Demonstration of a Rapid Ground Penetrating Radar Survey at Kaman-Kalehöyük

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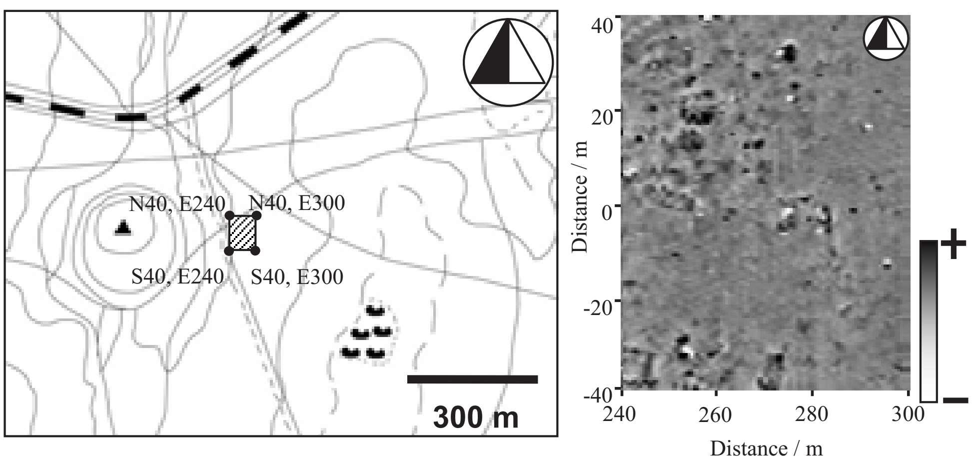
1. INTRODUCTION

Magnetic field gradient surveys have been used for mapping the site of Kaman-Kalehöyük and have disclosed several interesting circular and rectangular magnetic anomaly features (Fukuda *et al*. 2003, 2005). However, magnetic surveys provide little information on the depth of features and may not clearly detect underground objects that have no magnetism or the objects buried deeper than 2 m. This uncertainty is due to an expansive nature of magnetic anomaly associated with the depth and a decay of the magnetic signal. On the other hand, a ground penetrating radar (GPR) survey using a 200 MHz antenna is able to reach a depth more than 4 m in the dry soil of Central Turkey and has accomplished remarkable results, even at the site of Kültepe, which is covered with thick surface soil (Fukuda *et al*. 2004). This type of GPR survey is highly advantageous for investigating deep and missing architectural features, although it does have some problems regarding survey time and the laborious conveyance of the antenna, which makes it difficult to make three-dimensional maps of the radar signals. Such difficulties are expected to be overcome by a unique measurement system using a four-wheeled vehicle to transport the equipment and define the grid lines.

Here, we present a first demonstration of a rapid GPR survey at Kaman-Kalehöyük and compare the GPR data with previous results of the magnetic surveys. Our trial may contribute to future preliminary surveys on archaeological sites.



(a) (b)

Fig. 1 Surveyed grid is displayed as a shaded square in the left, (a). The symbols and numbers at the four corners of the grid show the direction and the distance in meters, respectively, from the standard point of the excavation shown as the triangular symbol. N, S and E mean north, south and east, respectively. Figure at the right, (b), is a distribution map of magnetic anomalies in the grid, surveyed in 2004 (Fukuda *et al*. 2005).

2. EXPERIMENTAL SECTION

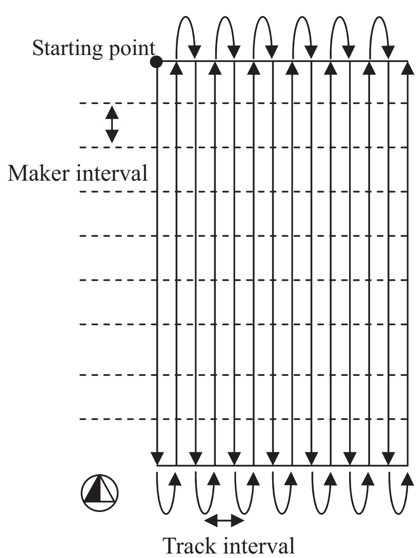
2.1. Measurement conditions and system

The GPR survey was conducted using a radar system with a 200 MHz antenna produced by Geophysical Survey System, Inc. (GSSI). A dielectric substance of target soil was estimated as 6.0 from a pre-survey of several stones exposed in the section of Sector 10 of the North-trench and was used for a calibration of depth of GPR signals. Each amplitude of the electromagnetic wave was recorded in 16 bit code. Sampling number of the instrument was determined as 16 times/sec in the north-south direction.

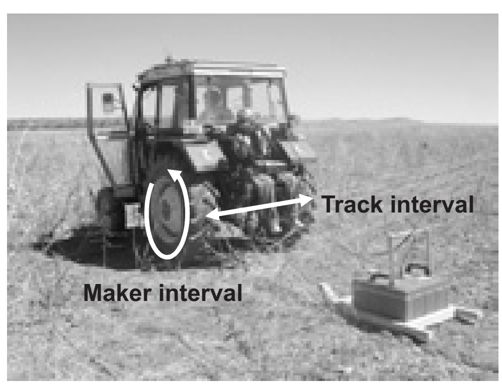
Four stakes were hammered down at (N 40 m, E 240 m), (N 40 m, E 300 m), (S 40 m, E 240 m) and (S 40 m, E 300 m) from the standard point of the excavation trench, which resulted in a rectangular grid of 80 m × 60 m (see Fig. 1 (a)). This area was chosen as a test grid for the present survey, because many magnetic features indicate buried objects in this area, as seen in Fig. 1 (b) (Fukuda *et al*. 2005). Fig. 2 represents a system concept for the rapid GPR survey. The instrument was mounted on a handmade sleigh and was pulled in the north-south direction by a tractor during the survey. After scanning one track, the tractor turned and pulled along a parallel line in the opposite direction, along one of the tire imprints made by its previous track. The interval between scanning lines was the width between the left and right tires of the tractor (Track interval: about 1.4 m). Markers which were used in the data analysis as indicators of the north-south position were added in the GPR data when the wheel made a rotation (Marker interval: about 4 m).

2.2. Data Analysis

The GPR data were processed and displayed with RADAN 5.0 for Windows (GSSI). The individual wave forms which offer depth information at one point were united to make a GPR profile for one scan. Horizontal noise was removed from the profile. The total number of wave forms in the profile was shrunk into 30 forms per 4 meters. The resultant profiles were combined to create two-dimensional distribution (2D) maps of the radar reflections at the depths of 0 m, 0.8 m, 0.9 m, 1.1 m, 1.5 m and 1.8 m from the ground surface. Areas of strong signals of reflected waves are drawn as light grey to white and background level is drawn as black in the 2D maps.



(a)



(b)

Fig. 2 Left illustration (a) shows the grid system for the present radar survey. A view of the measurement system used for the GPR survey is displayed in (b).

3. RESULTS AND DISCUSSION

GPR data including depth information up to at least 3 m were successfully obtained from the target area (4800 m^2) in only 150 minutes using the tractor to pull the radar instrument on the sleigh. The 2D maps of the GPR data are displayed as depth windows in Fig. 3. As can be seen in Fig. 3 (a), representing readings at the ground surface, 0 m, only one feature near the north-west corner was observed. This feature is identified as the present road whose surface has a generally higher density than that of the surrounding agricultural lands. Note that the road vaguely appears as a white line of negative magnetic anomaly in Figure 1 (b). The map at 0.8 m exhibits two interesting features (see Fig. 3 (b)). One is a possible corner, indicated by an arrow. This may correspond to the magnetic anomalies that are thought to reflect the architecture as (N 20 m, E 255 m) seen in Fig. 1 (b). The other feature is two lines located from southwest to northeast, around (S 10 m, E 270 m); there were no magnetic features detected at the same position. Judging by the liner nature, it is possible to think that the lines reflect an old road. However, they are parallel to furrows in the agricultural land, indicating that they may be noise due to the undulation of the ground. Although the above features disappeared at a depth of 0.9 m from the ground surface, their outlines became more clear and showed wider distribution at the depth of 1.1 m (see Fig. 3 (c) and (d)). This difference in distribution between the shallower and deeper levels may reflect uneven depth of the buried objects. Significant reflections are indicated by arrows in Fig. 3 (d). Their locations nearly correspond with distinct magnetic anomalies in Fig. 1 (b). All features begin to attenuate at the 1.5 m depth and, finally, no specific features were detected at a depth of more than 1.8 m.

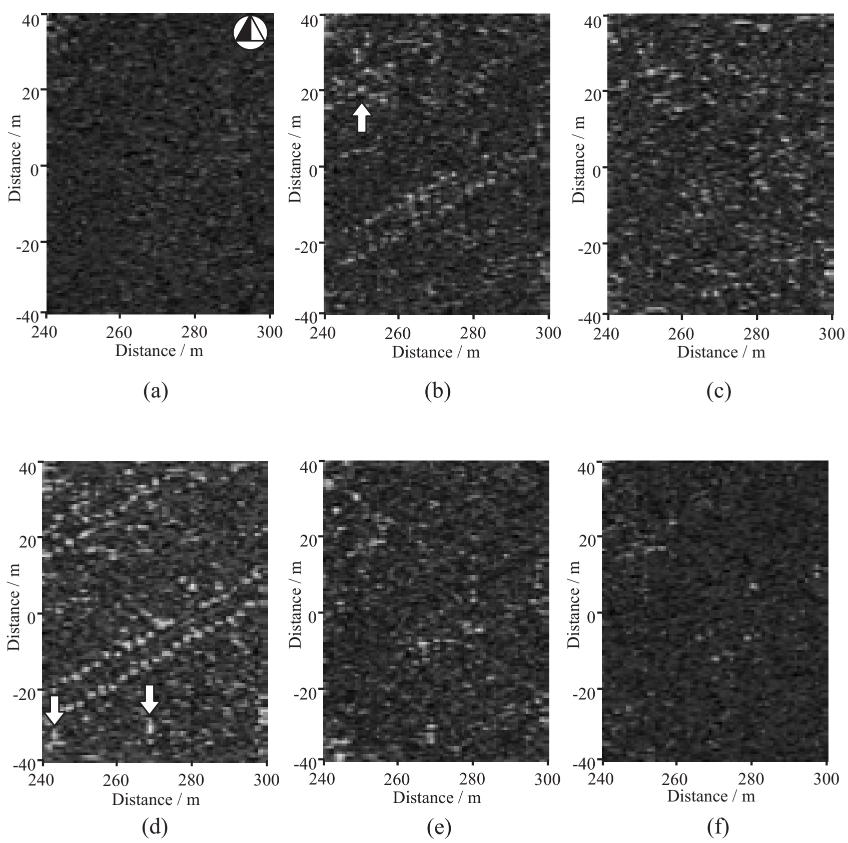


Fig. 3 2D maps of the GPR data at the depth of (a) 0 m, (b) 0.8 m, (c) 0.9 m, (d) 1.1 m, (e) 1.5 m and (f) 1.8 m from the ground surface. The numbers on the horizontal and vertical axes show the distance in meters from the standard point.

The good agreement between the magnetic anomalies and the radar reflections indicates that the origins are in common. Results indicate that the objects should be at the depth between 0.8 m and 1.5 m from the ground surface. The upper level is just under the surface soil. This suggests that the objects may be regarded as a first building level in the area, which belongs to a still unclarified period. Regrettably, it is difficult to identify the architectural plan from the present data. This may be explained by rough spatial resolution of the scanning in the east-west direction, which depends on the track interval and intrinsic resolution of the antenna. It should be noted here that the resolution of the 200 MHz antenna in the east-west direction expands to more than the antenna size of 0.6 m because the antenna emits diverged radar. Although a quantitative value of the actual resolution is not available, it is likely to be much larger than the constituent units (stone) of the buried objects, implying that the features are constructed of small units or have dissociated into pieces. In order to obtain detailed images of such objects at less than 2 m, a 400 MHz antenna with a smaller size, which allows improved spatial resolution by fine scanning, should be better than the 200 MHz one. Nevertheless, the present system using the 200 MHz antenna is useful for revealing the depth of target objects quickly, even those located at a depth over 2 m. A system with this capacity may help to examine widely distributed and deep architectural remains that have not been explored at other sites, such as Kültepe and Boğazköy.

It was possible to get three-dimensional maps of the radar signals in much less time by means of the four-wheeled vehicle as compared to the classical style in which one or more persons pull the heavy antenna and associated equipment along the transects. Our system, which dispenses with the hard labor, is very efficient in terms of working time. In this sense, GPR survey using a vehicle may become a useful tool on sites where archaeological investigation is limited to a short term.

4. CONCLUSION

We have demonstrated that the GPR survey system tested at Kaman-Kalehöyük can rapidly prove underground information up to at least 3 m. The aspects of the buried objects could be deduced from the 2D maps of the GPR data at different depth windows. The present study offers a unique concept for conducting GPR survey, which may be applicable for a variety of large-scale archaeological sites.

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