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NONDESTRUCTIVE 2-D GEOELECTRICAL SURVEYING INTO A BUILDING'S BASEMENT

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Abstract

In this paper the application of flat base electrodes into a building's basement is examined. The aim of this study was to locate ancient walls possibly situated underneath a building, lying on Ag. Dimitriou road in Thessaloniki (Greece). During ERT surveying, an archaeological excavation took place on the roadway outside the building. The excavation revealed ancient walls. A number of resistivity profiles were carried out on the concrete floor of the building. The dipole-dipole array was used in some sections, while in others the Wenner array was undertaken. The spacing "a" between electrodes was 1m and the maximum N-separation of N_{max}=8. In order to perform resistivity profiles in a nondestructive manner on the concrete floor, flat base electrodes were applied. The resistivity surveying indicated the existence of linear structures identified as resistive bodies. These anomalies may have been derived from various causes, but most likely they may have been derived from the continuation of the ancient walls revealed from the archaeological excavation on the roadway. Finally, it must be noted that flat base electrodes proved to be an efficient tool for measuring indoors.
Key words: *Flat base electrodes, contact electrodes, nondestructive ERT.*

Περίληψη

Η παρούσα εργασία εξετάζει τη χρήση των ηλεκτροδίων επαφής στο υπόγειο ενός κτηρίου. Σκοπός αυτής της μελέτης είναι ο εντοπισμός αρχαίων τειχών, τα οποία είναι πιθανόν θαμμένα κάτω από κτήριο που βρίσκεται επί της οδού Αγ. Δημητρίου στη Θεσσαλονίκη (Ελλάδα). Κατά τη διάρκεια λήψης των γεωηλεκτρικών μετρήσεων, πραγματοποιήθηκε αρχαιολογική εκσκαφή στο οδόστρωμα που διέρχεται έξω από το κτήριο. Η εκσκαφή αποκάλυψε αρχαία τείχη. Μια σειρά γεωηλεκτρικών τομών μετρήθηκε στο τσιμεντένιο πάτωμα του κτηρίου. Σε κάποιες τομές υλοποιήθηκε η διάταξη διπόλου-διπόλου, ενώ σε άλλες η διάταξη Wenner. Η απόσταση "α" μεταξύ των ηλεκτροδίων πάρθηκε ίση με 1 μέτρο και μέγιστη Ν-απόσταση N_{max}=8. Προκειμένου να πραγματοποιηθούν οι γεωηλεκτρικές τομές στο τσιμεντένιο δάπεδο με μια μη-καταστροφική μέθοδο, χρησιμοποιήθηκαν ηλεκτρόδια επαφής. Η γεωηλεκτρική έρευνα έδειξε την ύπαρξη γραμμικών δομών που προσδιομίζονται ως σώματα υψηλών αντιστάσεων. Αυτές οι γραμμικές ανωμαλίες είναι πιθανό να οφείλονται σε ποικίλους παράγοντες, με πιθανότερο την προέλευσή τους από τη συνέχεια κάτω από το κτήριο των τειχών που αποκαλύφθηκαν από την αρχαιολογική εκσκαφή στο οδόστρωμα. Τέλος, πρέπει να σημειωθεί ότι τα ηλεκτρόδια επαφής αποδείχθηκαν ένα χρήσιμο και αξιόπιστο εργαλείο για την πραγματοποίηση μετρήσεων μέσα σε κτήρια.
Λέξεις κλειδιά: *Ηλεκτρόδια επαφής, μη-καταστροφική μέθοδος ηλεκτρικής τομογραφίας.*

1. Introduction

Over the last decade, Electrical Resistivity Tomography (ERT) has been extensively used in geophysical investigations (Dahlin 2001). The most common applications of ERT are geological mapping (Caglar and Duvarci 2001), geothermal field exploration (Wright *et al.* 1985) hydrogeological studies (Flathe 1955, Dahlin and Owen 1998), engineering geology studies (Dahlin *et al.* 1994), environmental research (Rogers and Kean 1980, Van *et al.* 1991, Ramirez, *et al.* 1996) and archaeological prospection (Papadopoulos *et al.* 2006).

The rapid development of civil centers and various constructions resulted in the need to use geophysical techniques in urban environments (indoors, paved surfaces, roads, etc.) Among the existing geophysical techniques the method of GPR is highly popular (Daniels 2004) due to its fully non-destructive nature and survey speed. Further, the introduction of the newly developed technique of capacitive resistivity (Kuras 2002) holds the promise of efficient electrical imaging in areas where no (or poor) galvanic contact is possible, but its use is mainly restricted to map the shallow subsurface.

As far as standard geoelectrical methods concerns, new techniques have been developed recently, such as flat base electrodes, which allow resistivity measurements to be made in a nondestructive manner and, therefore extend the application of ERT to other environments (e.g. urban, indoors, etc.). Carrara *et al.* (2001), demonstrate the application of geoelectrical measurements using flat base electrodes on a mosaic floor of a Roman residence. The application of non-destructive geoelectrical grid to access wall structures is presented by Cosentino and Martorana (2001), while Karastathis *et al.* (2002) applied non-destructive ERT measurements on a cement dam in Marathon (Greece).

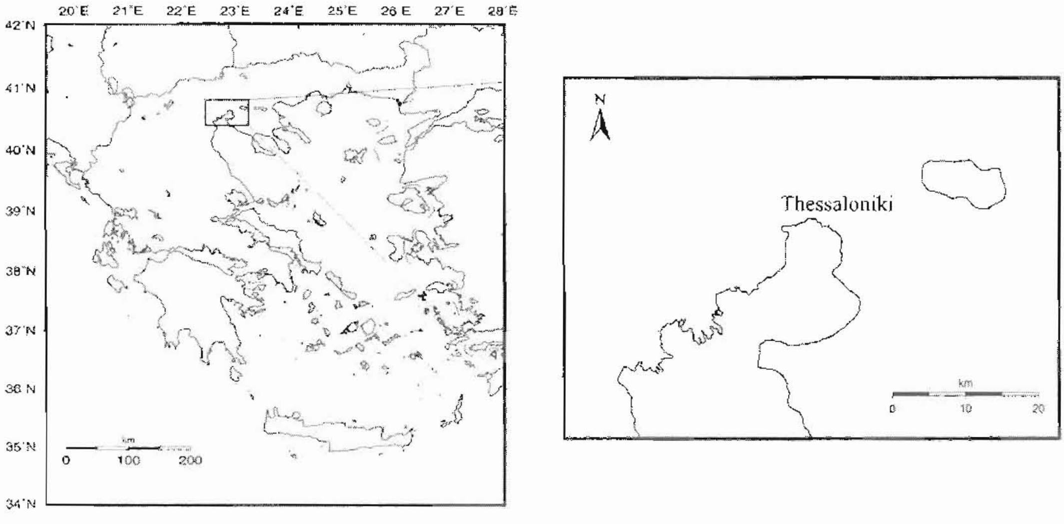

Figure 1 – Location map of the studying area

This work focuses on an application of flat base electrodes on a concrete floor of a building's basement. The aim of this study was to locate ancient walls possibly situated underneath a building, lying on Ag. Dimitriou road in Thessaloniki (Fig. 1). During ERT surveying, an archaeological excavation took place on the roadway outside the building (Fig. 2). The excavation revealed ancient walls. The question was if these walls continued underneath the studying building, situated next to the roadway, or not.

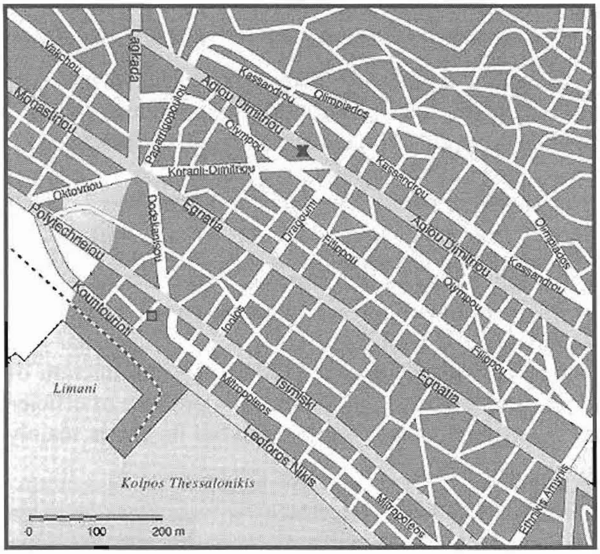

Figure 2 – Topographical sketch of the studying area. The building is depicted with a cross

2. Geological Setting

The area of Thessaloniki (Fig. 3) belongs to the Circum Rhodope belt (Kauffmann *et al.* 1976, Ricou *et al.* 1998), which consists of Paleozoic and Mesozoic metamorphic rocks covered by cenozoic metasedimentary rocks. The aforementioned rocks are covered in areas by Tertiary and Quaternary formations. More precisely, the formations of the wider area of study are the following:

- Holocene undivided deposits consisting of sand, gravel, valley deposits and red clay with calcareous concretionary bodies. At the base conglomerates dominate.
- Neogene red clay series with mica and calcareous concretionary bodies.
- Calcareous flysch, known as the Svoula group. It comprises of alternations of detrital or psammitic limestones or ferruginous calcareous sandstones with shales. Olistoliths are intercalated. The above formation's age is bracketed between Triassic to Middle Jurassic.
- Chortiatis magmatic suite, which consists of leucocratic albite-sericite-microcline gneisses, light brown or greenish epigneisses and dark green or brownish greenschists. The above rocks are younger than Upper Triassic and older than the granodiorite of Sithonia type.

The Circum Rhodope belt can be divided in three major units: the Deve Koran – Doumbia unit, the Melissochori - Cholomon unit and the Aspri Vrissi – Chortiatis unit. Two folding events and a greenschist facies metamorphic event have strongly affected the Circum Rhodope belt basement rocks.

The studying area is lying on the Chortiatis magmatic suite. The surface formations consist of a man-made ground in the first few meters and thereafter alluvial deposits, as well as deposits from the erosion of the bedrock. The bedrock is comprised mainly of gneisses, green epigneisses, which are representative of the region of Thessaloniki, and greenschists.

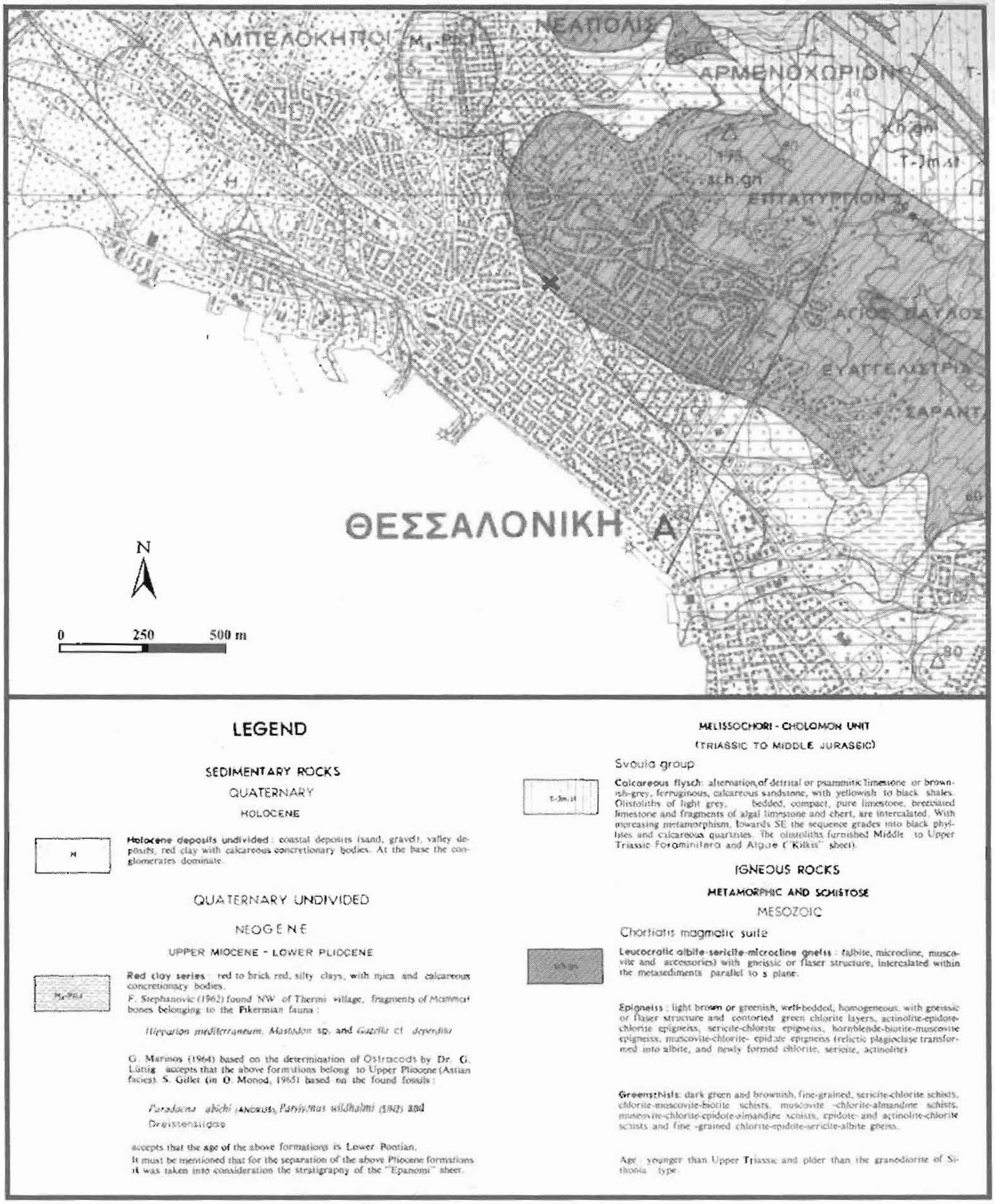

Figure 3 – Abstract of the geological map (IGME 1970). The area of study is depicted with a cross

3. Data Acquisition and Processing

The survey involved six parallel sections (2_1 - 2_6) with a northeast-southwest direction and eight parallel sections (1_1 - 1_8) with a northwest-southeast – vertical to the previous – direction (Fig. 4). The sections were spaced 3m apart from each other except from section (1_8), which was 1m far from section (1_7). The dipole-dipole array was measured in some sections, while in others the Wenner array was undertaken. The spacing "a" between electrodes was equal to 1m for sections (1_1 - 1_6 & 2_1 - 2_5) and equal to 0.75m for sections (1_7, 1_8 & 2_6). The maximum N-separation was N_{max}=8. The data were collected with the SYSCAL (V11.4++) resistivity meter (IRIS INSTRUMENTS).

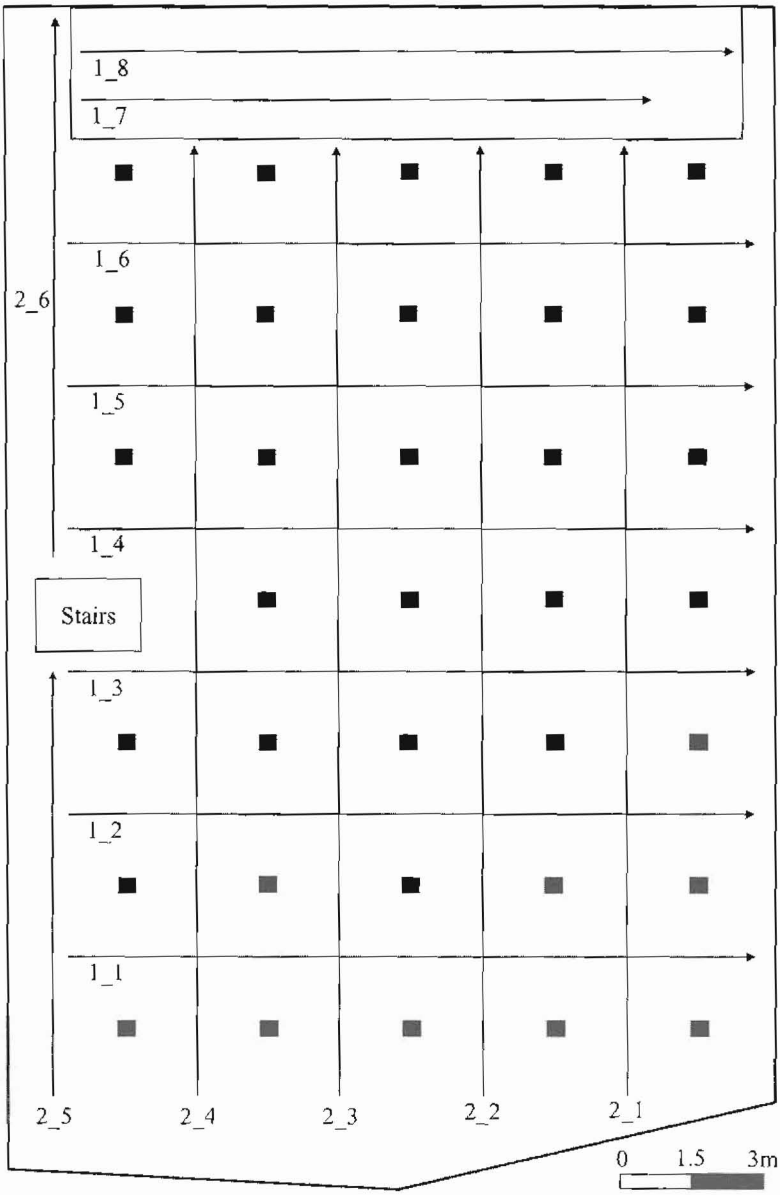

Figure 4 - Sketch of the surveying area, in which the measured sections are shown. (1_1) to (1_8) sections refer to ERT's with northeast-sonthwest direction, while (2_1) to (2_6) sections refer to ERT's with northwest-southeast direction

The building's basement, where the ERT measurements were carried out, had a 12cm thick concrete floor with a resistivity of approximately 300 Ohm-m, whereas its ceiling was leaning on columns with footing-bases of 1 m. The footing-bases are shown in figure (4) as small black squares.

The electrodes used in this survey consist of a square copper flat base (dimensions: 7 x 7 cm and thickness of 1 cm), which abuts on the surface of the surveying area and a thin cylindric copper segment (length of 7 cm) attached to the flat base part to facilitate cable connections (Fig. 5a).

To decrease the contact resistance a conductive gel was applied between the electrodes and the ground (Fig. 5b). This is extremely important since in relatively rough surfaces the somehow heavy electrode (more than 1 Kgr) pressures the gel which fills any open spaces left between the material and the electrode enabling in this way better conduct. The gel used in this work consists of water, salt and low cost cellulose powder (industrial thickener). Alternatively, conductive gel used in medical applications or even confectionery gel can be successfully applied but it is generally more costly. Moreover, it was found that spraying the contact area with salty water prior to the application of the gel helped to further decrease contact resistance (Athanasiou 2004).

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. Among others, the smoothness constraint inversion (Constable *et al.* 1987) has become the most popular for interpreting ERT data since it produces a simplified subsurface resistivity model which is a reasonable representation of the subsurface and at the same time guarantees inversion stability.

The collected resistivity data were inverted using a flexible non-linear 2-D scheme (Tsourlos 1995, Tsourlos *et al.* 1998) based on a smoothness constrained algorithm. The aim of the inversion is to construct an estimate of a subsurface resistivity distribution, which is consistent with the experimental 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 smoothness inversion scheme, used in this work, tries to calculate a subsurface resistivity estimate $\mathbf{x}$ for which the difference $\mathbf{dy}$ between the observed data and the modeled data (calculated using the forward modeling technique) is minimized under the condition that the roughness of the produced model is minimized. The resistivity correction at the k+1 iteration is given by:

$$d\mathbf{x}_{k+1}=[(\mathbf{J}_k{}^T\mathbf{J}_k+\mu\mathbf{C}_x{}^T\mathbf{C}_x+\mathbf{C}_z{}^T\mathbf{C}_z)]^{-1}\ \mathbf{J}_k{}^T\mathbf{J}_k\ d\mathbf{y}_k\ .$$

where Cx, Cz are matrices which describe the smoothness pattern of the model in the x, z, directions, Jk is the Jacobian matrix estimate and μ is the lagrangian multiplier.

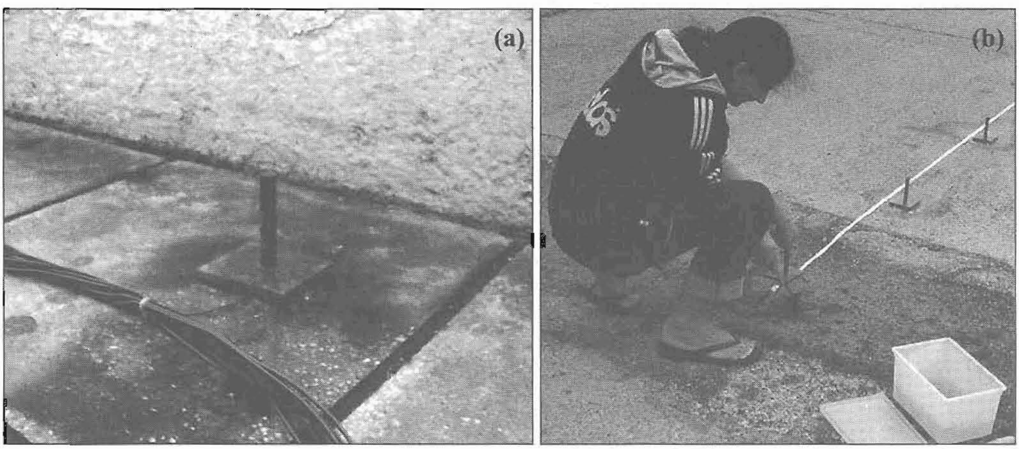

Figure 5 – (a) Flat base electrode used in the field applications, (b) Conductive cellulose gel used to ensure that flat base electrodes are electrically coupled to the surface

A proven 2.5-D Finite Element Method (FEM) scheme was used as the platform for the forward resistivity calculations. In 2.5-D modelling the change in resistivity is considered to be two-dimensional but the current flow pattern is a three dimensional one. In other words, the measured values correspond to a three dimensional subsurface where the resistivity is allowed to vary in only two dimensions and remains constant in the strike direction. The adjoin equation approach was incorporated into the FEM scheme in order to calculate the Jacobian matrix **J**.

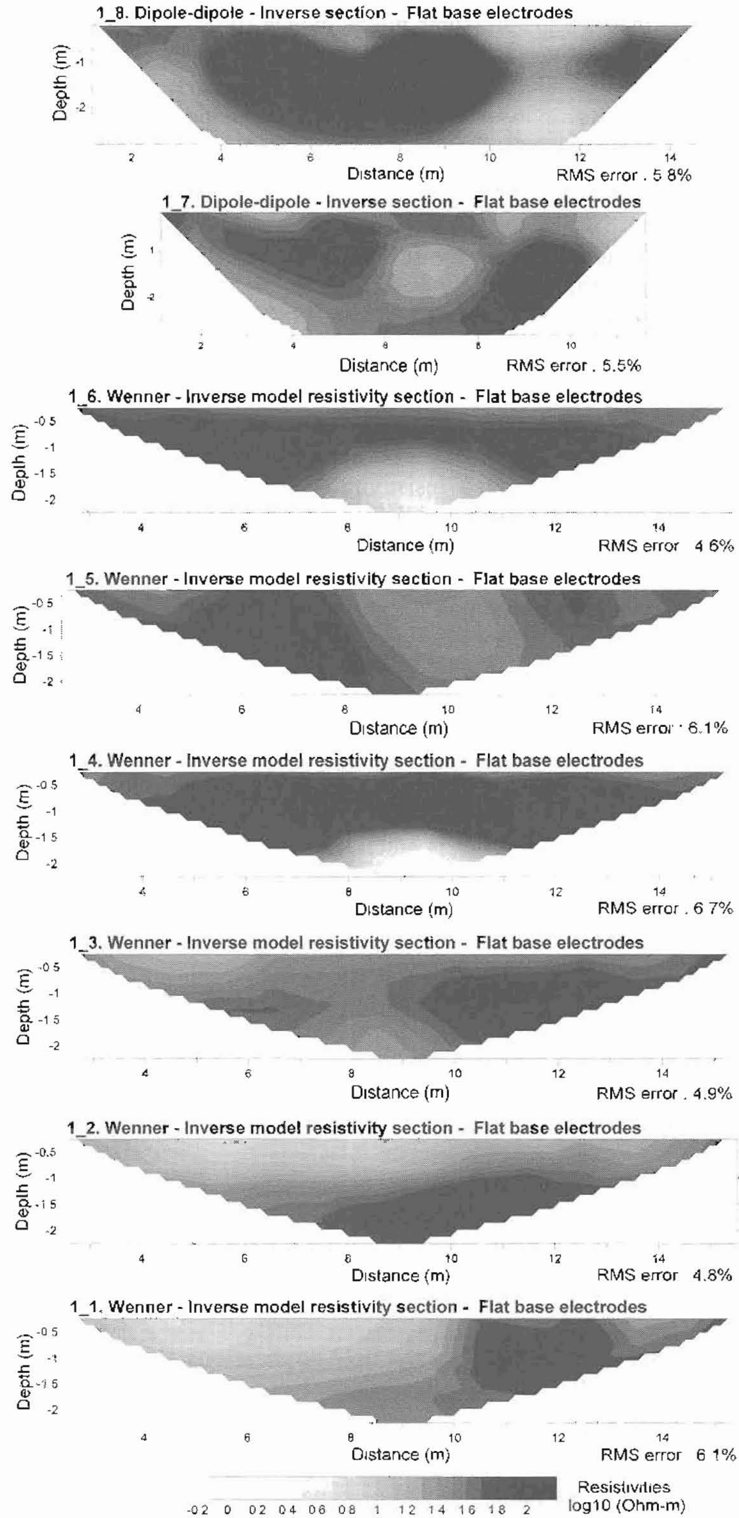

Figure 6 - Geoelectrical inverse model resistivity sections obtained by dipole-dipole and Wenner arrays. These sections have a northwest-southeast direction

4. Results and Interpretation

The inverse model resistivity sections are depicted in figures (6) and (7). The observation of all sections of figure (6) showed the existence of a highly resistive area, which appears in all sections and its center is situated at a distance of approximately 12m from the beginning of the tomographies. Also, a second area of high resistivity appears in section (1_3) and continues until section (1_8). Its center is situated at a distance of approximately 6m from the beginning of the tomographies. These two resistivity anomalies indicate the existence of linear structures at the area of study.

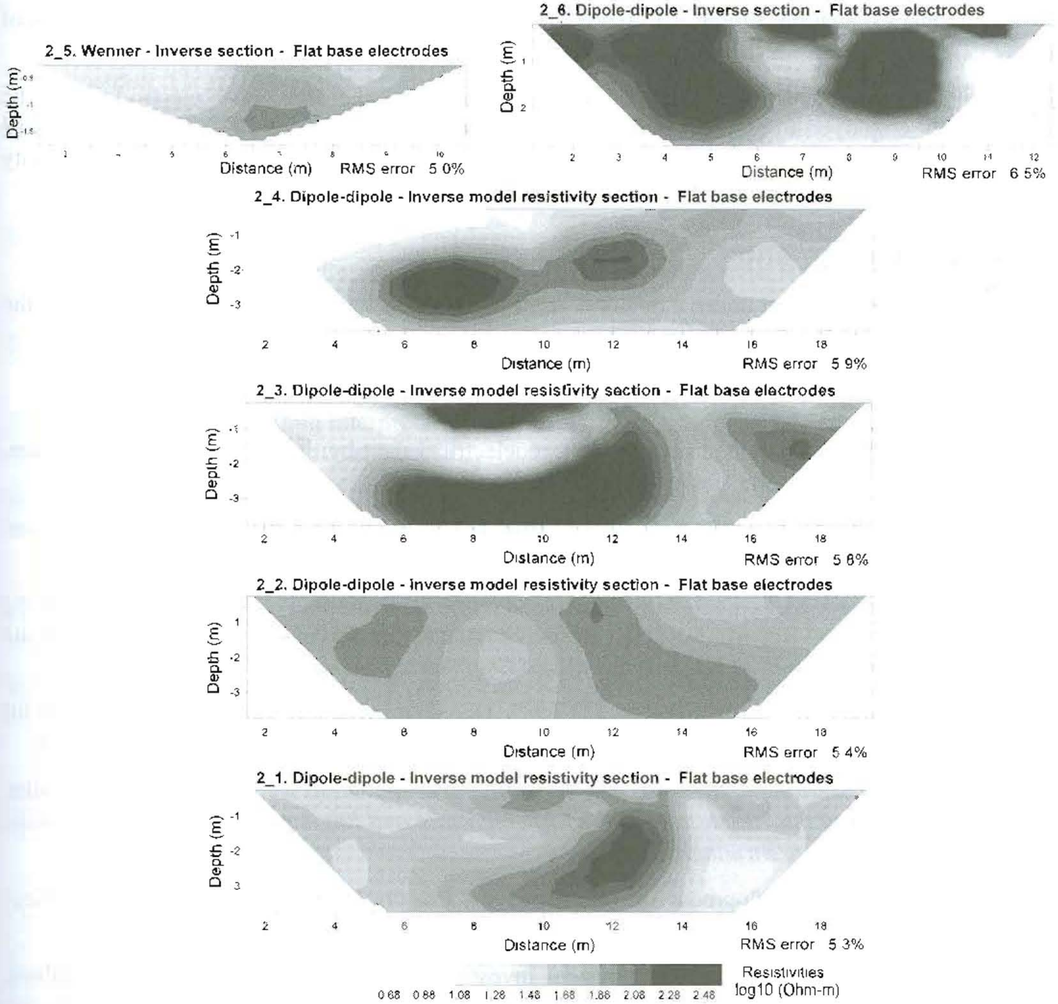

Figure 7 - Geoelectrical inverse model resistivity sections obtained by dipole-dipole and Wenner arrays. These sections have a northeast-southwest direction

The inverted sections of figure (7) are perpendicular to the inverted sections of figure (6). The observation of these sections showed the existence of a high resistive area, which appears in all sections and its center is situated at a distance of approximately 12m from the beginniug of the tomographies. Also, a second area of high resistivity appears in section (2_2) and continues until section (2_6). Its center is situated at a distance of approximately 7m from the beginning of the tomographies. These resistivity anomalies also derive from a subsurface linear structure.

Due to the fact that the above experiment has been conducted in an environment with a complicated structure, which was aggravated by anthropogenic activity (excavations, embankments, etc.), the linear anomalies may result from various causes. Moreover, the footing-bases of the columns are expected to add noise to the already heavy environment.

The linear anomalies of figure (6) may derive from a small scaled linear elevation of the bedrock, due to its intense folding observed in the area of study, or a linear deposition of high resistive alluvial materials. Though, by taking into account the geometry of the anomalies and the outcome of the archaeological excavation on the roadway of Ag. Dimitriou road, it is more possible that the above linear anomalies derive from the continuation of the ancient walls revealed from the archaeological excavation. In line with the last interpretation, the high resistive linear structures of figure (7) may derive from ancient walls perpendicular to the previous ones.

Resistivity measurements performed in this study indicate that flat base electrodes can be satisfactorily employed to map subsurface geoelectrical structures. Using flat base electrodes can extend the applications of geoelectrical techniques in environments that normally resistivity tomography wouldn't be suitable for resistivity tomography.

5. Acknowledgments

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