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Research Article

New historical findings discovery at inner areas of Akçakale Castle (Trabzon, Turkey) with GPR Method

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ABSTRACT

Ground-Penetrating Radar (GPR) can successfully image the buried archaeological findings depending on changes in the electromagnetic features of the researched materials. The GPR survey in the Akçakale (Kordyle) castle built in the 13th century was presented in this study. The castle is located at Akçakale district of Trabzon province on the Eastern Black Sea Coast of Turkey. The key focus of this research is to investigate whether there are archaeological findings in the inner area of the castle with GPR. For this purpose, GPR data were collected by using 250 and 500 MHz antennas at 95 transects within grid lengths ranging 30-50m in the study area. Anomalies considered to be important by evaluating the filtered data were marked on a sketch where the measurement lines are located. On this sketch, the overlapping areas of the anomalies obtained from the data in different directions on the measurement lines were shown by ellipses with red-cut as priority possible anomaly areas. Possible archaeological structures were been successfully determined from 2D and 3D images obtained GPR data in the study area. As a result, it has been suggested that archaeological excavations which will be planned in the study area should be conducted by considering these areas. After the excavations, archaeological findings which are compatible with anomalies were found in the studied area. Thus, it was seen that successful results were obtained with the GPR method in the study area.

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INTRODUCTION

Geophysical methods are widely used to reveal by displaying the artifacts in the buried state in archaeological sites. The locations and depths of the buried archaeological findings can be determined with the interpretation of the subsurface sections obtained by the processing and evaluating of the geophysical data taken from the study area. Thus, by using non-destructive geophysical methods in archaeological sites, investigation of artifact, that

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cannot be observed from the surface or whose location is unknown with preliminary information, provides significant gains in terms of time, cost, and work power to the archaeological team during excavation. In addition, the findings discovered in planned archaeological excavations made by the proposal of the geophysical study results are surfaced more sensitively and consciously by preserving the original conditions. There are many geophysical studies conducted in order to assist archaeologists during the planning of excavations in archaeological sites in the literature [1-21] In the 400 years old Sendai Castle in Japan, a geophysical study was carried out aiming to determine the old stone walls under the castle by applying ground penetrating radar method during archaeological excavations [22]. An example of ground penetrating radar measurements were applied in Geophysical studies carried out in Akalan Castle in Samsun Province of Turkey [23]. An archaeological study conducted by Bavusi et al. [24] is about a geophysical survey in the vicinity of King Carlo V in the Calabria Region of Italy. The results of this study, applied magnetics, ground penetrating radar and electrical resistivity tomography methods; pointed out some of the remains associated with the buried military walkway. In 2010 Barker et al. [25] conducted a geophysical study at Bodiam Hill in East Sussex, located between Hawkhurst and Hastings in the United Kingdom. In an archaeological geophysical study in the medieval times in Northern Marsican, distribution of high-amplitude scattered electromagnetic (EM) energy fields showing orthogonal regular models which are archeologically compatible with the buried stone walls have been determined [26].

Akçakale (Kordyle) Castle which has a historical background is located at Akçakale district of Trabzon province on the Eastern Black Sea Coast of Turkey (Figure 1a and b). The studied area (Figure 1c) is the inner part of the castle which was built in the 13th century. The castle, one of the greatest of the Trabzon Kingdom's monuments, is surrounded by thick rectangular walls with trapezoidal shapes (Figure 1d). There is also a large rectangular tower on the north-west wall of the castle. This tower is a typical example of Late Byzantine style [27].

Although the castle walls and bastions are in ruins, the castle is protected from external influences and by force of its high walls. Despite the collapse of much of the castle walls, which continued the military base function until the beginning of the 20th century, it has been continued to protect its building structure. It has been known that there are some remains (grave, cannonball, wall, etc.) in the inner area of the castle, which has been used for various purposes since its construction. Therefore, excavation works have been planned in the castle before restoration. No geophysical work had been done before on the site. The key focus

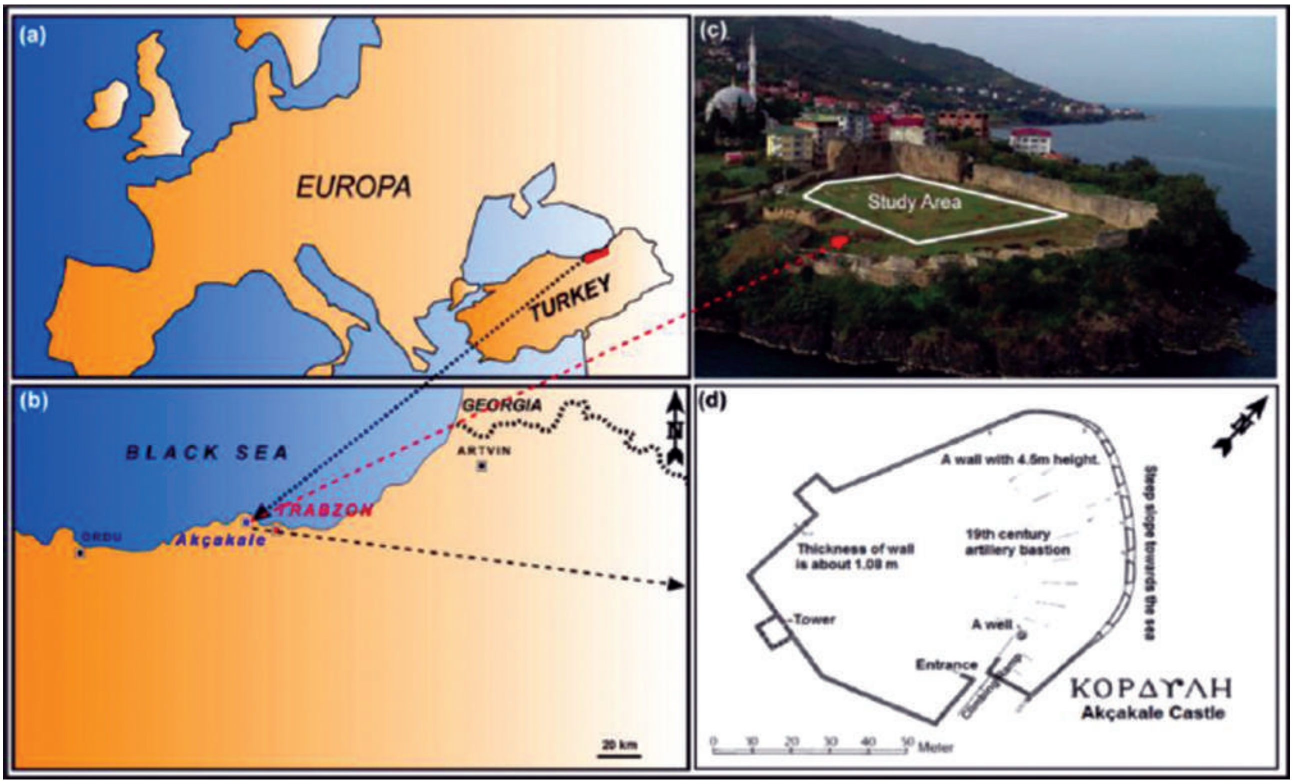

Figure 1. (a, b) Location maps, **(c)** aerial photo of study area and **(d)** an old structural plan of Akçakale (Kordyle) Castle [27].

of this research was to determine the location, depth and extent of possible findings to guide these excavations in the inner part of the castle for restoration. Ground penetrating radar (GPR), one of the non-destructive geophysical techniques, was applied in the study. We proposed that archaeological excavations planned in the study area should be performed by considering areas with high amplitude reflections (anomalies) on GPR sections. Archaeological findings which are compatible with these reflections were revealed in the site after the excavations.

HISTORICAL BACKGROUND OF AKÇAKALE (KORDYLE) CASTLE

Akçakale (Kordyle) historic castle located at the Akçakale town of Trabzon province was built on the seaside cliffs. Akçakale is located 25km west of the province of Trabzon. According to historical records, the castle was constructed between the years 1297 and 1330. The castle was built by II.Alexios made principality in Trabzon for being preserved from Seljuk Empire. After the conquest of Trabzon in 1461 years, the castle has been defended by residents for seven more years, and then the castle had been seized by Mahmut Pasha to be one of the Fatih Sultan Mehmet's commanders who was an Ottoman Sultan. Mahmut Pasha died in the siege was buried in the castle. The castle underwent repairs in the Ottoman era and expanded with some new additions, which was preserved as an important feature of being military bases until the beginning of the XIX. century. Although many sections of the castle collapsed, the castle was built of stone rubble and cut stone, still has not diverged much from its original appearance [28] (Figure 2a). The altitude above sea level of the castle is about 20m. The castle wall on the seaside is protected by the natural cliff. But the walls on the land do not have the same degree of protection (Figure 2b). Kordyle (Akçakale), one of the greatest of the castles of the Trabzon Kingdom, has a trapezoidal shape [27].

The southwest wall of the castle extending from the sea to the bastion has a height 9-10m and part of the northwest wall is also between 4 and 5m in heights. The other part of the castle was able to reach the present at a maximum height of 3m. The face wall is made up of small rectangular blocks arranged in regular rows. The wall thickness of the castle is 1.08m on the northwest side and 1.25m on the other parts. There is a large rectangular tower on the northwest wall. The tower is typical of the late Byzantine style. The cornerstones, which are cobbled in a long and short systematic way, consist of the processed blocks. The existing wooden reinforcement beams on the wall reflecting the 19th century workmanship have not yet decayed. The bastion of the castle protrudes from the southwest wall. A rectangular tower with a height of 10m is embedded in the central main wall of the castle. As far as the girder holes which were left for the cross beams were concerned, there were four floors in the tower. The only gate of the castle on the floor level has round arches and 1.70m in width. There is a window with a round arch and a width of about 2.0m on the inside of the castle. The windows at the outer side are also on the ground floor level. The outer sides windows on the upper floors are narrow rectangular. Two similar ones are found in the southwest wall of the middle floor and one in the northwest and southeastern walls. There are individual windows on three exterior sides of the top floor. It is understood that the wall elements on the inner walls are filled with cement. Stone workmanship in this section, it is similar to the lower parts of the city walls of Trabzon built by II. Alexios (1297-1330).

METHOD, DATA ACQUISITION AND PROCESSING

Ground penetrating radar is one of the shallow geophysical methods which have got approval because images of the underground geometries can be given with high resolution [29], [30], [31]. The method has a reputation as one of the more complex archaeological geophysical methods because it involves the collection of large amounts of reflection data from numerous transects with grids, often producing massive three-dimensional databases [32]. The data of GPR are generally acquired throughout nearly spaced transects within a grid, each of which comprises many

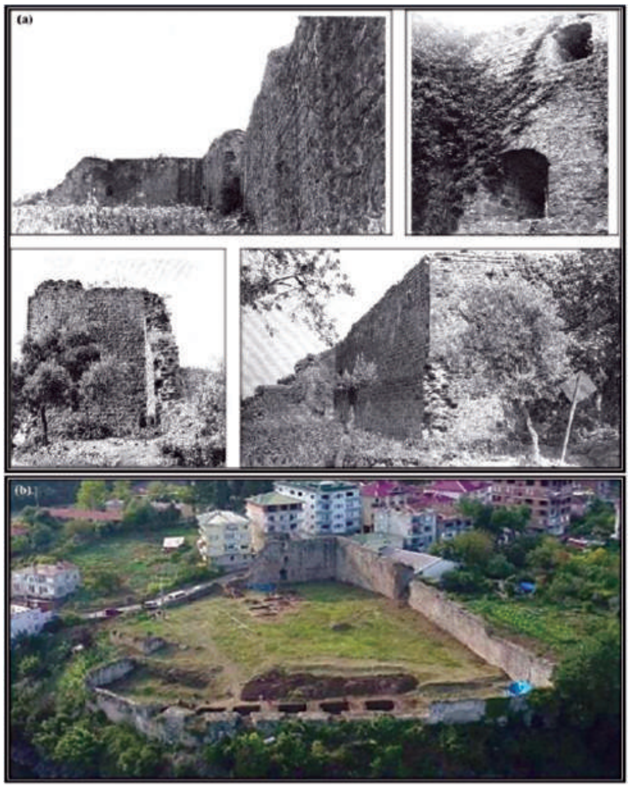

Figure 2. (a) The old and **(b)** new photographs of the Akçakale (Kordyle) Castle. Old photographs were modified by Köse [27].

thousands of radio waves that have been reflected from interfaces in the underground. An antenna radiates electromagnetic (radio) waves with high frequency the underground in the method. When the waves are transmitted, a certain number of energy is reflected from buried objects (archaeological findings or remains) or from the interface among soil and sediments whilst the rest of that energy is transmitted the underground. The reflected EM waves are taken back at the surface and recorded as wave amplitude and two-travel time (ns) [32]. The reflections and amplitudes of waves gain significance in relation to the contrasts in the dielectric properties of the underground structures [30]. When the antennas are carried through the surface, reflected signals are recorded about every 2 to 10 cm through transects, utilizing a variety of gathering technics. The form of the reflected waves that are taken from in the underground is digitized into a reflection trace, which is a series of waves reflected back to one surface location. When many traces are associated behind each other, a 2-dimensional vertical section (radargram) is generated through the transect which the antenna was carried. The reflection traces on many profiles in a grid can then be analyzed to generate both two-and three-dimensional images of what lies beneath the surface. Researchers using various imaging techniques (time/amplitude slices-map) have made successful interpretations [33],[34]. A block diagram depicting the main components of a Ground Penetrating Radar is given in Figure 3.

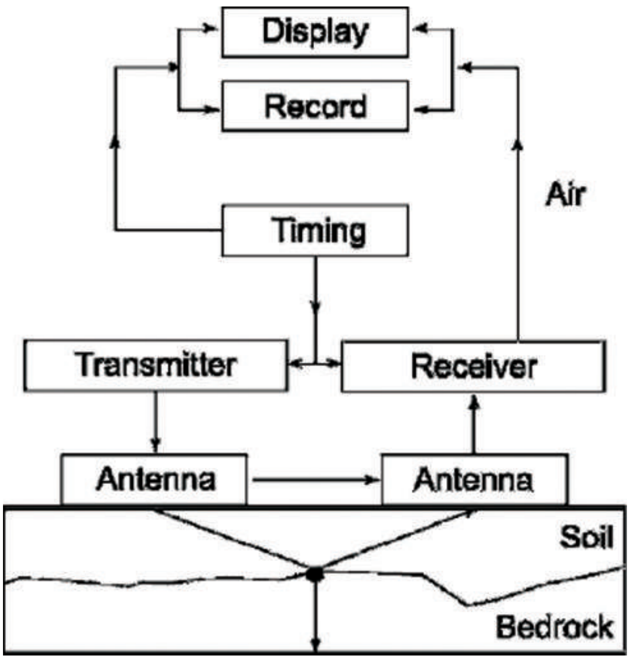

Figure 3. Block diagram depicting main components of Ground Penetrating radar [35].

The studied area was 50x45m^2 in size and gridded with 1m intervals in the inner area of Akçakale (Kordyle) castle on Figure 4a. The positions of the measurement lines drawn in this figure were arranged on a scale. GPR measurement lines on the aerial photo of study area were shown in Figure 4b.GPR data were collected by using the GPR technique with common offset mode to determine whether there are any archaeological findings within the area without any drilling/excavation/ trenching. A total of 190 profiles of GPR measurements by using Mala GPR Proex system were taken using both 250 MHz and 500 MHz frequency shielded antennas separately on 45 lines in the south-north direction and 50 lines in the east-west direction. The measurement lines are named GK_1-GK_45 for north-south and DB_1-DB_50 for east-west directions. These antennas

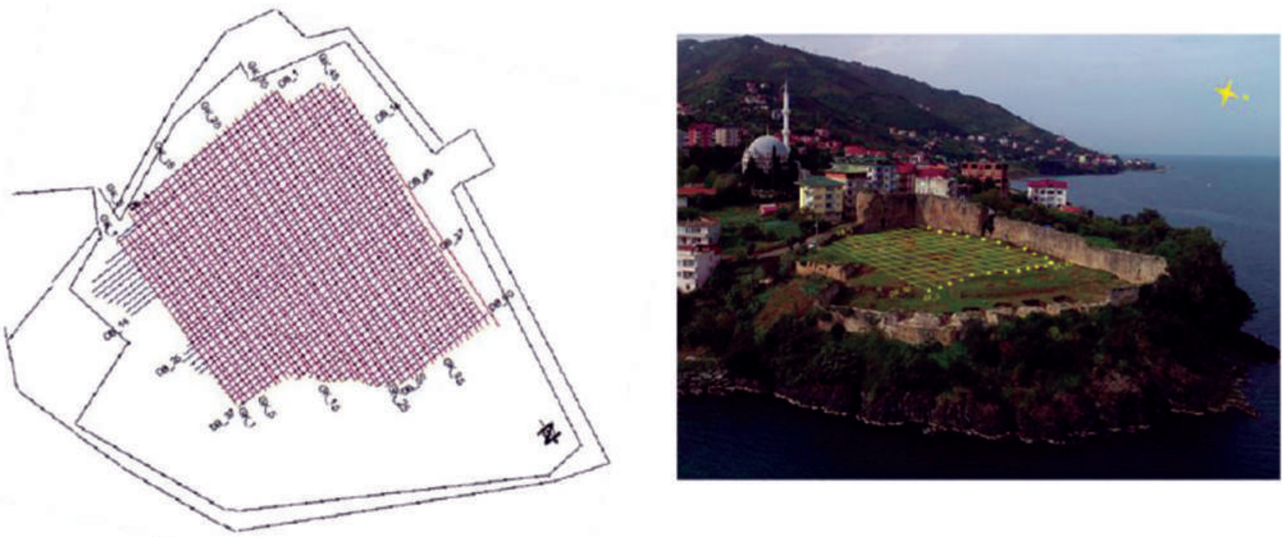

Figure 4. (a) Sketch of GPR measurements lines on the study area **(b)** GPR measurements lines on the aerial photo of study area.

were preferred to identify possible findings of different sizes and depths from deep to shallow right in the archaeological fields. The parameters of GPR measurement were given in Table 1.

Observing anomalies in underground structures from raw GPR data is not possible or difficult work. Hence, data must pass through some data processing technics until it becomes interpretable. The processing flow applied to the gathered GPR data encompasses: dewow, amplitude recovery (Gain), and background removal. Details of these data processing steps can be found in the Ground Penetrating Radar Principles book [22]. Overview of ground penetrating radar (GPR) data processing flow is depicted in Figure 5.

Since EM wave velocity is used in depth conversion, it is very important for determining the velocity of EM waves in archaeological applications. While details of velocity estimation techniques for common Offset GPR data can be found Forte et al [36]. Since this study area consists of basalts, the EM wave velocity used in-depth conversion is taken as 0.09 mns^{-1}. This velocity corresponds approximately to the EM wave velocity of basalt.

Processed GPR data which belong to the studied area need to be displayed in 2 and 3 dimensions (2D/3D) for

Table 1. Measurement parameters for each antenna in the GPR survey

Antenna frequency MHz	*Sampling Frequency Hz*	*Time window ns*	*Trace interval m*
250	2137.3	239.9	0.05
500	5078.6	98.5	0.05

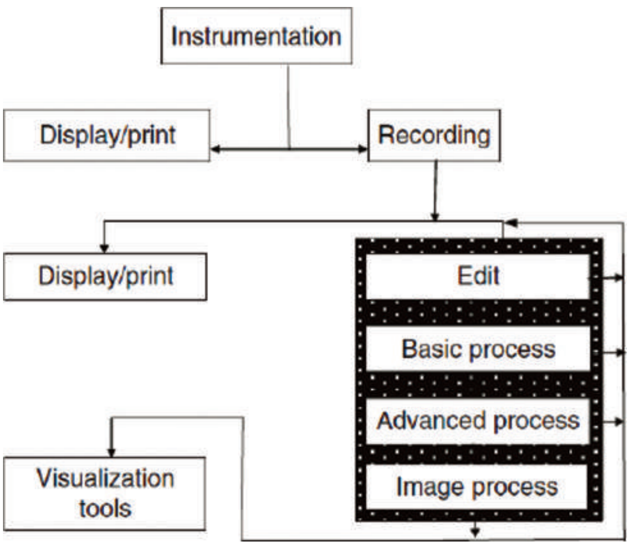

Figure 5. Overview of ground penetrating radar (GPR) data processing flow [35].

evaluation and interpretation. In this study, after applying to the data processing steps include the ReflexW software [37], radargrams and time slice maps were generated and interpreted in the way of archaeological structures (grave, wall, etc..).

RESULTS

GPR measurements were acquired and processed for the whole of the castle interior area. Radargrams corresponding to the parts planned as the priority excavation area were evaluated in this paper. Two sample radargrams in EW and NS directions (DB_9 and GK_13, respectively) created after the basic processing steps mentioned before were demonstrated in Figure 6 (a, b) with the main anomalies marked with a yellow dashed line. We have focused on the diffraction reflections with clear and large-sized that provide continuity between measurement lines on the radargrams obtained from studied lines. The reflections were interpreted taking into consideration the amplitude and shape of the ones that are continuous according to the measurement lines. It has been generally observed a cover soil layer between about 0.50 m and 1m in depth on the GPR sections.

When all 2-dimensional sections collected from the castle interior area were evaluated, the anomalies with high amplitude were observed at the beginning of lines DB_1-DB_4 and GK_5-GK_9 corresponding to in the southeastern corner of the castle. Also, the diffracted reflections with high amplitude, remarkable, and continuity in the lateral direction were determined in radargrams obtained from the area between GK_10-GK_35 and DB_5-DB_25 lines in the central and southern part of the castle. The locations and shapes of the reflections were interpreted and tried to indicate marks of the possible archaeological findings. Significant reflections (possible objects), observed between 1-4 m at DB_1 line, 0-4 m at DB_2, 3-6 m at DB_3, and 0-4.5 m at DB_4 on the radargrams obtained in an east-west direction with 500 MHz frequency antenna with different line starts, tend to the north as going to this direction. Besides, when it goes from the starting point to the west at the first three lines in this area, some anomalies have been observed. They are similar to each other at distances of 11-13 m on DB_1, 12.5-17 m on DB_2 and 21-23.5 m on DB_3. It has been interpreted that some objects, natural or made by people (archaeological findings), cause these anomalies. These reflections which are similar signs of these objects were observed in all radargrams in this direction in the investigation area. The reason that these reflections are seen at different locations in the radargrams comes from the fact that the line starts are different. In the radargrams obtained from GPR data collected by the 500 MHz antenna from south to north direction, some district reflections (probable objects) observed between 8-13 m on the GK_1 line, 7-13 m on GK_2, 9-13 m

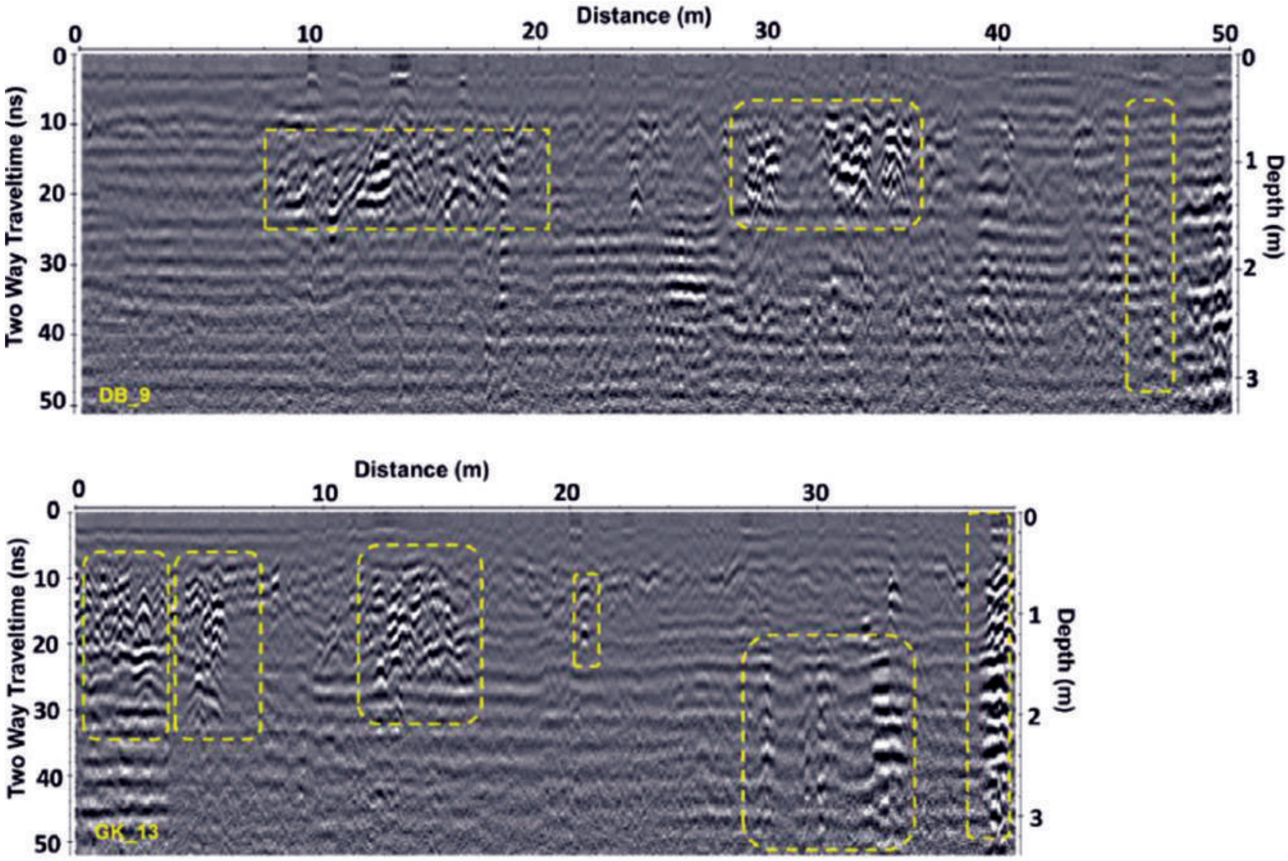

Figure 6. (a) Sample radargram on profile named as DB_9 taken with 500 MHz antenna at EW directions **(b)** Sample radargram on profile named as GK_13 taken with 500 MHz antenna directions at NS directions.

on GK_3, and between 0.75-2.5 m depths show continuity as moving northward.

The continuities in the lateral and vertical direction of diffracted reflections with high amplitude can be determined in time slice/amplitude maps obtained from 3D GPR images. To define the continuity of the reflections, time-slice maps were created for the interesting parts of the study area. The anomaly 1 is between 0-3 m distances and 1-2.5 m depths on DB_15-DB_17 lines from the maps given in Figure 7. The 2nd anomaly, at 43-45 m distances on DB_15-DB_19 lines, extends from 1.5 to 3 m depths on the same map. The 3rd anomaly defined on DB_21-DB_22 lines starts at distances of 3-18m and depth of 1.35 m and goes up to 3m depth on the time-slice map (Figure 7). Significant anomalies are shown as different dashed circles in Figure 7.

The 4th anomaly, described between GK_5-GK_20 lines from the maps given in Figure 8, extends to 12m at a distance on the first line and up to 3 m at the last line by narrowing the westward. The anomaly was observed as a zone and extends from 0.85 m depth to 2m at these lines. The 5th anomaly which is defined between GK_9-GK_20 lines is at distances of 12-16m on the first line on the same maps. The anomaly extends from 0.85 m depth to 1.5m depths, narrows the westward and terminates at the 12th meter of the GK_20 line (Figure 8). The 6th anomaly defined in this map was observed between 8 and 10m distances and 1.5 and 3.5 m depths on GK_14-GK_15 lines. The 7th anomaly defined between GK_7-GK_13 lines was observed to have an approximately linear structure extending from 22 to 32 m on the GK_13 line and then towards to GK_7 line between 32 and 38 m distances and the depth of this structure varies between 1.4 and 2.5 m (Figure 8). In this figure, significant anomalies are shown as dashed rectangles.

The 8th anomaly, defined at 0-15 m distances between GK_21-GK_35 lines from the maps given in Figure 9, was observed between 0.75 and 1.30 m depths as a distinct region. A linear structure extending a long distance of 22-34 m between GK_28-GK_30 lines was observed. This structure turns eastward and goes up to the GK_22 line. It is heading north again from this point and ends at 43 m of the GK_22 line. Since anomalies numbered 9, 10 and 11 are outside the preliminary excavation area, they were not addressed here The 12th anomaly, defined between DB_19 and DB_22 lines from the maps given in Figure 7, expresses

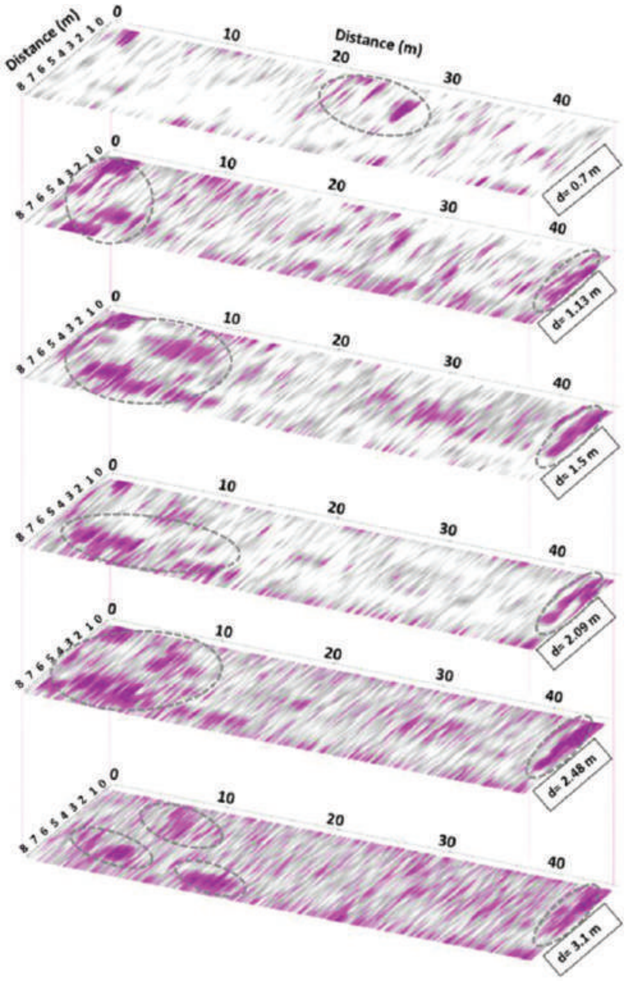

Figure 7. Slice maps generated at different depths from DB_15-DB_23 profiles collected with 500 MHz antenna ("d" indicates the depth).

a Y-shaped structure that goes towards to west between 27 and 38 m distances and lies between 1.70-2.16 m depths. In the same maps, the 13th anomaly, defined between 38 and 42 m distances on the DB_16-DB_18 lines, extends between 2.0 and 4.5 m depths. Remarkable anomalies significant are shown as dashed rectangles in Figure 9.

The 14th anomaly defined between the lines DB_22-DB_23 is located at distances of 0-6 m from the beginning of the profile and 2.80-6.0 m in depths (Figure 7). Since anomalies numbered 15 and 16 are outside the preliminary excavation area, they were not addressed here. The 17th anomaly is similar to the 4th anomaly and is located in the same area. In the area between GK_27-GK_30 lines from the maps in Figure 9, the 18th anomaly is defined as a part extending from 2 to 40m distances at the beginning of the line and between 1.5 and 6.0 m depths. The area, at distances of 12-18 m and depths of 4.3-6.0 m on DB_19 and DB_20 lines from the maps given in Figure 7, was named as the 19th anomaly.

In Figure 10, there are maps obtained from 250 and 500 MHz antennas along the same path. The depth of maps taken in the south-north direction is 1.5 m. When interpreted these maps, it has been identified that some reflections have different shapes/sizes from parts of the reflections with high amplitude on slice maps with 250 MHz and 500 MHz antennas. It has been thought that these reflections originate from ceramic pieces and collapsed Stones (rubble/debris and freestone) remaining underground due to several reasons (Figure 8).

We tried to draw a layout plan of possible archaeological findings by examining the depths and lateral extensions of these reflections observed in these maps. Some parts, determined by taking into account the extent and depths of the high-amplitude anomalies observed on 2D

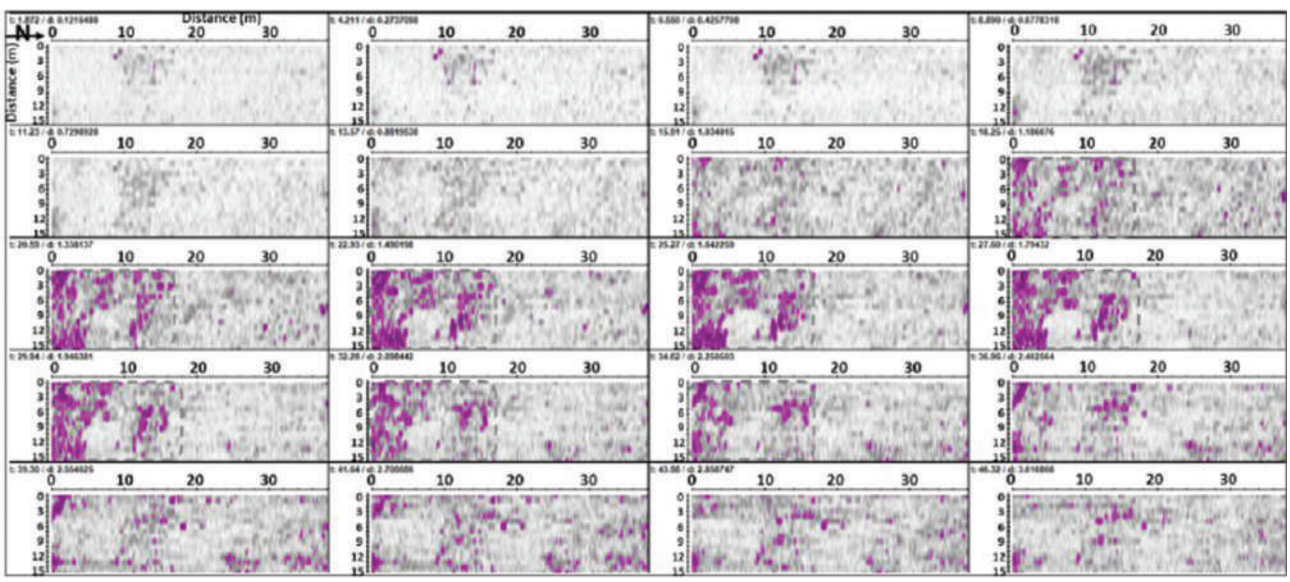

Figure 8. Time-depth-slice maps for GK_5-GK_20 profiles collected with 250 MHz antenna ("d" indicates the depth).

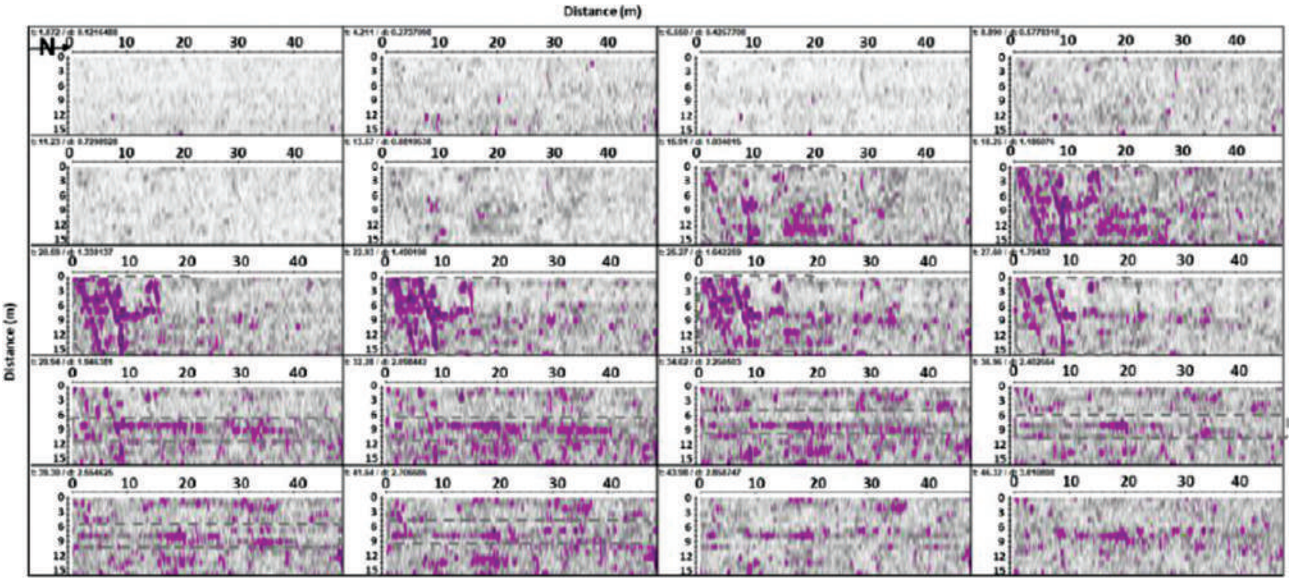

Figure 9. Time-depth-slice maps for GK_21-GK_35 profiles collected with 500 MHz antenna ("d" indicates the depth).

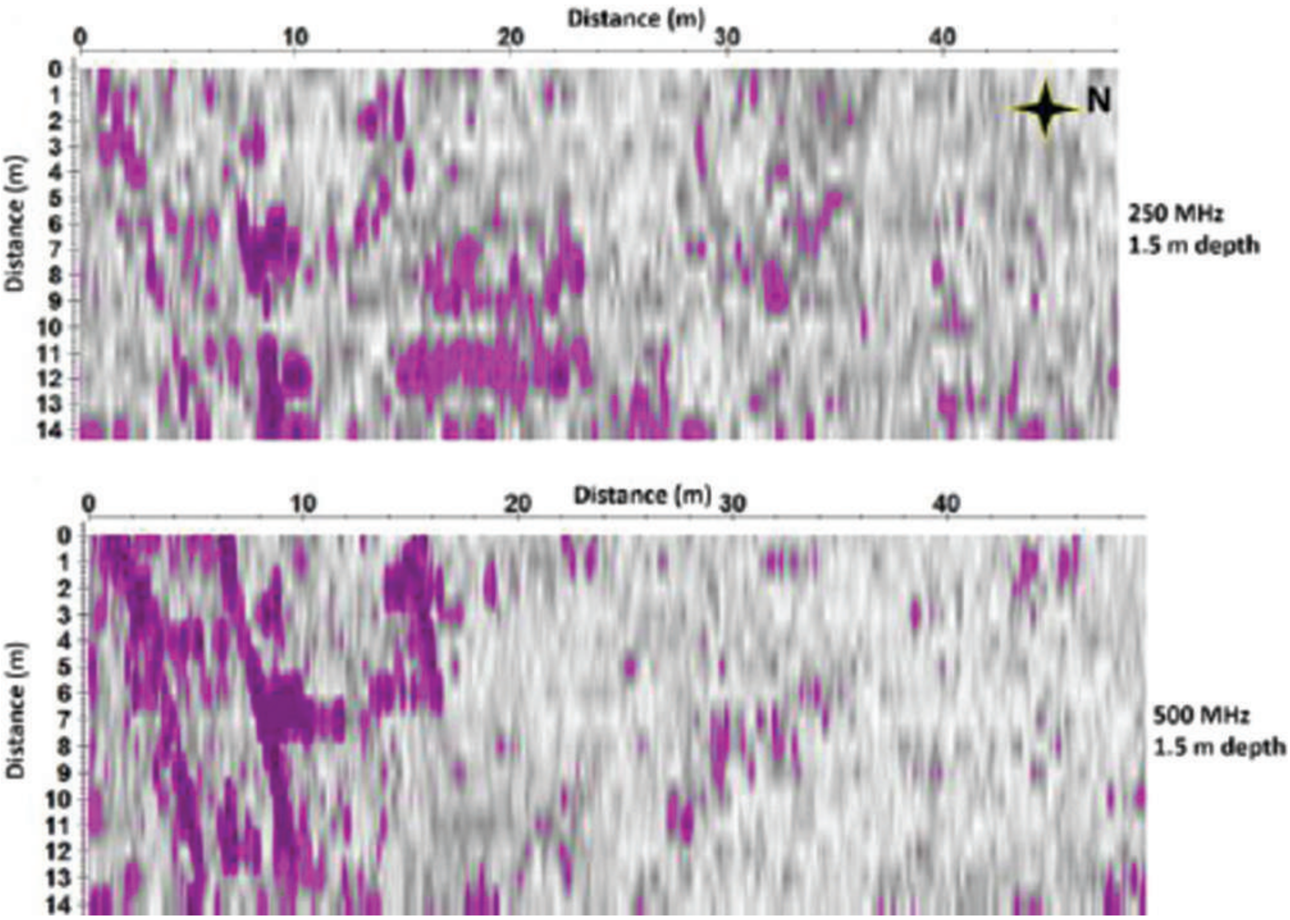

Figure 10. Two slice maps at 1.5 m depth from GK_21-35 profiles collected with 250 MHz and 500 MHz antenna.

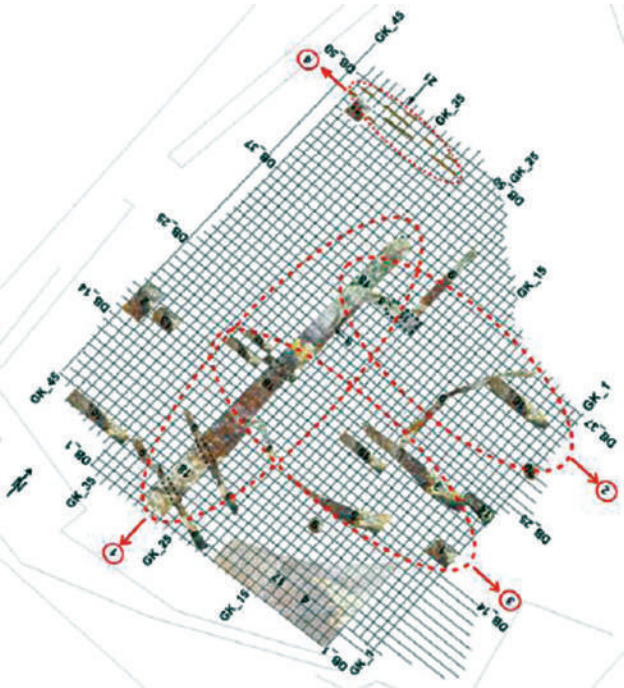

Figure 11. Distinct anomaly zones obtained from 2D/3D GPR images on the sketch.

and 3D images obtained from all GPR data, are shown as anomalies numbered from 1 to 21 on the plan of the study area (Figure 11). As described in detail above, 2D and 3D images obtained from all processed GPR data were evaluated in this study. The extent and depths of the distinct anomalies with high amplitude observed in these images were taken into consideration. The diffracted reflections observed in the slice maps and radargrams obtained with the 250 MHz antenna reveal the dimensions of the structures in general terms. The boundaries of the structures were determined more clearly in the radar images obtained at 500 MHz antenna. Thus, the identified parts were drawn anomalies named from 1 to 21 numbers on the plan of the studied area (Figure 11). Initial excavation work was carried out in the near south part of the castle interior area and in the southeast corner of the castle [38], [39]. Results of initial excavation and GPR images were together given in Figure 12. The anomalies interpreted to be wall findings in GPR maps created for depths of about 0.6-1.15 m are consistent with the excavation results in the southern part of the castle interior area. The scattered reflections, observed on the DB_3 GPR line through on the southeastern corner of the castle were also the sign of the structural findings that generated the results of the excavation. These reflections are shown about 2-7 m of the radargrams (named as DB_3).

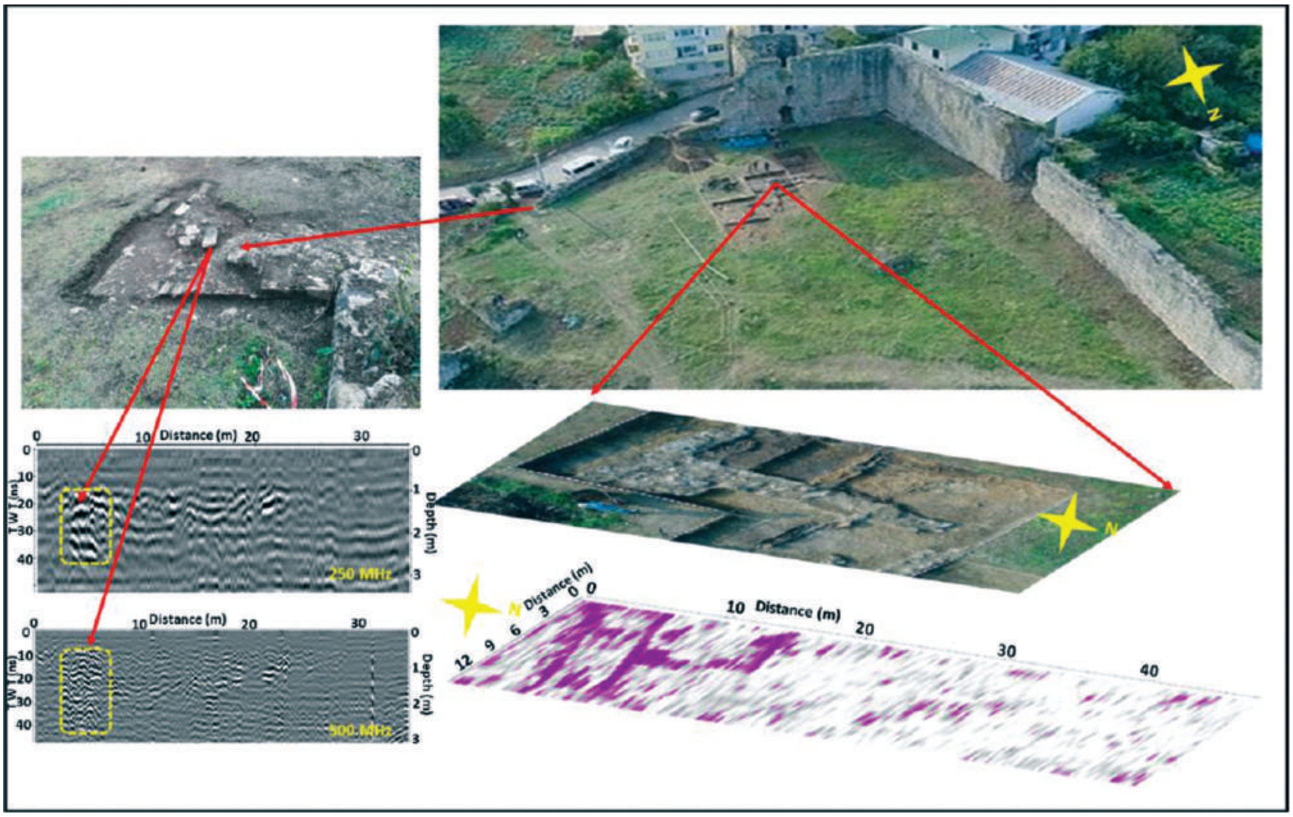

Figure 12. Joint presentations of GPR and excavation results.

CONCLUSIONS

The location, depth, and extent of possible archaeological findings that have not been observed from the surface in the castle interior area have been researched by the GPR method in Akçakale (Kordyle), which is located in the province of Akçaabat, Trabzon city on the northeast of Turkey. All evaluated GPR data on the initial excavation area were interpreted and the anomalies deemed important were marked on the sketch. On this sketch, areas of concentration of the anomalies obtained from the collected data in different directions are indicated ellipses with red-cut (1), (2), (3), and (4) according to the priority order. When we look at the possible finding anomalies on joint presentations of GPR and excavation results, it is thought that small anomalies originate in any archaeological structure like cannonballs, graves, ceramic pieces, and also, large anomalies originate in underground parts such as wall or cavity in the castle. Precise information will be obtained about anomaly sources observed from the materials obtained after the full excavation. Initial excavation work was conducted in the near south part of the Akçakale (Kordyle) castle interior area and in the southeast corner of the castle. Results of the excavation and GPR images were together given in the study field. The first part of the excavation work has been completed and the excavations will continue according to the budget and seasonal conditions. As can be seen from the excavations carried out, it is thought that especially the parts close to the surface are related to archaeological remains (wall ruins, fragment blocks, ceramic fragments). However, the deep structures are more likely to be related to the geological structure. The GPR results should be taken into consideration in the next excavation works that will be carried out in unexcavated parts of the castle interior area.

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AUTHORSHIP CONTRIBUTIONS

Authors equally contributed to this work.

DATA AVAILABILITY STATEMENT

The authors confirm that the data that supports the findings of this study are available within the article. Raw data that support the finding of this study are available from the corresponding author, upon reasonable request.

CONFLICT OF INTEREST

The author declared no potential conflicts of interest with respect to the research, authorship, and/or publication of this article.

ETHICS

There are no ethical issues with the publication of this manuscript.

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