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ERT METHOD FOR THE DETECTION OF BURIED ARCHAEOLOGICAL OBJECTS IN APOLLONIA & BYLIS, ALBANIA

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Abstract. During the period 2010–2011 geoelectric surveys using Electrical Resistance Tomography (ERT) method, have been applied on two archeological sites of Albania, Apollonia and Bylis. The purpose of this study was the detection of the cultural layer and the underground archeological buried features from the spatial distribution of true resistivity values. The geoelectric surveys were carried out throughout very dense 2-D ERT parallel profiles 1.5m from each other, with electrodes spaced apart by 1m. The squares were surveyed using two geometric configurations: Wenner and dipole–dipole arrays. The collected data were interpreted with use of the inversion resistivity method. True resistivity of the subsurface was obtained, with use of nonlinear equations defined with the least-squares inversion method, from the measured apparent resistivity values. 3-D interpretation of profiles was carried out and maps of different depths were compiled. The use of both arrays helps to better understand the spatial extent of archaeological featured from taken resistivity anomalies. The true resistivity models taken from the inversion of apparent resistivity measurements from both arrays, show little changes. The ERT method was found to delineate very well a thickness of cultural layer and buried archaeological objects inside it. The cultural layer on Bylis is depicted with lower resistivity values than the basement which is limestone, while the cultural layer in Apollonia has higher resistivity values than the basement which is clay-sand layer.

Key words: geoelectric; electrical resistance tomography; archaeological site; true resistivity; inversion; archaeological features.

1. INTRODUCTION

Surveys in archaeological geophysics in Albania began in 1964–1968 on Buthrotos ruins of ancient city by multidirectional studies, including electrical, magnetic, gravity and radiometric methods, where clear anomalies were obtained on the buried walls. After this similar surveys were carried out on Apollonia antique city ruins, ancient irrigation system etc. (1976–1983). Later on the surveys were made again in Buthrotos (1989–1990), on the ruins of city, on the Monastery of Margellic (1989–1990). After 1990, many studies have been carried out over the ancient sites in Albania from Academy of Sciences of Albania, Center of Geophysical and Geochemical Exploration and University of Tirana [1].

Short history of Apollonia and Bylis

Apollonia was an ancient city in Illyria, located on the right bank of the Aous river (modern-day Vjosa). Its ruins are situated in the Fier region, near the village of Pojani, in modern-day Albania. Apollonia was founded in 588 B.C, by Greek colonists from Corfu and Corinth, on a site initially occupied by Illyrian tribes and was perhaps the most important of the several classical towns known as Apollonia.

Bylis was the center of Illyrian tribe Bylins and one of the most important and largest Illyrian cities, which developed during 4th century B.C. During the 3rd century B.C, were build the theatre (8000 seats), the stadium, the gymnasium etc. By the 1st century A.D, Bylis became a Roman colony.

During the period 2010–2011, Electrical Resistance Tomography (ERT) technique is applied in archaeological sites of Apollonia and Bylis in grids with dense 2D parallel lines with 1.5 distance and 1m spacing between electrodes. ERT is an active geoelectrical prospecting technique used to obtain 2D, 3D and 4D (with time) images of the subsurface electrical resistivity distribution. It has been applied in many archaeological sites by many authors [1–5].

Technically the ERT is obtained by using different multielectrode arrays, such as the dipole-dipole, Wenner, Schlumberger, Wenner-Schlumberger, Gradient etc., the choice of which depends on the subsoil, the depth of investigation, the sensitivity to vertical and horizontal changes in the subsurface resistivity, the horizontal data coverage and the signal strength. Modern electrical ground prospecting techniques have led to an increase in the spatial resolution of the survey by adding more electrodes and using advanced excitation patterns. This method is also known as geo-electrical tomography. This is an improved method of moving the electrodes in the Schlumberger or Wenner configurations. Many electrodes are positioned, usually in line, and connected to a common multi-core cable. One transmitter and one receiver are commonly used. These are connected to the electrodes by an appropriate switching box. After a series of measurements data is collected, it is processed in such a way that it provides information about the resistivity or the conductivity distribution. A variety of systems and software are available for imaging conductivity distribution [6–7].

2. METHODOLOGY USED

The methodology used consists on 3-D surface resistivity survey, with very dense 2D parallel ERT lines. Successful applications of 2D-3D ERT technique in archaeological prospection have been reported in literature [8]. The ideal 3-D survey employs the arrangement of the electrodes in a rectangular grid and gathering the measurements along all possible directions (Fig. 1A). An alternative and nowadays most common strategy, is to gather the measurements along two perpendicular directions (*X* and *Y* survey) or along a single direction (*e.g.* *X*-survey) (Fig. 1B). In 3-D surveys composed of parallel two-dimensional (2-D) lines as applied in this study (Fig. 1B), the basic inter-electrode spacing should be almost equal to the inter-line distance to ensure the true "3-D" coverage of the subsurface resistivity properties [9]. A common approach for the model parameterization is to divide the earth into hexahedral blocks of unknown constant resistivity. The cell dimensions are related to the minimum electrode spacing (a) and they are set to (X, Y, Z) = (a, 1.5a, a/2).

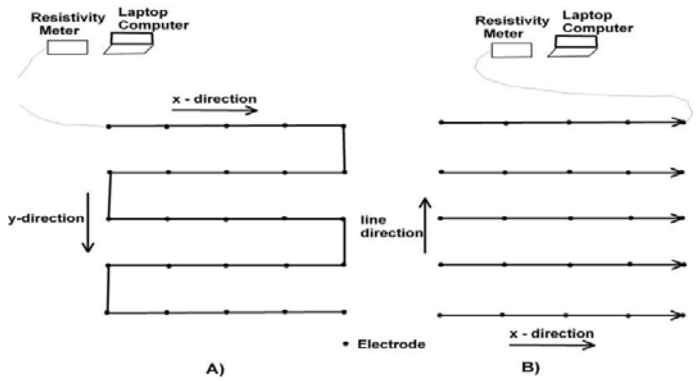

Fig. 1 – A typical arrangement of electrodes for a 3-D survey: A) 3-D survey; B) parallel lines with equal distance.

There are many methods for solving the inversion of physical parameters [11–17]. The method of choice for inverting electrical resistivity survey data was the application of smoothness constraint to a least-square minimization [10]. This approach has been extended to both 2-D and 3-D inversions of resistivity survey data. The reconstruction scheme reduces to the well-known equation (1),

$$(A^T A + \lambda R^T R)x = A^T b, \tag{1}$$

where: R is a matrix which defines the “roughness” of the model; λ is the Lagrange multiplier controlling the balance between misfit and roughness; x is the unknown resistivity vector; b is a vector of weighted function of the data mismatch,

$$(r(i) - m(i) / \sigma(i)).$$

The roughness of x, is defined as $h^T h$, where $h = Rx$ and $A_{ij} = J_{ij}/\sigma(i)$ and $\sigma(i)$ is the standard deviation of the “field” measurement; and J_{ij} is the element of the Jacobian matrix which is the partial derivative of the i^{-th} simulated measurement $m(i)$ with respect to j^{-th} resistivity parameter.

3. CASE STUDIES

The above methodology was applied in several squares, in archaeological sites of Apollonia and Bylis, Albania. The multielectrode system used to realize the 2D resistivity profiles is the WDJ-3 resistivimeter, composed on the central unit WDJ-3, the automatic link box WDJZ-3, and two multicore cables with 30 takeouts each. Below we present the results in two sites of Apollonia and Bylis.

"Roman Baths", Apollonia. Around this area, 5 squares have been surveyed with 2D parallel lines (Fig. 2A). In this paper we present only the results of squares 1 and 5, which show the presence of buried archaeological objects. The square 1 has dimension 30×20m. The distance between profiles was 1.5 m with electrodes spacing 1m. The square was surveyed using dipole-dipole and Wenner configuration. In Figs. 2B, C are presented the images of logarithmic resistivity values in different depths. The soils are represented with low resistivity values, which are of clayey content (blue up to light yellow color), characteristic for the basement on this area. The high resistivity values consist to the cultural layer (yellow up to red color). As seen from the figure, the anomalies in different depths are almost the same on both configurations used. Anomalies are extended in north-south and east-west direction and show regular geometric lineation, characteristic for dwelling walls and roads. Important is the anomaly with north-south extent, which is clear on depths 1–1.3 m and more, and cuts diagonally the square. This anomaly has a width of 5 m, and could be related to the "old road" that connects the "Roman baths" with the surrounding dwellings.

The square 5 has dimension 60×50m, and is located in the SE part of "Roman baths". The grid of measurements was 2×1m (distance between profiles 2m with electrode's spacing every 1m). There are used 60 simultaneously electrodes and the survey was realized with Wenner array. From the true resistivity images in different depths (Fig. 3) are clearly distinguished the high values of resistivity anomalies (> 100 Ωm, log R > 2), which can be related with archaeological features, whereas the low resistivity values, smaller than 50 Ω.m, represent the background corresponding with soils of clay or clay-sand content. In general the resistivity anomalies has regular geometrical extension (red color), and can be related to buried archaeological objects (walls, road or trenches). Those anomalies are present until a depth of 2–2.5 m which is the cultural layer. Below this depth the low resistivity values (< 30 Ω.m), depicts the clayey layer. The main direction of resistivity anomalies is approximately N-S, with another trend of E-W direction. Most important is the long anomaly of N-S extent, which starts in pickets 10–20 m and follows the pickets 20–30 at the end of the square. This anomaly is visible until a depth of 2 m (image maps at depths 1.3 and 1.9 m, Fig. 3), and could be related with the presence of the old road that connects the monument with the surrounding area and coincides in lineation with the anomaly taken in square 1. Interesting is the anomaly around the picket 50 m of the first profile and has a length of 30 m (image maps at 0.3 and 0.8 m depth), which can present most probably the remains of the old water furniture trench of the roman bath monument that archaeologists believe.

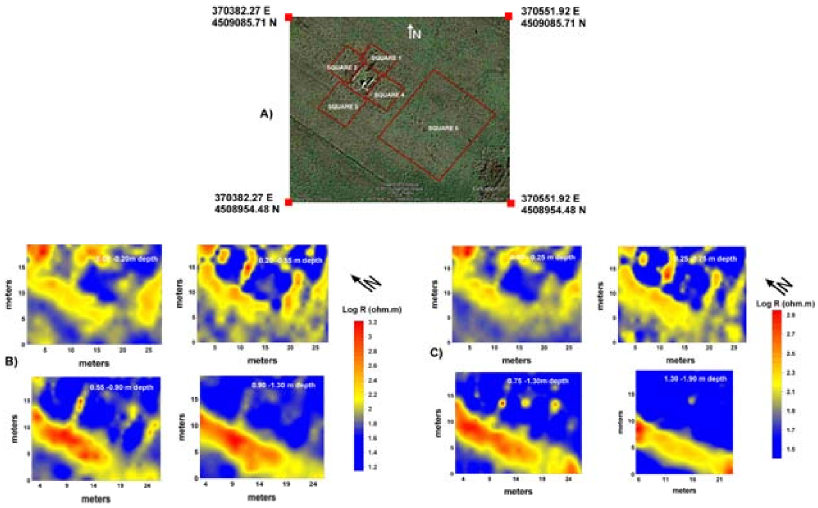

Fig. 2 – Images of true resistivity values in different depths in "Roman baths" (square 1) Apollonia: (Albania); 30 simultaneous electrodes used, distance between profiles 1.5m, electrode spacing 1m: A) layout of squares around the thermal baths; B) results taken from dipole-dipole array; C) results taken from Wenner array.

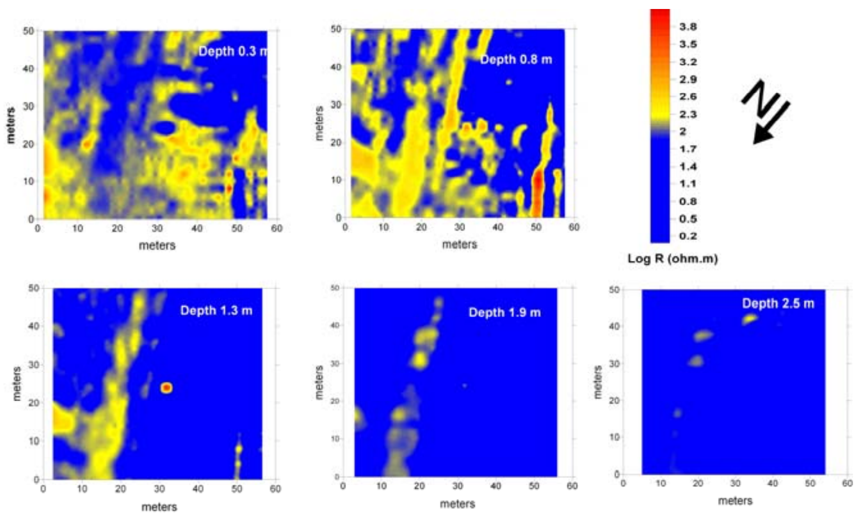

Fig. 3 – Images of true resistivity values in different depths in "Roman baths" (square 5) Apollonia, Albania. Wenner array used with 60 simultaneous electrodes, distance between profiles 2m, electrode spacing 1m.

Old Gymnasium, Bylis. In archaeological site of Bylis two squares have been surveyed, one near the "old gymnasium" and another close to the "old theatre" (Fig. 4A). The square near the old gymnasium monument has dimensions 30×27 m. The grid of measurements was 1.5×1 m (the distance between 2D lines was 1.5 m with electrode spacing 1 m). The configuration was Dipole-Dipole and Wenner arrays with 30 simultaneously connected electrodes.

In Fig. 4B, C are presented the images of true resistivity values in different depths. In this square there are several anomalies, which in places shown with regular geometries, could be related with remains of buried walls, of limestone content. All those anomalies are clear until to 2 m depth. Interesting is the anomaly in south-west corner of square with circular shape, characteristic for a fresh water collection pit, built over limestone. Deeper than 2 m, high resistivity values are present as a result of limestone basement.

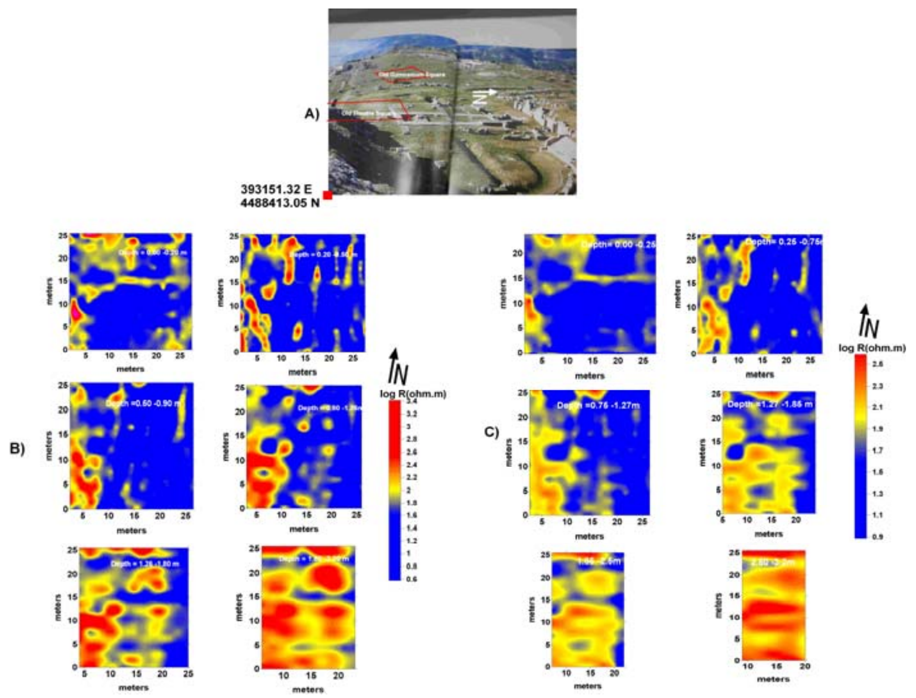

Fig. 4 – Images of true resistivity values in different depths in "Old Gymnasium", Bylis (Albania); 30 simultaneous electrodes used, distance between profiles 1.5m, electrode spacing 1m: A) layout of measurements; B) results taken from Dipole-Dipole Array; C) results taken from Wenner array.

Old Theatre, Bylis. Near the old Theatre, in the western part of it, a square with dimension 30×20 m (Fig. 3A), has been surveyed with ERT method with both Dipole-Dipole and Wenner arrays. The grid of measurements was 1.5×1 m (the distance between profiles was 1.5 m with electrode spacing 1 m). In Figs. 5A, B are presented the true resistivity images at different depths for both arrays used. In this square the main direction of resistivity anomalies is in the E-W, where the long anomaly on the right of the square is related with the presence of a ruined ancient wall, traces of which are in the earth surface. The cultural layer has a depth until 2 m, below it, is the presence of limestone bedrock with high resistivity anomalies (Figs. 5A, B).

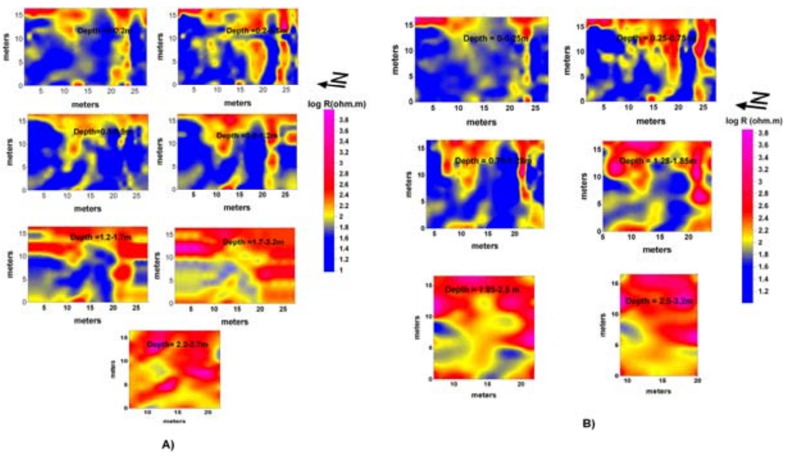

Fig. 5 – Images of true resistivity values in different depths in "Old Theatre", Bylis (Albania); 30 simultaneous electrodes used, distance between profiles 1.5 m, electrode spacing 1 m; A) Results taken from dipole-dipole array; B) Results taken from Wenner array.

4. CONCLUSIONS

With the use of ERT, dense 2D or 3D measurements can be carried out, which assure high resolution image maps of resistivity distribution in different depths, easily readable by archaeologists.

The methodology used, clearly separates the cultural layer with the basement rock. The true resistivity images from both arrays gave similar results with regard to depth. In the dipole–dipole array lateral changes are more distinctive than in the Wenner array. A combination of different arrays using the ERT technique should be used for a better understanding of the subsurface.

Resistivity anomalies presented by regular geometrical shapes, reflect buried archaeological objects. The high resolution ERT technique should be used before an excavating expedition.

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