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Buried underground archaeological structures investigation with electrical method: diyarbakır Ulu Mosque (Turkey)

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The study area used as a temple during the pre-Christianity term, Mar Thoma Church after the adoption of Christianity and currently used as The Ulu Mosque. The most important feature of this mosque which has hosted many civilizations is moving the architectural structures belongs to the church term to the present day. In this study, the presence of archaeological structures buried under the Ulu Mosque were investigated with geophysical methods. Magnetic, ground penetrating radar (GPR) and electrical methods were used for this purpose. Due to the distorting surface effects and presence of large underground water mass, the magnetic and ground penetrating radar methods did not give successful results. Despite the study are consist of basalt rocks, successful results have been obtained with the electrical method. The reason for this success can be explained by the buried underground archaeological structure filled with water. It is thought that the structure is to be a water cistern. The source of the water that feeding the cistern is not known. In order to be able to prove the presence of this water historical waterways were investigated. Diyarbakir waterways map were created from the obtained data. The map of the waterways drawn with as a result of historical research and geophysical surveys data obtained from The Ulu Mosque are consistent with each other.

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Keywords: Electrical method, 2D-3D inversion, archeogeophysics, The Ulu Mosque, Historical waterways

1. Introduction

The study area (Diyarbakir Ulu Mosque) is located inside the city walls of the Diyarbakir Castle where the west of the axis of the Yenikapi Gate and Mardin Gate in Balikcilarbasi neighborhood (Fig. 1). There are 8 churches inside the city walls of Diyarbakir which were made at various times. These are Mar Thoma, Mother Maria, Mar Kosma, Dumyana prophet Ilyas, Tehfilker Mar Yuhanna, Armenian and Saint Croc Churches. It is known that the Ulu Mosque was a temple before the Christianity term. The history of the temple construction started in prophet Musa (as Moses) term (XIV century BC) according to the Evliya Celebi's travelogue (Okumus 2006).

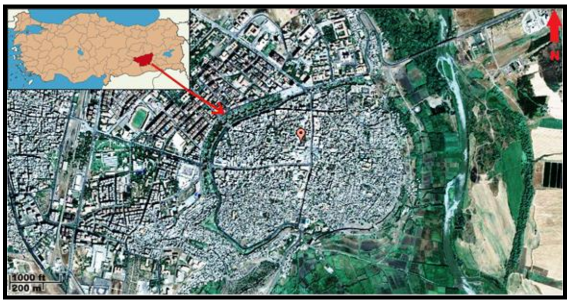

Fig. 1. The location of the study area.

It is considered that the temple had been converted to the church of Mar Thoma after the Christianity being an official religion. The church converted into a mosque in 639 and various repairs were made (Tuncer 1973). The Ulu Mosque is a group of structures covers a rectangular area on east-west direction. These structures are listed around the courtyard. The Hanifiler Mosque entrance is at the south of, Safiler Mosque and Madrasa of Mesudiye are at the north of, main entrance of the courtyard is at the east of and the second entrance is at the west of the rectangular courtyard. There is a fountain in the middle of the courtyard.

There are many spolia structural elements from Roman-Byzantine buildings in the mosque. The porches located in the east and west of the courtyard are two-storied. The columns have corinthian titles on each floor of the porches. Upper floor columns are formed from one piece and sub-floor columns are formed by combining two or three pieces. Square cross-section a tower-shaped minaret is adjacent to the southern wall of the mosque. The upper part of the minaret body ends with a cylindrical second body and a tapered conical hat. The underside of the body form is evidence that this part was a steeple during the church term.

Due to the wide basalt propagation in Diyarbakir and it's environment, it has been used as a building block in architectural structures during the historical term. The walls surrounding the city were made of basalt and has 12-

15 m height and 5 km length. Basaltic rocks had been used on the structure of the outer wall and floor coverings at Ulu Mosque. In this study, the presence of the buried archaeological structures under the Uu Mosque were investigated by geophysical methods.

2. Geophysical investigations

2.1 Study plan

The aim of this study was to investigate the presence of the buried archaeological structures under the Uu Mosque. Magnetic, ground penetrating radar (GPR) and electrical methods were used for this aim. In order to implement the magnetic and ground penetrating radar methods, the profiles were formed each 1 meter intervals outside areas of the fountain in the courtyard (1152 m^2 rectangular area). Due to the inside of the courtyard was decorated with basalt stones, the number of the profiles were restricted for the implementation of the electrical method. In this study, it was considered the use of flat-footed electrode technique for to avoid the destruction of historic buildings but because of the high air temperature (in the shade 50 °C) and basalt stones flooring classic electrode technique was preferred.

The number of the profiles were restricted for the implementation of the electrical method with classic electrode technique due to the inside of the courtyard was a protected area and also much and unplanned constructions at the outside the courtyard. Totally of 19 profiles were created inside and outside of the courtyard. The electrode and profile intervals were 1 meters (Fig. 3).

Fig. 2. Diyarbakır Ulu Mosque courtyard view.

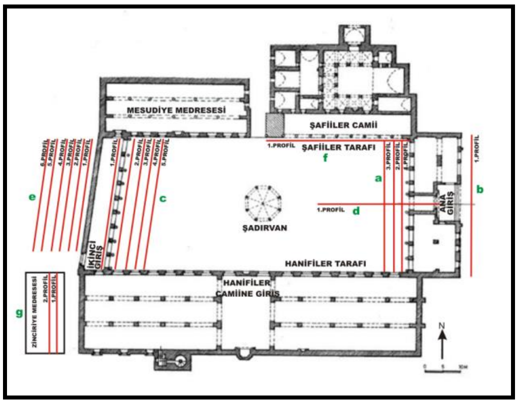

Fig. 3. Electrical measurements and profiles.

2.2 Geophysical surveys

2.2.1 Magnetic and GPR data acquisition and interpretation

Initially the magnetic method was applied in the study area. The use of magnetic methods in archeogeophysical studies is practical and as well as guidance for the other methods (Gibson 1986; Young and Droege 1986; Drahor et al 1995; Drahor and Kaya 2000; Ates 2002; Ozyalın 2003; Ekinci 2005). Due to the presence of electrical transformer, power cables, rusty iron and heavy metal structures around the study area only disruptive impacts can measured on the surface.

GPR method is very commonly used and preferred method in archeogeophysical researches because of the application easiness (Sambuelli, et al 1999; Daniels 2000; Kadıoğlu et al 2008). Due to the presence of buried structures preventing the penetration of EM signals under the ground, the GPR method yielded unsuccessful results.

2.2.2 Electrical resistivity data acquisition

Electrical method is one of the most widely used methods in the detection of buried structures in archaeological sites. This application is very successful method in detecting walls, building foundations and the caves. The success of the method depends on different resistance characteristics between the potential archaeological targets (walls, roads, caves, ruins, ditches, etc.) and the surrounding environment. The purpose of this technique is to display the underground through the selected electrode arrays (Wenner, Schlumberger, dipole-dipole, pole-pole, etc.) (Barker 1981; Griffıths et al 1993; Dahlin 2001; Drahor 2006). The electrical resistivity data interpretation obtained using inversion techniques has become widely used method in recent years. 2D and 3D inverse modeling techniques are used in imaging studies (Drahor 2006; Sasaki 1989; Loke and Barker 1996).

In this study, the electrical measurements carried out by using ARES GF multi-channel resistivity device. Wenner electrode array is very successful in determining the lateral discontinuities. Therefore, this array was preferred during the implementation of the method. The measurements were limited to the 19 profiles due to the previously mentioned problems in a total of 7 areas (a, b, c, d, e, f, g) inside and outside of the courtyard (Fig. 3). The profile numbers and lengths are changing according to the size and shape of measurement areas and electrode and the profile intervals were selected 1 meter for each area.

In order to ensure the current in the bottom of the ground covered with basalt, firstly 15-20 cm deep holes were excavated match the diameter of the electrode. The current passes were tested by nailing the electrodes in this holes. The profiles were created after observing the current passes. Salt water were used to overcome the contact resistance. The implementation of the electrical method on Basalt floor increased twice as much of this study importance.

2.3 Dimensional (2d) and (3d) inversion analysis and interpretation of electrical resistivity survey

The measured variable quantity, apparent resistivity, is used to calculate the true resistivity via different calculation methods, one of which is the inversion method. These data can be inverted automatically to create an image of the true resistivity. As a result of this electrical survey, we can create more realistic images correlated with the true resistivity and depth information for subterranean archaeological structures. The pseudosection forms the input for the inversion techniques, which produce a two-dimensional subsurface model (Loke and Barker 1996). The two-dimensional resistivity data collected were evaluated using a two-dimensional robust inversion technique via the Res2dinv software (Geotomo 2002; Dogan and Papamarinopoulos 2003) and the three-dimensional resistivity data collected were evaluated using a three-dimensional robust inversion technique via the Res3dinv software (Papadopoulos et al 2006). These are packages program prepared with the aim of conducting two and three dimensional inversion and view maps analyses of measurements taken for many arrays and were used in this study. In the inversion analysis of the Wenner data values, which were obtained from nineteen profiles in the work area, the smoothness-constrained least squares method was used and the inversion model sections of the resistivity data were obtained using Res2dinv and Res3dinv softwares. Afterwards, the data obtained from Res3dinv program, transformed into three-dimensional image by RockWorks program.

The values of the resistivity varies between 5-101 ohm.m according to the top view maps, vertical cross-sections and three-dimensional images (Figs. 4, 5, 6). There were 3 profiles created with north-south direction in the main door area located in the courtyard of the mosque. Length of the profiles were 28 meters and profile ranges were 1 meter. Top view maps, vertical sections and three-dimensional images obtained from these profiles shown on Fig. 4, respectively. The areas have different resistivity values are symbolized with A, B, C and S letters. The resistivity values varies between 77-101 Ohm.m in A area. The upper surface of this area at the same level with the floor and has approximately 24 m × 2 m × 1 m dimensions. The resistivity values varies between 77-101 Ohm.m in B area too. The upper surface depth of this area is 1,08 meters and has 7 m × 2 m × 4 m dimensions. The resistivity values varies between 35-58 Ohm.m in C area. The upper surface depth of this area is 0,50 meters and has approximately 3,6 m × 2 m × 2,29 m dimensions. The resistivity values varies between 3,5-29 Ohm.m in S area. This area is in two parts. The upper surface depth of the first part is 1,08 meters and has approximately 6 m × 2 m × 3.30 m dimensions. The upper surface depth of the second part is 1,08 meters too and has approximately 7 m × 2 m × 3.30 m dimensions. These two parts covers a large portion of the total area. Very low resistivity values (3.5 ohm.m) in the S area are noteworthy. It is considered that this area covered by water.

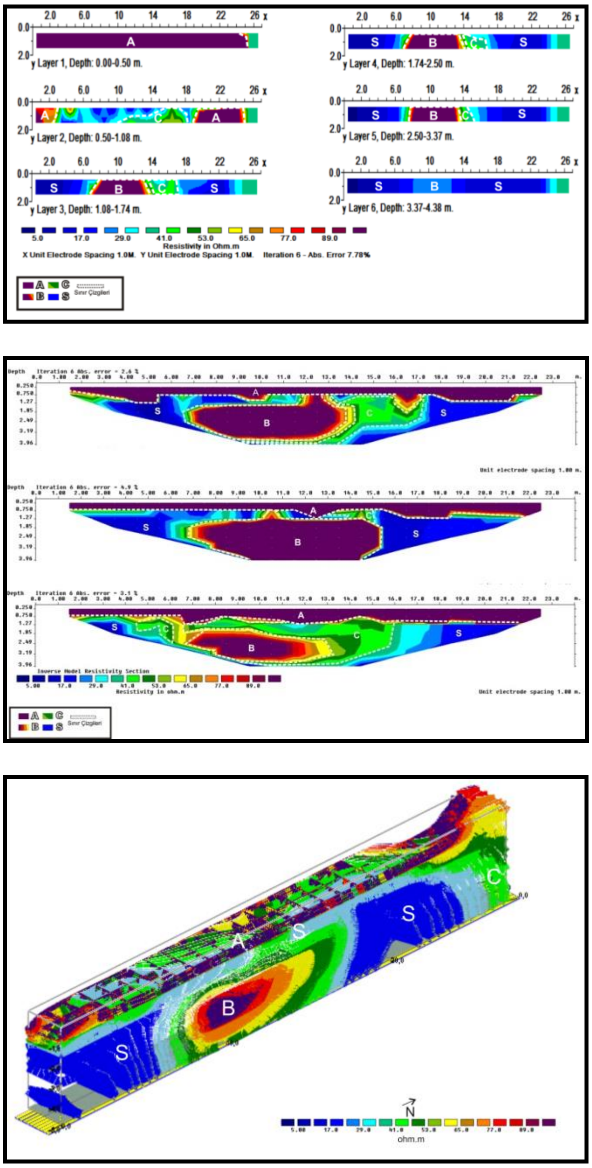

Fig. 4. Top view maps, vertical sections and three-dimensional images obtained from the main door area located in the courtyard of the mosque.

There were 5 profiles created in a north-south direction around the columns of the west gate located in the courtyard of the Ulu Mosque (Fig. 5). Length of the profiles were 24 meters and profile ranges were 1 meter. Top view maps, vertical sections and three-dimensional images obtained from these profiles shown on Fig. 5, respectively. The areas have different resistivity values are symbolized with A, B, E, F, G, M, S and K letters. The resistivity values varies between 77-101 Ohm.m in A area. The upper surface of this area at the same level with the floor and has approximately 27 m × 3 m × 1,74 m dimensions. The resistivity values varies between 41-65 Ohm.m in B area. The upper surface of this area at the same level with the floor. The resistivity values varies between 5-29 Ohm.m in S area. The upper surface depth of this area is 1,08 – 4,38 meters and has approximately 18m × 4 m × 3,30 m dimensions. It is considered that this area covered by water. The resistivity values varies between 5-29 Ohm.m in K area. The upper surface depth of this area is 0,75 meters and has approximately 21 m x 3 m x 1 m dimensions. The resistivity values varies between 35-58 Ohm.m in G area. It is seen on the top view maps that this area is situated between the depths of 1.74-2.50 meters. The resistivity values varies between 35-77 Ohm.m in E area. It is seen on the top view maps that this area is situated between the depths of 1.74-2.50 meters too. The resistivity values varies between 58-83 Ohm.m in M area. It is seen on the top view maps that this area is situated between the depths of 2,50-4,38 meters. It is considered that the G and E areas are the upper section of M area. The resistivity values varies between 35-58 Ohm.m in F area. The upper surface depth of this area is 1,74 meters and has approximately 5 m x 4 m x 1,80 m dimensions.

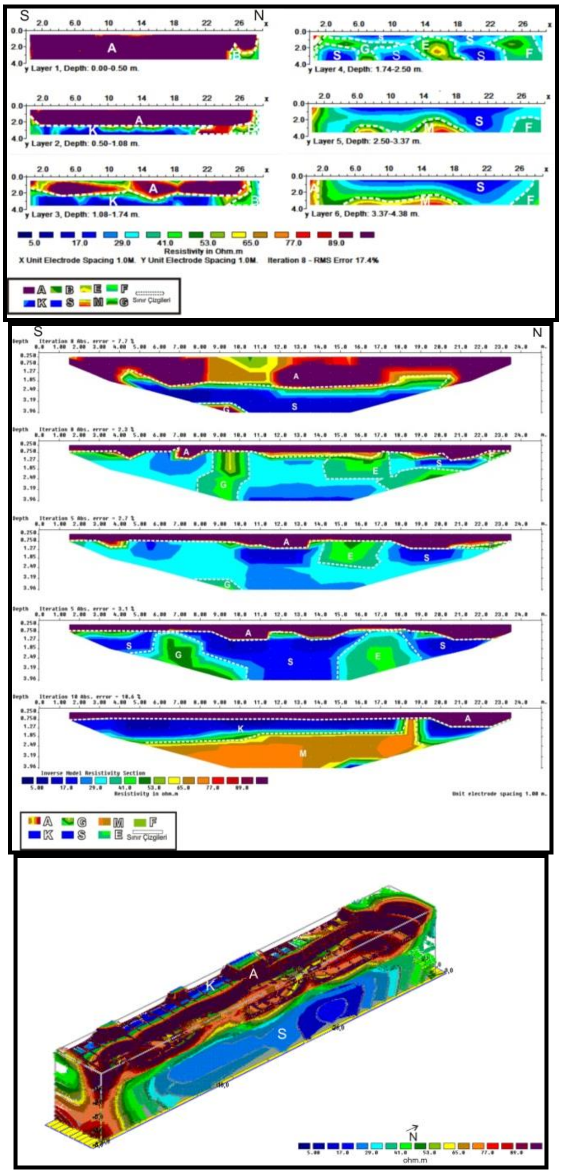

Fig. 5. Top view maps, vertical sections and three-dimensional images obtained from around the columns of the west gate.

There were 6 profiles created in a north-south direction behind the Ulu Mosque outside the courtyard (Fig. 6). Length of the profiles were 22 meters and profile ranges were 1 meter. Top view maps, vertical sections and three-dimensional images obtained from these profiles shown on Fig. 6, respectively. The areas have different resistivity values are symbolized with A, B, C, D, E, F, G, H, I, J, K, L, M and S letters. The resistivity values varies between 5-29 Ohm.m in S area. The upper surface depth of this area is 0,50 meters and has approximately 15 m × 4 m × 3,30 m dimensions. As seen in the three-dimensional images this area has rectangular shape. A, B, D, E, G, H, I, K and M areas are situated between the depths of 0 - 1,08 meters and they have different resistivity values and dimensions. The common feature of these areas is not be seen after the 1,08 meter depth. The resistivity values varies between 58-101 Ohm.m in A area, 65-101 Ohm.m in B area, 58-101 Ohm.m in D area, 58-101 Ohm.m in E area, 58-101 Ohm.m in G area, 41-71 Ohm.m in H area, 41-71 Ohm.m in I area and 58-101 Ohm.m in M area, respectively. It is considered that the different resistivity values due from the different geological units and contacts with S area covered by water. The resistivity values varies between 5-29 Ohm.m in K area. The upper surface of this area at the same level with the floor. The resistivity values varies between 29-58 Ohm.m in C area. This area is situated between the depths of 1.74-2.50 meters in pieces. The resistivity values varies between 58-101 Ohm.m in F area. The upper surface depth of this area is 0,50 meters and has approximately 9 m × 2 m × 2,19 m dimensions. J and L areas are situated between the depths of 0 - 1.74 meters and their resistivity values varies between 47-58 Ohm.m and 58-101 Ohm.m, respectively.

3. Discussion

There were 3 profiles created with north-south direction in the main door area located in the courtyard of the mosque (Fig. 3). Accordingly, the thickness of the fundamental building was found average 1.08 m. There was a large mass of water observed between 1:08 to 4:38 m depth which has 7 m × 2 m × 3.30 m dimensions in this area. This structure surrounding the mass of water has a geometric shape and a covered swimming pool is the view. It is seen that there is a part of the S area between A and B area over the pool. The upper surface depth of this area is 0,50 meters and has approximately 9 m × 1 m × 0,50 m dimensions. It is clearly seems that on the top view maps, vertical sections and three-dimensional images this area is a water canal.

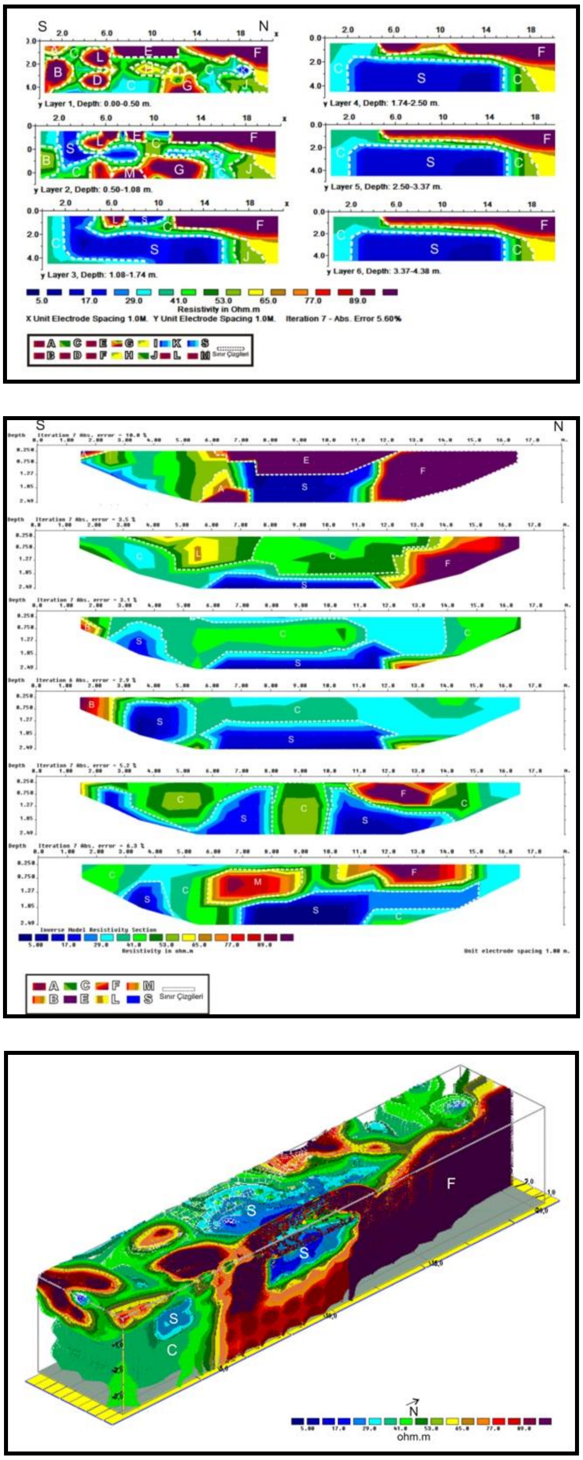

Fig. 6. Top view maps, vertical sections and three-dimensional images obtained from behind the Ulu Mosque.

There were 5 profiles created in a north-south direction around the columns of the west gate located in the courtyard of the Ulu Mosque (Fig. 5). Accordingly, the thickness of the fundamental building was found average 1.74 m. There was a large mass of water observed between 1:08 to 4:38 m depth which has 18 m x 4 m x 3.30 m dimensions in this area. This structure surrounding the mass of water has a geometric shape and a covered swimming pool is the view too. There is a thin, long and filled with water structure located over the pool with 21 m x 3 m x 1 m dimensions. This structure also seems that as a water canal too.

There were 6 profiles created in a north-south direction behind the Ulu Mosque outside the courtyard (Fig. 6). Accordingly, the thickness of the fundamental building was found average 0.50 m. There was a large mass of water observed between 1:08 to 4:38 m depth which has 15 m x 4 m x 3.30 m dimensions in this area. This structure surrounding the mass of water has a geometric shape and a covered swimming pool is the view too.

3.1 Determination of the water canals

As a result of the resistivity measurements large water areas have been observed in geometric areas under the Ulu Mosque. This water confirming the resistivity data flowing from the fountain year-round and the source is unknown. Unknown water source in the pool suggest that the water canal here is done in the archeological time. The ancient water resources of Diyarbakir walls inside seen in Fig. 8. There are some informations about the historic water canals and aqueducts although they could not come up to the present (Fig. 7). However, it could not be reached further information about the water system providing transportation to city

Fig. 7. Diyarbakır aqueduct.

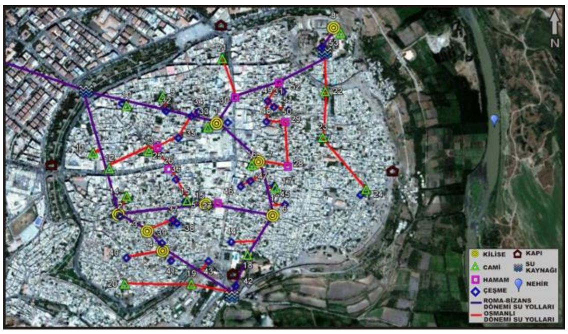

Fig. 8. Roman-Byzantine and Ottoman Period waterways in Diyarbakir.

There is very efficient water potential existing even today in Diyarbakır Ulu Mosque. The water is continuously flowing from the fountain in the mosque. It is unknown that which water system transport the water to the Ulu mosque. The places that the water channels can pass through were investigated across the city. The Researches show that there are three water supply in the city area. These are Kal'a, Biophysics and Alidede sources (Fig. 8, 9). It is considered that the system carrying the water from sources have been established during the Roman period and developed in the Byzantine and Ottoman periods. The reason of this idea is the Romans that prevailing 342 years in this region, who are famous in ancient architecture, urban planning and water transport systems. The best evidence of the system developing in Byzantine and Ottoman period is the Ulu Mosque. There are some architectural structures from Roman, Byzantine and Ottoman periods even today in the Ulu Mosque and it is known that this place have been used as Mar Thoma Church during the Byzantine period (Tuncer 1973). In order to draw the historic Diyarbakir water system determined the places of ancient buildings (church, mosque, bath, fountain, etc.). Throughout the history, people have been gave great importance to religious places for worship and established the infrastructures at these places. Therefore, the places of the surviving churches which were built in the Roman-Byzantine periods were determined and drawn the water canals from water resources to these churches (Fig. 8).

Due to the beginning of the Ottoman period after the Roman-Byzantine periods in the region, the water ways of the Ottoman period marked on the map in Fig. 8 by taking into consideration the mosques, baths and fountains. While drawing the waterways a distribution was made according to the importance of historical buildings. As can be seen in Fig. 6, the Ottoman used and developed the Roman and Byzantine's structures.

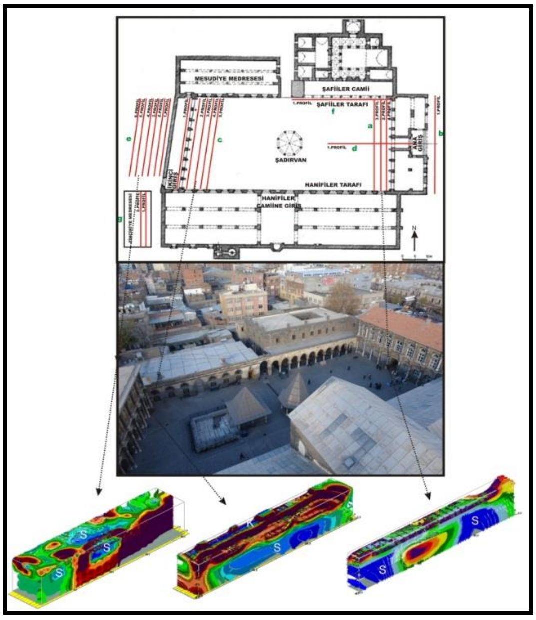

Fig. 9. Three-dimensional images obtained from in the courtyard, the western door pillar edge and behind the Ulu Mosque.

3.2 Comparison of historical waterways with geophysical data

The establishment of the city of Diyarbakir dates back to BC VII thousand years (Beysanoglu 1998). It is known that the Ulu Mosque was used as the Mar Thoma Church in the archaeological historic (Tuncer 1973). Therefore, it is not too difficult to interpret that the mosque waterways based on the ancient history. The source and arrival path of the water flowing from the fountain in the courtyard of the Ulu Mosque are unknown. It is evidence that this water has not been carried by recent historic water system.

Three-dimensional images obtained from in the courtyard, the western door pillar edge and behind the Ulu Mosque are given in Fig. 9 with positions in accordance. If we consider that the areas symbolized as S are water in these images, it is possible to see the view of the water cistern and related channels in the courtyard.

As can be seen in Fig. 10, the water carrying by canal A to the cistern and distributing by canal B and C to the city. In this study it is clearly understood that the waterways map that drawn as a result of historical researches is compatible with geophysical data obtained from the Ulu Mosque.

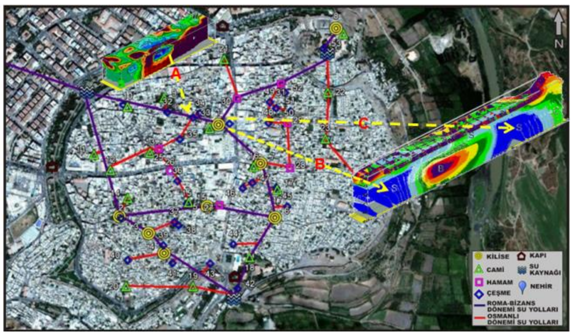

Fig. 10. Comparison of three-dimensional images obtained from in the courtyard, the western door pillar edge and behind the Ulu Mosque with historical waterways.

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