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Study of the cross-border geothermal field in the Sarandoporos-Konitsa area by electrical soundings

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Abstract: *The geothermic field in Sarandaporos-Konitsa lies in the cross-border area between Albania and Greece. The field has several surface manifestations and extended geological investigations, including tectonic and geomorphological studies have been carried out. This work presents the field application and interpretation of vertical electrical sounding (VES) data in both sides of the borders. The purpose was to study the structure down to the depth of 1000 m, in a relative large area, where information about the deep structure would have an extreme cost if acquired by a network of boreholes.*

Two main geoelectrical formations that coincide with the flysch and the limestone basement are revealed. The area appears faulted in the NW-SE and NE-SW directions and a few concealed graben and horst structures exist. Low resistivity values were observed above basement uplifts and major faults. These values were attributed to hot fluid circulation.

Key words: *Electrical Sounding, Geothermal Field, Sarandaporos-Konitsa Area, Albania, Greece.*

INTRODUCTION

The studied area lies north of the city of Konitsa in Greece and includes the Albanian village of Koukes (Fig.1). Specifically, it lies between the geographic latitude (φ) $40^o\ 02^'$ up to $40^o\ 07^'$ and in geographic longitude (λ) $20^o\ 37^'$ up to $20^o\ 45^'$.

Figure 1 shows also the topography of the studied area and the locations of VES measurements. The soundings are arranged along profiles ranging approximately NE-SW. Thermal springs are present both in the Greek and Albanian sides. Consequently, it is reasonable to assume that the same geothermal field extends in both sides of Greek –Albanian borders. Thermal springs known in the Greek part of the region are the thermal springs of Kavassila – Piksaria where the water temperature reaches up to 31^o C. In the Albanian side, the existence of hot springs (Koukes) is also well known, where the water supply is provided by the hot springs situated in the Skordili bridge (Fig.1).

The main target of the present study is the detection of geothermal fluids, tectonic zones and faults using electrical methods. Mapping of the relief of the basement, which is considered as the ceiling of the limestone formation, comprises also a target of the present study. Further, quantitative geoelectrical models of the subsurface were produced along seven sections by means of 1-D inversion of the VES data using the steepest descend method (Koefoed, 1979).

GEOLOGICAL AND TECTONIC SETTING OF THE REGION

The area belongs to the External Hellenides, the geological and tectonic zones which range parallel to the Adriatic Sea and cross both countries. In the Konitsa region, in particular, the geological formations belong to three different geotectonic zones; namely in the Ionian, Pindus and in the Subpelagonian zones (Koukuza and Perrier, 1963-1964) (Fig. 2).

The Ionian zone is assumed to be an indigenous zone. Above its formations we have the thrusts of formations of the Pindus zone. The formations of Subpelagonian zone comprises fragmented tectonic covering. This covering is situated above the formations of the Pindus zone. In the tectonic context, the region presents a complicated picture of successive Nappe and Flake tectonics, overlaid one above the other (Dimopoulos *et al.*, 1990).

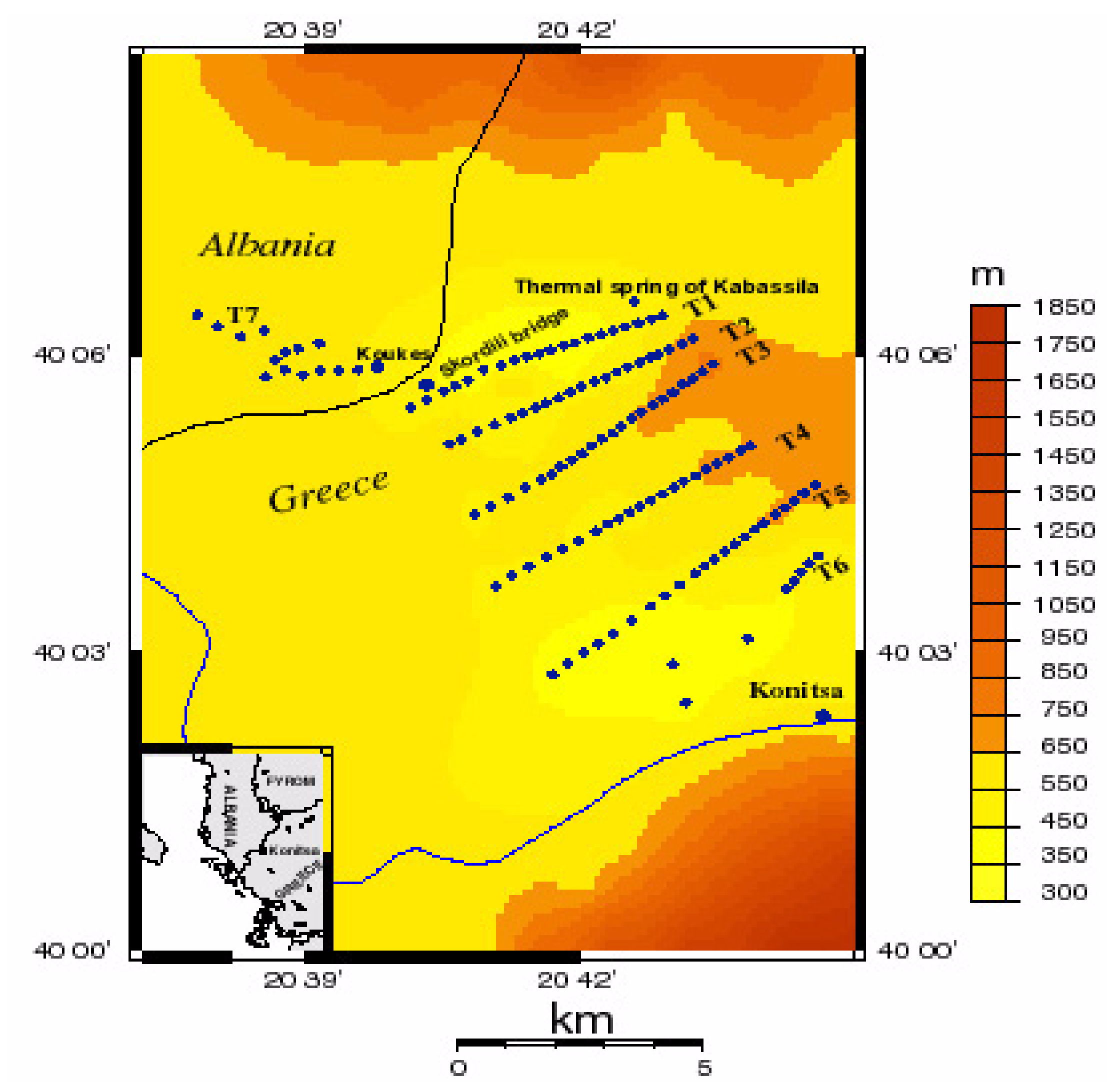

FIG. 1. The geographic position of the studied area. Hot springs are presented both in the village of Koukes (Albania) and in the location Kavasilon (Greece). The locations where VES's were performed are marked by circles. These soundings were arranged along sections marked from T1 to T7

The tectonic structural characteristic of the Ionian zone comprises of anticlinal and synclinal series with NNW-SSE up to NW-SE directions, thrusted one above the other towards the west. The main anticlinal structures in the region of interest are the Konitsa's anticline and the anticline of Skrodoli Bridge (Fig. 2). The main directions of faults are orthogonal and intersecting each to the other. The primary fault system is of NNW–SSE direction (Dinaric direction). The secondary fault system trends in the NE–SW direction. The Konitsa's fault belongs to the later system and it comprises an important component of the overall setting of the studied area.

THE GEOELECTRICAL DATA

Concerning the Greek side, the resistivity measurements were carried out in the area of Konitsa from the Institute of Geological and Mineral Explorations (IGME), in two stages. During the first stage, in the spring of 1985, resistivity and self-potential (SP) measurements were carried out (Thanasoulas, 1986a). The second stage took part during the period June-July 1986 (Thanassoulas, 1986b). In this stage, the investigations extended towards to the western side of the region which found to be of particular interest, after the preliminary interpretation of the results of the first stage.

A total number of 114 VES data measured in the Greek part was used in the present study. These are arranged along the profiles T1 to T6, as shown in the map of Figure 1. The soundings were spaced at about 200 m each from the other. Also, the results of 14 deep soundings are used (Avxhiu, 1992), which were carried out in the Albanian side of the borders (Fig.1, Fig.2). Some of these soundings are arranged along the profile T7 and they are not spaced at equal intervals.

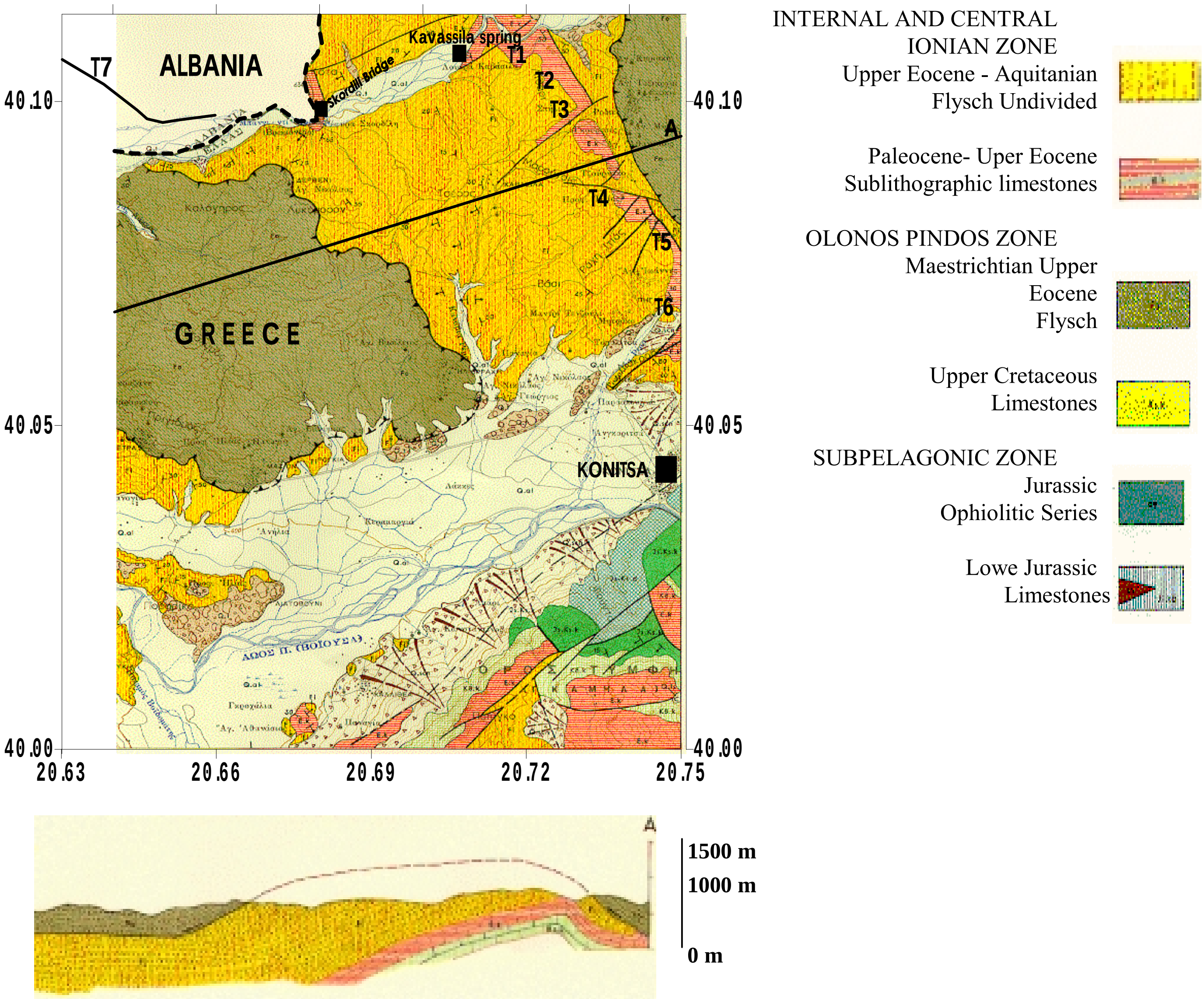

FIG. 2. Regional geological map of the studied area (Koukuza and Perrier, 1963-1964). The locations, where VES's have been conducted , are marked by dots

All the resistivity measurements were carried out using the Schlumberger array. The current line length was 1600 m (AB/2=800 m) for the majority of the soundings. Nevertheless, for a small number of VES, located mainly in the centre of the Konitsa's basin, the current line length was 4000 m (AB/2= 2000 m).

DATA PROCESSING AND QUALITATIVE INTERPRETAION

The analysis of VES data was done along the baselines described below. At the beginning, an approximate model was assessed to each sounding curve either guessing the subsurface conditions or using the three layers master curves and the associated auxiliary ones (Keller and Friscknecht, 1970). The model parameters, consisting of layer resistivities and thicknesses, were fed into a computer program along the re-digitised observed field curve. The program is based on the steepest descent optimisation method (Koefoed, 1979). At first it constructs a curve which corresponds to the given model through the solution of the direct problem by means of Ghosh's filters (Ghosh, 1971). Next, a measure of the misfit is assessed. The sum of the squared deviations between the two types of the data is considered in this case. Then, the model parameters are changed successively, until the misfit measure falls below a predefined value. The minimisation of the misfit measure is achieved through the steepest descent method. Thus, the refined model parameters that give a misfit below the predefined level, are used in the next stages of the study.

However, qualitative interpretation of the geoelectric measurements was first attempted. Thus, maps of the spatial distribution of apparent resistivity were constructed for various current line expansion lengths, i.e. the quantity

$\rho_\alpha(AB/2) = F(x,y)$

was mapped. Figures 3 and 4 show the spatial distribution of apparent resistivity for different half-current line spacing (AB/2). All apparent resistivity distribution maps refer to the same elevation plane, which is +405 m above the sea level.

The study of apparent resistivity distribution maps shows the following:

A) Generally, the direction of resistivity contours is NW- SE. This direction corresponds to the direction of the contact between flysch and limestone, which appears north of Konitsa (Fig.2).

B) In all maps, the distribution of apparent resistivity values ρ_α shows that high values (ρ_α > 100 Ohm.m) dominate the northeastern and eastern part of the region. The limestone formation outcrops in these particular locations.

C) The locations where the apparent resistivity values are less than 100 Ohm.m are those where the flysch has a considerable thickness.

D) Zones of a high conductivity (1/ ρ_α) are detected in the region where the flysch dominates and they are arranged along the NW- SE direction. The existence of these zones might be attributed to the circulation of fluids (cold or hot) in the tectonic faults of the flysch.

E) From the tectonic point of view, the main features that dominate the area are the alignments

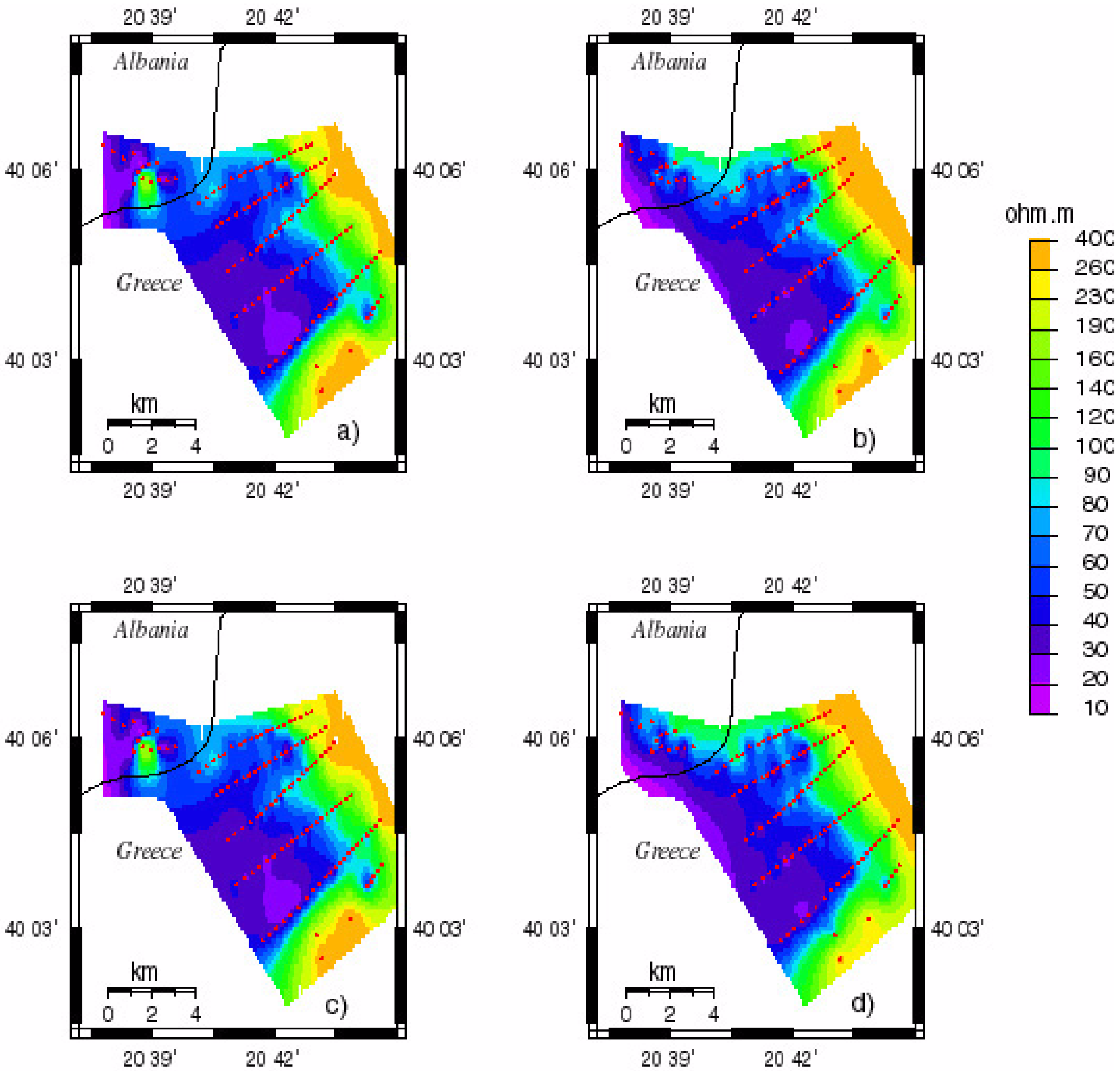

FIG. 3. Distribution of apparent resistivities for half current lines (AB/2) a) 250 m, b) 320 m, c) 400 m, d) 500 m. The locations where VES's were performed are marked by small circles.

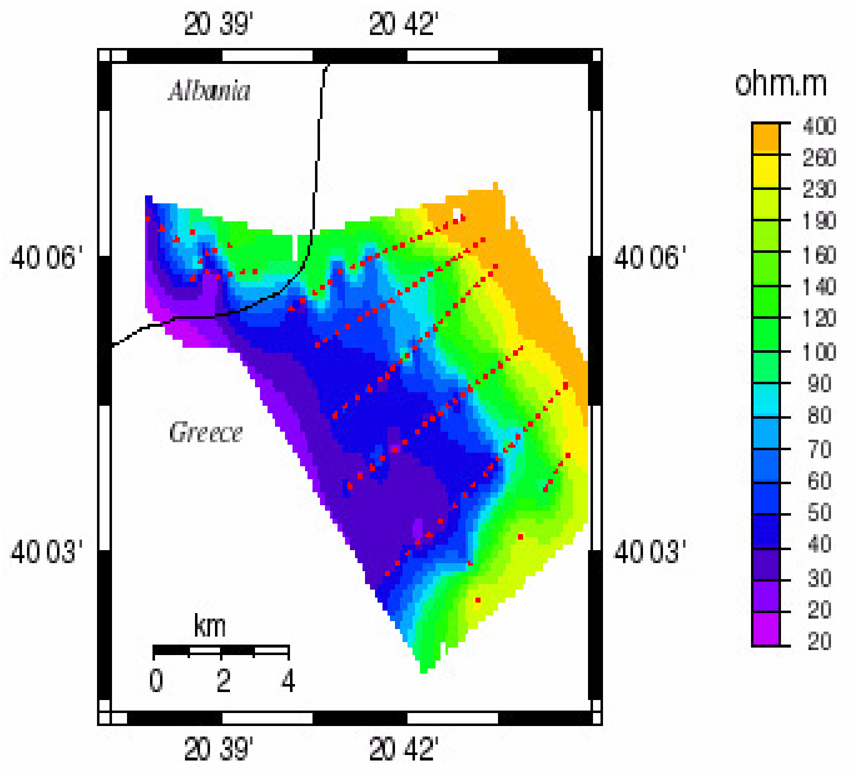

FIG. 4. Distribution of apparent resistivities for half current lines AB/2 = 640 m. The locations where VES's were performed are marked by small circles.

observed in the eastern part of the maps. They should reflect the existence of major tectonic features along the NW- SE direction. Both these alignments are attributed to the presence of Limestone either outcropping or uplifted near the ground surface.

GEOELECTRIC SECTIONS T_1-T_7

The one-dimensional inversion of the VES data produces geoelectical models for each sounding location. The next step was to combine these models to construct some pseudo 2-D models along the profiles where the soundings were arranged. These sections are shown in Figures 5, 6 and 7. Each section summarises the results along one of the profiles T1 to T7. The apparent resistivity distribution versus electrode spacing values (AB/2), the so-called pseudosection is also shown for each profile.

The study of the geoelectric sections T_1-T_7 shows the existence of two main geoelectric formations. The first one has resistivity values in the range of 100-5000 Ohm.m. These are relatively high resistivity values that are associated with the deeper formation. Therefore, we assume that this formation represents the limestone basement. The second geoelectric layer, which is overlying the limestone, has relatively small resistivity values (3-120 Ohm.m) and corresponds to the flysch.

In section T_1 (Fig. 5a), three geoelectric formations are observed. The first one with resistivity values ranging between 91 and 1230 Ohm.m corresponds to the limestone basement. The second one is considered to be the flysch with apparent resistivity values 36-153 Ohm.m that appears to overlay the basement. The third formation with resistivity values 14–1 Ohm.m, appears inside the limestone basement (VES-10 till 0) and probably corresponds to some reservoirs of hot water.

The form of the anomalies in the upper part of Figure 5a, implies the existence of intense fault tectonics. The position of the thermal springs of Kavasila is projected on the profile T1 and evidently coincide with the position of a fault between VES26 and 28. The fault uplifts the limestone in that particular location.

The section T_2 (Fig. 5b) represents the same tectonic and geoelectric picture as the section T_1. The geoelectric basement shows resistivity values of 114 up to 1110 Ohm.m. The flysch is represented by the resistivity values in the range of 30 up to 400 Ohm.m. The geo-electric formation with small values of resistivity (ρ_α = 2 up to 30 Ohm.m) is visible above the tectonic horst (VES-0) and also in the location between VES-13 and 21. This layer corresponds probably to the existence of hot water reservoirs in the particular locations.

In the section T_3 (Fig. 6a), the geoelectric basement plunges towards the west and disappears completely

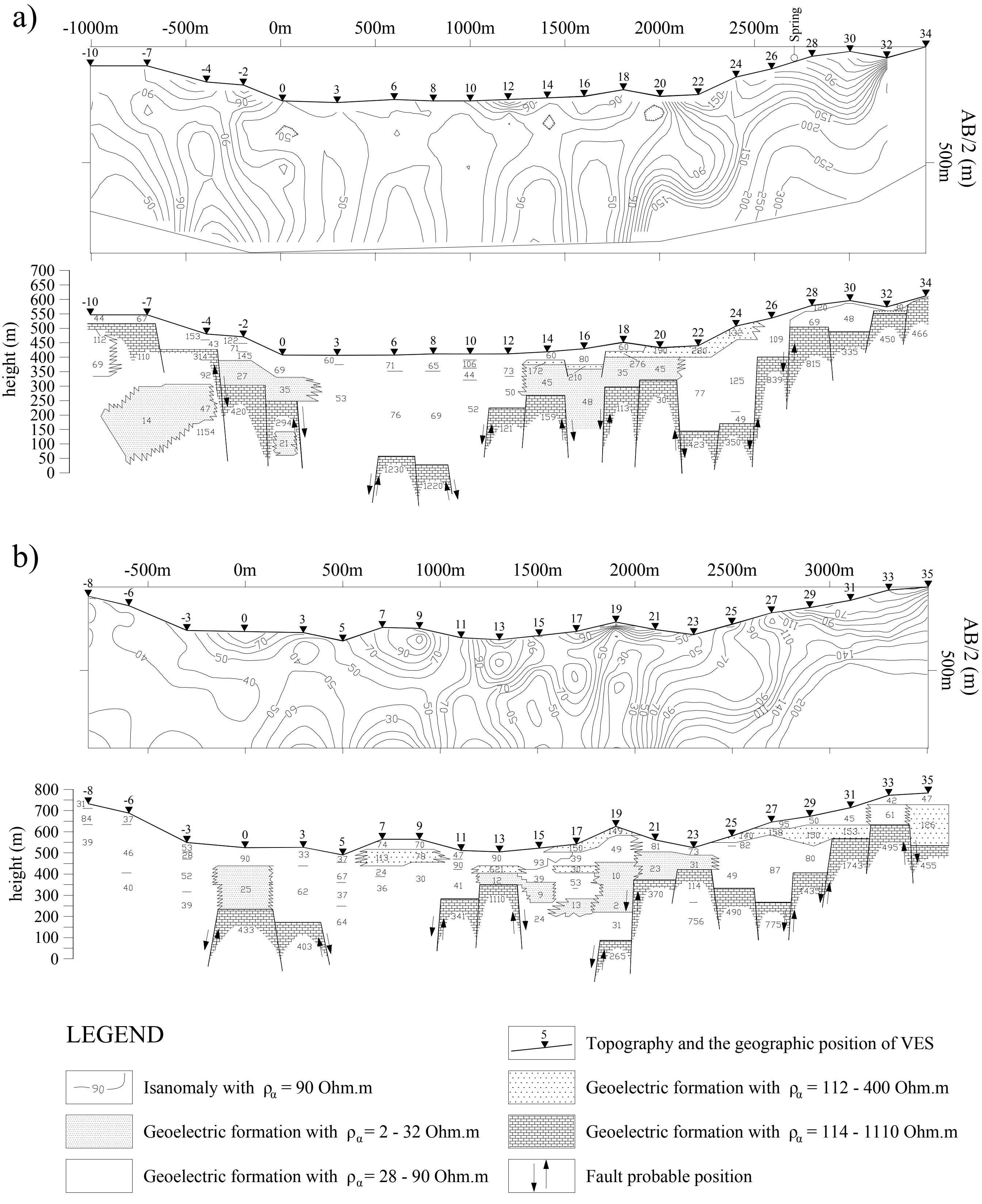

FIG. 5. Geoelectric sections of Konitsa’s region. a) Section T1; b) Section T2

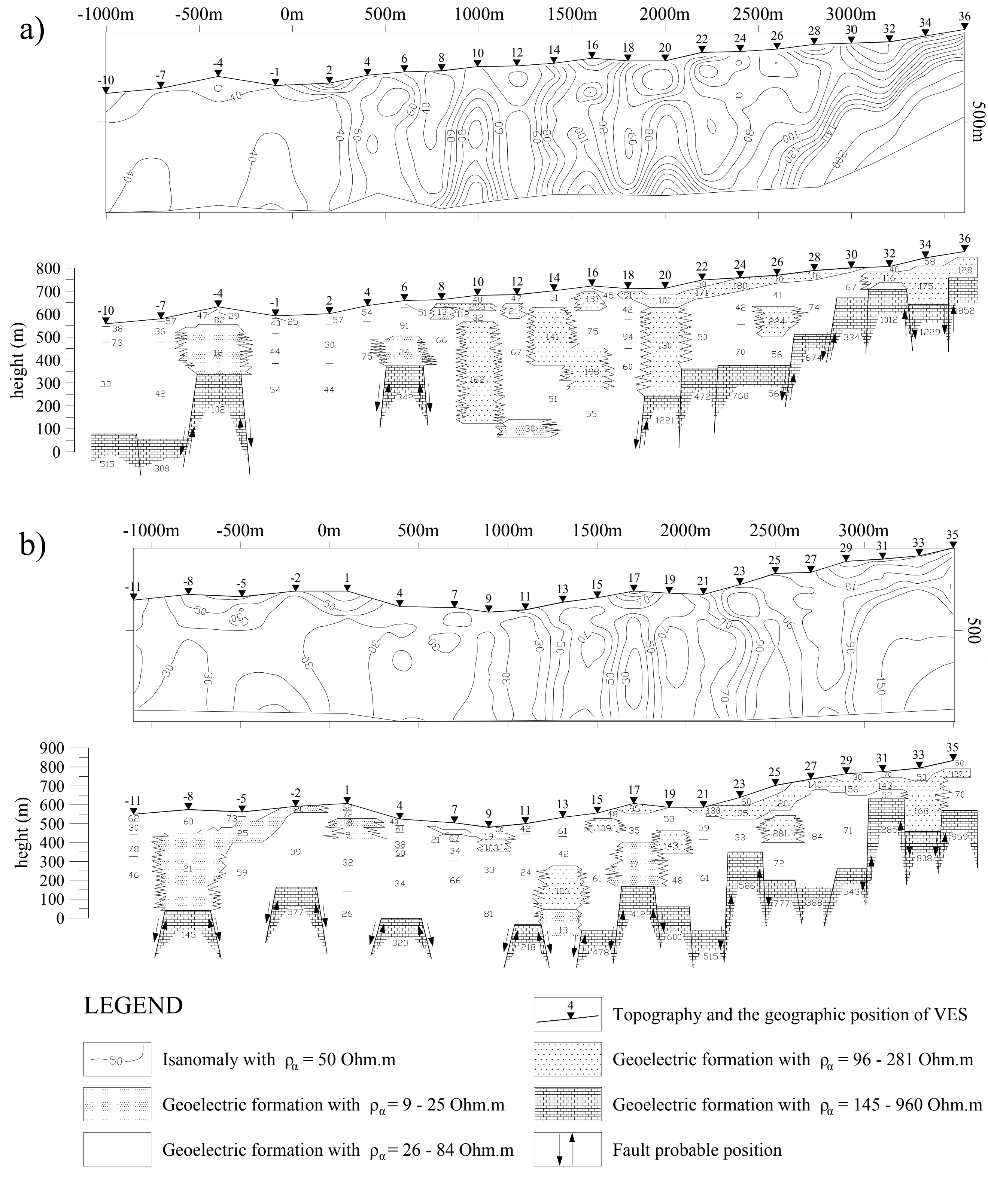

FIG. 6. Geoelectric sections of Konitsa's region. a) Geoelectric section T3; b) Geoelectric section T4

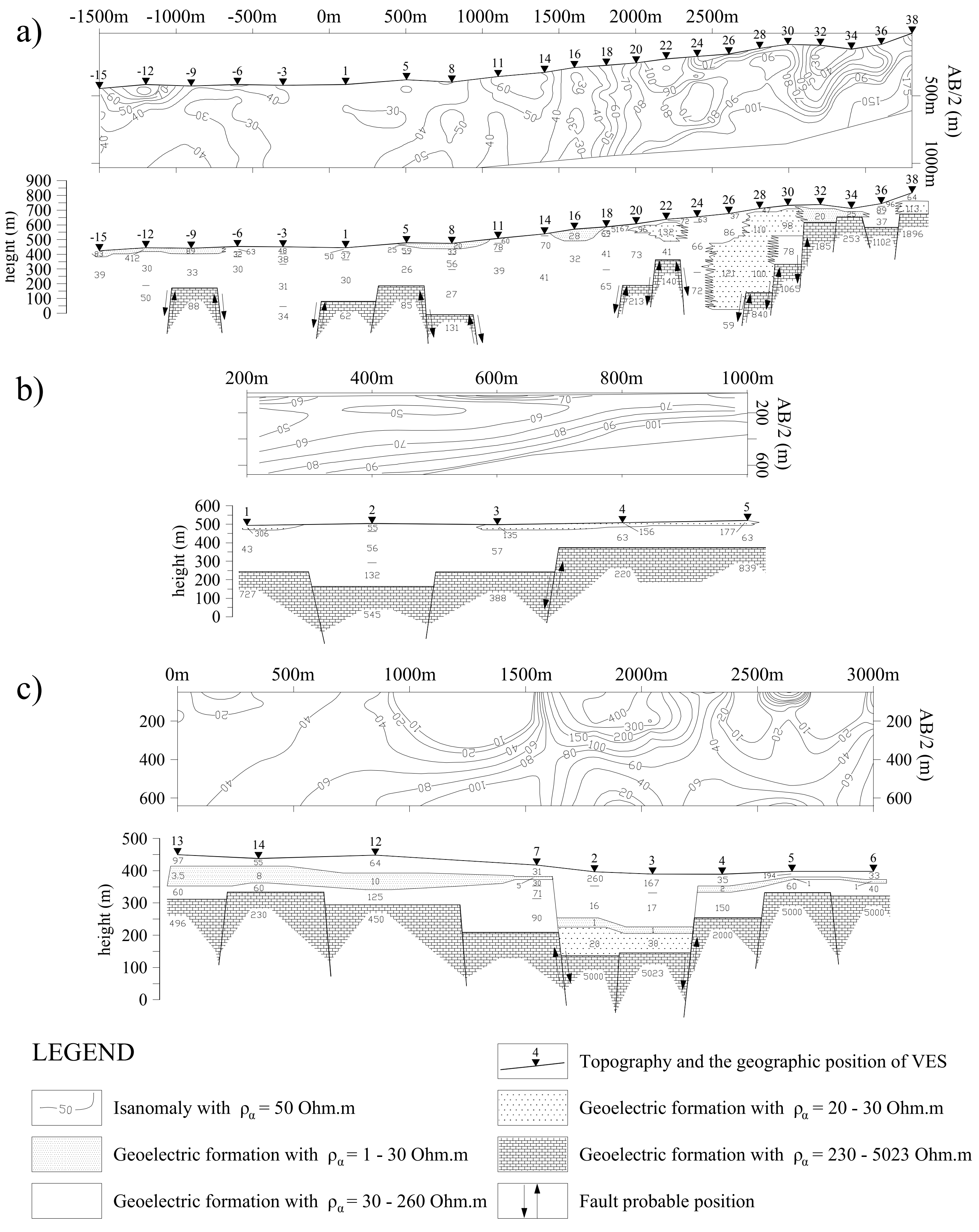

FIG. 7. Geoelectric sections of Konitsa's region. a) Section T5; b) Section T6; c) Section T7

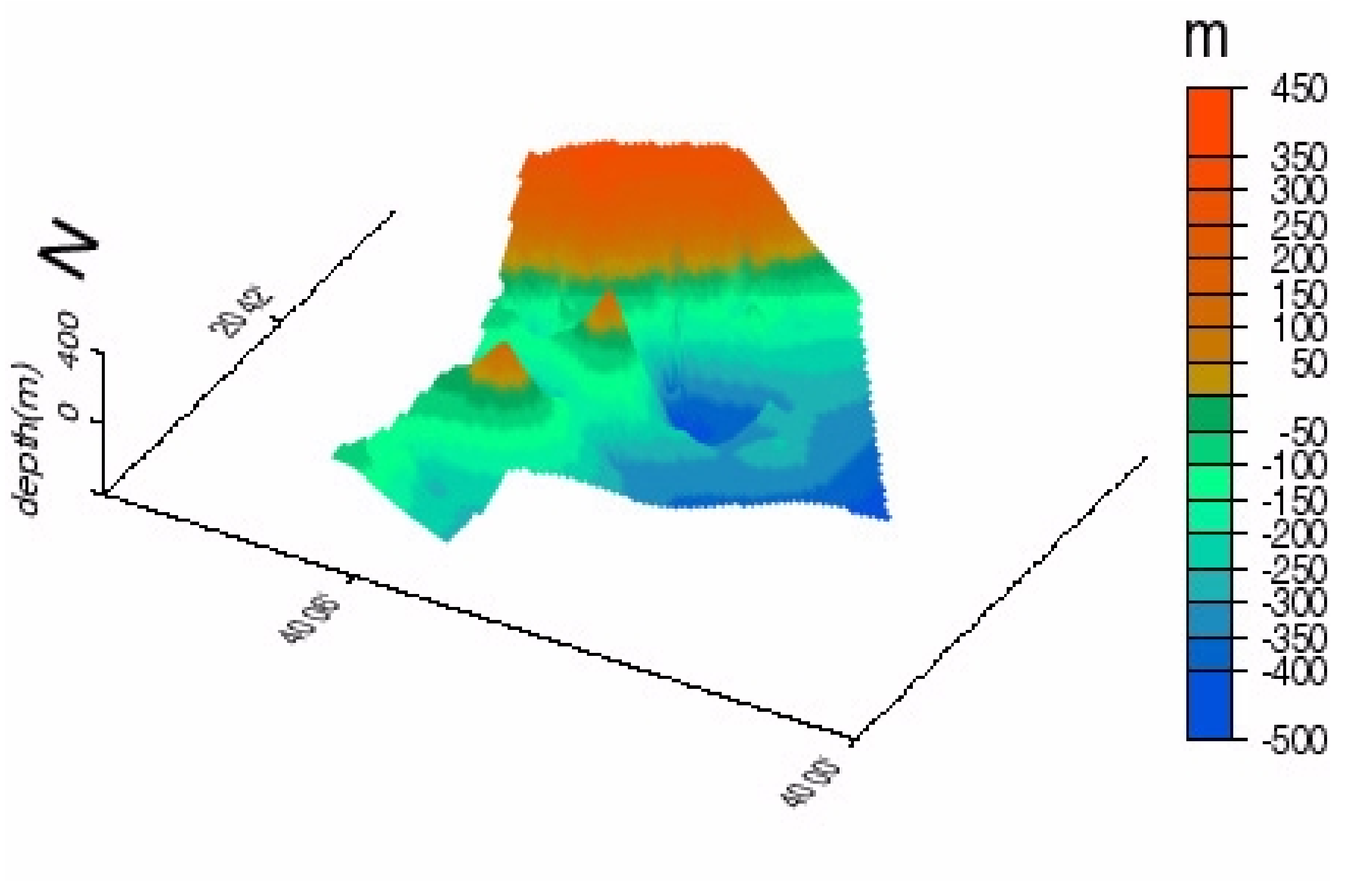

FIG. 8. 3D view of geoelectrical basement ceiling (reference level +405 m)

from the position of VES-4 till 6. Taking into account the fact that this profile is in the highest topographical level of the area under investigation, and it is very difficult to detect the geoelectric basement in the southwestern part of the section (positions -1 till 4) where the basement is deeper.

The same observations are valid for the geoelectric section T_4 (Fig. 6b). In fact, the geoelectric formations in the studied area are the limestone basement (ρ = 145 up to 960 Ohm.m) and the overlaying flysch (ρ = 28 up to 281 Ohm.m). The low resistivity values (ρ_α=34 Ohm.m) are observed above the tectonic horst on the VES station of 23.

In the geoelectric sections T_5 and T_6 shown in the Figures 7a and 7b respectively, the geoelectric formations correspond to the limestone basement and the overlaying flysch. The subsurface picture is almost the same as in all other sections discussed so far.

The section T_7 is located in the Albanian part and topographically is in the lowest topographical level of the region (Fig. 7c). Three geoelectric formations are present. One of them, which has a thickness of 30 to 50 m poses very low resistivity values (ρ = 1–10 Ohm.m) and it is located inside the impermeable formation of the flysch. This geoelectric formation shows the existence of hot water circulation in the flysch formation.

The 3-D map of the basement ceiling is shown in Figure 7. The plane +405 m above the sea level was used as reference. The positive values depict uplifting of the basement above this plane whilst the negative ones show plunging below the reference plane. This map shows the existence of rupture zones of NW-SE and NE- SW direction. Also, the existence of tectonic grabens and horsts is presented in the 3-D sense. These features range mainly in the NW-SE direction.

CONCLUSIONS

The geophysical study of Sarantaporos-Konitsa area has shown that mainly two geoelectric formations were present. The first one has resistivity values up to 150 Ohm.m and corresponds to the flysch. The second formation is underlying flysch having relatively higher resistivity values (ρ > 110 Ohm.m) and it reflects the limestone basement.

The limestone basement appears to be faulted in all sections, with main rupture zones of NW- SE direction and secondary one in the NE-SW direction. The tectonic graben and horst structures of the geoelectric basement of the NW-SE direction are also well shown. Thermal springs located in this region are related with the existence of tectonic faults in the limestone basement.

The low resistivity values above all basement horsts and fault zones of the limestone basement are mostly related with the circulation of the hot water inside the basement at the corresponding positions. Thermal springs manifest themselves at the locations where big faults of the basement are observed and the limestone reaches the ground surface (Skordili Bridge and thermal springs of Kavassila (Greek part) and Koukes (Albanian part).

REFERENCES

Avxhiu, R., 1992. Geophysical experimental results in the Thermal springs of Koukes: Internal report, Geophysical Center of Tirana, Tirana, Albania.

Dimopoulos, G., Zouros, N., and Dafnis, C., 1990. A contribution in geological study of geothermic field of Konitsa: Bulletin of the Geological Society of Greece, **26**, 155-165.

Ghosh, D. P., 1971. The application of linear filter theory to the direct interpretation of geoelectrical resistivity soundings measurements: Geophysical Prospecting, **19**, 192 –217.

Fytikas, M., 1997. Geological and geothermal study of Milos Island: Ph.D. Thesis, University of Thessaloniki, 228 p.

Keller, G. V., Frischknecht, F. C., 1970. Electrical methods in geophysical prospecting: Pergamon Press, 517 p.

Koefoed, O., 1979. Geosoundings Principles I: Elsevier, 276 p.

Koukouza, K. and Perrier, R., 1963-1964. Geological mapping of Konitsa Area: Institute of Geological and Mineral Explorations of Athens (I.G.M.E) and Institute Francais du Petrole (I.F.P).

Thanasoulas, C., 1986a. Geoelectrical study in the area of the mineral waters of Konitsa: I.G.M.E., E4873, 20 p., (in Greek)

Thanasoulas, C., 1986b. Geoelectrical study in the area of the mineral waters of Konitsa, results of the supplementary survey: I.G.M.E., 9 p.