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GEOPHYSICAL PROSPECTION FOR MAPPING OF THE QANAT SYSTEMS: APLLICATION TO THE QANAT SYSTEM OF AGIA PARASKEYH-CHORTIATI OF THESSALONIKI (N. GREECE)

TSOURLOS P.[1], VARGEMEZIS G.[1], TSOKAS G.[1], ALEXANDROU K.[1] AND TZELI P.[1]

ABSTRACT

In this paper the application of the 2-D electrical and ground penetrating radar (GPR) geophysical techniques for locating subsurface water collective systems (qanats) is demonstrated.

Qanats can be found in many Greek regions and despite the fact that most of them are inactive, in some areas qanats are still being used as water providing systems. For both environmental and historical reasons there is a need that existing qanats are protected, fully mapped and studied in view of their geological and hydrogeological environment.

Geophysics can play a significant role in this procedure. Synthetic modeling and inversion examples presented in this work support the above claim.

Further, in this paper the electrical and GPR techniques are used to map a well-known and already studied Qanat system at the area of Agia Paraskevi at the outskirts of the Chortiatis village 20 kilometers away from the city of Thessaloniki. The interpreted features delineated by the geophysical techniques are in very good agreement with the known qanat structure.

Overall, it is shown that geophysical techniques can be used to aid qanat mapping as well as to provide useful information about their general setting.

KEY WORDS: qanat, GPR, 2-D resistivity, inversion

1. INTRODUCTION

The technique of building subsurface tunnels for collecting and transporting water (qanats) has its roots probably in the pre-historic era and has been used widely all over the world for many centuries.

Qanat systems are abandoned in Greece. Most of them are inactive either due to the change of water demands or due to natural disasters (earthquakes, floods). Yet, there is a significant number of active systems which are still being used for providing water for agriculture and domestic use. Vavliakis (1989) and Vavliakis and Sotiriadis (1993) have presented thorough studies of Qanat systems in Greece.

Due to the vicinity of qanat systems to the ground surface, their waters are susceptible to pollution. Thus, it is important that active qanats are fully charted and explored in view of their geological and hydrogeological condition.

Further, a study of inactive qanats will either help to explore the possibility of reusing these systems or will provide significant historical information.

In this framework, geophysical techniques can be used to chart qanats and to provide information regarding their geological environment. In particular, since qanats are effectively shallow buried voids (either air or clay filled), they are an ideal geophysical target. 2-D electrical and GPR techniques are widely used for void detection and many successful applications of the techniques can be found in literature (Tsourlos, 1995; Tsokas et al., 1997). These techniques were tested to the known qanat system and proved particularly successful.

2. AGIA PARASKEVI QANAT

The explored qanat system is situated at the area of Agia Paraskevi at the outskirts of the Chortiatis village (*prefecture of Thessaloniki*) (Figure 1).

The qanat of Agia Paraskevi was fully studied by Vavliakis et al. (1995). The qanat system was build during the Othoman period to supply water to the city of Thessaloniki and currently is still being used to provide water to several facilities (hosp

1. Geophysical Laboratory, Department of Geology, Aristotle University of Thessaloniki, 54006 Thessaloniki, Greece

The qanat is constructed at the tectonic contact between Triassic limestone and the Triassic-Jurassic phyllitic basement. The qanat was bored into quaternary sediments and uses the impermeable phyllites as its floor. Water comes from an aquifer related to the fractured Triassic limestone and is driven into the qanat tunnels. A sketch map of the water collection system is shown in Figure 2.

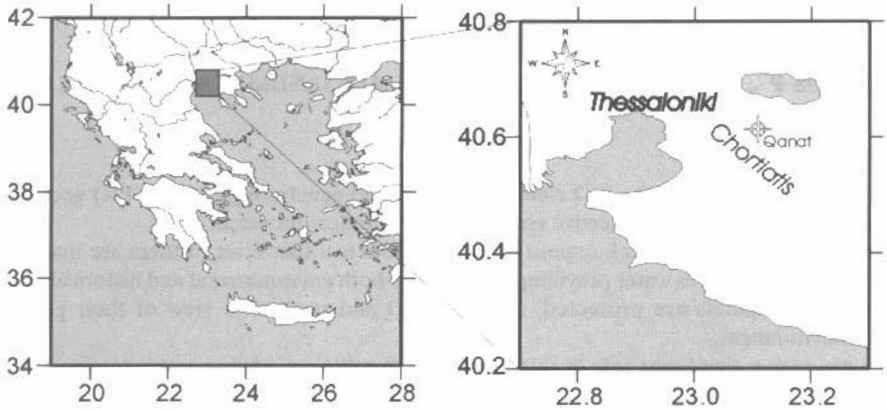

Figure 1: Location map of the Agia Paraskevi qanat

The qanat has two tunnels A, B (Figure 3) with a total length of 74m. The average tunnel width is 0.6cm and its maximum height is 1.6m. There are several observation wells and at places tunnels are quite wide. The maximum burial depth is 7.9m and tunnel A is situated approximately 1.5m higher than tunnel B.

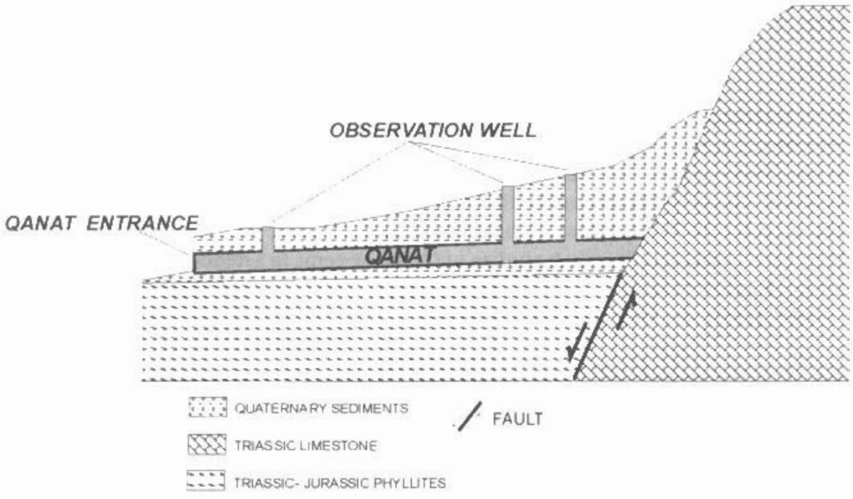

Figure 2: A sketch showing the Agia Paraskevi qanat and the geological setting

3. MODELLING AND PROCESSING

2-D resistivity measured data in the form of pseudosections of apparent resistivity produce a distorted image of the subsurface resistivity. Inversion is currently the standard procedure to obtain a realistic estimate of the true resistivity based on the field observations. In this work a flexible non-linear 2-D scheme (Tsourlos, 1995; Tsourlos et al., 1998) based on a smoothness constrained algorithm was used to invert the collected resistivity data. The algorithm is iterative and fully automated and is based on a reliable 2.5D finite element forward modeling scheme, which is also used for calculating the Jacobian matrix when necessary.

The inversion aims to calculate a subsurface resistivity estimate **x** for which the difference **dy** between the

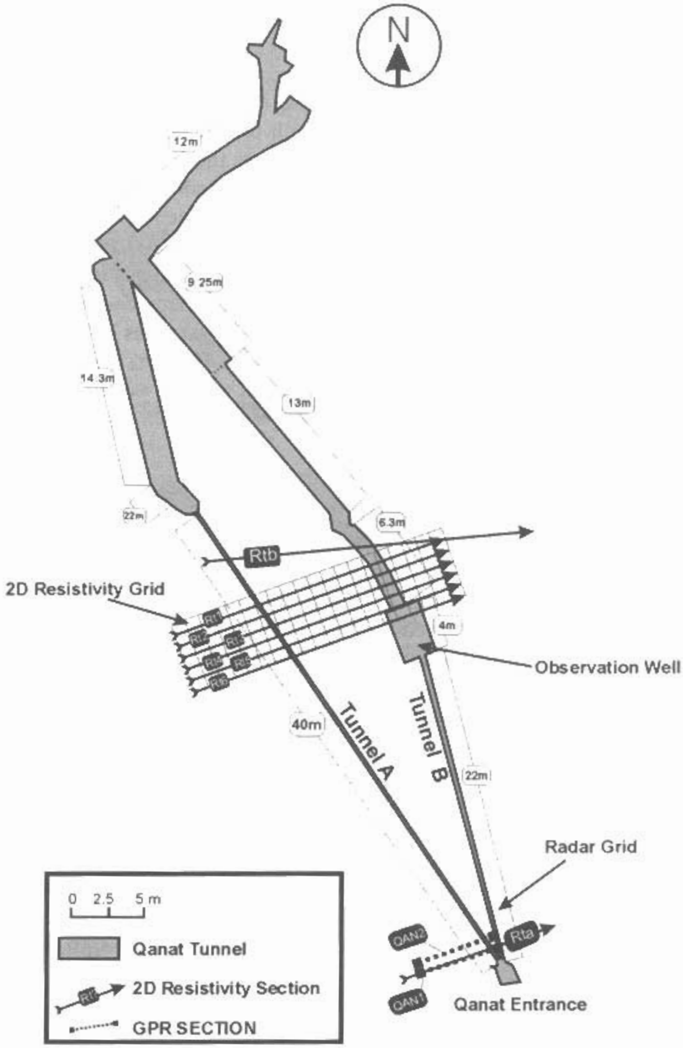

Figure 3: A plan view of the Agia Paraskevi qanat (after Vavliakis et al., 1995) with the measured geophysical sections.

observed data $\mathbf{d}_{obs}$ and the modeled data $\mathbf{d}_{calc}$ (calculated using the forward modeling technique) is minimized. The smoothness inversion scheme, tries to minimize the data difference vector **dy,** under the condition that the roughness of the produced model is minimized. The resistivity correction at the k+1 iteration is given by:

$$\mathbf{dx}_{k+1}=[(\mathbf{J}_k^T\mathbf{J}_k+\mu\mathbf{C}_x^T\mathbf{C}_x+\mathbf{C}_z^T\mathbf{C}_z)]^{-1}\,\mathbf{J}_k^T\mathbf{J}_k\,\mathbf{dy}_k \qquad (1)$$

where $\mathbf{C}_x$, $\mathbf{C}_z$ are matrices which describe the smoothness pattern of the model in the x,z, directions, $\mathbf{J}_k$ is the Jacobian matrix estimate and $\boldsymbol{\mu}$ is the lagrangian multiplier.

To illustrate the effectiveness of the above procedure the model of Figure 4a, which simulates two qanats (filled with air and clay respectively) was used, to produce a 2-D data set using the 2.5 FEM forward modeling scheme. The obtained apparent resistivity data, depicted in a pseudosection form in Figure 4b, were subsequently inverted and the results are shown in Figure 4c. The inverted subsurface resistivity image is very close to the initial model and is definitely a major improvement when compared to the pseudosection of Figure 4b, illustrating that qanats are a particularly good target for the resistivity method. Note that a similar processing procedure was followed for all the real data collected from the studied area.

GPR is another geophysical technique that is particularly suited for shallow void detection. To illustrate its effectiveness we used a 2-D Finite Difference Time Domain GPR forward modeling technique (Giannopoulos, 1997) to simulate the 2-D response of an air filled qanat (Figure 5a). FDTD is a marching-on in time procedure. It propagates the EM waves in the mesh originated by imposing the initial conditions at the source node. For the model presented here, we used a mesh of 300x300 nodes with the elementary spatial step being set to 0.02m resulting in a simulated space of 6x6m. Scan line is centered above the air-earth interface and have a length of 4m (200 nodes). The transmitter and receiver separation was 0.08m and one trace was obtained every 0.08m as well. The time step was 4.7E-11 seconds and 1000 time iterations were calculated for each trace, resulting in a 47 nanoseconds time window. The produced model is shown in Figure 5b and the pronounced hyperbola-like anomaly indicates the pattern of the anomalies, which we would anticipate in the field data.

GPR data processing is a very delicate procedure and should me made cautiously. The processing for the GPR data collected in this work involved simple procedures. The data was subjected to temporal low pass filtering in order to cut the instrument induced high frequency noise. Further, dewow was performed to remove the inductive component from the received signal. Finally a 7 point window was employed for temporal stacking which enhanced the signal strength.

4. MEASUREMENTS AND INTERPRETATION

All resistivity 2-D data sets were collected using the dipole-dipole array with a maximum N separation maxN=11. Data were obtained with a SAS 4000 Terrameter using a multicore cable with a hand driven switch box. Survey lines positioning was arranged so that physical obstacles existing in the site (buildings, fences) were avoided.

Two initial reconnaissance 2-D resistivity sections Rta, Rtb were measured at the area as shown in Figure 3. Twenty-four (24) electrodes were used and the inter-electrode spacing for Rta was 0.5m and for Rtb was 1m. The pseudosections of the data sets Rta, Rtb are depicted in Figures 6a, 6b respectively.

The inversion results of section Rta (6 iterations, RMS error 2.5%)are shown in Figure 6c. Tunnel A is clearly depicted as the central high resistivity anomaly. Further, part of Tunnel B is depicted on the right hand side of the section. A similarly good inversion picture (Figure 6d) was produced for section Rtb (6 iterations, RMS error 4.2%): Tunnel B is depicted clearly. Note that for both cases the tunnel dimensions and burial depth produced by the geophysical interpretation are in a very good agreement (within 10%) with the existing structures.

Further, a grid of 18 GPR sections was measured at a selected region shown in Figure 3. The PULSE EKKO 1000 bistatic system was used with an antenna separation of 0.5m. The nominal frequency of the antennas was 225MHz and the spatial sampling was set to 10cm. Data processing was carried with the procedure explained in the previous section.

Two of the measured transects are presented here. The first one (Qan01) coincides with the resistivity section Rta and is shown in Figure 6e. At 6 meters from the start of the section, a diffraction hyperbola can be seen. This is the pronounced response of the Tunnel A and is in very good agreement with the modeled response shown in Figure 4e. At the end of the section, part of the anomaly produced by Tunnel B can be seen. Both features appear to be at a depth of approximately 0.5 meters. A similar image is presented in Figure 6f for section Qan02 (see Figure 3).

A full grid of 6 2-D resistivity sections (Rt1-6) were measured in the area (Figure 3) in order to decide the effectiveness of the technique in locating both tunnels when at different depth. An array of 21 electrodes was used and the inter-electrode spacing was 1m. The inverted results for all sections are depicted in Figure 7.

Both tunnels are successfully reconstructed and their location is marked into the Figure. At this area Tunnel B is situated 1.5m deeper than Tunnel A and this is clearly seen in the inverted images. The anomaly corresponding to Tunnel A is not always very pronounced. This is due to the fact that the tunnel width is approximately 0.6m which is smaller than the 1m inter-electrode spacing used in the measured array. However, Tunnel A is still easily detectable due to its huge resistivity contrast with the surrounding material. Further, it is worthwhile noticing that the anomaly corresponding to Tunnel B is becoming much bigger in dimensions in sections Rt5 and Rt6. This is due to the to the observation well (denoted in Figure 3) at this point.

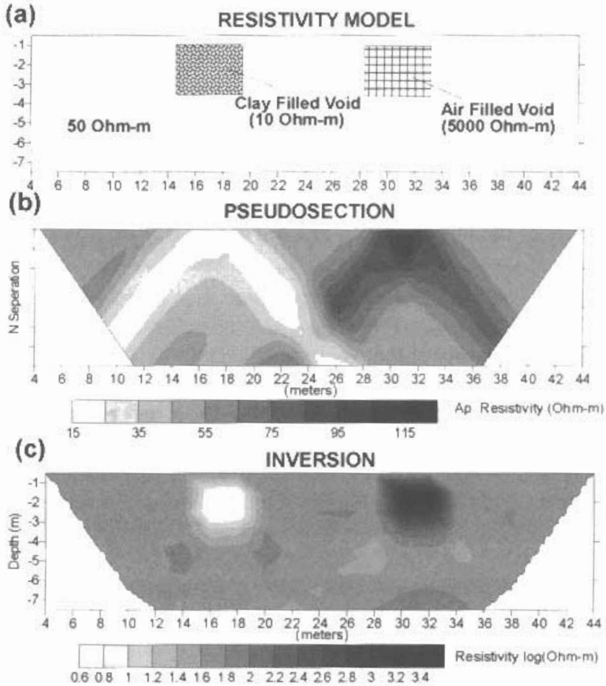

***Figure 4:** (a) Resistivity model simulating two qanats. (b) Synthetic data in a pseudosection form obtained for the model (a). (c) Inverted image of the synthetic resistivity data. (d) GPR model simulating a void. (e) Synthetic radagram of model (d).*

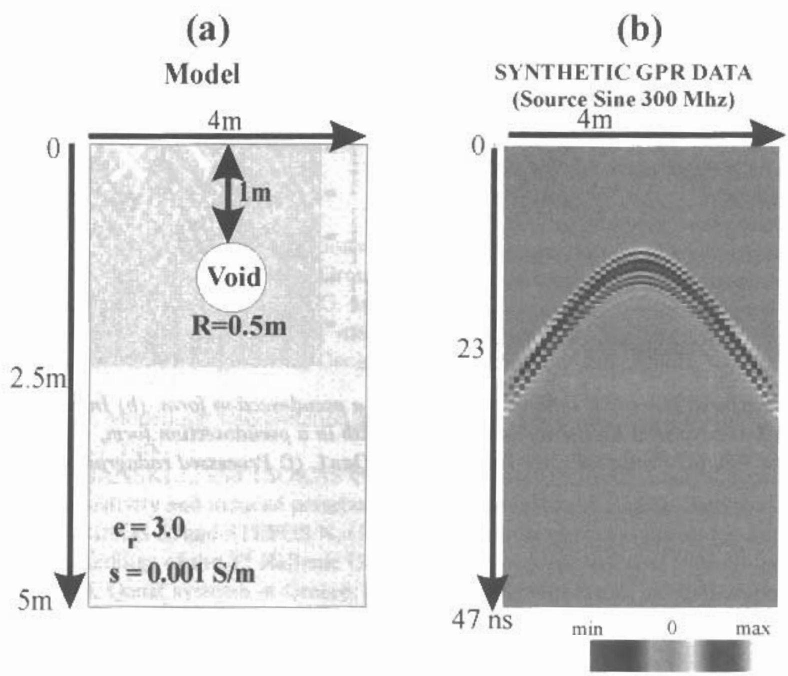

***Figure 5:** (a) GPR model simulating a qanat. (b) Synthetic radagram of model (b).*

5.CONCLUSIONS

Overall it was shown with both modeled and real data that the 2-D electrical and GPR geophysical techniques are particularly suited to qanat exploration. This is due to the fact that the qanat systems are very close to a 2-D structure (large extend at the y-strike axis). Further it is shown that air filled qanats are easily detectable even if their size is smaller than the sampling interval due to their huge resistivity contrast to the surrounding material. The processed geophysical data can delineate with a remarkable accuracy the dimensions and burial depths of qanat systems. Using both electrical and GPR techniques has the advantage that results comparison can further improve the quality of the interpretation and aid the interpreter to draw more safe qualitative and quantitative conclusions.

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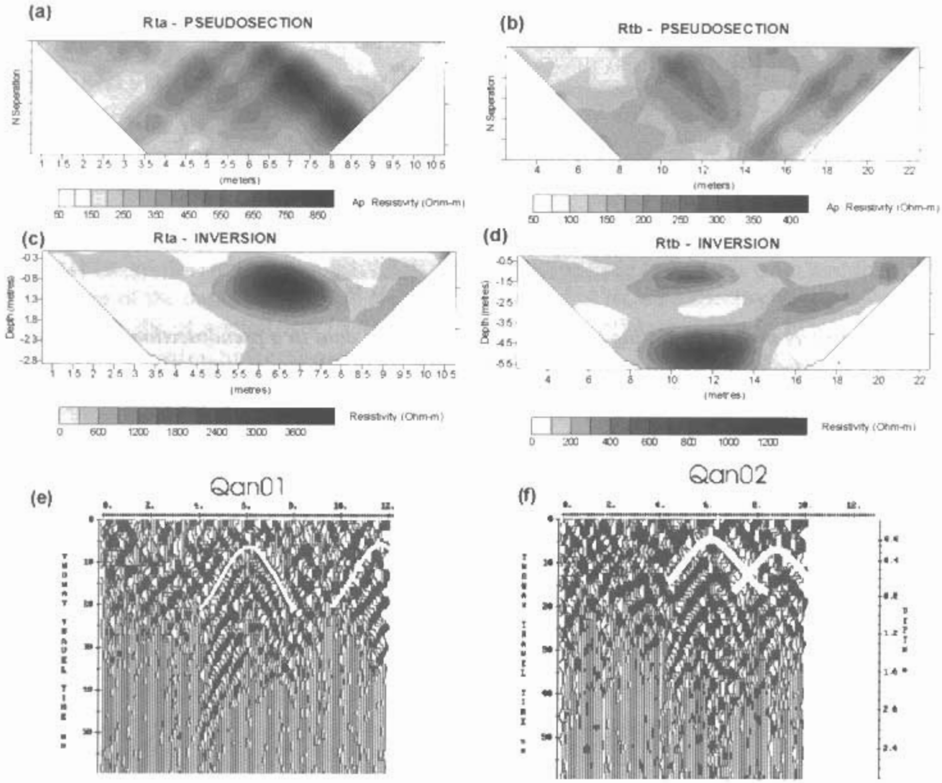

Figure 6: (a) 2-D measured Resistivity data of section Rta in a pseudosection form. (b) Inverted resistivity image of section Rta. (c) 2-D measured Resistivity data of section Rtb in a pseudosection form. (d) Inverted resistivity image of section Rtb. (e) Processed radagram of section Qan1. (f) Processed radagram of section Qan2.

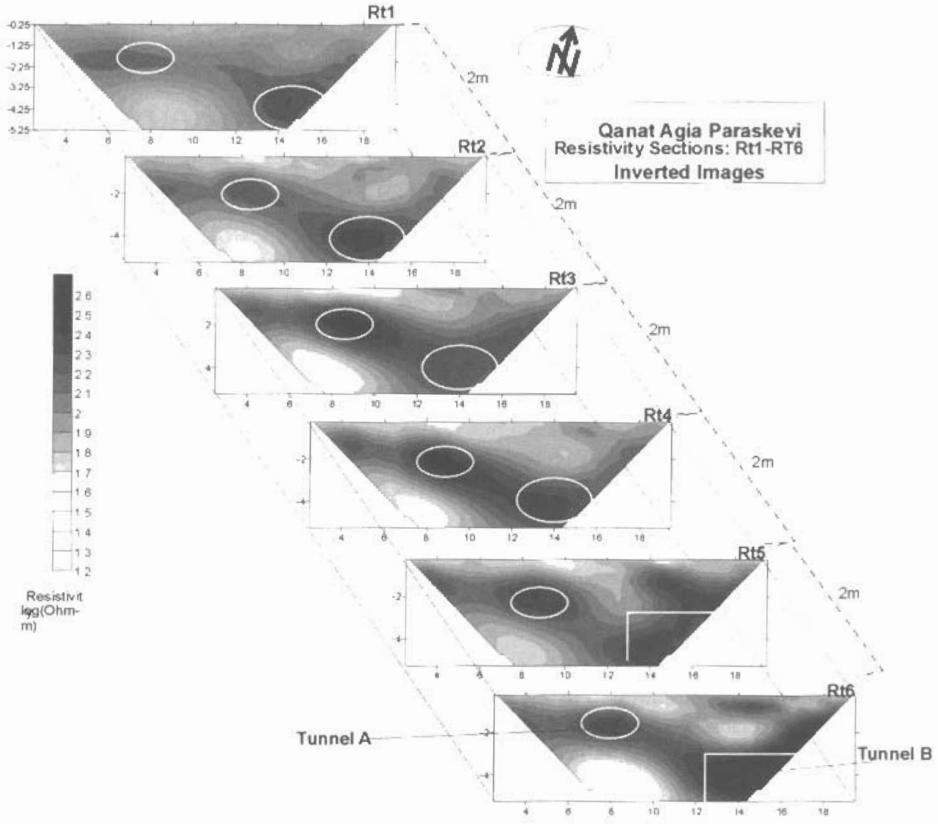

Figure 7: Combined pseudo-3D resistivity image of the inverted sections Rt1-Rt6.

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