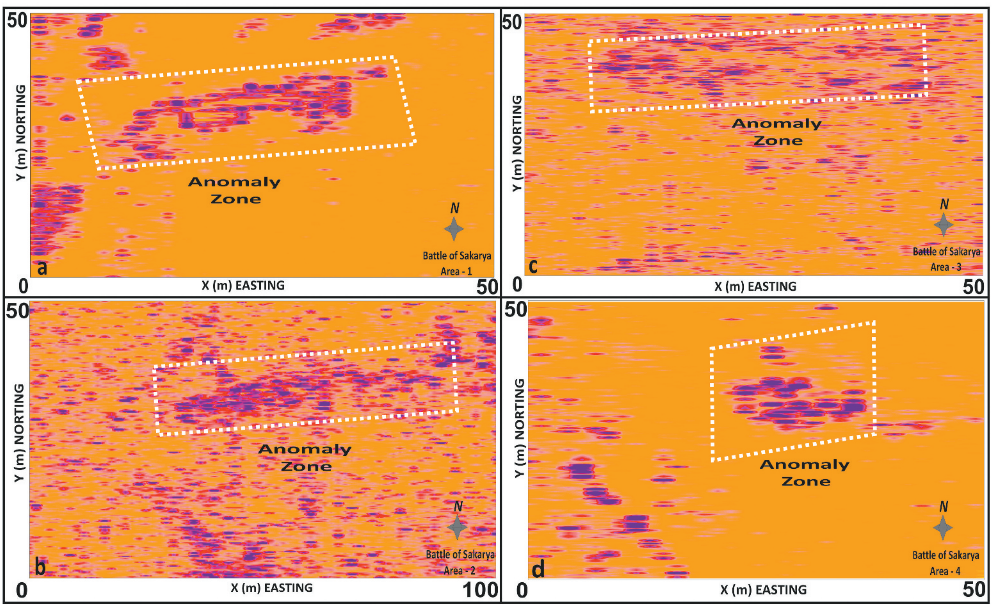


Figure 6. Satellite images taken from Google Earth showing the locations of the areas where GPR measurements were made and the GPR measurement results of the fields (Depth levels were taken as −1 metre).

dimensional sections (Figure 8(a)). The depths and boundaries of burials were determined by three-dimensional modelling (Figure 8(b)). When the obtained data were evaluated and the surface signs were examined, it was understood that individual burials were made in this area (Figure 8(c)).

Area-2 is north of Soğulca village. It was decided to make GPR measurements in the region due to the different levels observed in the field in this area. GPR measurements were made along parallel profiles at 1-metre intervals in 2 areas (50 × 50 m in size) in this study area. The presence of reflections giving an anomaly along a certain line was

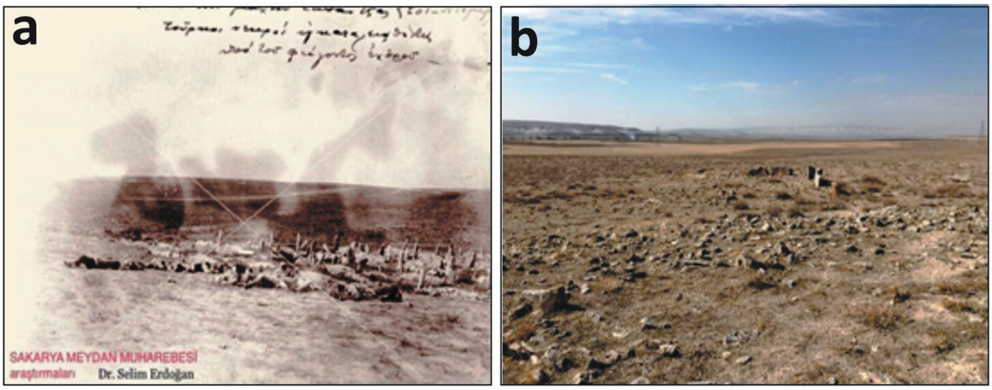


Figure 7. Old and New photograph of Area-1 measurement area.[31]

observed from the two-dimensional sections (Figure 9(a)). Data processing steps were applied to the measurements and three-dimensional depth maps were created (Figure 9(b)). The borders of the burial area, which is 35 metres long and 2.5–3 metres wide, in the direction of the Qibla in accordance with the Islamic burial tradition, were determined from this map (Figure 9(c)).

GPR measurements were made along parallel profiles at 1-metre intervals in Area-3 with 50 × 60 m size (southwest of Polatlı). Near-surface reflections were observed along a certain line in the field during the data evaluation (Figure 10(a)). The obtained data were separated according to depth levels (Figure 10(b)). As a result of the measurement, the area thought to be a qibla-oriented burial area in accordance with the Islamic burial method was found in the 3D diagram (Figure 10(c)).

Area-4, located in the southern foothills of Çal Mountain, is in a field where agricultural activities are carried out. However, due to the respect shown by the field owner to the martyrs, no damage was observed in the area where the graves of the martyrs were found, and it was observed that even the gravestones were erect. In the studies, it was understood from the GPR results that singular burials were made in this area, and the boundaries of the area and the depths of the graves were determined (Figure 11).

Two-dimensional sections are very important in evaluating GPR data. The decay of the human body underground and the organic material filling induce a difference in GPR reflections. However, the continuity of the anomaly areas is revealed by preparing three-dimensional depth level maps. In addition, iso-amplitude maps were prepared in the areas with anomalies. In these maps, the amplitude values of the anomaly were determined on 2D sections and the effects that cause other reflections in the area were filtered from the measurement. It was observed that the anomalies were clearly revealed with the help of these maps.

Apart from areas observed to be singular burial sites, sequential burial sites were also found. It was understood that the soldiers were buried sequentially in a channel opened in these burial areas, which are defined as canal type burial. 2D sections were combined and 3D maps were created, and it was observed that there were burials oriented to qibla in accordance with Islamic traditions in the identified burial areas. The burial depths are approximately 75–150 cm. GPR results and surface observations showed that the locations

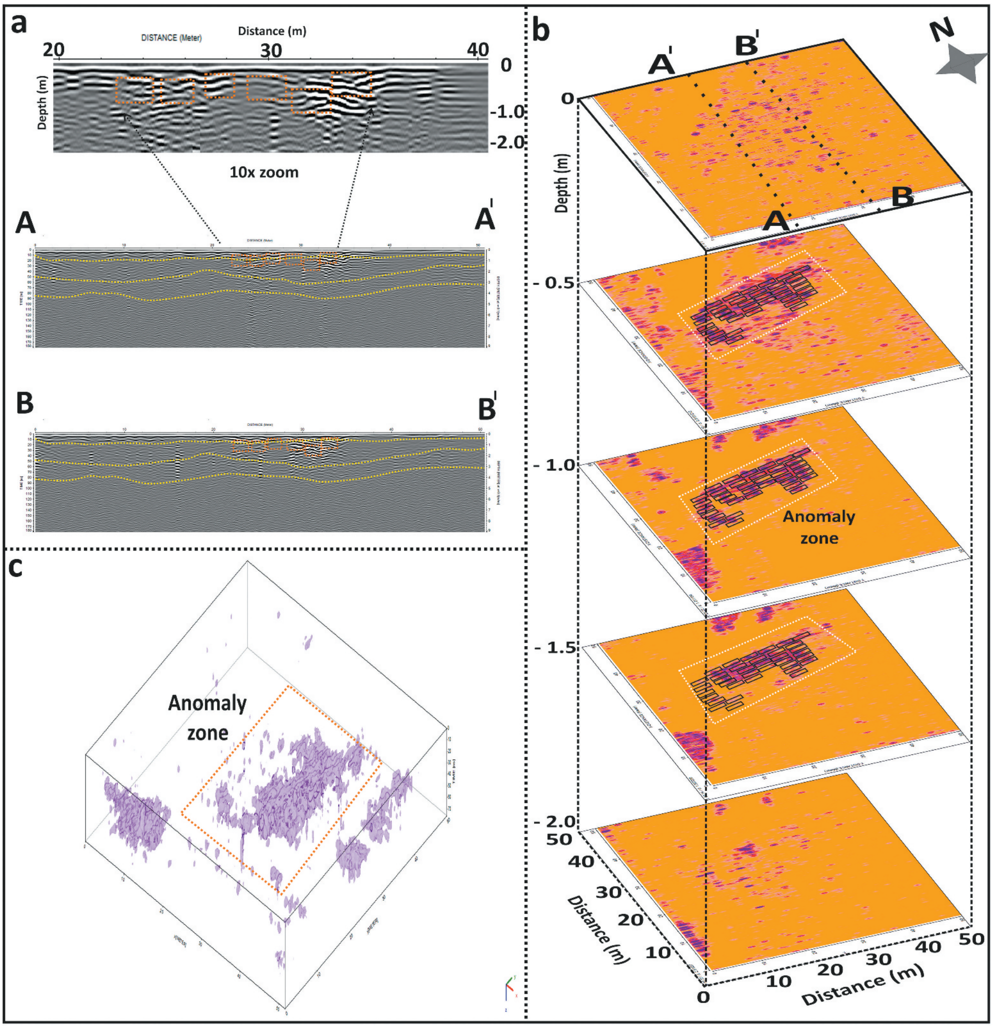


Figure 8. (a) GPR 2D sections in Area-1. Orange boxes indicate burial sites, yellow lines indicate geological strata boundaries. (b) 3D depth level maps and depth variations of anomalies. (c) 3D modelling of the iso-amplitude map.

in the measurement areas are historical cemeteries. This study once again demonstrated that the GPR method is an effective method in determining and delimiting historical burial sites. This study revealed that other suspicious burial sites in similar areas can also be identified.

Discussion and conclusions

Funeral ceremonies are a necessity of existence and a sign of respect that should be shown when a man leaves the world. However, deaths on the battlefield are the scene of burials as painful as the horrors of war. Wars, which are a kind of interruption of civilization, also prevent the cultural ritual of burial that humankind has developed over time. Generally, fast and mass burials take place, so grave depths in battlefields are also shallow. In addition, as in many

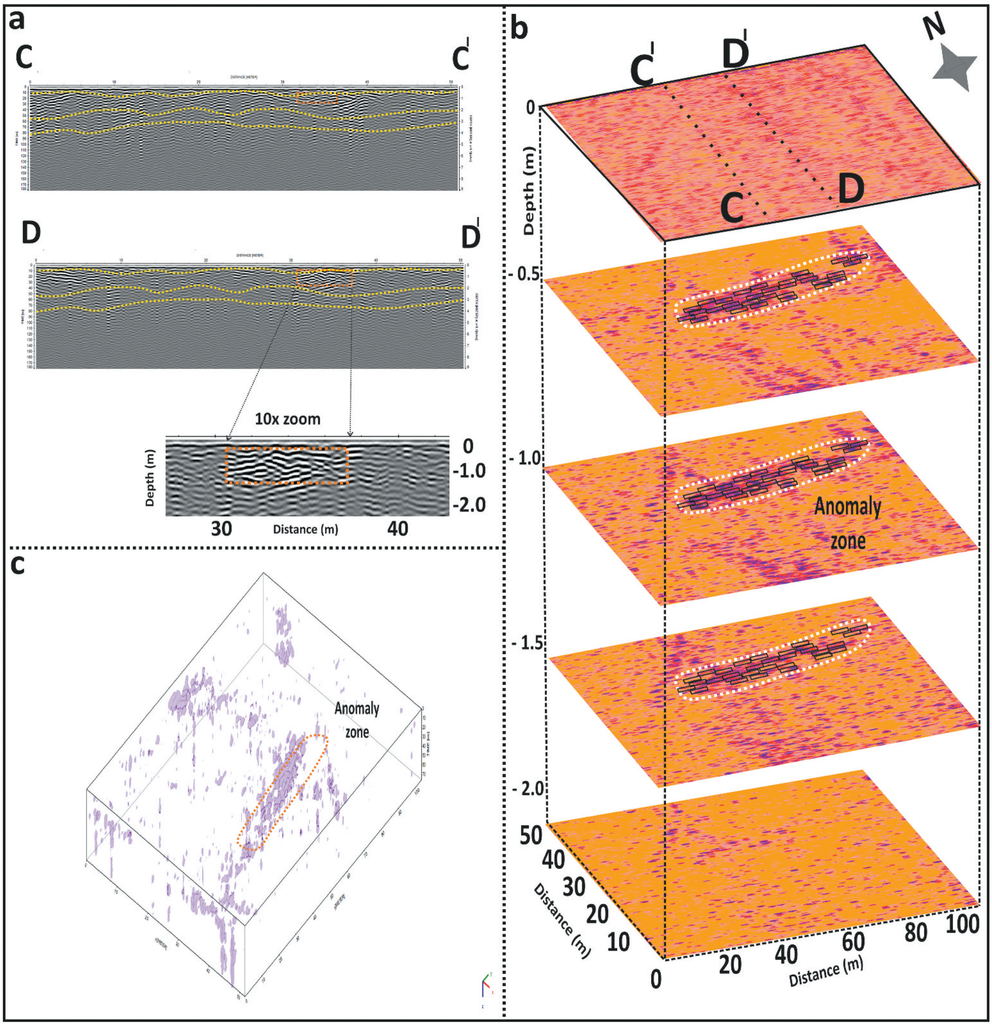


Figure 9. (a) GPR 2D sections in Area-2. Orange boxes indicate burial sites, yellow lines indicate geological strata boundaries. (b) 3D depth level maps and depth variations of anomalies. (c) 3D modelling of the iso-amplitude map.

religious beliefs, the ritual of purifying farewell cannot be applied to deaths during war. On the other hand, the rules that can be applied to a certain extent both fulfil the respect for the dead partially and form clues for determining the burial place later, as in this study.

The Sakarya Field Battle is an important milestone in the effort of the Turkish nation to save their lands from occupation after World War I and is an epic war that took place nearly 100 years ago. It has entered the war literature of the world in terms of the methods used in the war and its results. Research activities were initiated in order to determine the graves of the martyrs by the General Directorate of Nature Protection and National Parks for the Republic of Turkey to fulfil our duty to the soldiers who lost their lives in this battle and to respect to the history. In this context, first of all, historical records were examined, the evidence existing on the battlefields was researched, and the information conveyed to the

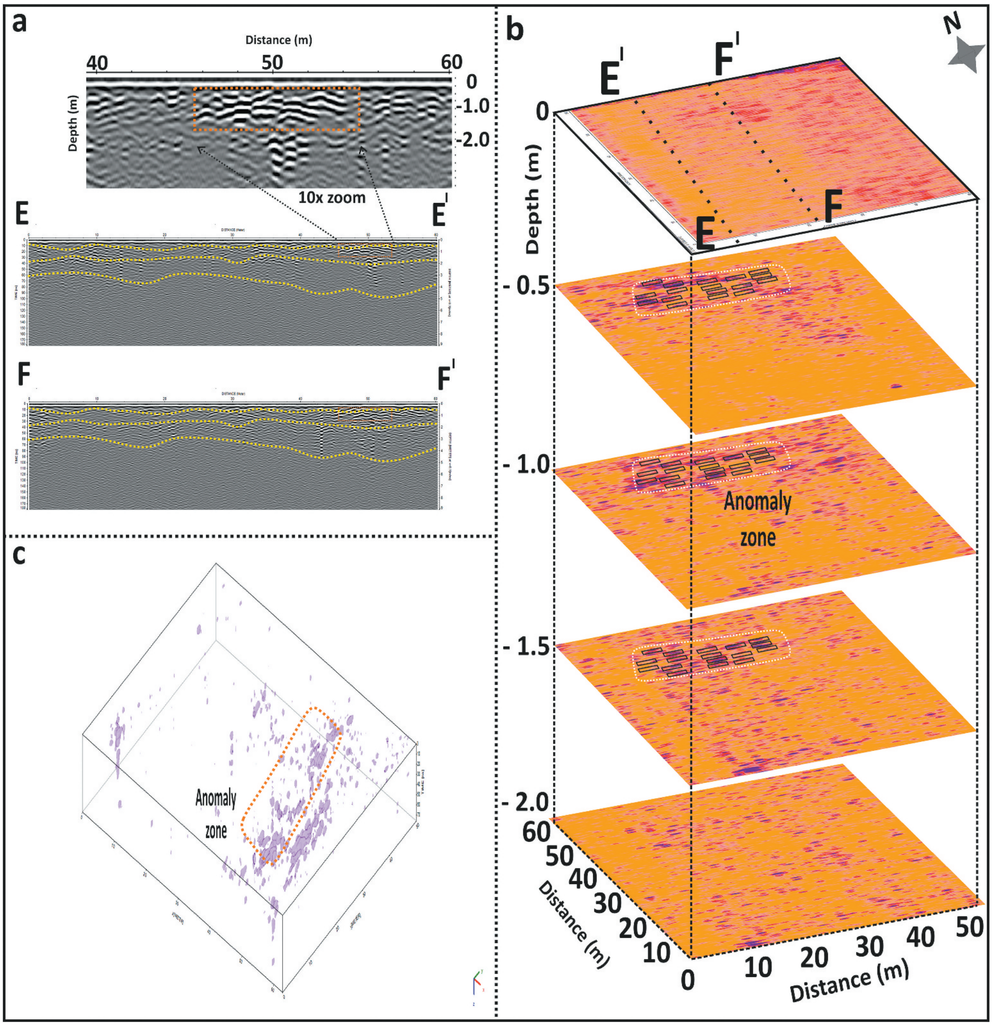


Figure 10. (a) GPR 2D sections in Area-3. Orange boxes indicate burial sites, yellow lines indicate geological strata boundaries. (b) 3D depth level maps and depth variations of anomalies. (c) 3D modelling of the iso-amplitude map.

relatives of the people who participated in the war or resided in the areas where the war took place were collected. According to the course of the battles, war geography studies were carried out and possible burial areas were determined by comparing them with these positions. 'Possible martyrdom cemeteries' were determined by comparing those with physical surface findings from these areas with literature findings and local expressions. These possible cemeteries were restricted regionally, and geophysical ground studies were carried out in these areas. GPR, chosen as the geophysical method, was successfully applied in the study area as in many similar studies. GPR studies are naturally interpreted by considering the differences in many influencing factors in the field. The main one is burial orientation according to Islamic traditions. Accordingly, the dead body is placed towards the Kaaba, which is located in the Masjid al-Haram in Mecca and regarded as the most

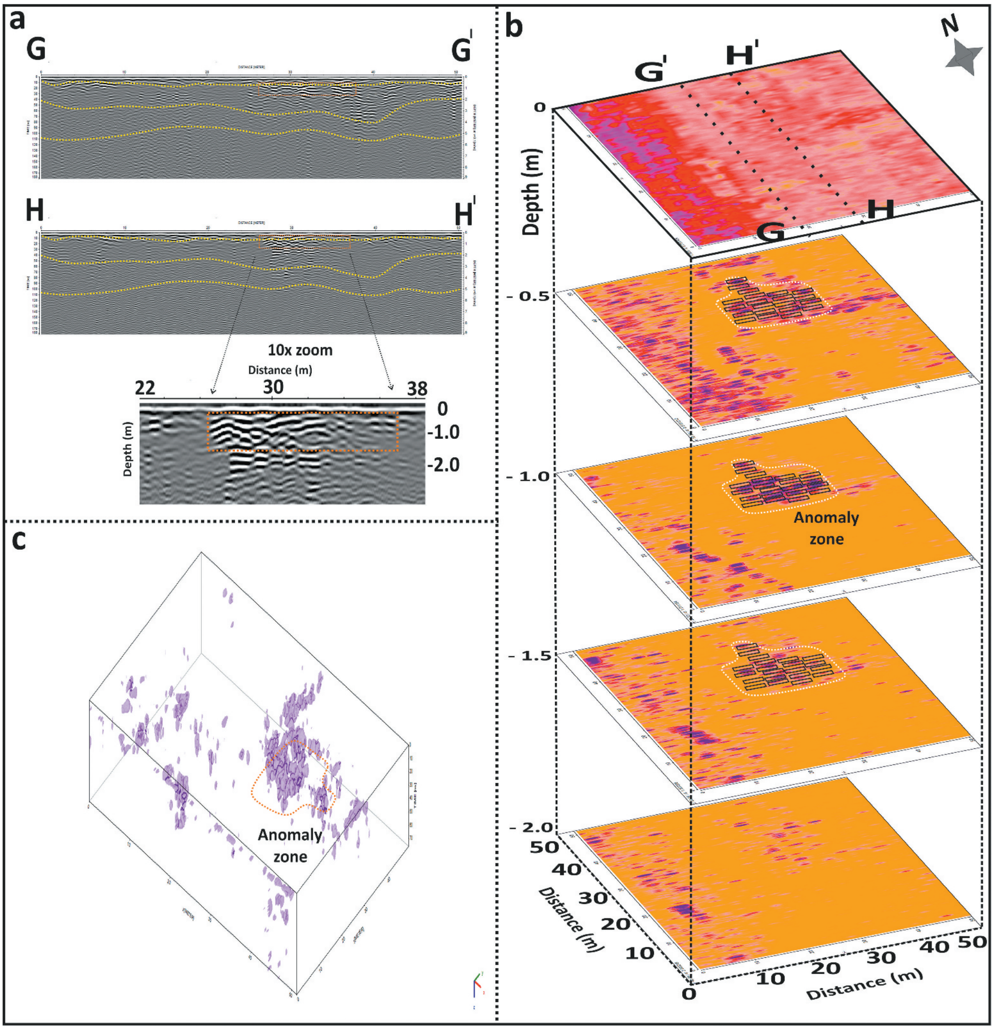


Figure 11. (a) GPR 2D sections in Area-4. Orange boxes indicate burial sites, yellow lines indicate geological strata boundaries. (b) 3D depth level maps and depth variations of anomalies. (c) 3D modelling of the iso-amplitude map.

sacred place in the religion of Islam, in the direction of the Qibla. The direction of Qibla is approximately to the southeast in the study area. For this reason, the body is buried in an east-west direction and its face is turned nearly south. This method of burial was not compromised, even during wartime. Therefore, a search for direction emerged first in GPR anomalies. On the other hand, in many measurements, it was observed that burial could not be made at a depth of more than 1 metre due to the necessity of war conditions. The second decisive evidence thus appears in tems of depth. Another case is that the soldiers who lost their lives in the war were buried with their uniforms. War materials such as metal parts in their uniforms, bullets etc. that hit their bodies also differ significantly from the insulating terrain properties around them. Sedimentation occurs by compression as new material comes is loaded above during the formation of soils. Therefore, the porosity and cavities in the ground decrease in a certain order. However, before the burial process performed during the war, when the body is placed and the ground closed, this area has a distinctly different porosity compared to its surroundings. Although the dead body is reduced to skeletal dimensions over time, the soil around it differs from the natural ground. Although the excavated soil is replaced after the dead body is placed in the grave, there is a slight trace of pitting on the surface of the excavation area. This is because the removed soil and material are not completely replaced or not replaced with the same orientation or compaction that was originally characterized[18]. In addition, the burial places are surrounded by stones, especially around the head and feet, in order to be visible on the surface. While it is usual to have stone surroundings in regular cemeteries, it is carried out with simpler and local stones for graves created during the war. However, over time, the stones on the surface can be buried or removed due to agricultural activities, etc., if the ground is made of soft soil. Some of these stones can be preserved if there are landowners who respect the martyrs. The presence of preserved or buried stones in GPR measurements significantly strengthens the findings of hyperbolas. During the evaluation of the GPR measurements carried out in the study area, attemps were made to observe all this evidence in the measurements. Anomalies of the graves begin from approximately 0.5 metres and the signs disappear at the level of 1.5 metres. Grave orientations are in accordance with Islamic traditions and when two-dimensional sections are examined, the place where the graves are located is encountered with a ground structure whose homogeneity is disturbed from the surface.

In the studies conducted in Polatlı and Haymana, the skeletal structure was relatively easier to distinguish, since the burial sites are generally located in sandy-pebbly-marly soils. Differentiation can be much more difficult due to the interaction that occurs over time in clay soils. In the study area, the burial areas could be clearly distinguished due to the mostly marly and clastic ground structure in Area-1. Since there were too many misleading rock fragments on the surface in Area-2 and Area-3, differentiation was quite difficult. However, the determination could be made especially since the burial depth of the martyrs was different from the depths of the rocks on the surface. Units close to the surface in Area-4 are composed of clastic rocks. For this reason, the excavation made for the graves and the distinctive rock fragments used around them provided a distinctive feature compared to the other areas.

Acknowledgements

We are grateful to the reviewers for useful critiques and valuable contributions. This research was carried out on behalf of the Ministry of Agriculture and Forestry, General Directorate of Nature Conservation National Parks, and necessary permissions were obtained for publication. We would like to thank to General Directorate of DKMP, and Directorate of Sakarya Field Battle Historical National Park for their support and assistance in all phases of the study. This study was supported financially by the Project unit of Süleyman Demirel University within the scope of the PhD Thesis (project no: FDK-2019-7316).

Disclosure statement

No potential conflict of interest was reported by the author(s).

References

1. Cannell RJS, Gustavsen L, Kristiansen M, Nau E. Delineating an unmarked graveyard by high-resolution GPR and pXRF prospection: the medieval church site of Furulund in Norway. J Comput Appl Archaeol. 2018;1(1):1–18. doi:10.5334/jcaa.9.
2. Doolittle JA, Bellantoni NF. The search for graves with ground-penetrating radar in Connecticut. J Archaeol Sci. 2010;37(5):941–949. doi:10.1016/j.jas.2009.11.027.
3. Pringle JK, Ruffell A, Jervis JR, Donnelly JD, McKinley J, Hansen JD, Morgan R, Pirrie D, Harrison M. The use of geoscience methods for terrestrial forensic searches. Earth Sci Rev. 2012;114:108–123. doi:10.1016/j.forsciint.2012.01.010.
4. Hansen JD, Pringle JK, Goodwin J. GPR and bulk ground resistivity surveys in graveyards: locating unmarked burials in contrasting soil types. Forensic Sci Int. 2014;237:e14–e29. doi:10.1016/j.forsciint.2014.01.009.
5. Aziz AS, Stewart RR, Green SL, Flores JB. Locating and characterizing burials using 3D ground-penetrating radar (GPR) and terrestrial laser scanning (TLS) at the historic Mueschke Cemetery, Houston Texas. J Archaeol Sci.: Rep. 8;2016:392–405.
6. Jones DM. Geophysical survey in archaeological field evaluations. Swindon (U.K): English Heritage Publishing; 2008.
7. Bevan BW. The search for graves. Geophysics. 1991;56(9):1310–1319. doi:10.1190/1.1443152.
8. France DL, Griffin TJ, Swanburg JG, Lindemann JW, Clark Davenport G, Trammell V, Armbrust CT, Kondratieff B, Nelson A, Castellano K. A multidisciplinary approach to the detection of clandestine graves. J Forensic Sci. 1992;37(6):1445–1458. doi:10.1520/JFS11337J.
9. Owsley DW, Compton BE. Preservation in late 19th Century iron coffin burials. In: Haglund WH, Sorg MH, editors Forensic taphonomy: the post-mortem fate of human remains. Boca Raton (Florida): CRC Press; 1997. p. 511–526.
10. Miller PS. Disturbances in the soil: finding buried bodies and other evidence using ground penetrating radar. J Forensic Sci. 1996;41(4):648–652. doi:10.1520/JFS13970J.
11. Nobes DC. The search for "Yvonne": a case example of the delineation of a grave using near-surface geophysical methods. J Forensic Sci. 2000;45(3):715–721. doi:10.1520/JFS14756J.
12. Davenport GC. Remote sensing applications in forensic investigations. Hist Archaeol. 2001;35 (1):87–100. doi:10.1007/BF03374530.
13. Dupras TL, Schultz JJ, Wheeler SM, Williams LJ. Forensic recovery of human remains; archaeological approaches. Boca Raton. Florida: CRC Press, Taylor and Francis Group; 2006.
14. Büyüksaraç A, Yalçıner CC, Ekinci YL, Demirci A, Yücel MA. Geophysical investigations at agadere cemetery, Gallipoli Peninsular, NW Turkey. Aust J Forensic Sci. 2014;46(1):111–123. doi:10.1080/00450618.2013.804948.
15. Fernandez-Alvarez J, Rubio-Melendi D, Castillo JAQ, Gozzalez-Quiros A, Cimadevilla-Fuente D. 2017. Combined GPR and ERT exploratory geophysical survey of the Medieval Village of Pancorbo Castle (Burgos, Spain). J Appl Geophys. 114:86–93. doi:10.1016/j.jappgeo.2017.07.002.
16. Gonzalez-Jarge H, Solla M, Sanchez M, Arias P. Comparison between laser scanning, single-image rectification and ground-penetrating radar Technologies in forensic science. Measurement. 2012;45(5):836–843. doi:10.1016/j.measurement.2012.02.013.
17. Parker R, Ruffell A, Hughes D, Pringle J. Geophysics and the search of freshwater bodies: a review. Sci Justice. 2010;50(3):141–149. doi:10.1016/j.scijus.2009.09.001.
18. Pm B, Wjm G. Multidisciplinary approaches to forensic archaeology: topics discussed during the European Meetings on Forensic Archaeology (EMFA). Berlin (Germany): Springer International Publishing; 2018. ISBN 978-3-319-94397-8.
19. Blau S, Ranson D, O'Donnell C. An atlas of skeletal trauma in medico-legal contexts. London: Academiz Press; 2018. 701.
20. J-p F-A, Rubio-Melendi D, Martinez-Velasco A, Pringle JK, Aguilera D. Discovery of a mass grave from the Spanish Civil War using GPR and forensic archaeology. Forensic Sci Int. 2016;267:e10–e17. doi:10.1016/j.forsciint.2016.05.040/0379-0738.

21. Molina CM, Pringle JK, Saumett M, Evans GT. Geophysical monitoring of simulated graves with resistivity, magnetic susceptibility, conductivity and GPR in Colombia, South America. Forensic Sci Int. 2016;261:106–115. doi:10.1016/j.forsciint.2016.02.009/0379-0738.
22. Widodo W, Aditama IF, Syaifullah K, Mahya M, Hidayat M. Detecting buried human bodies using ground-penetrating radar. Earth Sci Res. 2016;5(2):59–68. doi:10.5539/esr.v5n2p59.
23. Schultz J, Collins ME, Falsetti AB. Sequential monitoring of burials containing large pig cadavers using ground-penetrating radar. J Forensic Sci. 2016;51(3):607–616. doi:10.1111/j.1556-4029.2006.00129.x.
24. Solla M, Riveiro B, Alvarez MX, Arias P. Experimental forensic scenes for the characterization of ground-penetrating radar wave response. Forensic Sci Int. 2012;220(1–3):50–58. doi:10.1016/j.forsciint.2012.01.025.
25. Ruffell A, Pringle JK, Forbes S. Search protocols for hidden forensic object beneath floors and within walls. Forensic Sci Int. 2014;237:137–145. doi:10.1016/j.forsciint.2013.12.036.
26. Molina CM, Pringle JK, Saumett M, Hernandez O. Preliminary results of sequential monitoring of simulated clandestine graves in Colombia, South America, using ground penetrating radar and botany. Forensic Sci Int. 2015;248:61–70. doi:10.1016/j.forsciint.2014.12.011/0379-0738.
27. Schultz JJ, Walter BS, Healy C. 2016. Long-term sequential monitoring of controlled graves representing common burial scenarios with ground penetrating radar: years 2 and 3. J Appl Geophys. 132:60–74. doi:10.1016/j.jappgeo.2016.06.015.
28. Cavalcanti MM, Rocha MP, Blum MLB, Borges WR. 2018. The forensic geophysical controlled research site of the University of Brasilia: results from methods GPR and electrical resistivity tomography. Forensic Sci Int. 293:101.e1–101.e21. doi:10.1016/j.forsciint.2018.09.033.
29. Barone PM, Swanger KJ, Stanley-Price N, Thursfield A. 2016. Finding graves in a cemetery: preliminary forensic GPR investigations in the Non-Catholic Cemetery in Rome (Italy). Measurement. 80:53–57. doi:10.1016/j.measurement.2015.11.023.
30. Anonim, Türk İstiklal Harbi II. Cilt Batı Cephesi 5. Kısım, 2. Kitap. Sakarya Meydan Muharebesi ve Sonrasındaki olaylar (23 Ağustos 1921-10 Ekim 1921). Genelkurmay Başkanlığı Harp Tarihi Dairesi Başkanlığı. 1973.
31. Erdoğan S. Sakarya Türk Bitti Demeden Bitmez. Istanbul, Turkey: Kronik Yayınevi. 2020;336.
32. Baykoç H. İstiklal Savaşında Sakarya Meydan Muharebesi. 134 sayılı Askeri Mecmua'nın Tarih Kısmı. 1944;63.
33. Müderrisoğlu A. Sakarya. Deniz Kültür Yayınları.2007;887.
34. Sandmeier KJ. Reflexw 4.3 Software Manuel Book Sandmeier Software. Zipser Strasse 1, D-76227. Karlsruhe (Germany). 1998; 272.
35. Metje N, Atkins PR, Brennan MJ, Chapman DN, Lim HM, Machell J, Muggleton JM, Pennock S, Ratcliffe J, Redfern M, et al. Mapping the underworld – state-of-the-art review. J Tunnelling and Underground Space Technol. 2007;22(5–6):568–586. doi:10.1016/j.tust.2007.04.002.
36. Kenyon JL. 1977. Ground-penetrating radar and its historical application to a historical archaeological site. Hist Archaeol. 2:48–55. doi:10.1007/BF03374467.
37. Ellwood BB. Electrical resistivity surveys in two historical cemeteries in Northeast Texas: a method for delineating unidentified burial shafts. Hist Archaeol. 1990;24(3):91–98. doi:10.1007/BF03374139.
38. Mellett JS Location of human remains with ground penetrating radar, In: Hanninen P, Autio S (Eds), Fourth International Conference on Ground Penetrating Radar, June 8–13, 1992, Rovaniemi, Finland. Geological Survey of Finland. Special Paper. 1992; 16:359–365.
39. King JA, Bevan BW, Hurry RJ. The reliability of geophysical surveys at historic-period cemeteries: an example from the Plains Cemetery, Mechanicsville, Maryland. Hist Archaeol. 1993;27(3):4–16. doi:10.1007/BF03373565.
40. Calkin SF, Allen RP, Harriman MP. 1995. Buried in the basement: geophysics role in a forensic investigation, Proceedings, SAGEEP. Environ Eng Geophys Soc. 397–403.
41. Nobes DC. 1999. Geophysical surveys of burial sites: a case study of the Oaro Urupa. Geophysics. 62:357–367. doi:10.1190/1.1444540.

42. Davis JL, Heginbottom JA, Annan AP, Daniels RS, Berdal BP, Bergan T, Duncan KE, Lewin PK, Oxford JS, Roberts N, et al. Ground penetrating radar surveys to locate 1918 Spanish flu victims in permafrost. J Forensic Sci. 2000;45(1):68–76. doi:10.1520/JFS14642j.
43. Hammon WS, McMechan GA, Zeng X. Forensic GPR: finite-difference simulations of responses from buried human remains. J Appl Geophys. 2000;45(3):171–186. doi:10.1016/s0926-9851(00)00027-6.
44. Powell K. Detecting buried human remains using near-surface geophysical instruments. Explor Geophys. 2004;35(1):88–92. doi:10.1071/E604088.
45. Watters M, Hunter JR. Geophysics and burials: field experience and software development. In: Pye K, Croft DJ, editors Forensic geoscience: principles, techniques, and applications. Special Publications. Geological Society of London. 2004; 232: 21–31. doi:10.1144/GSL.SP.2004.232.01.04.
46. Ruffell A. Searching for IRA "disappeared": ground-penetrating radar investigation of a churchyard burial site, Northern Ireland. J Forensic Sci. 2005;50(6):1430–1435. doi:10.1520/JFS2004156.
47. Conysers LB. Ground-penetrating radar techniques to discover and map historic graves. Hist Archaeol. 2006;40(3):63–74.
48. Stanger R, Roe D. Geophysical surveys at the West End Cemetery, Townsville: an application of three techniques. Aust Archaeol. 2007;65(1):44–50. doi:10.1080/03122417.2007.11681858.
49. Schultz JJ. Sequential monitoring of burials containing small pig cadavers using ground penetrating radar. J Forensic Sci. 2008;53(2):279–287. doi:10.1111/j.1556-4029.2008.00665.x.
50. Fiedler S, Illich B, Berger J, Graw M. The effectiveness of ground-penetrating radar surveys in the location of unmarked burial sites in modern cemeteries. J Appl Geophys. 2009;68(3):380–385. doi:10.1016/j.jappgeo.2009.03.003.
51. Billinger MS. A technoethical approach to the race problem anthropology. Handb Res Technoethics. 2009;44–68. doi:10.4018/978-1-60566-022-6.ch004
52. Ruffell A, McCabe A, Donnelly C. Location and assessment of an historic (150–160 Years Old) mass grave using geographic and ground penetrating radar investigation, NW Ireland. J Forensic Sci. 2009;54(2):e11–e16. doi:10.1111/j.1556-4029.2008.00978.x.
53. Dionne CA, Wardlaw DK, Schultz JJ. 2010. Delineation and resolution of cemetery graves using a conductivity meter and ground-penetrating radar. Tech Brief Hist Archaeol. 20–30.
54. Novo A, Lorenzo H, Rial FI, Solla M. 3D GPR in forensics: finding a clandestine grave in a mountainous environment. Forensic Sci Int. 2011;204(1–3):134–138. doi:10.1016/j.forsciint.2010.05.019d.
55. Damiata BN, Steinberg JM, Bolender DJ, Zoëga G. Imaging skeletal remains with ground-penetrating radar: comparative results over two graves from Viking Age and Medieval churchyards on the Stóra-Seyla farm, northern Iceland. J Archaeol Sci. 2013;40(1):268–278. doi:10.1016/j.jas.2012.06.031.
56. Dick HC, Pringle JK, Sloane B, Carver J, Wisniewski KD, Haffenden A, Porter S, Roberts D, Cassidy NJ. Detection and characterisation of Black Death burials by multi-proxy geophysical methods. J Archaeol Sci. 2015;59:132–141. doi:10.1016/j.jas.2015.04.010-0305-4403.
57. Fernandez G, Teixido T, Pena JA, Burillo F, Claros J. Using shallow geophysical methods to characterise the monumental building at the Segeda I site (Spain). J Archaeol Sci.: Rep. 2015;2:427–436. doi:10.1016/j.jasrep.2015.04.006-2352-409X.
58. Salsarola D, Poppa P, Amadasi A, Mazzarelli D, Gibelli D, Zanotti E, Porta D, Cattaneo C. The utility of ground-penetrating radar and its time-dependence in the discovery of clandestine burials. Forensic Sci Int. 2015;25(3):119–124. doi:10.1016/j.forsciint.2015.06.006-0379-0738.
59. Leucci G, De Giorgi L, DiGiacomo G, Ditaranto I, Miccoli I, Scardozzi G. 3D GPR survey for the archaeological characterization of the ancient Messapian necropolis in Lecce, South Italy. J Archaeol Sci Rep. 2016;7:290–302. doi:10.1016/j.jasrep.2016.05.027.
60. Ribolini A, Bini M, Isola I, Coschino F, Baroni C, Salvatore MC, Zanchetta G, Fornaciari A. GPR versus Geoarchaeological findings in a Complex Archaeological Site (Badia Pozzeveri, Italy). Archaeol Prospect. 2017;24(2):141–156. doi:10.1002/arp.1561.

61. Turner JR, Stine RS, Stine LF. A comparison of ground-penetrating radar, magnetic gradiometer and electromagnetic induction survey techniques at House in the Horseshoe State Historic Site. J Archaeol Sci.: Rep. 2018;20:33–46. doi:10.1016/j.jasrep.2018.04.005.
62. Schultz JJ, Martin MM. Controlled GPR grave research: comparison of reflection profiles between 500- and 250-MHz antennae. Forensic Sci Int. 2011;209(1–3):64–69. doi:10.1016/j.forsciint.2010.12.012.
63. Wu Z, Xia T, Nie J, Cui F. The shallow strata structure and soil water content in a coal mining subsidence area detected by GPR and borehole data. Environ Earth Sci. 2020;79(22):500–508. doi:10.1007/s12665-020-09178-x.