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Investigation of Probable Princes's Graves and Wall Remains In Alacahöyük Archaeological Site with Ground Penetrating Radar Method

Yer Radarı Yöntemi ile Alacahöyük Arkeolojik Alanındaki Olası Prens Mezarları ve Duvar Kalıntılarının Araştırılması

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ABSTRACT

The aim of this study is to determine the probable Princes's graves and wall remains using geophysical Ground Penetrating Radar (GPR) method at two study areas defined by archaeologist before in Alacahoyuk archaeological site, Çorum-Turkey. GPR data were continuously collected in the first site (Area 1) by using the reflection profiling measurement technique with a 100 MHz unshielded antenna on four parallel profiles spaced 1 m apart probable Princes's graves could be buried there. On each profile, measurements were taken for two different positions of the transmitter-receiver antenna due to the directivity properties of the antenna. Probable wall remains could be buried in the second site (Area 2), which has 12 m length and 10 m in width. GPR data were also acquired as in the first study site. On the site, 44 GPR profile measurements have been collected on 22 profiles. After data processing, time slices/amplitude maps were produced from the data collected on 52 profiles according to the different positions of the transmitter-receiver antennas in these sites.

It was concluded that the presence and lateral extends of strong reflections on time slices/amplitude maps indicate the locations of some wall remains and probable Princes' graves. In accordance with these results, excavations were recommended where the presence of anomalies was observed on these maps. Archaeological finds corroborated the existence of remains during the following excavations when strong reflections were observed on the maps.

Keywords: Alacahöyük, GPR, time slices/amplitude maps, Princes's graves, wall remains.

ÖZ

Bu çalışmanın amacı, Türkiye'nin Çorum ilindeki Alacahöyük arkeolojik alanında daha önceden arkeologlar tarafından tanımlanan iki ayrı çalışma sahasında jeofizik yöntem olan yeraltı radarı (GPR) kullanılarak olası prens mezarları ve duvar kalıntılarını belirlemektir. Olası prens mezarlarının gömülü olabileceği düşünülen ilk çalışma (Alan 1) sahasında, GPR verileri; birbirine paralel 1 m aralıklı dört profilde, 100 MHz korumasız antenle yansıma profil ölçüm tekniği kullanılarak sürekli modda toplanmıştır. Antenin yönelimine göre elektromanyetik dalganın farklı yayınım özelliğini kullanmak için, GPR verileri; alıcı-verici antenin iki farklı konumunda ölçülmüştür. Olası duvar kalıntılarının gömülü olduğu tahmin edilen ikinci alan (Alan 2); 12 m uzunluğunda ve 10 m genişliğinde bir alandır. Bu alanda, 22 hatta 44 GPR profil ölçümü alınmıştır. Bu iki çalışma alanında, verici-alıcı antenlerin farklı konumlarına göre, 52 profilde toplanan GPR verilerine uygulanan veri işlem adımlarından sonra zaman düzlemleri/genlik haritaları oluşturulmuştur.

Zaman düzlemleri/genlik haritalarındaki kuvvetli yansımaların varlığı ve yanal uzanımları; bazı duvar kalıntılarını ve olası prens mezarlarını işaret ettiği sonucuna varılmıştır. Bu sonuçlar ışığında, haritalar üzerinde gözlenen anomalilerin olduğu yerlere arkeolojik kazılar önerilmiştir. İzleyen kazılardan ortaya çıkarılan arkeolojik bulgular; haritalarda gözlenen kuvvetli yansımalarla uyumluluk göstermiştir.

Anahtar Kelimeler: *Alacahöyük, GPR, zaman düzlemleri/genlik haritaları, Prens mezarları, duvar kalıntıları.*

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INTRODUCTION

Determining locations and depths of buried archaeological structures is one of the most important goals of archaeologists who try to bring them to light. Geophysics is a science that allows archaeologists to reveal archaeological remains before the excavations. Archaeogeophysical studies are very important for minimizing time and economic losses and give the results in a non-destructive way. Therefore, geophysical methods such as resistivity, magnetic surveys and ground penetrating radar (GPR) are essential in archaeological terms and have paved the way for a new discipline: archaeo-geophysics. The new discipline rests on geophysicist and archaeologist's joint interpretation of subsurface structures found by measuring variations in geophysical properties of the surveyed area from the ground surface and obtaining images. These geophysical measurements also give to more detailed information about lateral and vertical extensions of subsurface structures compared with small scale test excavations. So, geophysicists are guides laying the groundwork for appropriate excavations contribute substantially to archaeological finds (Johnson and Johnson, 2006).

The paper aims at discovering probable Princes' graves, wall boundaries and other archaeological features by utilizing GPR method in the ancient city of Alacahöyük. In the next sections we presented the GPR methodology, data acquisition and interpretation results, respectively.

METHODOLOGY

Ground Penetrating Radar (GPR) method is one of the near-surface geophysical methods that has gained acceptance because images of the subsurface geometries can be obtained rapidly with high resolution (Daniels, 2004; Annan, 2003; Goodman et al., 1995; Conyers, 2004; Orlando, 2005, 2007). In this method, an antenna radiates high frequency electromagnetic waves into the ground. When transmitted, a certain amount of that energy is reflected from buried objects (archaeological remains or ruins) or from the interface between sediments and soil whereas the rest of that energy is transmitted within the ground. The reflected electromagnetic (EM) waves are received back at the surface and recorded as wave amplitude and two-travel time (nanoseconds) with a receiver antenna. The amplitudes and reflections of the waves gain importance in relation to the contrasts in the dielectric properties of the subsurface structures (Annan, 2003). However, in order to effective use of GPR method, there are some factors that are independent of the researcher such as the electromagnetic waves not reaching the buried feature and not giving back reflections. This is due to the system and subsurface conditions which generate adverse effects when archaeological objects are very deep. Moreover, the depth of investigation is limited with respect to the conductivity of the surveyed area and the antennas frequency used in the system. Lower the antenna frequency, the higher the investigation depth but with lower resolution. In addition, the shale or clay content of the underground causes an increase in conductivity and consequently prevents the propagation of the electromagnetic wave. Thus, the complex subsurface conditions, overlapping archaeological features of varying sizes which are located at different depths compel the researcher to interpret GPR data as standard sections. There have been successful interpretations of researchers who have used various imaging techniques such as time slices/amplitude map (Malagodi et al., 1996; Orlando, 2005, 2007). In these studies, the images of the soil, sediments and archaeological structure remains were obtained with receiver antenna that help to measure and record thousands of radar reflections within the study area along selected profiles parallel to one another.

There is extensive literature concerning the applications of GPR in the archaeological field (e.g. graves, walls, roads, channels) (Hruska and Fuchs, 1999; Basile et al., 2000; Piro et al., 2001; Rizzo et al,. 2005; Gibson and George, 2006; Leucci and Negri, 2006; Leckebusch et al., 2008; Seren et al., 2008; Negri et al., 2008; Shaaban et al., 2009; Tsokas et al., 2009, Yalciner et al., 2009; Kadioglu and Kadioglu, 2010; Kadioglu et al., 2010; Seren et al., 2010; Kadioglu et al., 2011; Orlando, 2013; Moscatelli et al., 2014). Bonomo et al. (2010) carried out an archaeo-geophysical investigation near the Palo Blanco archaeological site, Catamarca, Argentina. A large area on the site was investigated with the GPR method in order to detect archaeological structures ruins by composing GPR time slices. Finally, systematic excavations confirmed the GPR maps providing further relevant information about the characteristics of the walls and the occupational floor in their study. Porsani et al. (2010) presented and discussed the results of GPR-2D and GPR-3D surveys performed at an archaeological rock shelter site, Lapa do Santo, localized in the karstic region of Lagoa Santa, central Brazil. The results showed the efficiency of GPR method in identifying potential buried archaeological targets. A GPR survey carried out near the earlier-discovered tombs at Kilo-6 El-Bahariya to Farafra Oasis road by Shaaban et al. (2009). The final results of the survey, in the form of 2D radar records, time slices and 3D block diagrams, were used to guide the archaeologists during the excavation process. It is worthy to mention that, the excavations and location of tombs and cavities matched strongly with the GPR results.

STUDY AREA AND DATA ACQUISITION

Alacahöyük is an ancient city in the Çorum province that is located 15 km northwest of the district Alaca in central Anatolia of Turkey (Figure 1a,b). According to archaeologists, the site consists of 14 settlements or structure layers (strata-foundations) dating from four different cultural periods. The findings of previous researchers have brought to light some buried features (princes' graves) in this ancient city (Figure 1c), which is of great significance in terms of archaeological finds (Arık, 1937; Koşay, 1938; Koşay and Akok, 1966). The first and real systematic excavations in the strictest sense of the word were ordered by Mustafa Kemal Atatürk during the first Republic. In 1935, digging activities were begun by Hamit Zübeyr Koşay, Remzi Oğuz Arık and Mahmut Akok for the Turkish History Association and continued until 1983. During the excavations, archaeological remains dating from the Bronze-Stone Ages to the Ottoman Period were uncovered. Excavations were suspended in 1983 then restarted by Prof.Dr. Aykut Çınaroğlu (Çınaroğlu, 2003). In order to accelerate these excavations at low cost and time, applications of the GPR method were performed in the site.

As a result of interviews with archaeologists, two distinct sites were defined to find probable wall and archaeological structure remains (Figure 1c,d). GPR data were continuously collected in the first site (Area 1) by using the reflection profiling measurement technique (the distance between the transmitter-receiver antenna was constant and measurements were taken by moving the antenna along the profiles) with a 100 MHz unshielded antenna and using the Mala CU II GPR system on four parallel profiles being 1 m apart (Figure 2a).

In general, the antennas used for GPR are dipolar and radiate with a preferred polarity. The antennas are normally oriented so that the electric field is polarized parallel to the long axis or strike direction of the target. There is no optimal orientation for an equidimensional target. In some instances, it may be advisable to collect two data sets with orthogonal antenna orientations in order to extract target information based on coupling angle. If the antenna system is one which attempts to use a circularly polarized signal, the antenna orientation becomes irrelevant. Since most commercial systems employ polarized antennas, orientation can be important. Antenna orientation affects the subsurface footprint size. As the simplified beam pattern indicates, the simple dipole antenna has a broader footprint in the "broad side" direction than in the "end fire direction" (Annan, 2003). In each profile, measurements were taken for the two different positions of the transmitter-receiver antenna due to the directivity properties of the antenna (in XX mode, transmitter–receiver antenna were parallel to one another, parallel to the profile – in YY mode; transmitter–receiver antenna were parallel to one another and perpendicular to the profile as shown in Figure 2 a,b).

The GPR data of the other site (Area 2), which is 12 m in length and 10 m in width, where probable wall remains are thought to be located were acquired with the same system (Figure 2b). The previous excavations uncovered wall remains in an area is next to the present study area. A question arose as to whether these ruin a continuation of walls. To answer this question, detailed measurements were taken by using both XX and YY modes on all the profiles of area 2 to confirm the existence and define the orientation of these probable walls. The measurement profiles and their directions are clearly visible in Figure 2b. For both modes of the antenna, 44 GPR profile measurements have been collected on 22 profiles and their directions are indicated with P and H (Figure 2b).

DATA PROCESSING

Observing anomalies in subsurface structures from raw GPR sections are impossible or a difficult task. Therefore, the data must go through basic data processing steps until they become interpretable. The

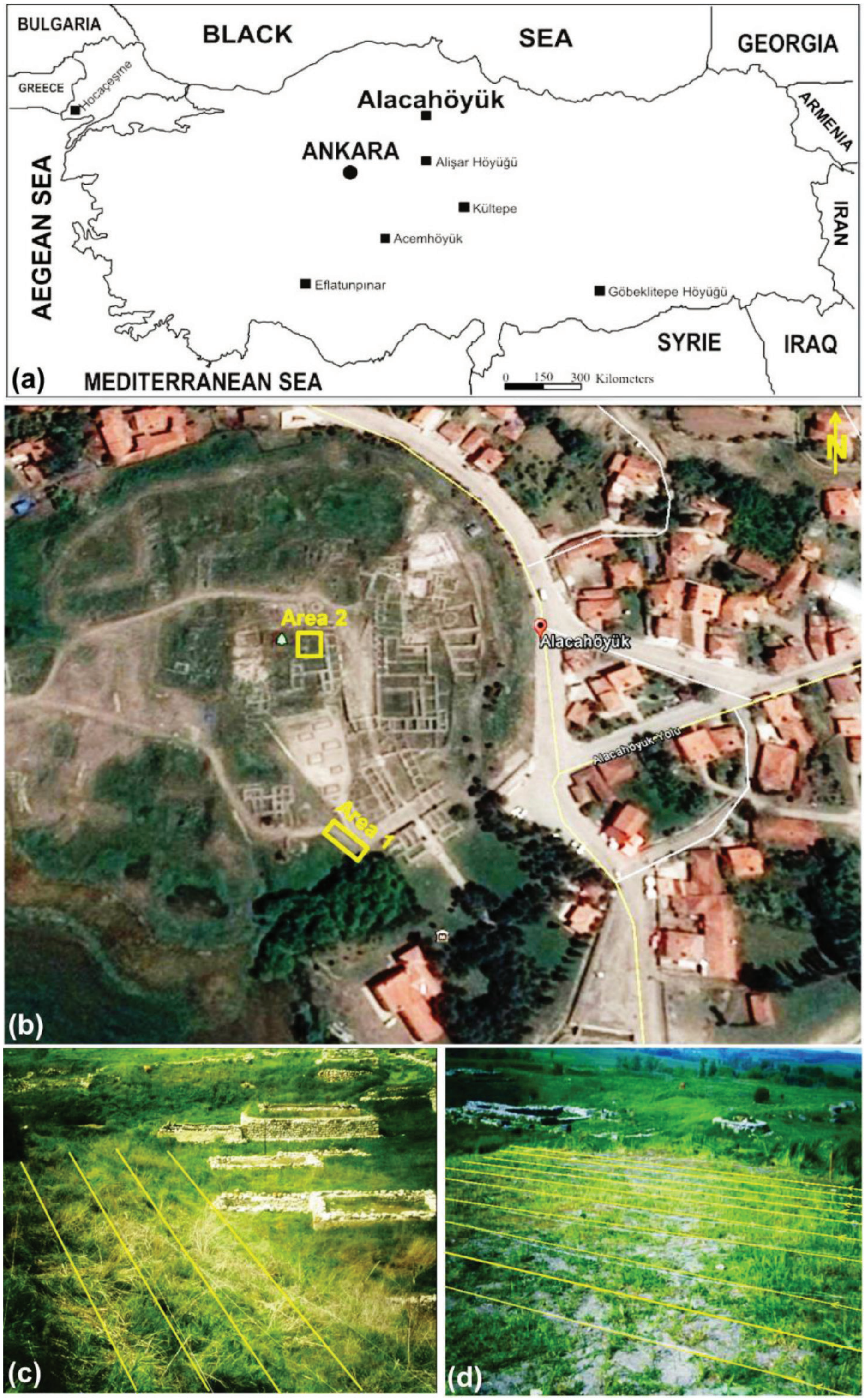


Figure 1. (a) Location map of Alacahöyük ancient city in the Çorum province in central Anatolia, (b) an aerial photo of the ancient city, (c) measurement profiles of Area 1 and (d) measurement profiles on H direction of Area 2 in study area.

Şekil 1. Anadolu'nun merkezinde yer alan Çorum ili Alacahöyük antik kentinin (a) yer bulduru haritası, (b) antik kentin hava fotoğrafı, (c) çalışma alanındaki Alan 1 in ölçü profilleri ve (d) Alan 2 in H yönündeki ölçü profilleri.

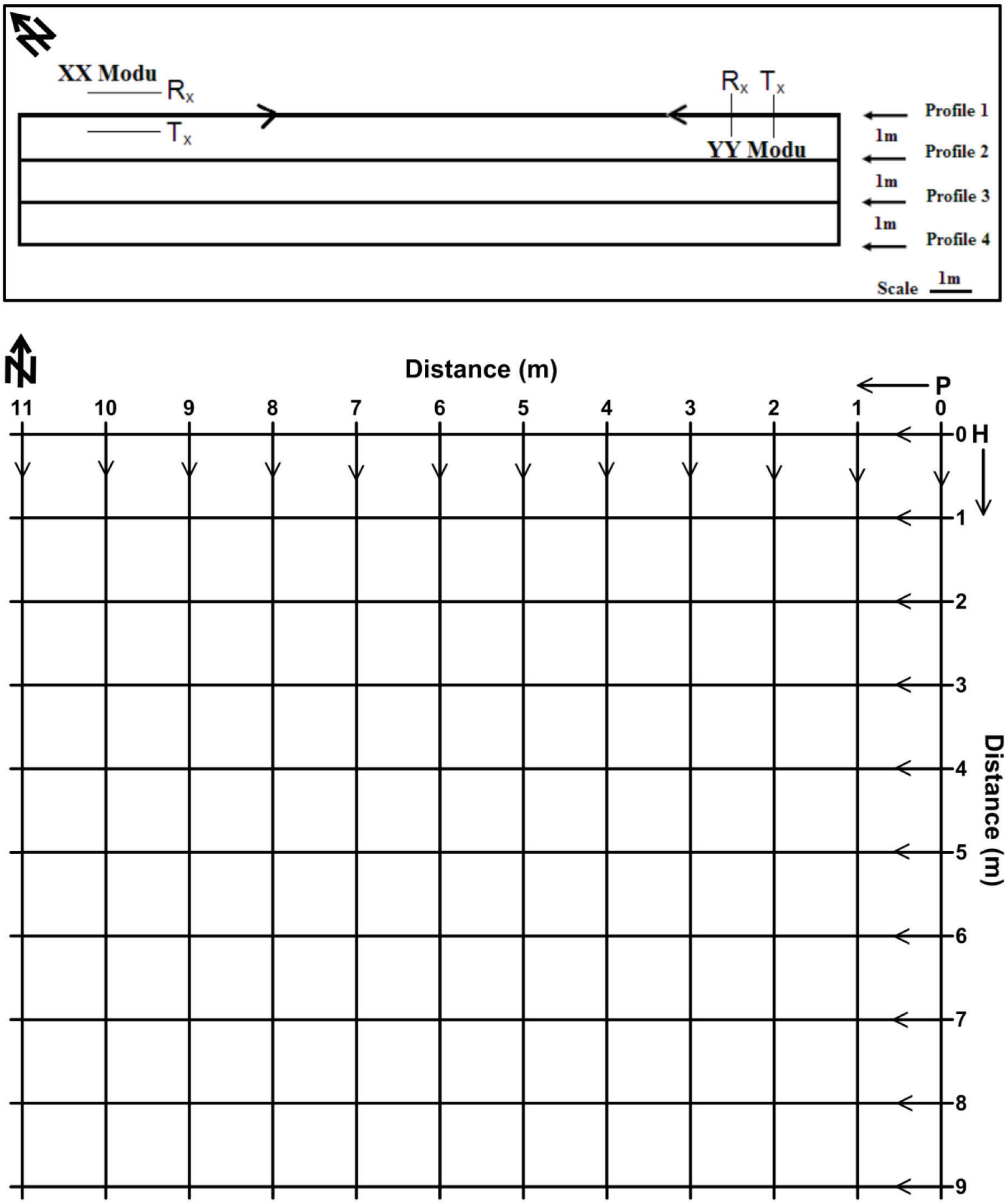


Figure 2. Measurement profiles of investigated site, (a) area 1 and (b) area 2
Şekil 2. İnceleme alanındaki ölçü profilleri, (a) alan 1 ve (b) alan 2

basic processing steps applied to the collected GPR data of this paper consist of dewow, gain (energy decay) and background removal. Since the studied field was flat, applying static correction to the data was not considered necessary. The fact that there were no sources of artificial noise in the surroundings of the surveyed area enabled us to acquire high signal to noise ratios. Dewow, the first data processing application used in this survey, is the removal of low frequency waves from the traces. While performing this task mathematically, the selection of the time window is of great significance with respect to the running mean value. Energy decay, one of the amplitude gain types, is performed to compensate for the decrease in amplitude due to the distance of the electromagnetic wave propagating within the ground. During this process, a ratio of decrease is calculated from all the traces in the measurement profiles. With resulting energy decay curve obtained by the help of the ratio, trace amplitude adjustment is done by dividing the amplitude value of each point. The final data processing application named as background removal, one of the methods removing of ringing effect on radargrams, is thought to constitute an important step in the analysis of GPR data. The ringing effect, a common type of coherent noise, is generally observed in the GPR data and has a negative impact on the radargram signals. Furthermore, the presence of this type of random noise in traces, when strong, indicates that the noise has not been removed and thus completely masks deeper features such as reflections, diffractions etc. Therefore, ringing which is regarded as horizontal and periodic events in the sections is one of the most important phenomena to eliminate with data processing. Given that the ringing effect is nearly consistent along the whole section when reflected events are less correlated and more random, it can be considered the average trace containing ringing noise only for the whole section. Removing that average trace in a simple way compensates for the horizontal appearance of the ringing in the radargram (Kim et al., 2007). In this study, the data processing steps described above include the ReflexW software applying to the data (Sandmeier, 2015).

The left vertical axis of the radargram traces shows the recorded two-way travel time whereas the right axis indicates depth. To calculate the depth of probable archaeological remains from the surface, electromagnetic (EM) wave velocity of the medium is determined. The velocity of the EM wave surrounding the archaeological object to be identified was calculated as 0.08 m/ns following the analysis conducted using the diffraction that occurred in the GPR section. The sections were converted from time to depth sections by using two-way travel time and this velocity value. The observed depths of the strong reflections in the sections were analysed.

RESULTS AND DISCUSSION

Princes' graves and structure walls are more resistant than surrounding formations because they have formed from massive rock in geological terms (Wilchek, 2000). So, GPR signals reflect strong waves from these structures. Structures in subsurface is often complicated in archaeological sites. The orientation of potential remains is not exactly known in these sites. Therefore, to define these structures with different oriented, GPR data have been collected with different antennas modes (XX and YY). The extents of possible archeological structures have been tried to define from strong reflections on observed all radargrams.

In this study, the measurements taken in both areas (Area1 and 2) were processed and shown as GPR sections and maps. In the area 1, when all sections were analysed on profile 1-4, strong reflections (Figure 3) were observed at depths of about 11 m. Figure 3 show GPR sections collected with XX mode (on the left of this figure) and YY mode (on the of right this figure) on profile1-4 in the area 1. Lateral changes at a depth of up to 3 m from the surface have the same characteristics along the profiles on all sections. Especially, high amplitude reflections were observed and indicated potential ruins walls of Prince's graves with frames on some of these sections on Figure 3. For example, while strong amplitude reflections are traced between 3 and 7 m in distances on radargram collected with XX mode on Profile 1, these reflections are not seem on the radargram belonging to other mode (Figure 3).

To determine the lateral and vertical changes of strong reflections observed on GPR sections, time slices/amplitude maps were obtained from these sections. Considering the shallowest part to be uncovered in the planned excavations, time slices/amplitude maps were contoured to show change by grouping parallel profiles belonging to the first part up to 3 m in depth from the surface. Then the geography coordinate locations and the approximate depths of probable walls and other features of archaeological interest could be determined on these maps. Amplitude changes were mapped in time/amplitude slices with the first, 26 ns, 51 ns, 76 ns reflections (Figure 4). Amplitude changes in these slices were obtained by combining recorded amplitude with time values according to the coordinates of measurement points in each profile after basic data processing. Given that the travel time of the recorded signal in the GPR data is two-way travel time, each time of these slice-maps was multiplied by 0.08 m/ns for converting to depth and the result was divided by two. Consequently, depths that approximately corresponded to each map were determined. When studying Figure 4, structures extending on X axis were detected at all depth levels in the changes of

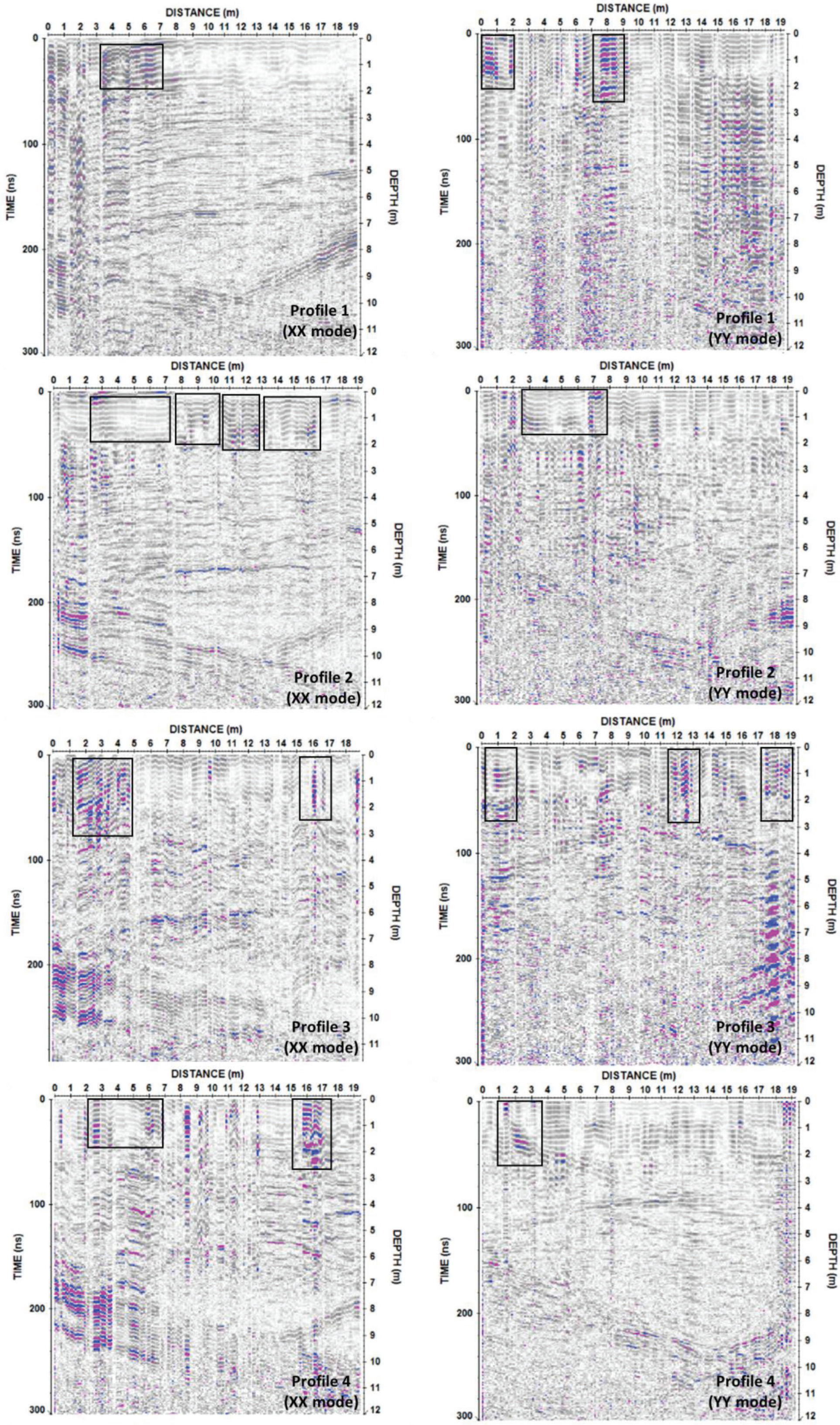


Figure 3. Radargrams on profile 1-4 in the area 1, XX (on the left) and YY (on the right) modes
Şekil 3. Alan 1'deki profil 1-4'ye ait radargramlar XX (solda) ve (b) YY (sağda) modları

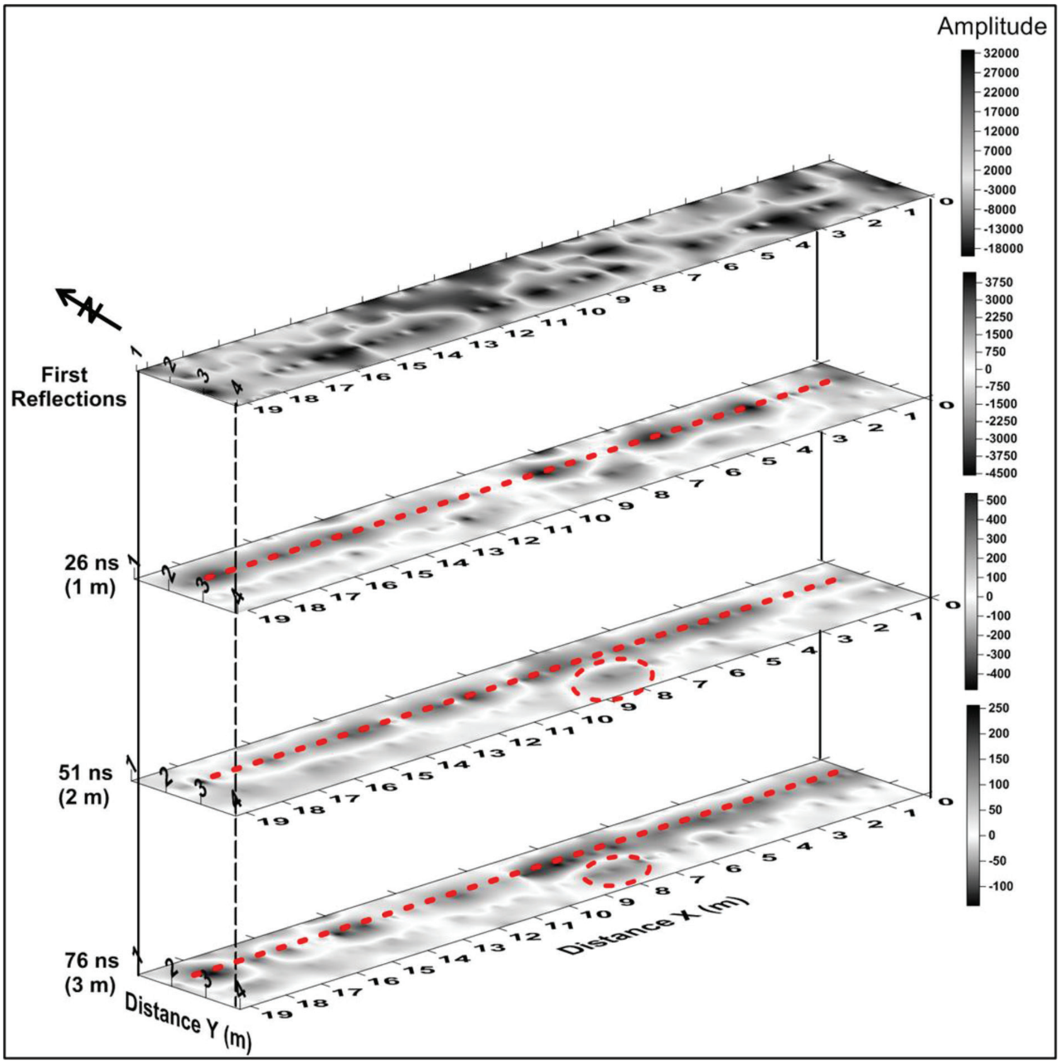
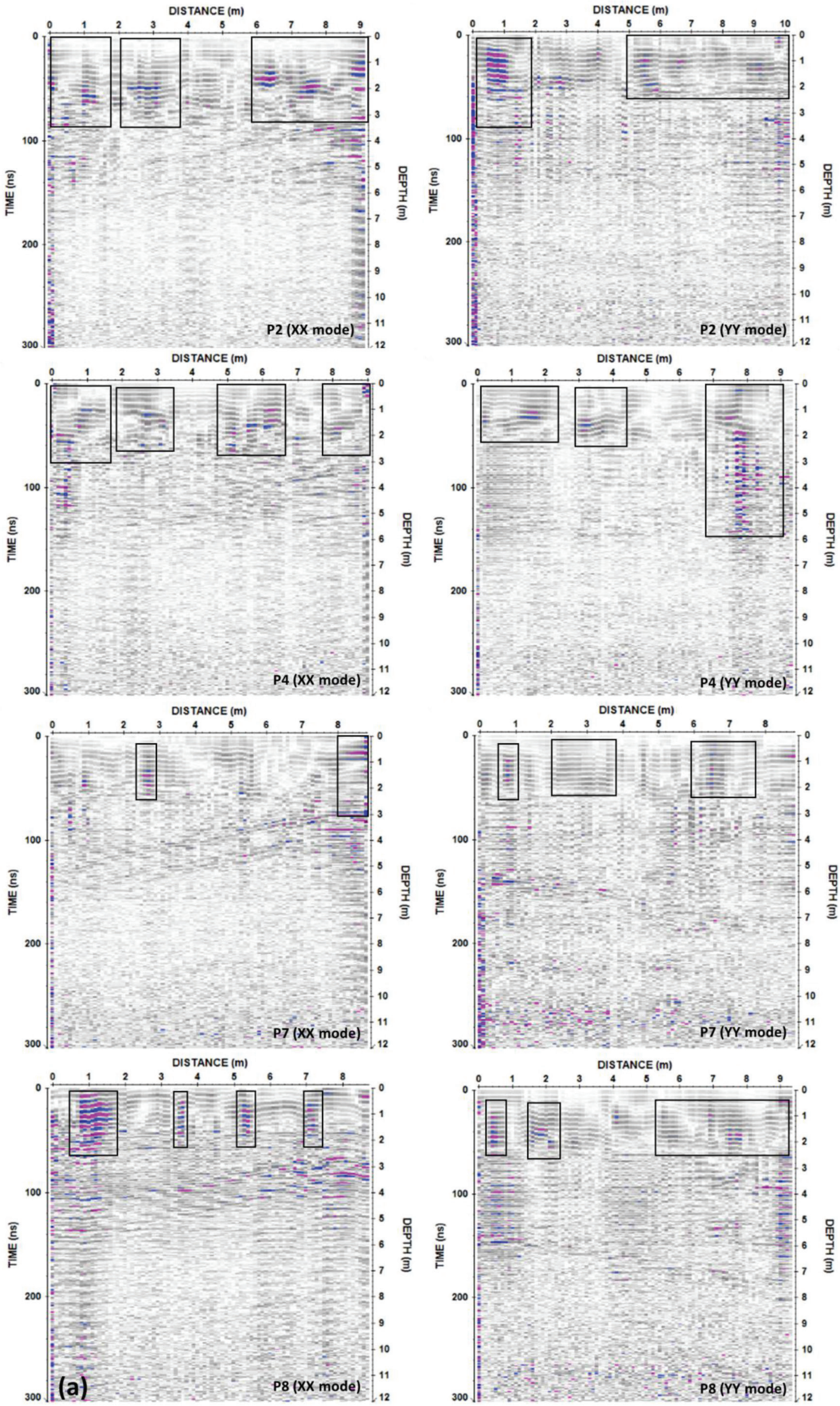


Figure 4. Time slice/amplitude maps with the first, 26 ns, 51 ns and 76 ns reflections in area 1
Şekil 4. Alan 1'deki 1 ns, 26 ns, 51 ns ve 76 ns' lere ait zaman düzlemleri/genlik haritaları

strong reflections present in plane areas (time slice / amplitude map) 1 m apart starting from the surface up to 3 m. Anomalies of extended shape at 26 ns (≅1 m), 51 ns (≅2 m) and 76 ns (≅3 m) on the time slices/ amplitude maps are drawn by red dashed lines. Besides, strong reflections about circular shape at 51 ns (≅2 m) and 76 ns (≅3 m) on the amplitude slices maps are marked with red dashed circles in Figure 4.

In the surveyed area 2, GPR measurements were taken to locate probable extensions of wall remains. The GPR sections of the collected GPR data in XX (on the left of Figure 5a) and YY (on the right of Figure 5a) modes along profile 2, 4, 7 and 8 in P direction are shown on Figure 5a. Also, radargrams collected GPR data on the other measurement direction (H) in XX (on the left of Figure 5b) and YY (on the right of Figure 5b) modes along profile 2, 5, 6 and 7 are given on Figure 5b. Once the sections were examined, similar distribution of the data in both modes at an approximate depth of up to 3 m from the surface was observed. From the collected GPR data in XX mode, two reflection boundaries of dipping shape starting from 3.5 to 5 m in depth were detected to the Figure 5a whereas the data collected in the other mode on the section to the Figure 5a reveal horizontally extended reflections between 2 and 6 m in depth and a strong horizontal reflection boundary was observed at the exact depth of 6 m both to the Figure 5a. Once the sections were examined, similar distribution of the data in both modes at an approximate depth of


DISTANCE (m)
TIME (ns)
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P2 (XX mode)
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P8 (XX mode)
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(a)

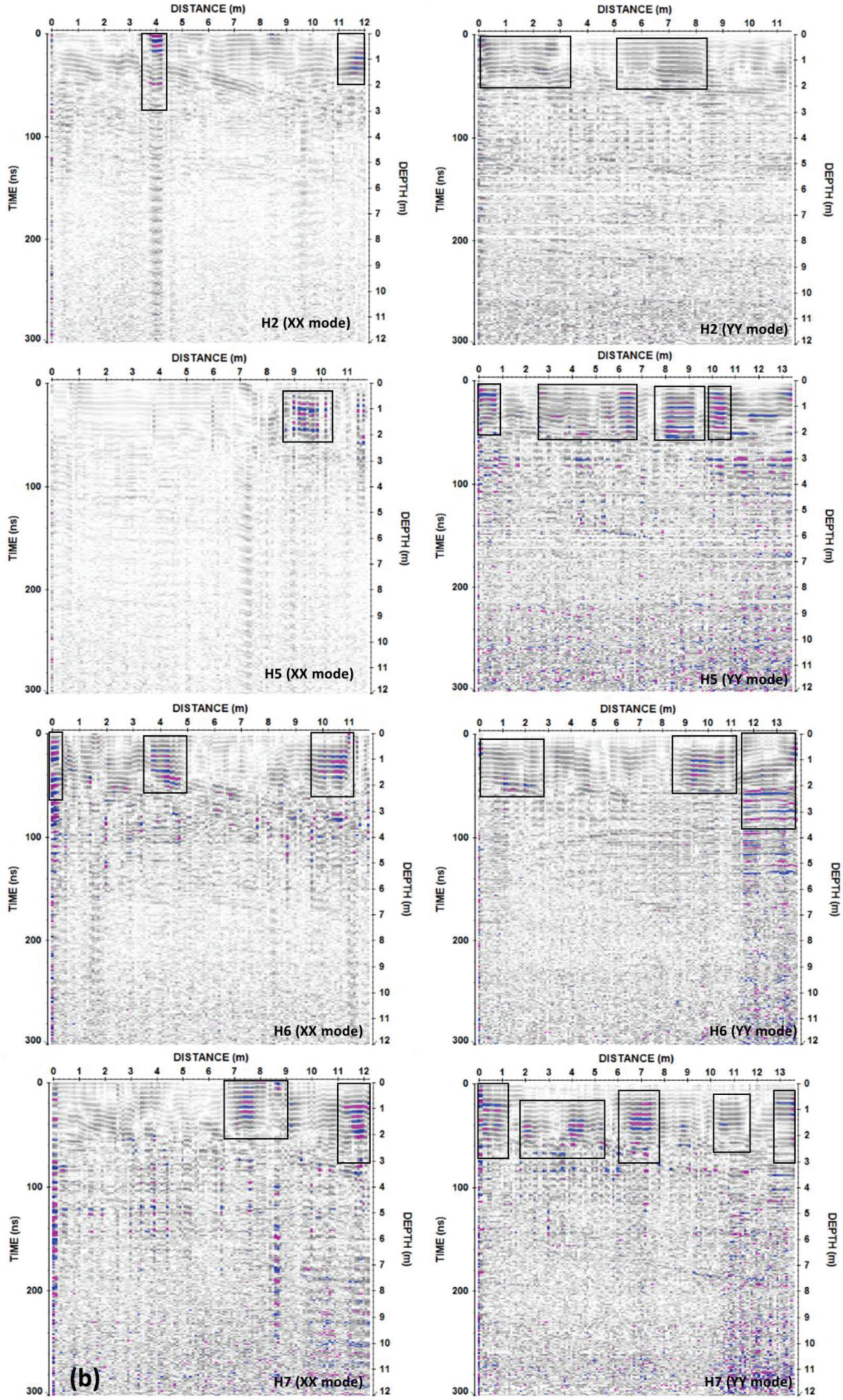


Figure 5. (a) Radargrams along profile 2, 4, 7, 8 on P direction in the area 2, XX (on the left) and YY (on the right) modes, b) Radargrams along profile 2, 5, 6, 7 on H direction in the area 2, XX (on the left) and YY (on the right) modes.

Şekil 5. (a) Alan 2'de H yönündeki profil 2, 5, 6, 7'ye ait radargramlar XX (solda) ve YY (sağda) modları, (b) Alan 2'de P yönündeki profil 2, 4, 7, 8'e ait radargramlar XX (solda) ve YY (sağda) modları up to 2 m from the surface was observed. In particular, high amplitude reflections were observed and lined probable remains walls with frames on some of these sections on Figure 5 a,b. For instance, when high amplitude reflections are appeared between 3 and 7 m in distances on radargram collected with XX mode on Profile 1, these reflections are not seem on the radargram belonging to other mode (Figure 5a). Looking at Figure. 5b, once very high amplitude reflections are traced in 0-1 m, 2-5.5 m and 6-7.9 m on distances of radargram acquired with YY mode on H7, these reflections are weakly shown on that of XX mode. In general, when all radargrams with XX and YY modes are compared, these similar situations are seemed (Figure 3, Figure 5 a,b).

In order to define an expansion of buried wall structures including their size, shape and location, time slices/amplitude map (Figure 6 a,b) were created by mapping after the processing of the collected GPR data in 10 parallel profiles in H direction and in 12 parallel profiles in P direction (Figure 2b). Lateral amplitude changes caused by the reflections on the acquired sections were surveyed in the slice maps. The collected GPR data in P and H directions with YY mode revealed the distribution of amplitudes by reflecting from 0.11 m to 3.6 m depths as shown in Fig. 6a,b. As shown these figures, reflections with relatively high amplitudes are clearly visible on the slices. We also draw some relatively high amplitude as yellow dashed lines and blue dashed curves with the same direction on the slice maps. Thus, the continuation of the investigated archaeological structure (wall) was brought to light by means of imaging techniques. It's a well known fact that high amplitude reflections indicate the interface between soil and rock (archaeological structure) that have high electric conductivity contrast. Thus, the archaeologist's attention has been to the locations of these interfaces. Archaeologists have been primarily directed to those areas with a view to undertake appropriate excavations.

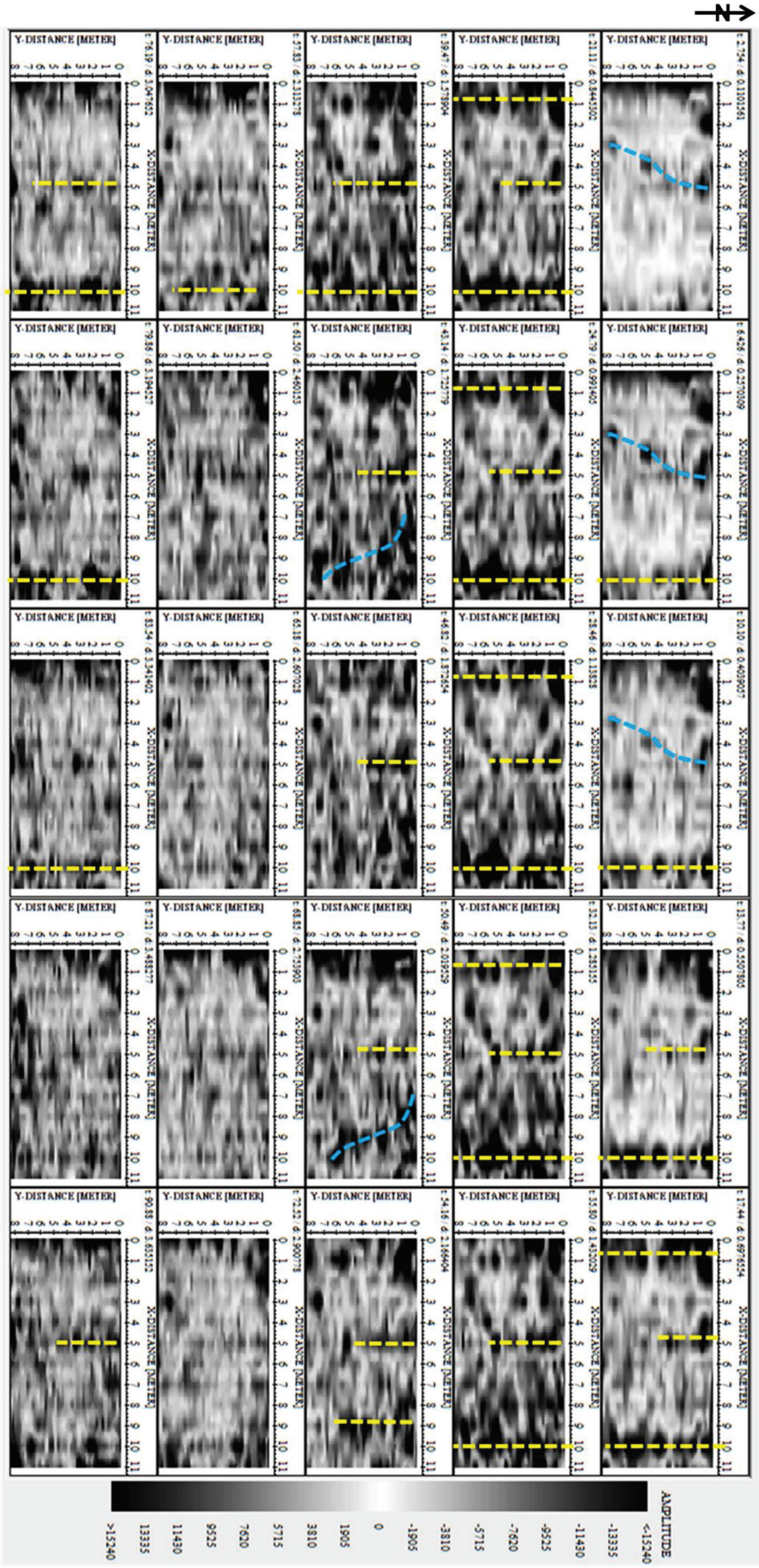
CONCLUSION

According to time slices/amplitude maps, wall remains have been detected under a thin layer of soil at different depths and it has been concluded that these features are located at a very shallow depth. As a result, it has been decided that strong reflections with high amplitudes as shown in the maps can be regarded as important indicators of structures of archaeological interest. On the other hand, the walls that have been demolished have lost their resistivity and which are rich in soil can produce scattered reflections with lower amplitudes. Not to lose sight of these facts, it must be taken into account all the extensions shown in the maps.

As mentioned above, excavations have been recommended where the presence of strong reflections and anomalies of extended shape, which are indicative of the location of princes' graves and probable wall remains, detected in interpretable maps. The archaeological findings in the subsequent excavations of the surveyed areas have confirmed the hypothesis that the location of strong reflections observed in the maps correspond to the location of archaeological remains (Figure 7 a,b and 8 a,b). Remains of prince's graves can be seen on Figure 7a. In Figure 4, anomalies of extended shape at 26 ns (≅1 m), 51 ns (≅2 m) and 76 ns (≅3 m) on the time slices/amplitude maps are indicated by red dashed lines. In the image of the excavation area, structures resembling stairs adjacent to the exposed wall have been considered the sources of high amplitude reflections along 2 m on axis Y and between 1-19 m on axis X (Figure 4). Besides, strong reflections at 51 ns (≅2 m) and 76 ns (≅3 m) in the amplitude slices maps are present where between 2.5-3.75 m on axis Y and 7.5-9.75 m on axis X are intersected as shown with red dashed circles on the figure.

In area 2, the locations of the recommended excavation areas resulting from the survey have not been completely dug out. The uncovered wall remains (Figure 8 a,b) correspond to defined anomalies with blue dashed curves on Figure 6b. Images of the discovered wall which is visible from different angles in Figure 8 a,b have been watched. When examining the image, the presence of cement between the stacked stones is quite evident. Besides, the archaeological remains that diffracted in a chaotic way due to demolition in places are consistent with the anomaly distribution shown in Figure 6 a,b.

It has been concluded that the results of the study have quite effectively enabled us to identify prince's graves, structure walls and other archaeological features in the ancient city of Çorum Alacahöyük by investigating two distinct areas with the GPR method from which data was acquired, processed and mapped at short notice.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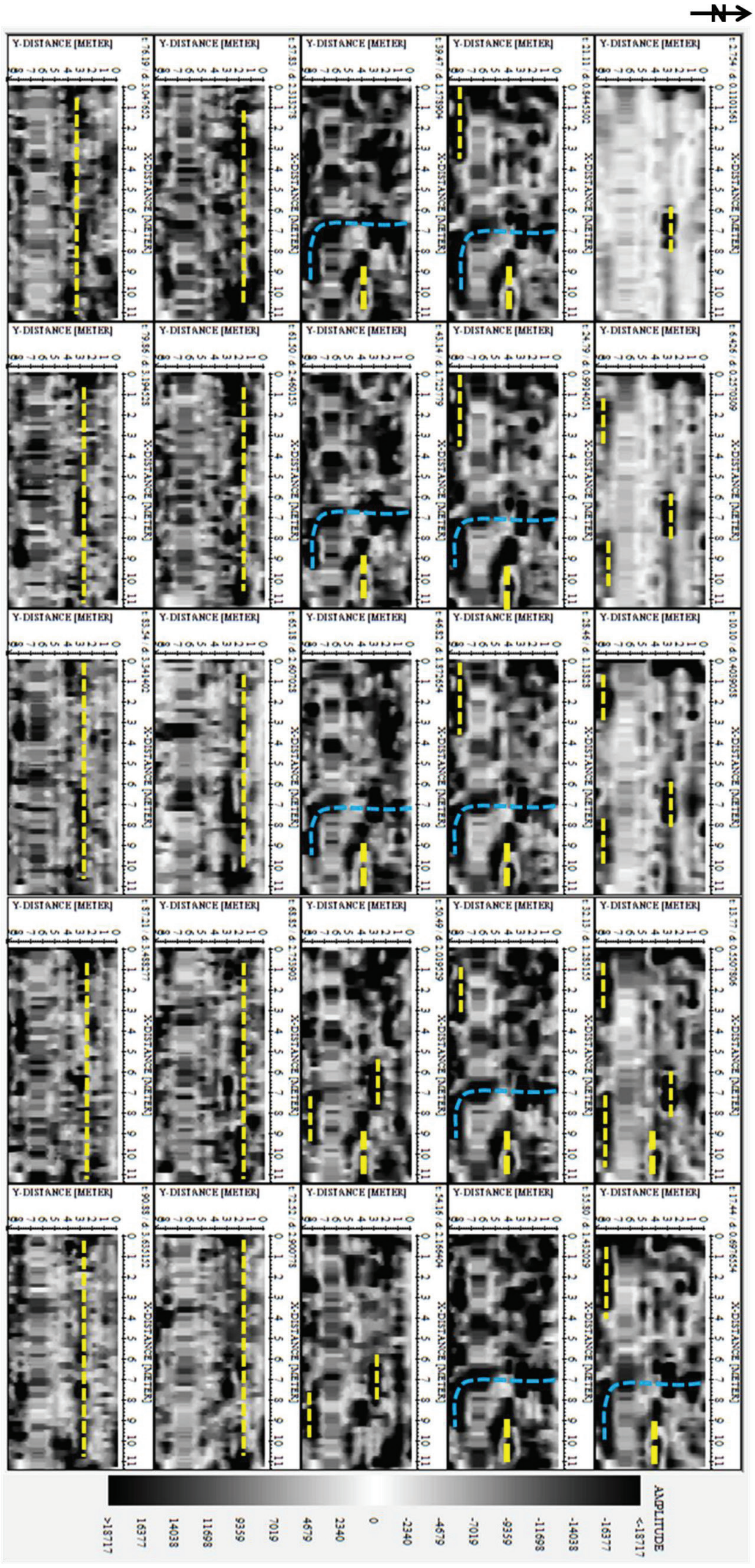

Figure 6. Area 2: time slices/amplitude maps (0.11–3.6 m of depth) (a) P and (b) H directions with YY mode
Şekil 6. Alan 2' de YY modu ile (a) P ve (b) H yönlerindeki zaman düzlemleri/genlik haritaları (0.11-3.6 m derinliklerde)

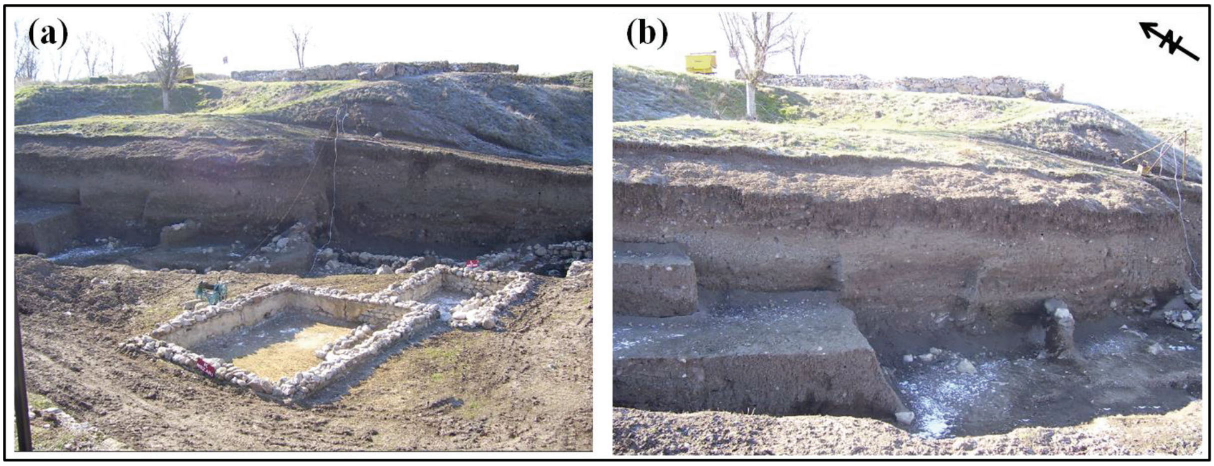

Figure 7. Images of the excavations on Area 1, (a) remains of prince's graves (b) structures resembling stairs adjacent to the exposed wall
Şekil 7. Alan 1'e ait kazı görüntüleri (a) prens mezarlarının kalıntıları (b) duvarlara bitişik merdiven benzeri yapılar

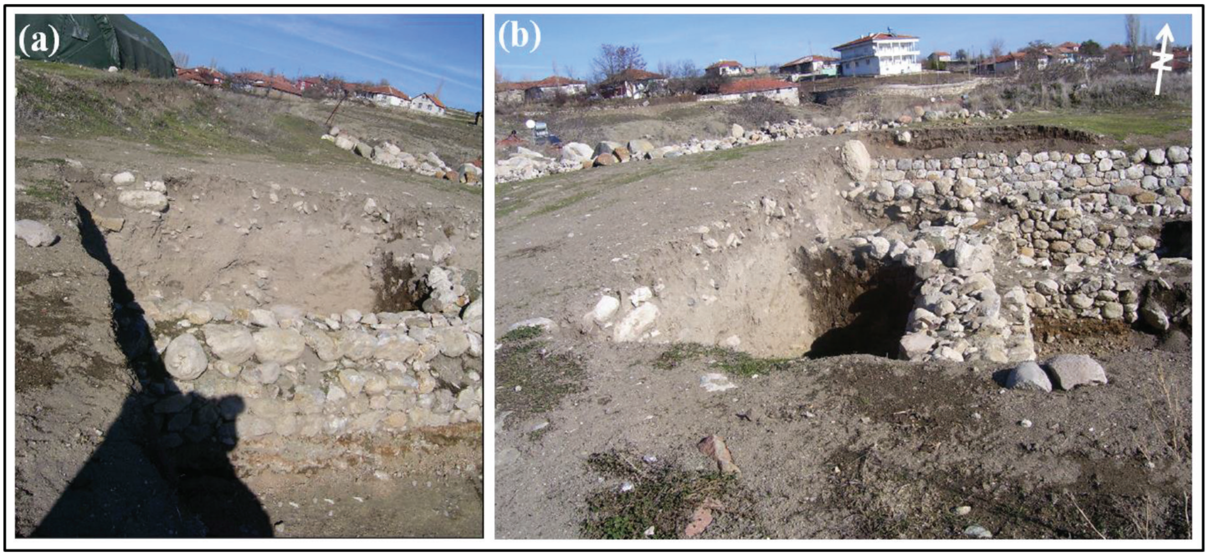

Figure 8. (a-b) Images of the discovered wall which is visible from different angles on Area 2.
Şekil 8. (a-b) Alan 2'de ortaya çıkarılmış duvarın farklı açılardan görünümleri

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