# ERT AND VES STUDIES FOR THERMO-MINERAL WATER IN TOPLITA AREA, ROMANIA

**Dumitru IOANE[(1)], Florina CHITEA[(1)]**

*[(1)]University of Bucharest, Faculty of Geology and Geophysics, 6, Traian Vuia Str., 020956 Bucharest, Romania;*
*d_ioane@yahoo.co.uk, f_chitea@yahoo.com*

**Abstract.** The development of Toplița geothermal spa for tourism requires new geothermal resources, geophysical and hydrogeological works being carried out during the last decades. A geophysical study based on the new ERT (Electric Resistivity Tomography) technique was recently performed, the resistivity tomography data being integrated with gravity, magnetics and previous VES (Vertical Electric Sounding) measurements (Ursu, 1994). Experiments related to applying the ERT technique in the Bradul spa area (Toplița) showed that the Schlumberger array provides better results for deeper levels as compared to the Wenner one. To better illustrate the spatial distribution of apparent resistivity within the subsurface structures the VES sections were calculated for AB/2 and AB/3. The integrated interpretation of ERT and VES resistivity data lead to the drilling of a new hydrogeological borehole in the Bradul spa area. A highly tectonized zone containing thermo-mineral water was twice crossed at 190m and 200m depth, its temperature being similar to that exploited in the Bradul spa (27 $^0$C). When estimating the depth of apparent resistivity anomalies in the Bradul spa area a better fit was offered by the VES section calculated for AB/2.5.

**Key words:** geophysics, ERT and VES resistivity survey, thermo-mineral groundwater, Toplița-România

## 1. INTRODUCTION

During the last decade the Toplita town tried to replace former industrial activities with tourism, benefiting of a mountainous picturesque location and the fame of an old Transylvanian spa.

The thermo-mineral water offered for more than one hundred years for leisure or therapeutic treatment discharges since the XIX-th century in two main pools, these springs being situated in the immediate northern and southern vicinity of river Mures.

The development of Toplita geothermal spa for tourism requires geophysical and hydrogeological surveys followed by drilling works in order to identify new thermo-mineral sources.

Electric and electromagnetic geophysical investigation methods are among the most efficient techniques for detecting mineral water resources, for exploring geothermal areas or analyzing the geothermal processes (Tamburriello *et al*., 2008). Such a geophysical survey, aiming at locating new sources of thermo-mineral groundwater was carried out in 2011 (Chitea *et al*., 2012), being based on ERT and VES measurements.

In this paper the ERT results were analyzed, interpreted and integrated with previous VES measurements (Ursu, 1994), in the framework of regional gravity and aeromagnetic data.

## 2. GEOLOGICAL AND HYDROGEOLOGICAL SETTING

Toplita town is located on the Mures river valley, in an area situated between the southern limit of Calimani Mts and the northern limit of Gurghiu Mts.

Metamorphic rocks belonging to the Rebra crystalline limestone have been encountered at small depths in boreholes drilled in the Mures valley within the town limits. Older geological observations described these rocks as Triassic limestone with karstic voids.

**Fig. 1** Travertine deposit associated with a thermo-mineral spring (River Mures left bank - Toplita)

The topography of the area is built mostly on Neogene and Quaternary extrusive formations and effusive rocks, intrusive magmatic rocks being usually developed beneath the ground surface. The postvolcanic processes are still active, being here represented by several thermo-mineral springs and a 10m thick travertine deposit located on the left bank of river Mures (Fig. 1).

Local tectonics revealed an unexpected situation, a basement horst being located by boreholes in the Toplita depression area. The fault systems are trending E-W, ENE-WSW, NNW-SSE and N-S (Alexandrescu *et al*., 1968).

High permeability rocks, capable of storing groundwater, are considered to be the Rebra crystalline limestone, affected by tectonic and karst processes. Boreholes located in the Mures valley penetrated tens of meters of alluvium and volcaniclastics before reaching highly fractured and altered crystalline limestone.

The thermo-mineral water temperatures, both in natural discharges and in boreholes, range between 17$^0$C and 27$^0$C, while its mineralization varies between 1779 and 1796 mg/l. The gaseous components are represented by carbon dioxide and nitrogen, Toplita area being located in the northern part of the regional "halo" of postvolcanic manifestations characteristic for the Gurghiu and Harghita Mts (Ionescu, 2005; Gabor *et al*., 2010; Airinei, 2011).

## 3. PREVIOUS GEOPHYSICAL STUDIES

The regional Bouguer gravity map of the Calimani-Gurgiu-Harghita Mts was measured and calculated during the 60-ties (Suceava *et al*., 1969), detailed gravity surveys and anomalies interpretation being later carried out in both Gurghiu and Calimani Mts (e.g. Ioane, 1995). The gravity map of the Toplita area displayed, after filtering, a residual anomaly of increased gravity located south of river Mures, between the Magheraus and Bradul valleys (Ionescu *et al*., 1985), its cause being considered either an uplifted basement block, or a buried magmatic intrusion.

The aeromagnetic works led by M. Cristescu during the late 60-ties illustrate in the map of Toplita area a discontinuity of the regional NW-SE trending magnetic anomalies, separating the magnetic highs situated in the southern Calimani and northern Gurghiu Mts, anomalies usually associated with large magmatic intrusions.

Detailed geothermal data contoured in the Toplita town area an important anomaly of the superficial geothermal gradient, the main local high (20 $^0$C/100m) being situated in its south-eastern part, in the Bradul geothermal spa (Veliciu, 1988).

DC resistivity measurements in Bradul area were carried out in 1994 by Geotehnofor and consisted in Vertical Electric Soundings. Along three NW-SE trending survey lines, situated either on the right, or on the left side of the valley, there has been completed a total number of 22 VES which were positioned at 25m from one another. In order to investigate deep subsurface geological structures and thermo-mineral water accumulations, the VES measurements were performed using the Schlumberger array with a maximum injection line (AB) of 500m (Ursu, 1994).

## 4. GEOPHYSICAL DATA AQUISITION AND PROCESSING

### 4.1 Electric Resistivity Tomography (ERT)

In the Bradul spa area a number of seven ERT profiles were measured, their length ranging from 65m to 440m (Fig. 2).

By considering the complex geological structures expected to be encountered, as well as the local topography and location of roads and buildings, the orientation of the ERT survey lines was variable: NW-SE, NE-SW and W-E. The ERT survey was carried out using mainly a 10m electrode-separation, aiming to reach large depths of investigation.

In order to establish the optimum electrode configuration for investigating the Bradul area, several arrays were tested. The measurements were performed using the SuperStingR1 Resistivity and IP Meter (AGI-USA), a multi-electrode system which supports different classical array configurations (Schlumberger, Wenner, Gradient) and hybrid ones (e.g. Wenner-Schlumberger). The results showed that the Wenner array was not suitable for the resistivity survey of this area, the hybrid configuration of Wenner and Schlumberger being more stable in cases of high electrical noise. The Gradient array offered good data coverage in depth but low resolution at shallow levels and it proved to be time consuming. Considering that the poor lateral data coverage at the extreme parts of the profiles measured with a Schlumberger array can be compensated for long ERT survey lines by using the roll-along advancing technique, the Gradient array was applied only for the two parallel profiles, namely T1-1-S and T1-3-S (Fig. 2). M-4-S and T1-2-S profiles were measured using 28 electrodes and the roll-along techniques, with a 25% advancing step of the total array.

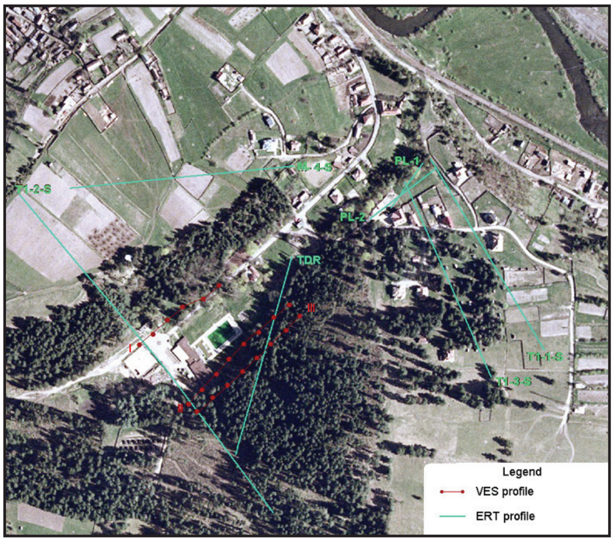



**Fig. 2** Satellite image showing location of ERT and VES profiles in the Bradul spa area

During measurements, strong effects of geophysical noise were noticed on two sectors of the T1-2-S profile, when crossing the Bradul valley. The electrical noise was mainly caused by anthropogenic objects such as underground large metallic pipelines, concrete tubes or reinforced concrete building infrastructures. Such anthropogenic structures strongly affect the spatial distribution of resistivity, distorting the electrical effects of geological structures and/or aquifers (Fig. 3).

Data processing was carried out by using the ErthImager2D software, the ERT data being inverted using the smooth modeling inversion procedure (Newman no-flow imposed boundary condition at the ground surface and Dirichlet condition for lateral and bottom boundaries). The resistivity data measured and processed in the Bradul spa area were represented as 2D apparent resistivity sections (Fig. 4) and 2D inverted resistivity sections (Fig. 5).

2D data on the ERT parallel profiles T1-1-S and T1-3-S were acquired using the same technical parameters (28 electrodes, 10m separation, Schlumberger and Gradient arrays) and the resulted resistivity values were used for generating a 3D resistivity model in the surveyed area (Fig. 6). The 3D resistivity model was obtained using the finite element method for resolving the forward problem and Occam's algorithm for inversion modeling.

As most of the ERT profiles had been deployed in areas with uneven topography, terrain models were created for each of them and incorporated during the resistivity data inversion (Figs 5 and 6).

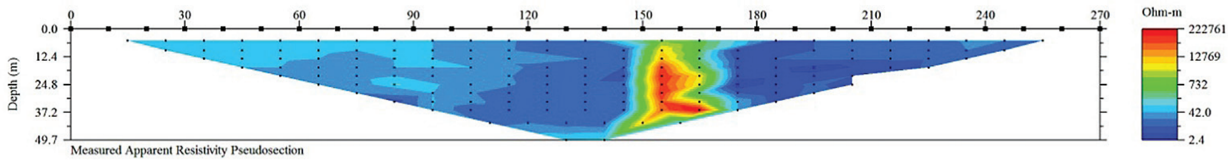



**Fig. 3** Resistivity perturbation of ERT apparent resistivity data determined by an underground concrete structure

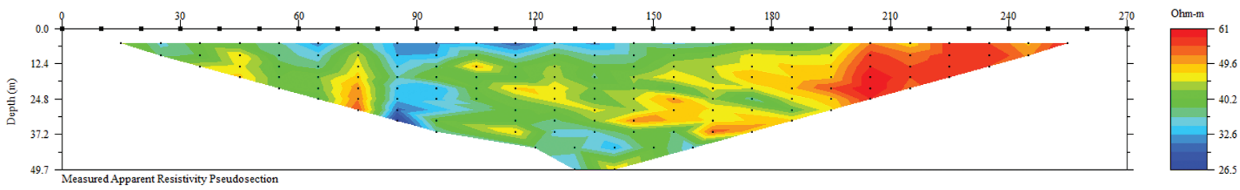



**Fig. 4** Apparent resistivity section on profile T1-3-S using Schlumberger array

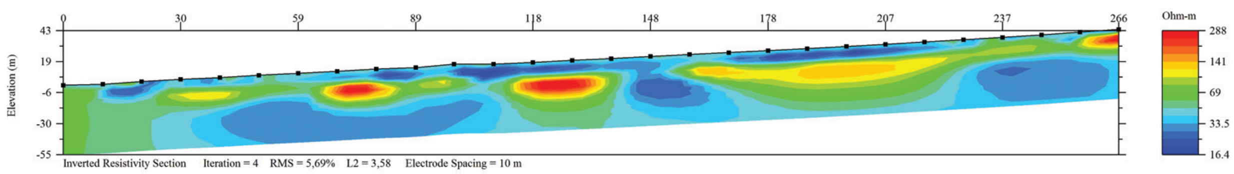



**Fig. 5** Inverted resistivity section on profile T1-1-S using Schlumberger array

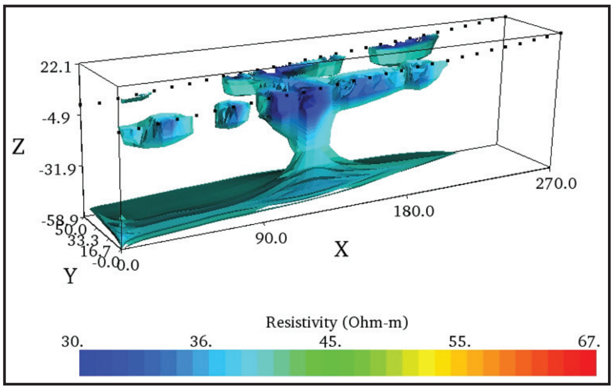



**Fig. 6** 3D resistivity model (contour plot) in the Bradul spa area

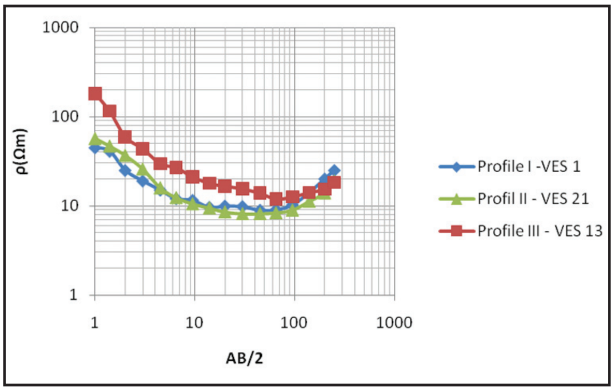



**Fig. 7** Vertical Electrical Soundings in the Bradul spa area

### 4.2 Vertical Electric Soundings (VES)

Resistivity data in the Toplita area previously obtained by using the Vertical Electric Sounding technique (Ursu, 1994) were reprocessed and reinterpreted in order to benefit of the long arrays which could be deployed at that time (AB = 500m), offering information from greater depths.

VES curves selected from the three survey lines show similar features in the investigated area (Fig. 7): a) high resistivity values at shallow depths; b) thick low-resistivity structure; c) increase in resistivity at highest depths.

The resistivity values on the selected VES II and III profiles (Fig. 2) were used to build apparent resistivity sections (Figs 8 and 10), the depth being first evaluated as AB/2. Since the geological structure in the Bradul spa area is not consistent with the horizontal sedimentary beds assumption which had been originally considered for the interpretation of VES data (the crystalline basement and the Neogene volcaniclastic deposits being characterized by large in-depth and/or lateral lithological and compaction inhomogeneities), the AB/3 depth evaluation for the resistivity anomalies was considered a good option (Figs 9 and 11).

The layered distribution of apparent resistivity, as interpreted from data presented in Figure 7, is preserved in both versions (AB/2 and AB/3) of VES data on profiles II and III. However, the shape of the resistivity anomalies changes from the mainly horizontal layering illustrated by profile III, to a rather steep thickening of the low resistivity anomaly, on profile II.

## 5. INTERPRETATION OF GRAVITY, AEROMAGNETIC, ERT AND VES DATA

### 5.1 Interpretation of gravity and aeromagnetic anomalies

Regarding the local deep structural features, the authors of this study assume that the residual anomaly of increased gravity is due to an intrusive volcanic body consisting of Sarmas basaltoid andesite, closely associated with the postvolcanic processes in this area. The intrusive processes deter-

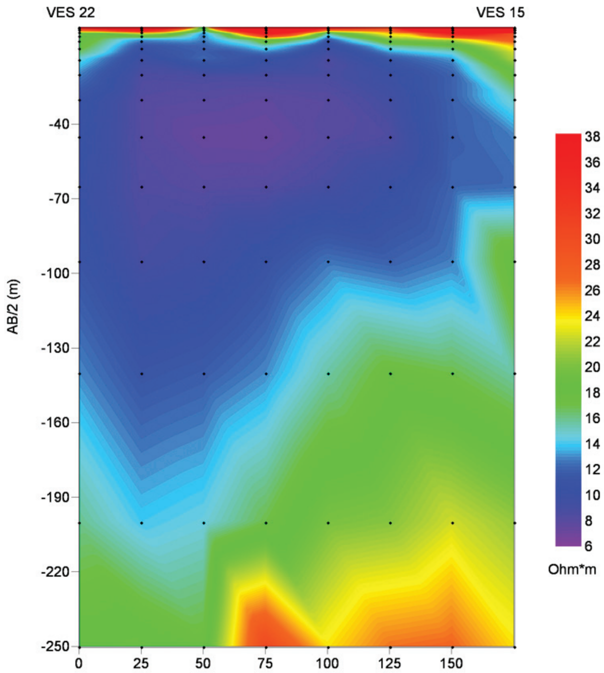



**Fig. 8** Apparent resistivity section on VES profile II (AB/2 evaluated depth)

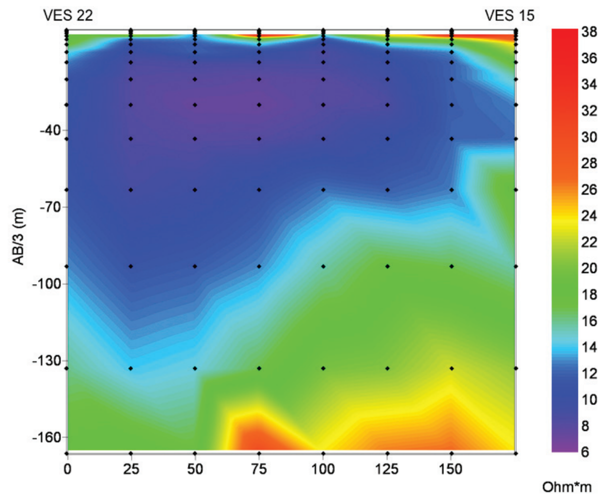



**Fig. 9** Apparent resistivity section on VES profile II (AB/3 evaluated depth)

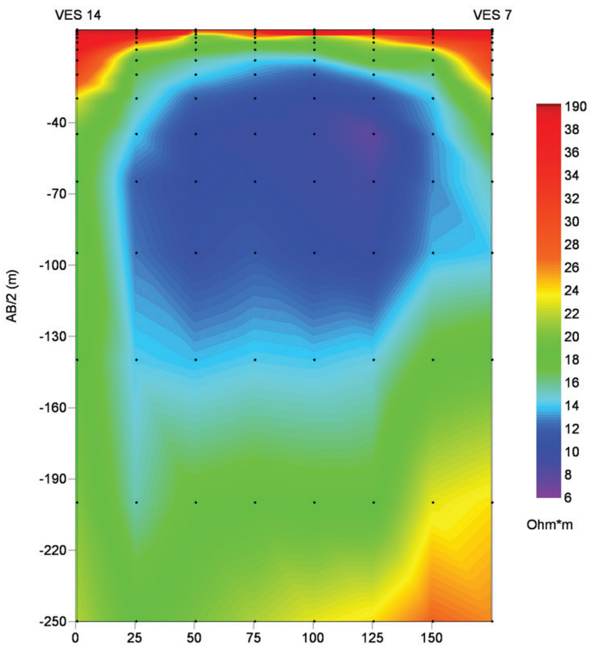



**Fig. 10** Apparent resistivity section on VES profile III (AB/2 evaluated depth)

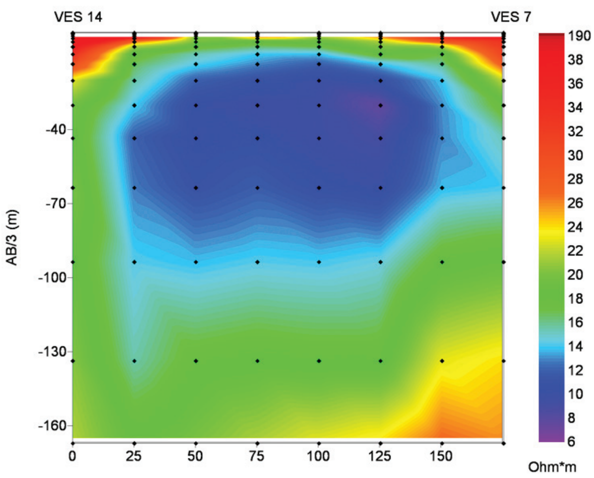



**Fig. 11** Apparent resistivity section on VES profile III (AB/3 evaluated depth)

mined intense fracturing and faulting within the uppermost metamorphic formations of the crystalline basement, with subsequent karstic phenomena within the Rebra crystalline limestone.

The deeply situated magmatic body suggested by the residual anomaly of increased gravity south of Toplita presumably generates a magnetic effect which is being largely attenuated by intense clayey alterations that can be presently observed in outcrops or in sectors where the soil was removed.

### 5.2 ERT and VES data interpretation

Electrical resistivity is highly influenced by mineral composition and state of host rocks (porosity and pore structure), pore fluid properties having a strong effect on the electrical resistivity of rocks. The fluids amount and their chemical composition can cause important electrical resistivity variations within the same type of rock.

Variations of water resistivity were recently employed to discriminate between underground fresh water and salty water, the latter brought in aquifers by marine intrusions (e.g. Georgescu *et al*., 2010; Chitea *et al*., 2011).

In geothermal areas, besides groundwater mineralization, rock alteration and temperature are other parameters that can cause variation of resistivity values. High mineralization and high temperature of water, together with clay minerals in rocks are causes for a significant decrease of measured resistivity (Hersir and Bjornsson, 1991).

The electrical resistivity of fresh water in Toplita area was previously determined as 59.5 Ωm, while in the Bradul spa the thermo-mineral water showed a much lower value, of 5.54 Ωm (Ursu, 1994). This important difference in electric resistivity represents a significant contrast of physical properties that was used when interpreting ERT and VES anomalies in terms of either fresh, or thermo-mineral groundwater.

ERT survey lines PL-1 and PL-2 showed no geophysical evidence of thermo-mineral water resources, the shallow low resistivity anomalies ranging between 16 and 30 Ωm being entirely associated with soil moisture related to precipitations (Fig. 12).

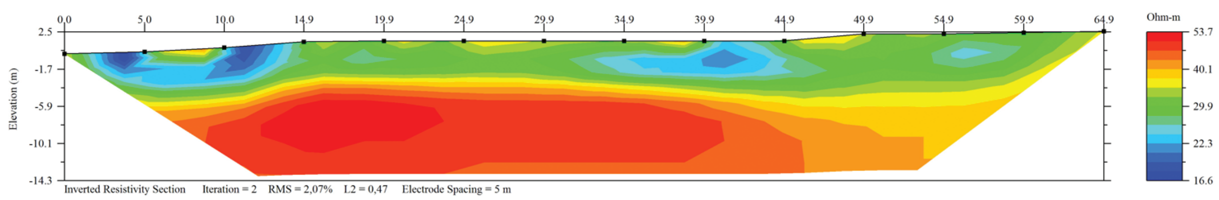



**Fig. 12** ERT inverted resistivity section on profile PL-1

Resistivity sections obtained on the ERT M-4-S, T1-2-S, T1-1-S, T1-3-S and TDR survey lines showed geophysical evidences of local tectonics in this area, the high conductivity vertical sectors, as shown in Figure 13, being interpreted as fractured rocks along faults, with higher permeability for groundwater flows.

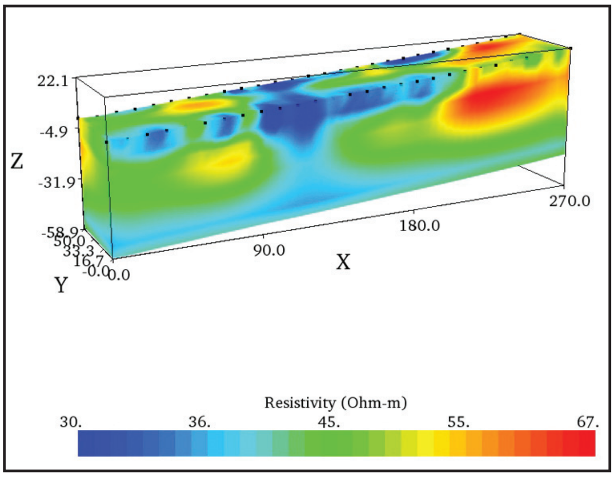



**Fig. 13** Vertical low resistivity anomaly related to local tectonics depicted by inverted ERT data

As already mentioned, the 3D resistivity model presented in Figure 13 was obtained using the ERT data measured on T1-1-S and T1-3-S profiles. The vertical low resistivity anomaly suggests the presence of a vertical high permeability sector, but the resistivity values, ranging here between 30 and 40 Ωm, indicate a vertical flow of fresh groundwater and cannot be interpreted as being due to thermo-mineral water.

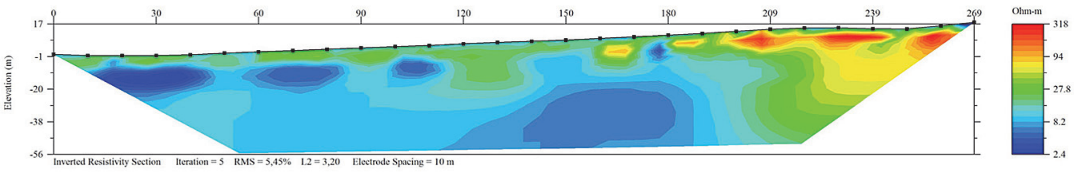
The ERT investigations over the T1-2-S and TRD survey lines showed vertical contacts between high and low resistivity zones. A few sectors located on the TRD profile, displaying extremely low resistivity values (4–10 Ωm), are considered to be characteristic for thermo-mineral groundwater (Fig. 14).

The high conductivity zone (resistivities ranging between 6 and 14 Ωm) located in the right bank of the Bradul valley and illustrated on both ERT and VES sections (Fig. 14), is interpreted as an upward flow of thermo-mineral water using a vertical fracture system.

At depths ranging between 20 and 40m, high permeability levels in the Neogene volcaniclastic rocks offered the possibility for a quasi-horizontal displacement of the thermo-mineral water, characterized here by resistivity values of 2–10 Ωm.

The main fracture that controls the upward movement of thermo-mineral water is trending parallel to the Bradul valley (NE-SW), close to its right bank, the vertically developed low resistivity anomaly being best illustrated on the TDR ERT survey line and VES profile II. It is virtually absent on VES profile III, situated uphill in its close vicinity, due to rapid variations of apparent resistivity on short distances (Figs 10 and 11).

Based on the integrated interpretation of gravity and resistivity data (ERT and VES) in the Bradul area (Ionescu *et al*., 1985; Ursu, 1994; Chitea *et al*., 2012), a hydrogeological bore-



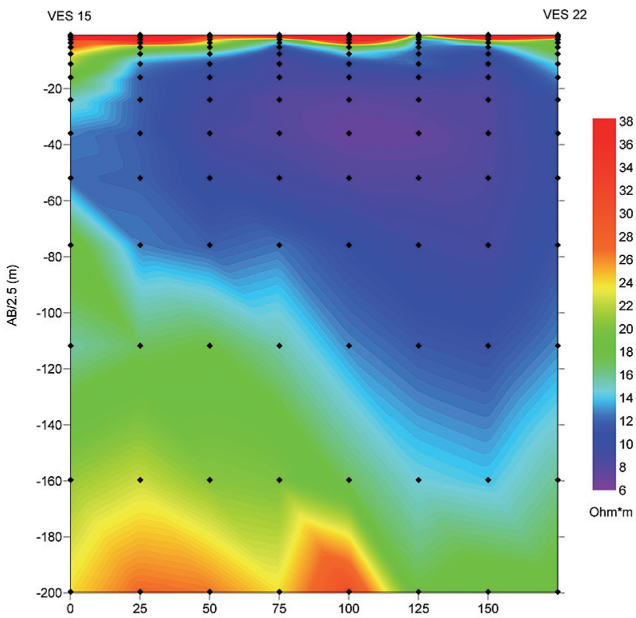




**Fig. 14** Inverted ERT resistivity data for TDR profile overlapping VES apparent resistivity anomalies on profile II

hole was drilled. A highly tectonized fault zone was twice crossed between 190m and 200m depth, the presence of thermo-mineral water being here indicated by resistivity well logging and hydrogeological borehole procedures (Chitea *et al*., 2012).

Since the drilled borehole crossed the vertical faults and the up-flow of thermo-mineral water at ca 200m depth, the depth evaluation for the VES apparent resistivity section was again calculated using AB/2.5 (Fig. 14). Doing this, the apparent resistivity data (low resistivity anomaly specific for thermo-mineral groundwater), the structural information (faults and highly tectonized sectors) and the hydrogeological one (up flow of thermo-mineral water sampled in borehole) are well accommodated in a single model.

## 6. CONCLUSIONS

Experiments related to applying the Electric Resistivity Tomography (ERT) geophysical technique in the Toplita area showed that the Schlumberger array provides better results for deeper levels as compared to the Wenner one.

The ERT data obtained during this study as apparent or inverted resistivity sections were integrated with previous VES and gravity results, locating a vertical fractured sector characterized by the lowest resistivity values.

The newly projected hydrogeological borehole crossed at 190-200m depth a highly tectonized zone containing thermo-mineral water, its temperature being similar to that exploited in the Bradul spa (27 $^0$C).

## ACKNOWLEDGEMENTS

The authors acknowledge the support of the Toplita Municipality for carrying out the ERT measurements and for providing VES data for the Bradul spa area.

The authors are indebted to the reviewers for their contributions to an improved version of this paper.

## REFERENCES

Airinei I., 2011. Hydrogeological report of the FH3-Toplita borehole (in Romanian). Agata SRL, Miercurea Ciuc

Alexandrescu G., Muresan G., Peltz S., Sandulescu M., 1968. Geological Map (Toplita sheet) scale 1: 200,000. Geological Institute, Bucuresti

Chitea F., Georgescu P., Ioane D., 2011. Geophysical detection of marine intrusions in Black Sea coastal areas (Romania) using VES and ERT data. GEO-ECO-Marina, 17, Bucuresti

Chitea F., Ioane D., Georgescu P., Orza R., Airinei I., 2012. Resistivity tomography study in Toplita area, Romania. GEO 2012 Abstracts Volume, Bucuresti

Gabor P., Piroska F., Szakely S., 2010. Hydrogeological study in the Toplita town area, Harghita county (in Romanian). Aquaprofit SRL, Miercurea Ciuc

Georgescu P., Ioane D., Niculescu B.M., Chitea F., 2010. Geoelectrical investigations of marine intrusions on the Romanian Black Sea shore. GEO-ECO-Marina, 16, Bucuresti

Hersir G.P., Bjornsson A., 1991. Geophysical exploration for geothermal resources. UNU Geothermal Training Programme, Report 15, Iceland

Ioane D., 1995. A status of volcanic structures determination in Romania by gravity data analysis. Cahiers du Centre Europeen de Geodinamique et de Seismologie, Vol. 8

Ionescu F., Polonic P., Teodorescu V., 1985. Deep structure of the Neogene volcanics in the Calimani-Gurghiu-Harghita mountains (in Romanian). Geofizica, 23, 44-52

Ionescu L., 2005. Geological boreholes for thermal waters in Toplita area (in Romanian). Geolex SRL, Miercurea Ciuc.

Suceava M., Proca A., Fotopolos S., 1969. The gravity anomaly of the Calimani-Gurghiu-Harghita volcanic mountains (in Romanian). Geofizica, Vol. 6, no. 2

Tamburriello G., Balasco M., Rizzo E., Harabaglia P., Lapenna V., Siniscalchi A., 2008. Deep electrical resistivity tomography and geothermal analysis of Bradano foredeep deposits in Venosa area (Southern Italy): preliminary results, Annals of Geophysics, Vol 51, N. 1

Ursu D., 1994. Geophysical study in the thermo-mineral springs area of Bradul spa, Toplita (in Romanian). Geotehnofor SRL, Bucuresti

Veliciu S.,1988. Contributions to the geothermal prospecting of thermal waters with applications in Romania (in Romanian). Geofizica, D, 15, 85-201

*** 2007. Instruction manual for EarthImager 2D, Resistivity and IP inversion software. Advanced Geosciences Inc (AGI), 2007. Austin, Texas.