# RECONNAISSANCE GEOPHYSICAL STUDIES OF THE GEOTHERMAL SYSTEM IN THE AREA OF HYPATI HOT SPRING IN THE SPERCHIOS RIVER BASIN

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## A B S T R A C T

Detailed gravity observations and SP measurements were applied in the Hypati Hot Spring area, a region of geothermal interest, in the mid-southern part of the Sperchios River Basin. The purpose of these surveys was to investigate the major and minor faulting zones in the area and to examine whether these faults are geothermally active, that is if fluid circulation takes place in them. The interpretation of two gravity profiles suggests that a major normal fault extends under the position of the Hot Spring area, cutting the flysch formation. The total field electrode configuration was selected for the SP measurements made along eight profiles, with the electrode polarization being monitored by a bath with a reference electrode in a saturated solution of copper sulfate. A 3-D interpretational attempt based on Fitterman's approach, resulted in two minor faults and their associated parameters. It therefore appears that the hot mineral water is ascenting from larger depths through the major fault in the flysch reaching the surface through the two identified minor faults, forming thus the position of the present Hot Spring and the Old Hot Spring in a different place. The Old Hot Spring is inactive due to seismic activity.

# ΑΝΑΓΝΩΡΙΣΤΙΚΕΣ ΓΕΩΦΥΣΙΚΕΣ ΕΡΕΥΝΕΣ ΤΟΥ ΓΕΩΘΕΡΜΙΚΟΥ ΣΥΣΤΗΜΑΤΟΣ ΠΕΡΙΟΧΗΣ ΛΟΥΤΡΩΝ ΥΠΑΤΗΣ, ΛΕΚΑΝΗΣ ΣΠΕΡΧΕΙΟΥ ΠΟΤΑΜΟΥ

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## Π Ε Ρ Ι Λ Η Ψ Η

Η μέθοδος Φυσικού Δυναμικού (SP) και η βαρυτική μέθοδος είναι γεωφυσικές μέθοδοι εντοπισμού ρηξιγενών ζωνών και ερευνούν αν οι ζώνες αυτές είναι γεωθερμικά ενεργές. Για το λόγο αυτό εφαρμόσθηκαν στην περιοχή των Λουτρών Υπάτης.

Δύο βαρυτικά προφίλ εντόπισαν με την ερμηνεία τους ένα κανονικό ρήγμα σε μεγάλο βάθος (700m) με πάχος μετάπτωσης στον φλύσχη 550m κάτω από την θέση των Λουτρών Υπάτης. Με την χρησιμοποίηση της μεθόδου ολικού πεδίου για την ανάπτυξη των ηλεκτροδίων, ελήφθησαν μετρήσεις Φυσικού Δυναμικού κατά μήκος οκτώ προφίλ. Η πόλωση των ηλεκτροδίων μετράται σε σχέση με ηλεκτρόδιο αναφοράς σε μονωμένο λουτρό διαλύματος θειϊκού χαλκού. Η 3-Δ ερμηνεία του Χάρτη Φυσικού Δυναμικού, όπως την προτείνει ο Fitterman (1984), δίνει δύο γεωθερμικά ρήγματα. Το γεωθερμικό

νερό ερχόμενο από τους βαθείς ορίζοντες δια μέσου του ρήγματος στο φλύσχη φθάνει στην επιφάνεια δια μέσου των γεωθερμικών ρηγμάτων που εντοπίσθηκαν με τη μέθοδο του Φυσικού Δυναμικού και δικαιολογεί τις θέσεις των Παλαιών Λουτρών και των εν ενεργεία Λουτρών Υπάτης.

## INTRODUCTION

One of the interesting areas of the Sperchios River Basin is that of the Hypati Hot Spring. The study of the geothermal field is of great interest for the exploitation of the mineral waters by the Hellenic Tourist Organization and the local authorities. Extensive geological research has already been carried out in the area by (Marinos et al, 1973). The purpose of the geophysical survey (SP and gravity measurements) was to investigate the major and minor faulting zones in the area and to examine whether these faults are geothermally active, that is if geothermal fluid circulation takes place in them. The latter is believed to be detected by the SP measurements and its associated interpretation.

## GENERAL GEOLOGY

The area under investigation is in the southern part of the Sperchios River Valley, which is a tectonic graben detached from Oiti Mountain with a steplike faulting of direction WNW- ESE. The valley is filled by alluvial deposits (clay, sand, pebbles) intercepted by torrential deposits, while the bedrock consists of flysch. Surface exposures of limestone on hills in the southern part of the area represent intercepted masses. Travertine is being developed in depth in the sediments indicating the path of the ascending mineral hot water.

## GEOPHYSICAL STUDIES

Two survey teams - one geophysical group and one surveyor's - were carried out gravity, SP and precise levelling measurements along specific survey lines (profiles). The SP profiles were in the vicinity of the Hot Spring (Fig. 1), while the gravity profiles covered a more extended area ("A" and "B" are shown in figure 1). Each profile had a length of more than 2000m. The gravity observations were taken at about 100m apart.
Considering the SP data aquisition procedure, the SP measurements were made at a step of 50m with the total field electrode configuration.

i. The Gravity Observations.

The height control for each gravity station was ±1cm and the terrain corrections carried out at a radius of about 17km around each gravity station.

The estimated gravity anomalies were of high accuracy (estimated error ±0.5gu) due to the precise levelling measurements and the detailed terrain corrections.

The determination of the proper Bouguer density and its subsequent use in the estimation of the gravity formula yields the proper amplitude of the observed gravity anomaly, which may correspond to a geological feature (e.g. fault etc.). The density value of 2.2gr/cm was finally determined by fitting a third-degree trend surface to the gravity anomaly of the stations (Lagios 1979; Hipkin and Lagios, 1980).

Deep electrical soundings have been done by the University of Hamburg for the Public Power Corporation, Department of Alternative Energy Resources, in the valley of Sperchios River and the results of the interpretation of some of them

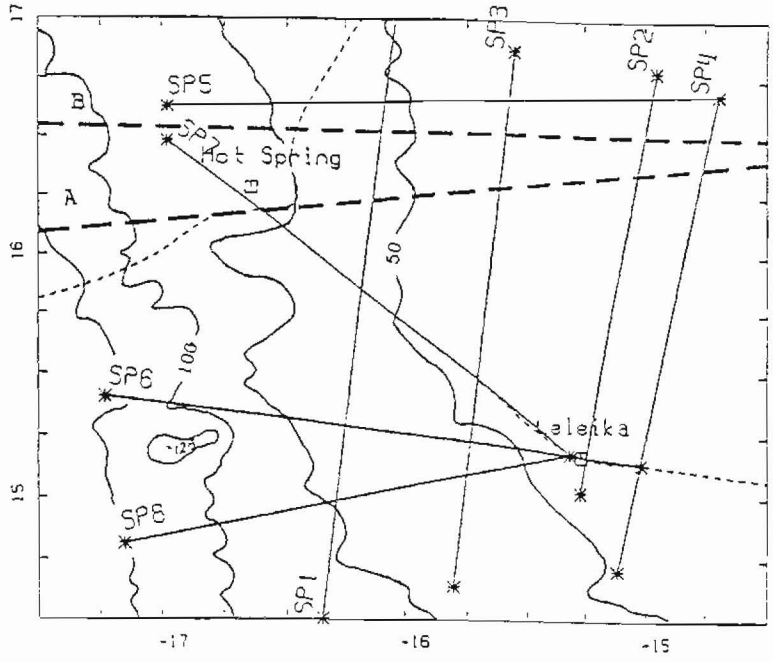


**Fig.1.** Topographic map of the area of Hypati Hot Spring (scale 1:25000) with the SP profiles (straight lines) and the gravity profiles (dashed lines).

(Apostolopoulos, 1993) which are in the area under investigation have been used in the 2-D interpretation of the gravity profiles "A" and "B", shown in figure 2.

It has to be noted that density measurements on samples taken from the area gave (Apostolopoulos, 1993) for the flysch formations an average density of 2.655 gr/cm$^3$ and for the underlying limestone a value of 2.716 gr/cm$^3$. The density of the sendiments as mentioned above is 2.2 gr/cm$^3$ and the layer of conglomerate and hot spring deposits is considered to have a density of 2.5 gr/cm$^3$.

The 2-D gravity interpretation (Fig. 2) gave a deep normal

fault cutting the flysch which is observed in a depth of about 700m under the position of the Hot Spring (H.S.). The flysch is sinking to about 1250m depth.

ii. The SP Measurements.

Self Potential (SP) anomalies are generated by flows of fluid, heat and ions in the Earth, so SP investigations have been used to help locate and delineate sources associated with such flows (Corwin and Hoover., 1979; Corwin et al., 1980; Corwin et al., 1981; Thanasoulas, 1989).

In the map of figure 1 the SP survey lines carried out on a relatively flat topography except of the "SP6" which starts on the top of a hill with limestone outcrops. The anomaly in the topography as well as the anomaly in the resistivity of the underground (in the whole area there are alluvial deposits and in this part limestone) can cause SP anomalies by themselves. This is the reason that in the proccessing these anomalies are taken out.

The crossed directions of the survey lines are chosen in a way to be approximately vertical to the existing faults. Their total legth (= 2200m) is assumed to be adequate of having the whole SP anomaly created by each fault (Total length > Wavelength of the anomaly). The 50m electrode separation is enough for the detailed detection of the SP anomalies generated by the faults of the area.

The total field electrode configuration is chosen due to the rough field conditions (intense agricultural cultivation) and due to the continuous potential measurement with respect to a fixed point which gives the advantage that small zero errors between the electrodes do not accumulate.

The electrode polarization, for each of the working electrodes, was observed by measuring every two (2) hours the potential difference of the working electrode and a reference electrode in the saturated solution of copper sulfate in a bath, thermally isolated (Fig. 3). The SP measurements for each station was then corrected using the variation of electrode polarization with time.

The measurement of the electrode contact resistance was an additional checking for the quality of the SP values. The telluric activity was being monitored using a strip-chart recorder connected across a stationary dipole (1000m length) in the survey area. The total field electrode configuration suffers by the telluric activity in large distances of the working electrodes. Nevertheless, the amplitudes of the electric potentials generated by telluric currents with periods shorter than four (4) hours did not exceed a few mVolts.

The corrected field SP values were then subjected to a high-cut filter ("five point moving average"),causing a smoothing on the observed SP estimated curves. The resultant SP anomalies, correlated between each other in the whole area, were used to make the Self Potential Anomaly Map (Fig. 4).

Considering the Self Potential Anomaly Map of the area, the presence of dipole-like anomalies is detected in the area near the Hypati Hot Spring region, indicating the existence of a fault, in which, most probably, fluid circulation takes place.

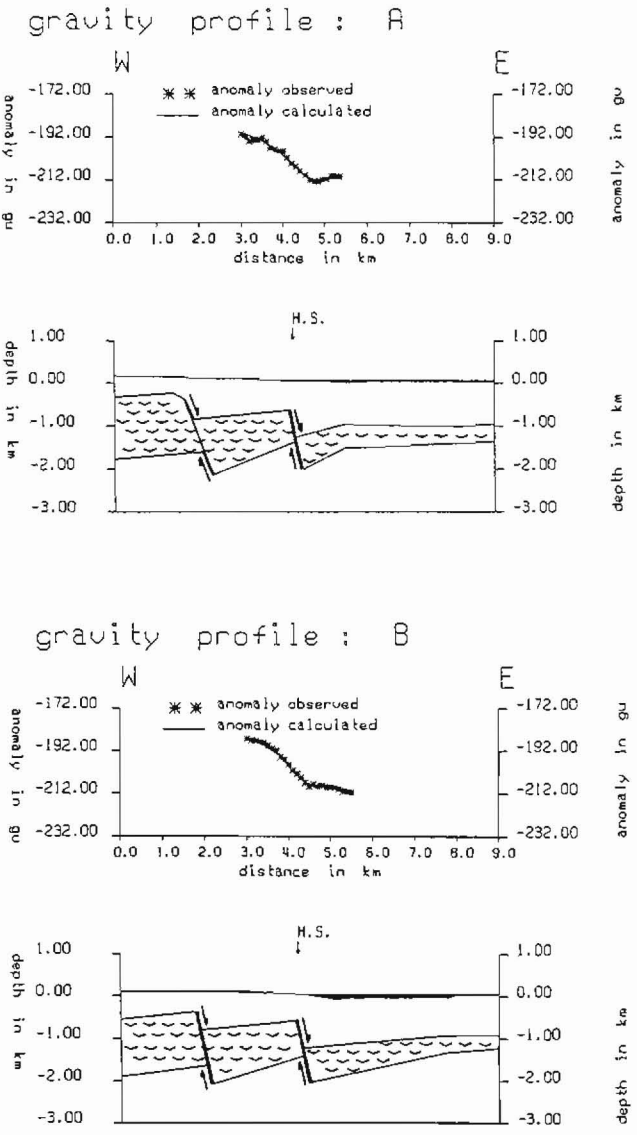


**Fig.2.** Gravity profiles with their interpretation (The drawn body is the flysch which is above the limestone. The body with the black shade is a dense layer of conglomerate and hot spring deposits).

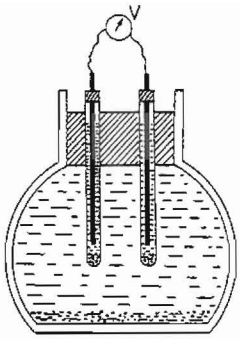


Fig.3. The thermally isolated bath with the working and the reference electrodes in a saturated solution of copper sulfate.

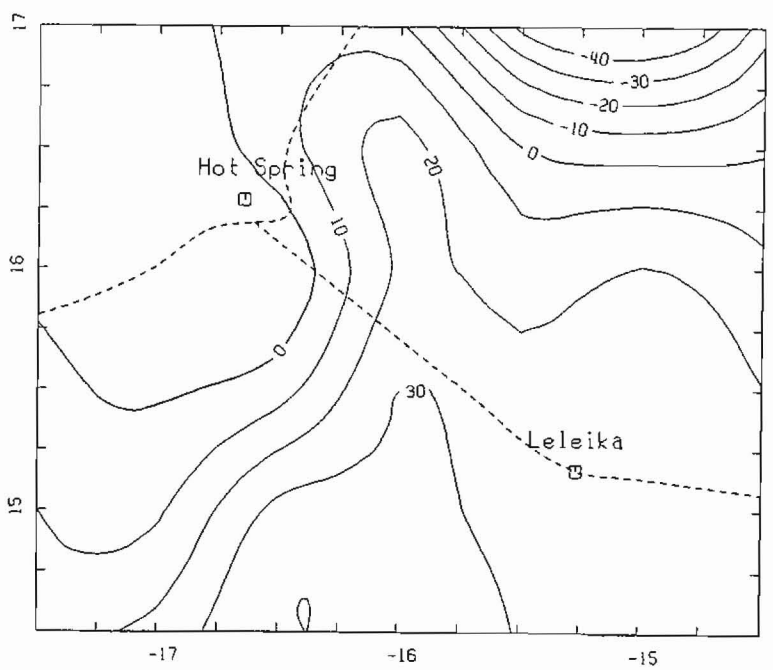


Fig.4. The Self Potential Anomaly Map (scale 1:25000).

These anomalies seem to have appreciable amplitude and such wavelengths, which can easily be interpreted following Fitterman's (1984) mathematical analysis. According to this procedure, the theoretically "Synthetic Self Potential Anomaly Map" generated by a "patch model" (each fault in the model is

represented by the parameters shown in figure 5), is fitted to the Self Potential Anomaly Map of the area. A computer program (Noutsis and Skianis, 1987) with an inversion scheme suggested by Marquart (1963) was used for the 3-D interpretation.

The gridding for the construction of the Self Potential Anomaly Map acts as a high cut filter of the higher frequency electrokinetic SP anomalies of shallow origin. The remaining SP anomalies are of deep geothermal origin. This is the reason that the 3-D interpretation is chosen. The results of the interpretation are shown in Table 1. The position of the detected "geothermal" faults is shown in the map of figure 6.

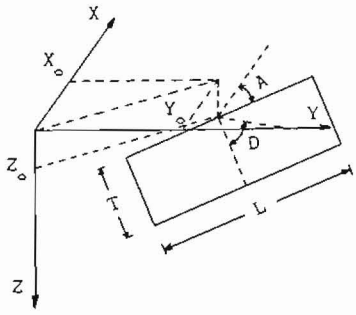


**Fig. 5.** The parameters of the model suggested by Fitterman (1984) which represents a geothermally active fault.
[F : polarization charge, L: strike length, T: dip extent, X and Y : cartesian coordinates of the center of the strike length, Z : depth of burial, A: strike angle, D: dip angle].

## CONCLUSIONS

The combined interpretation of gravity and SP profiles proved particularly successful in determining those faulting features which are responcible for the existence of hot springs and other surface geothermal manifestations in the study area.

It therefore appears that the hot mineral water of Loutra Hypatis Hot Spring is ascending from deeper horizons to shallower depths through the major fault determined by the gravity measurements. Subsequently, these fluids reach the surface through the more superficial faulting features, Fault 1 and Fault 2 (Table 1), determined by the SP measurements, forming thus the Present and Old Hot Spring places. The Old Hot Spring is inactive due to seismic activity. In detail, the hot mineral water passes through the fault in the flysch (found with the gravity interpretation) and then through the geothermal fault "1" (found with the SP interpretation) reaching the surface. The deep fault of the flysch "supply" with hot mineral water and the geothermal fault "2" giving the proof for the position of the Old Hot Spring.

Table 1. Parameters of the model which represent the geothermal faults in the area of Hypati Hot Spring, found with the 3-D interpretation (Fitterman, 1984) of the SP Anomaly Map (Fig. 4). The model gives the "Synthetic SP Anomaly Map" of Fig. 6.

| "Fault" | $F_o$ (mV) | $X_o$ | $Y_o$ (m) | $Z_o$ (m) | T (m) | L | D | A |
|---|---|---|---|---|---|---|---|---|
| (1) | -45 | -16.9 | 16.5 | 50 | 1250 | 1500 | 61.5° | 136.8 |
| (2) | -60 | -16.4 | 15.5 | 195 | 1250 | 750 | 85.6° | 38.4 |
| (3) | -447 | -15.0 | 16.5 | 455 | 1000 | 1170 | 83.4° | 84.3 |

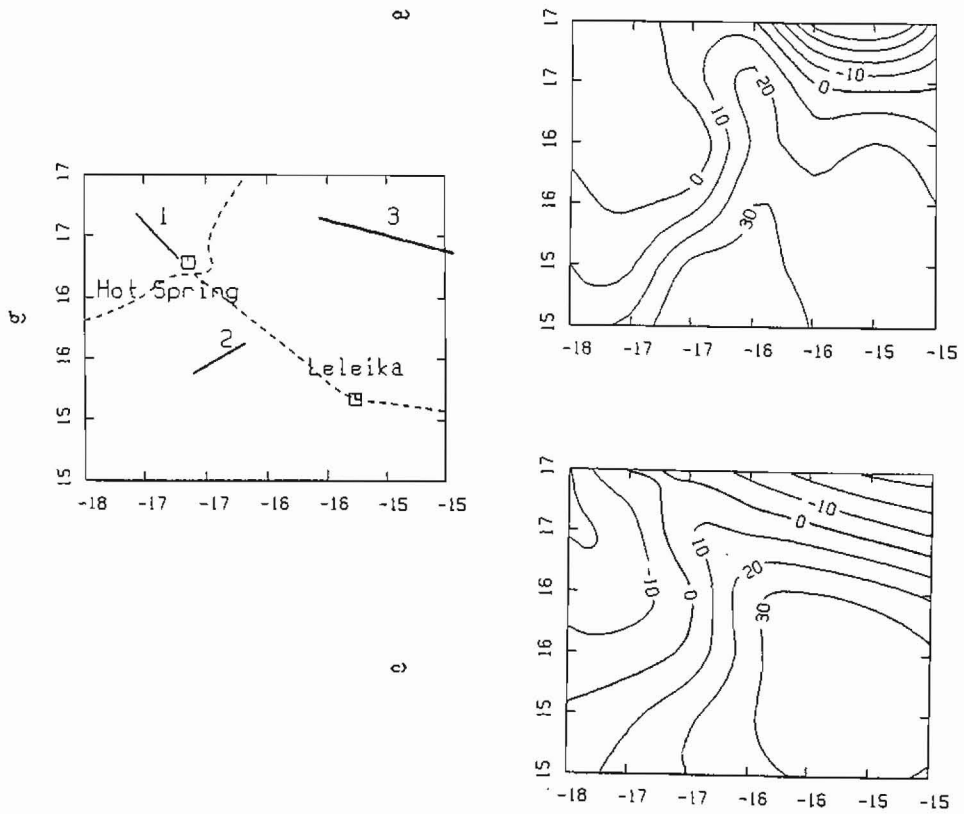


Fig.6. Maps of scale 1:50000: a) The SP Anomaly Map, b) The Map with the geothermal faults found with the 3-D interpreation of the map (a) and c) The Synthetic SP Anomaly Map.

In the gravity interpretation a surface layer of conglomerate and hot spring deposits was found forming so a layer of different resistivity than that of the environment. This change of resistivity creates a SP anomaly by itself. Therefore, the geothermal fault "3" is a "product" of that change.

The use of the bath to record the electrode polarization of the working electrodes is an additional technique to improve the quality and reliability of the SP measurements. The gradient electrode configuration can be used in irregular topography or other places with rough topographic conditions without the disantvantage of the accumulation of small errors due to the electrode polarization, since the above technique has been proved remarkably successful in overcoming the latter problem (Lagios et al, 1992).

The 3-D interpretation based on the values of the SP Anomaly Map is more reliable than the interpretation of a single SP profile since the gridding for the construction of the SP Anomaly Map acts as a high-cut filter on the higher frequencies, which correspond to electrokinetic SP anomalies of shallow structures. The remaining SP anomalies are thus of deeper geothermal origin.

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