Detecting ancient water distribution system using GPR in Patara, Antalya, Turkey

Ali Aydin
Pamukkale University, Engineering Faculty
Department of Geophysical Engineering
Denizli, Turkey

Orhan Baykan
Pamukkale University, Engineering Faculty
Department of Civil Engineering
Denizli, Turkey

Erdal Akyol
Pamukkale University, Engineering Faculty
Department of Geological Engineering
Denizli, Turkey
eakyol@pau.edu.tr
Corresponding author

***Abstract*— The technique of Ground Penetrating Radar (GPR) has been applied for investigation of archeological structures. The study focusses on ancient water buried distribution lines in Patara, Antalya. The archaeological remains of water distribution system in the area are mainly characterized by baked terra-cotta for water pipe line, which were buried in the layers of sandy sediments. The selected several GPR profiles were acquired using a RAMAC system with a 200 frequency antenna which penetrates to the soil of about three or four meter in depth. The dielectric permittivity contrasts between the underground water lines and the host media are given very useful information in order for possibly significant features identified in GPR sections. GPR is a very effective method for identifying such buried archaeological remains.**

Keywords*— Ground Penetrating Radar; Water Distribution System; Patara; Antalya

I. INTRODUCTION

Development of new portable technologies in geophysics and using techniques such as the magnetic, resistivity, ground penetrating radar (GPR) and seismic refraction in archaeology gives valuable information [1], [2]. GPR is a geophysical technique used in modern archaeology which has become more accessible since the development of new portable radar technologies. The GPR method has been successfully used for archaeological prospecting and detecting shallow subsurface objects [3], [4], [5] [6], [7].

Exploitation of water distribution systems is one of very important problems in archaeology; therefore with this study has been aimed to understand the usability of GPR for detecting the baked clay pipes of the water distributing element in the ancient Patara, Turkey. GPR has been extensively used to map the surface materials at variable scales in near vicinity and it is also useful to detect the buried water lines.

Because of different electrical properties between geological formations, especially surface soils, the groundwater and baked clay objects could be obtained by electrical and electromagnetic techniques. GPR is an electromagnetic technique based on the measurement of the rate of propagation of electromagnetic waves under the ground. Such as the groundwater, the baked clay objects have a very high electromagnetic impedance contrast. At the same time, GPR can be used to show the location of the different objects under the ground which are metallic and non-metallic objects, different geological units, water table, soil thickness and sediment strata, cave and fractures, underground storage tanks, timbers, metal and baked clay objects. The GPR measurements are taken very easily that one person can control the radar by using only one hand, or optionally can be managed it with a vehicle. The measurements could be taken the speed from 0,8 to 8 kmph, also it can be adapted to the vehicle and the speed reaches to 80 kmph and it gives us the interpretation possibility of the field.

A transmitter of the GPR system is used to send electromagnetic waves to the ground. Then the waves reflect from geologic interfaces because there is a dielectric contrast between the boundaries of the layers. The reflected energy produces a picture of the reflected waves that reflects the tomography of the underground. The electromagnetic energy is reflected very strongly from prominent dielectric interfaces and these waves are recorded by the receiver and it is used the arrival times and magnitudes of the waves. After the processing of the measurements, the traces are obtained that are from adjacent source locations which are generally plotted side-by-side to form an essentially continuous time-depth profile of the stream bottom and shallow sub-strata. Consequently, GPR records including the velocities of waves can be

used to transform the time-depth profile into a depth-profile. The velocities in the sections of GPR are a function of physical properties of ground. GPR method can be used without any processing, but it is suitable for removing unwilling noise and enhancing the amplitude events of interest, after these steps, it can be uses the horizontal filtering, the velocity corrections, the distance normalization, the horizontal stacking, the gain, the migration and the vertical frequency filtering.

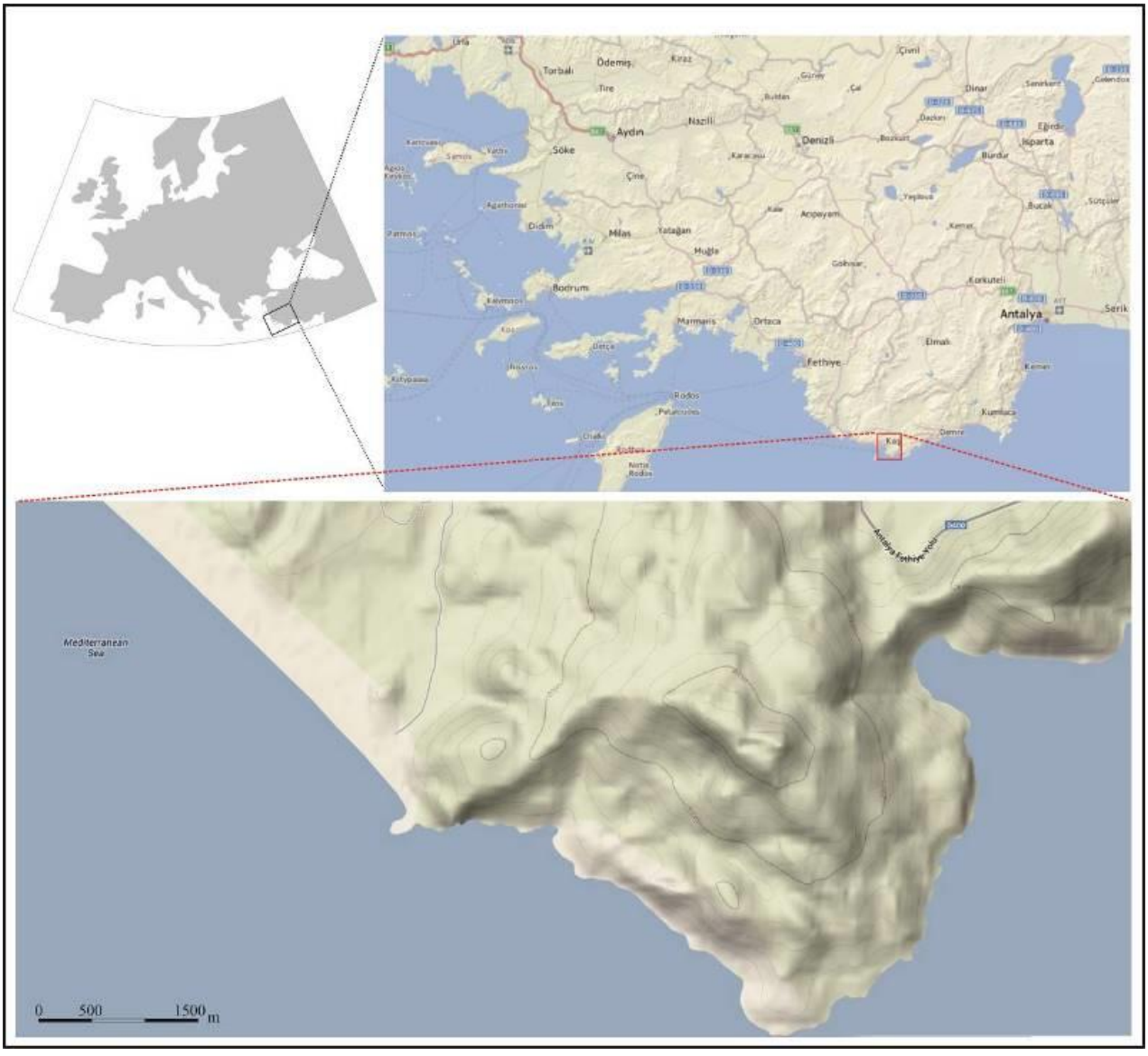
In this study it was characterized especially the water distribution systems and the subsurface ancient structures. The GPR method was used in the study which allows identifying natural and man-made structures at the near surface obtaining information for archaeological studies. This geophysical method supports showing and detecting buried water distribution elements as well as other buried remains of the ancient city Patara, Antalya, Turkey.

II. Material and Method

Patara is at the coast of the Mediterranean, nearby the modern small village Gelemis that is a small settlement of Kas, 210 km far from the famous touristic city Antalya. Patara was the major naval and trading port of Lycia, located at the mouth of the Xanthos River, until it is silted up and turned into a malaria-plagued marsh (Fig. 1).

About ten years ago, an exploration study was done by using some geophysical techniques for finding the builds which buried underground. But there were not any information of the water system in the studies. GPR is a low cost method, instrumentation is relatively simple to use, and is highly recommended for the first recognition and evaluation to address further explorations. We took the GPR profile in the dry season to avoid as much as possible water content and thus improve penetration. We will discuss the details of GPR methods with processing, the analysis and interpretation in the next section

.



A geophysical technique based on the propagation and attenuation of electromagnetic energy throughout underground, which is GPR method, is widely used to show the shape of shallow structures and objects. Its penetrations depth is very important and dependent on the dielectrical contrast of the subsoil and also the frequency of electromagnetic pulses. GPR technique designed transmitter antennas and collected after reflection in receiving devices based on the electromagnetic waves which are sent to the underground, and different the dielectric constants of the object or geologic formations will cause anomalies in the GPR records. Therefore the wave energy depends on the value of electrical conductivity of the geological units.

We used a RAMAC system with a 200 frequency antenna for this study on the researching profiles. Each profile was recorded on the geographic positioning system with high precision GPS. Profiles were given on the goggle earth position software and they were given in Fig. 2. Data acquisition of each profile was done at 200 scans/m, 1024 samples/scan and 8 bits/sample. We used the filtering processing using an acquisition Infinite Impulse Response vertical filter. The filter was ranged from 200 MHz low pass and 5 MHz high pass with 5 stacking rate. After this processing, the GPR sections are suitable for interpretation (Fig. 4).

Ten profiles were taken from the study area named as Pa3-1 which is the starting point of the profile and Pa3-2 is the end of the profile, these are shown in Fig. 2. The filtered radargrams is shown in Fig. 4. Even in unprocessing GPR radargrams sections it is possible to distinguish objects very easily. The found pipes with different diameters from GPR data or the excavation based on different parts of the city are shown in the Fig. 3.

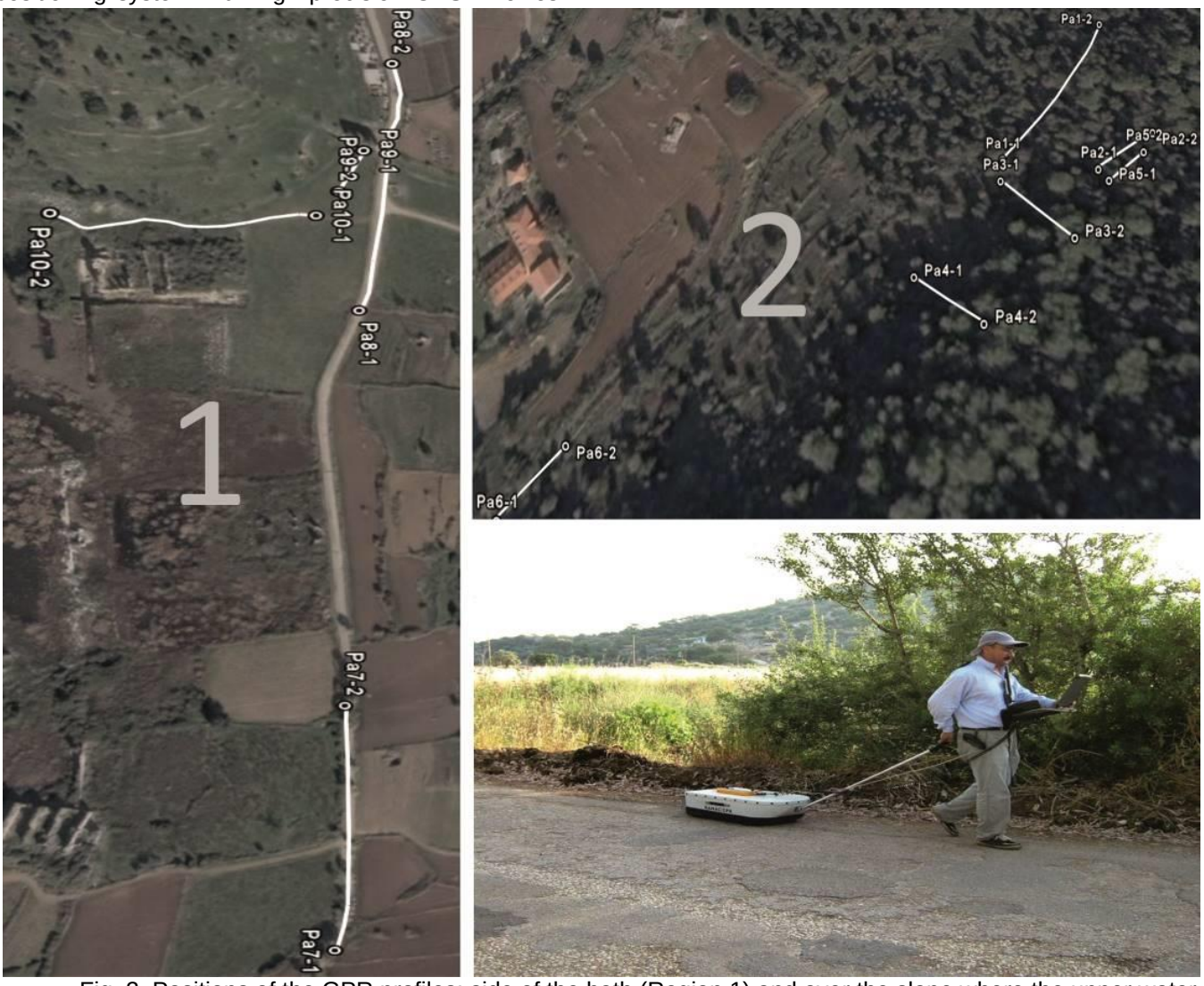


Fig. 2. Positions of the GPR profiles; side of the bath (Region 1) and over the slope where the upper water balancing reservoir exist (Region 2) and steps of GPR measurements

Fig. 3. Pipe samples obtained after excavation

III. RESULTS ANS DISCUSSION

The baked clay materials have very important variable electric and electromagnetic properties in soil medium. Using the GPR in the as study is an effective measuring method with high spatial resolution. GPR measurements were carried out on soil and sandy soil surfaces which are classed according to soil properties such as conductivity, dielectric permittivity, electric conductivity and soil electrical properties allows using geophysical exploration to detect the presence of such objects under the ground.

We have carried out a geophysical technique which was used to show the water distribution systems of the Patara ancient city, Turkey. The results of the GPR recording sections are shown in Fig. 4. The GPR radargrams images included noise using of higher frequency sources and some of GPR sections contain discontinuous stratification in the uppermost layers, which contrasts with a rapid signal attenuation below about 2 meter depth or 98 ns. In edition distinctive features in the GPR radargrams present close correspondence with surfaces, we showed the place of the water distribution systems. We selected the only three profiles for showing these buried archaeological remains. Generally the top of the water distribution system appears at a time between 42 and 50 ns, which corresponds to a depth between 0.5m and 1m as seen in Fig. 4. As seen the section of the GPR in Fig. 4 the baked clay pipes are signed the cycles and the floor of the build showed the rectangular. The same signs are used on the other radargram sections. We could use to identify geologic stratigraphy on some of the sections as seen in Fig. 4, to map the location and burial depth of columns, to identify the subsurface. Baked clay pipes in the profile 1 were seen on the radargram section in Fig. 4 at 32, 36 and 49m. In the profile 2, we could see the pipes at 11, 16 and 17m. In the radargram section it was seen very much ruin stones along the profile. As Fig. 4C, in the Profile 4 given in the Fig. 4D, the anomalies of pipes under the ground were seen very easily on the radargram at 4, 6 and 20m. All positions of the pipes taken from the radargram section were put on the map, than the lines of the water distribution systems were drawn the same map. The possible mash of the water distribution systems of the Patara system is given in the Fig. 5.

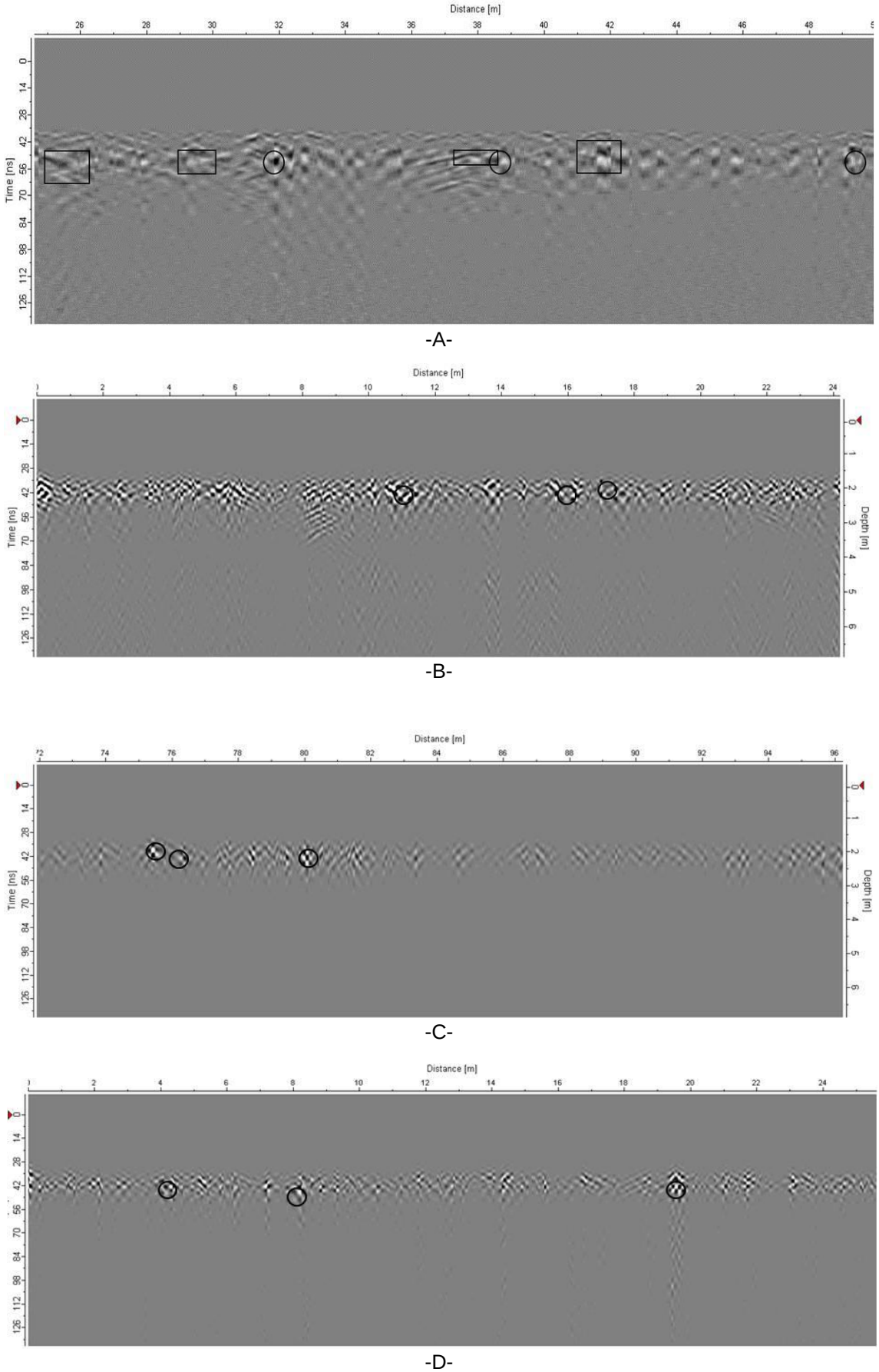


Fig. 4. GPR radargram records of the A: Profile 1, B: Profile 2, C: Profile 3, D: Profile 4 (Possible position of the buried pipe marked in circle)

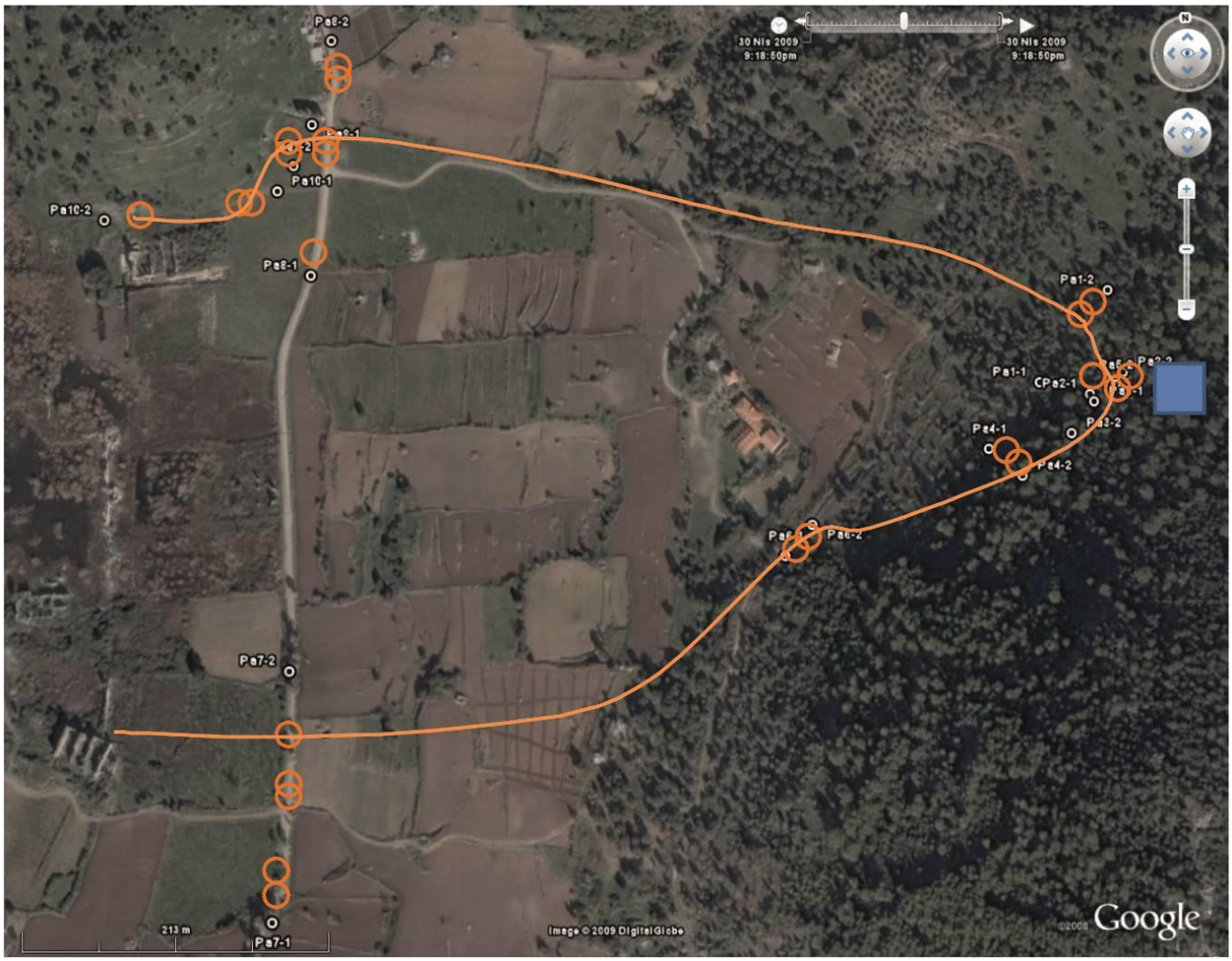


Fig. 5. Possible pipeline locations in the city Patara detected by GPR (some of them presently proofed by excavations)(Based on Google Maps)

IV. CONCLUSIONS

As illustrated above, GPR is a powerful tool to find the locations of the baked clay materials close to other ancient ruins under the ground. In ancient city Patara in the Mediterranean region which was ceremonial center in ancient age looking about the water distribution system which were demonstrated that the effective geophysical method enhance the capabilities of individual technique, providing useful information at different depth ranges of a buried structure based on the contrast of physical properties of the subsoil.

The method offer the possibility to characterize and reconstruct the geometry of the structures without destroying the ancient ruins as the water distribution systems, helping to find solutions to a question of archaeological or engineering significance. In the particular case of archaeological studies, the high precision imagining of these GPR radargram sections allows inferring the interface of successive constructive stage boundaries and walls (see Fig. 4). Otherwise such characteristics are impossible to define unless the structure is exposed and excavated which may result in an exhaustive and much more expensive task. The geophysical method in addition with surface archaeological studies in the zone provides a high resolution image of a buried structure.

In the last decades to explore the shallow subsurface phenomenon, GPR is a relatively modern and effective and widely utilized technique. GPR for searching and finding of water distribution system has been applied to Greek-Roman ancient city Patara, and given very useful clues. Some of them are as follows: mapping the location and burial depth of columns, terra-cotta (baked clay) pipes, imaging man-made subsurface structures, detecting the different types of canals, archaeological remains, cemeteries, floors of buildings etc.

ACKNOWLEDGMENT

We are thankful for their support and encouragement during the field studies to the staff of the excavation team in Patara, namely the chief consultant Prof. Dr. Fahri Isik and head of excavation team Havva Isik from Archeology Department in Akdeniz University.

REFERENCES

[1]R. E. Chavez, M. E. Camara, A. Tejero, L. Barba, L. Manzanilla, “Site characterization by geophysical methods in archaeological zone of Teotihuacan, Mexico,” Journal of Archaeological Science, 2001, vol. 28, pp. 1265–1276.

[2]D. De Domenico, F. Giannino, G. Leucci, C. Bottari,. “Integrated geophysical surveys at the archaeological site of Tindari,” Journal of Archaeological Science, 2006, vol. 33, pp. 961–970.

[3]J. L. Davis, A. P. Annan, “GPR for high resolution mapping of soil and rock stratigraphy,” Geophysical Prospecting, 1989, vol. 37, pp. 531-551.

[4]A. P. Annan, J. E. Scaife, P. Giamou, “Mapping buried barrels with magnetics and ground penetrating radar,” 60th Annu. Int. Mtg. Soc. Expl. Geophys, 1990, pp. 422-423.

[5]V. Basile, M. T. Carrozzo, S. Negri, L. Nuzzo, T. Quarta, A. V. Villani, “A ground penetrating radar survey for archaeological investigations in urban area (Lecce, Italy),” Journal of Applied Geophysics, 2000, vol. 44, pp. 15-32.

[6]G. Leucci, “Ground-penetrating radar survey to map the location of buried structures under two churches,” Archaeological Prospection, 2002, vol. 9 (4), pp. 217-228.

[7]M. T Carrozzo, G. Leucci, S. Negri, L. Nuzzo, “GPR survey to understand the stratigraphy at the Roman ships archaeological site (Pisa, Italy),” Archaeological Prospection, 2003, vol. 10 (1) pp. 57-72.