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THE ELECTRICAL CONDUCTIVITY DISTRIBUTION ON GÖLPAZARI (NW PART OF TURKEY) AS INFERRED FROM MT SURVEY AND ITS CONNECTION BETWEEN GEOTHERMAL PARAMETERS IN THE EARTH

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ABSTRACT

High conductivity at the Earth's crust may be associated with a geothermal event. A magnetotelluric (MT) survey supported by our university have been carried out to Gölpazari and surrounding area, in frequency band 25 - 0.002 hz to investigate the distribution of conducting layer (CL) in the crust. MT tensorial apparent resistivities were calculated by using six different estimates of the impedance tensor elements in frequency domain.

Two CL may be evaluated from the MT interpretations: First CL (FCL) in the Earth's crust at depth 15.8 ± 6.2km and Intermediate CL (ICL) in the upper mantle at depth 60.0 ± 15km. Territorial distribution of heat flow calculated as q=2.9 HFU ("115mWm-2) from empirical exponential relation using the FCL's depth value and the temperature in the upper mantle was estimated as 1000° - 1100°C from ICL's depth.

INTRODUCTION

The North Anatolian orogenic belt is geologically established by three regions considering the Mesozoic - Cenozoic tectonic evaluation (Yilmaz, 1990). In one of these, situated in the west part and called Sakarya continent, there are located several famous geothermal sites (in west:Bursa - Gönen and Yalova; in east: Bolu - Akyazi). Ilkisik(1990) defined a highly conducting layer (CL) in Earth's crust from his magnetotelluric (MT) measurements taken on two sites, Kadilar (latitude: 40°24'05"N, longitude: 30°15'13"E) and Gölpazari (latitude: 40°17'01"N, longitude: 30°18'56"E), placed in the southern sector of Sakarya continent(middle Sakarya Basin).

In presented study, seven MT soundings were made in Gölpazari - Tarakli - Geyve trigular region (fig. 1) to investigate the distribution of this CL and also to describe the indicator parameters for geothermal signature (i. e. terrestrial heat flow and temperature in the lower crust). Several examples, based on such parameters, estimated from the results of MT investigation by using empricial relation between temperature and the CL's depth, could be found in geothermal literature (Adàm, 1987; Adàm et al., 1989).

The only geophysical investigation prior to the present study was a DC resistivity survey (Mumcu, 1976) carried out by the Turkish Government Water Research Organization. The aime of this survey was to determine the aquifer zones beneath of Gölpazari Quaternary alluvial basin.

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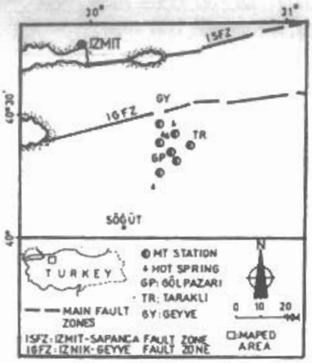

Fig. 1: The location map of the MT sites and springs at surveyed area. ISFZ and IGFZ are the parts of North Anatolia Fault Zone.

GEOLOGICAL SETTING

In the Sakarya continent, remnants of the Karakaya marginal sea and Neo - Tethyan ophiolitic fragments are exposed (Sengör & Yilmaz, 1981). Two different sectors may be distinguisthed within the Sakarya continental region. In the sediment - dominated southern sector where our MT sites are placed (figure 2) there are also some metamorphic rocks occuring at the base of the sequence (Yilmaz, 1990; Fig. 3), but these do not resemble the metamorphic rocks of the northern sector interms of lithology, age, or metamorphic facies. Two tectonostratigraphic units may be distinguished in the metamorphic rocks of the southern sector. One of these composed slate - phyllite schists and migmatitic gneisses are intruded by a post - tectonic granitic pluton. The other metamorphic unit consists primarily of basic igneous rocks of Triassic age, with associated deep - sea sediments, which underwent high - pressure metamorphism.

The middle Sakarya region lies over the inner sector of the North Anatolian Fold Belt. The structural features in general trend ENE - WSW, which are reflected in aeromagnetic and gravity anomaly maps (given in the project's report). This is almost parallel to the direction of the metamorphic basement. Muzafferiye anticline (sited at north of Muttalip), and also Kiran, Hacidurmuslar and Aliplar senclines lies over E - W direction of the region (Saner, 1978). The Molasse beds to the N of Gölpazari are also folded in ENE - WSW direction. Pirler Upthrust (or Cemiski Upthrust named by Eroskay, 1965) caused changes in that trend of anticlines to the E of Gölpazari. The faults are mostly longitudinal and run parallel to the trend of the folds. Geyve - Mekece fault run along the southern limit of Pamukova alluvial plain (see fig. 2).

Hot Springs and Temperature Data

The mineral springs in the treated area are Ahibaba, Gazlisu (in Muttalip site), Tarakli - Kayabogazi and the hot springs are Kilhamami (39.5°C), Gelinyutan (39.5°C) (nearly to Pasalar site and which are popularly known as Tarakli baths), Çiftlik - Hamambogazi (26°C),

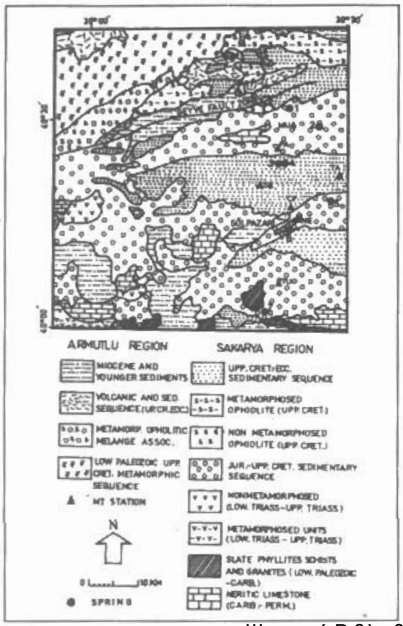

Fig. 2: Geological map of surveyed area and surroundings, locations of MT sites, minerals and hot springs. The southern sector of Sakarya region bounded by Geyve Fault Zone from the northern sector. Minerals and hotsprings: 1 - Ahibaba, 2 - Gazlisu, 3 - Gelinyutan, 4 - Kilhamami, 5 - Kayabogazi, 6 - Hamambogazi, 7 - Koyunlu. MT sites: MU - Muttalip, PA - Pasalar, SE - Seyfiler, TA - Tarakli, CF - Çiftlik, NE - Neçinler, TU - Turkmenköy. (adapted from Yilmaz, 1990).

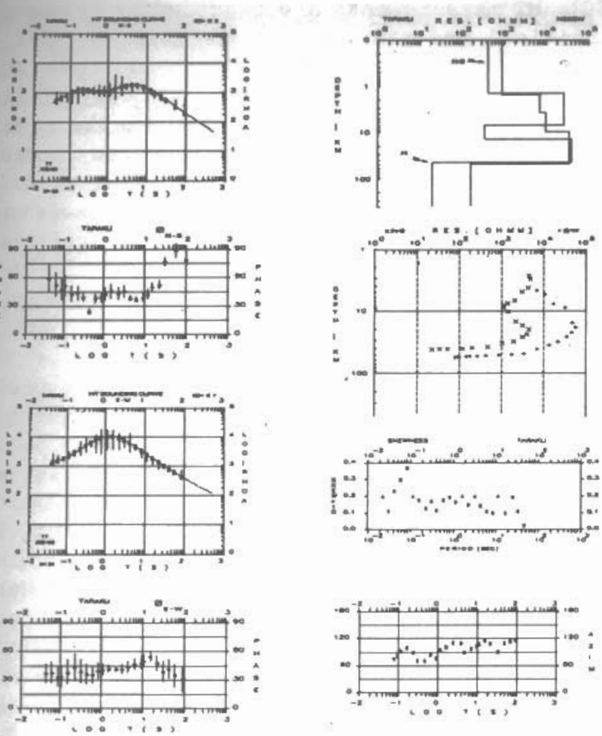

Fig. 3: The MT Apparent resistivity data and modelled curves, phase, geoelectrical models for orthogonal resistivity curves, Niblett - Bostick transforms, skewness and azimuth of rotation at site Tarakli.

Koyunlu (28°C). These springs are situated in the southern part of the area (fig. 2). Kayabogazi, Hamambogazi and Koyunlu springs were firstly mapped in during the field observations of this project. The water discharges at the surface from the Kilhamami and Koyunlu hot springs were very much when compared with others. Chemical analysis of spring water is useful for predicting sub - surface temperatures of hot water system. The preliminary evaluation of a geothermal system as suitable or un - suitable can be commonly done by this method. There are various chemical indicators of sub - surface temperatures in hot water system. But SiO2 contents and atomic ratios of Na/K of spring waters are the significant indicators of sub - surface temperatures (Kolesar & Degraff, 1978). Heat flow values on the surface for a few location of these spings which could be located later are already estimated (Ilkisik, 1991) from SiO2 contents. Chemical analysis of Ahibaba, Gazlisu and Kilhamami - Gelinyutan spring waters have been reported by Çaglar (1955) and Yenal et al. (1975). The spring waters of Ahibaba, Gazlisu and Kilhamami - Gelinyutan are characterised by very high boracite (1402.8, 904.5 and 61.0 ppm respectively). SO4 (63.7, 55.6, 782.6 ppm respectively), calcium (80.9, 57.4, 23.1), H2SiO3 (20.8, 267.8, 64.4 ppm) are also high. Cl, I, Na, K, Mg (51. 9, 70. 4, 24. 4 ppm), Al, Fe have been detected. The waters are alkaline, pH is around 6.3 - 8.2. Total mineralization does not exceed 3800 ppm. Low Ca/Na ratio (Ahibaba: 0.222, Gazlisu: 0.0388, Kilhamami: 0.745) probably further indicates high "base" temperature (Gupta et al., 1974).

THE FIELD STUDIES

In the frame of a research project supported by Istanbul Technical University, the MT measurements were taken in the Gölpazari and surroundings in summer 1991 using the instrumentation system manufactured by Geotronics Corporation (USA). The observations for four MT component being made in six overlapping frequency bands covering the range 25 - 0.002 hz. Orthogonal magnetic field variations were recorded by using two ì - metal cored induction coils while the horizontal components of electric field were measured by pairs of electrodes 100 m apart, using either Cu - CuSO4 electrodes or an Pb - PbCl2 type (produced in our laboratory) (Petiau & Dupis, 1980). MT measurements are regarded by equipment noise, but often much more by artifical and man - made noise(Szarka, 1988). Therefore the qualities of the electrical contacts between the electrodes and the ground were controlled by taking resistance measurements (Corry et al, 1982) and all instruments were isolated against direct sun to minimize a part of such noises. The strange values exceed to 50 KOhm indicates bad contact weren't observed (the mean value at all sites was about 377 Ohm in both direction). The horizontal magnetic and electric components were measured in the N - S and E - W directions at all sites where choosed as free of artifical and man - made noise as possible.

MT DATA ANALYSIS

General Considerations

For the MT range, time series windows having 512 digitised values for each component were produced from MT records. The sampling intervals varied according to the frequency range (for example: the sampling interval of 12 s was taken for 0.025 - 0.002 hz frequency band). Pre - processing of each data series include trend removal by a least squares interpolating polynomial and augmentation by zeroes to the next power of 2 if the data produced as less any power of 2. After pre - processing, each data series was fast Fourier transformed, and the Fourier spectra were corrected for instrument response. These spectra were then multiplied with the complex conjugate of the others to give the raw auto - and cross - spectra. To derive frequency band averaged auto - and cross - spectra the raw spectra smoothed by a spectral tapering window.

Conventional Tensorial Resistivity

Techniques for analyzing the data acquired with the MT method has been established (e. g. Sims et al., 1971; Swift, 1986). The elements of impedance tensor Z, which correlate the E - fields with the H - fields, is estimated from the following equation:

$$\begin{pmatrix} E_x \\ E_y \end{pmatrix} = \begin{pmatrix} Z_{xx} & Z_{xy} \\ Z_{yx} & Z_{yy} \end{pmatrix} \begin{pmatrix} H_x \\ H_y \end{pmatrix} \qquad (1)$$

To obtain the impedance elements Z_{ij} in conventional analysis scheme, different combinations are possible from equation (1). So that six different values of each Z_{ij} can be calculated. Performing the multiplications and solving the equation (1) gives the four expressions covering the Z_{ij} tensorial elements.

For the estimations of each Z_{ij} the spectral values of H_x, H_y, E_x and Ey were averaged and taken after coherency analysis (this method automatically selects 'good' data from the time series) with a reliable coherence (generally ≥0.8) which could be enhanced the signal to noise ratio. Two of six combinations for each Z_{ij} not considered since these are relatively unstable in the one dimensional case when the indicent fields are unpolarized. The meaningful MT apparent resistivities (i. e. in N - S and E - W directions) for two - dimensional structures may be calculated from the principles values of the impedance tensor averaged from valid other four combinations. However, it must be noted that the estimate considered here is biased to high side by random noise on E, while is biased to low side by random noise on H. For similar percentages of random noise on E and H, an average of the various estimates (in case taken our study) hopefully will be better than any one estimate by itself. In the processing of all data, conventional tensorial procedures detailed above were adopted with special attention being paid to the reduction of the effect of the biasing which results from random noise. For each site, the apparent resistivity and phase versus period - in principal directions are presented in project report (Çaglar, 1993) together with values of the frequency dependence coherence function, the skew parameter (a measure of dimensionality).

MT RESULTS

Definition of Signal and Noise in MT Data

The magnetotelluric method requires homogeneously induced fields, which in the following are called signal. Therefore noise in that part in the measured data Ei and Hi which either is not induced or not homogeneously induced. The first group, the non - induced part, is noise measurable in the magnetic and electric channels. The noise measurements in these channels are independent from each other, i. e. incoherent (Kroger et al., 1983). Examples are the noise of the measurement equipment, activity caused by moving vehicles, or mechanical vibration of the sensors. We were avoided from the important part of this kind by taking resistance readings and the isolation of equipments.

The second group comprises noise caused by inhomogeneously induced fields. Physically these are the man made electromagnetic fields of electrical power lines or industrial areas. Since the MT sites unindustrialed such enviromental distrubance weren't observed in our records. In contrast to the first group, the noise in the electrical field is related to that in the magnetic channels, i. e. the noise is coherent.

One - Dimensional (1 - D) Modelling And Inferred Conductivity Structure

In order to find the unknown resistivity (or conductivity) distribution below the surface of Gölpazari and surroundings, MT sounding curves ña and phase values for two orthogonal directions in seven sites were derived from tensorial impedance analysis. The examples of site Tarakli are summarized in figure 3. In most cases the ña values have a standard deviation of less than 8%. In addition, the corresponding skewness coefficients in bottom of the figure which indicate the electrical strike over the measured frequency range are on the whole quite small (generally less than 0.4), indicating a reasonably non 3 - D structures.

The sounding curves were approximated by 1D model fitting, separately for ñaN-S and ñaE-W curves. The number of layers are increased until the improvement in fit becomes negligible. The fit is determined by error bars of one sigma which show the differences between the observed and modelled apparent resistivity values. A complete agreement between observed and theoretical curves (model) was not always reached, e. g., sharp peaks and valleys at the station Çiftlik could not be approximated (may be due to MT distortions).

In 1D modelling, the ideas about the layered Earth model's parameters resistivity and thickness were yielded from *Niblett - Bostick transform* which is inverting of resistivities and phase data. For all sites the optimum number of layers generally was 6. The shorter periods values indicate shallower structures and the longer periods values deeper structure. Several distortions occurenced in MT data are partly caused by the relief or tectonics of the basement.

MT results in both directions covers the approximate depth range 0.35 to 85 km. Since the two apparent resistivity curves (and phases) at shorter periods (less than 10 s) generally resulted due to the effects of inhomogeneous structures or faulting, according to orthogonal MT measurements at some sites the thickness of shallower sediments in each direction(e. g. N - S) were clearly differ to in other direction (e. g. E - W).

In Çiftlik site the thickness of Eocene sedimentary sequence (Yilmaz, 1990) were interpreted as 350 m. in major direction (N - S) which is smaller than the minor (E - W) direction (850 m.) due to upper Createse sediments (more resistive) located SE of the Çemiski upthrust (Eroskay, 1965). Similar features were oppositely found (i. e. the thickness in N - S direction more less than E - W direction) for Muttalip site where Aliplar upthrust lies over E - W direction and separates upper Createse sedimentaries (at northern of upthrust) and pre - Permien (southern) metamorphics (Saner, 1978).

At Türkmenköy near to elongated high mountains bordering highly resistive metamorphic materials with a sharp transition, in the H - polarization case, the sounding curve distorted (over the range of period 0.4 - 3 s) as indicative highest resistivity (11000 Ohm m) than E - polarization (6000 Ohm m).

On basis 1D modelling, the second layer of different thickness shaped by structural relief with highly resistive (about 10700 Ohm m. on average) may be interpreted as a signature of the crystalline basement and could be named as "upper crust" which is identical to Ilkisik's (1990) descripition on site Kadilar and Gölpazari (the location of these sites were given in the introduction of the paper). We inferred a conducting layer of resistivity least 105 Ohm m. at depth 15.8 ± 6.2 km beneath of second layer.

Several assumptions can be made as to the origin of this conductive underlying strata e. g. granitization and melting at the boundary of the amphibolite and granulite facies (Feldman, 1976). Additionally, a "granite" layer with high resistivity reaching a depth of 45.6 ± 6.1 km was interpreted as "lower crust" for the surveyed region in middle Sakarya basin. Since the all of MT sounding curves required a more conductive layer at longer periods we could be easily constructed a second highly conductive overlying strata in upper mantle. It may be called as Asthenosphere when supported by seismic data includes low Q (Kadinsky - Cade et al., 1981).

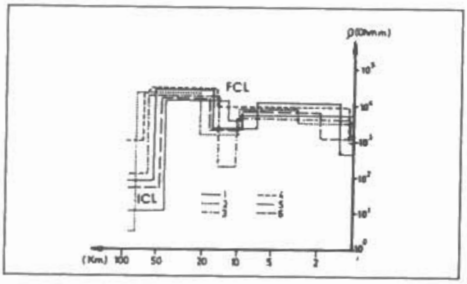

Fig. 4: Summary of the electrical models for treated area. FCL: First conducting layer, ICL: Intermediate conducting layer. 1 - Tarakli, 2 - Pasalar, 3 - Seyfiler, 4 - Türkmenköy, 5 - Muttalip, 6 - Çiftlik

CONNECTION BETWEEN TERRESTRIAL HEAT FLOW AND TEMPERATURE IN THE LOWER CRUST

As shown in Figure 4 which represents the summary of the reasonable geoelectric models for all sites produced from the interpretation of MT data, two conducting layer could be described; First Conducting Layer (FCL) in the Earth's crust at a depth of 15.8 ± 6.2 km and Intermediate Conducting Layer (ICL) in the upper mantle at a depth 60.0 ± 15.0 km.

Since the temperature strongly affects the physical properties of rocks (i. e. decreasing in electrical resistivity when increasing in temperature), this fact

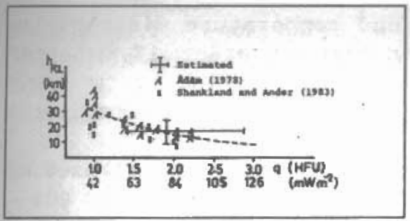

Fig. 5: The h(q) empirical curve and regional heat flow estimated from the depth of crustal conductive layer FCL. Heat flow value corresponds to hmin and hmax marked with the bars. And the other data (Adàm, 1978; Shankland & Ander, 1983) from the central Europe.

serves as basis for the correlation between heat flow and geophysical data such as electrical conductivity distribution yielded from MT survey in the middle Sakarya basin, as well as, the position of physical boundaries in the crust and mantle. Therefore the presence of two conducting layers FCL and ICL in the Earth's crust may be associated with geothermal parameters.

In this case, it seems as suitable to estimate the surface terrestrial heat flow values due to FCL and ICL using the h(q) curves (where h is the depth (in km) of FCL or ICL; and q is heat flow value (in HFU)) calculated from the empricial relation $h=h_oq^{-a}$ (where h_o(FCL)=35 km and ho(ICL)=155 km; a (FCL) = 1.3 and a (ICL) = 1.46)(Adàm, 1978; Adam, 1980). The highest heat flow values in middle Sakarya basin caused by FCL and ICL estimated as q=2.9 HFU (≈115 mWm^{-2}) (h_{min}=9.4 km) and q=1.92 HFU (≈81mWm-2) (h_{averag} = 60 km), respectively. These values pointed with the bars indicate their extrems for the depths h_{FCL} =15.8 ± 6.2 km and h_{ICL} = 60.0 ± 15.0 km in figure 5 and figure 6.

From fig. 6 it may be seen that the average depth of ICL and its standart error fits to the empirical connection between the depth of the asthenosphere and the regional heat flow (Adàm, 1976). The temperature can be similarly estimated as 1000o - 1100oC from the depth of the conducting zone below the lithospheric plate (ICL) using the T - d (temperature - depth) curve taken from Pollack & Chapman, 1977. The terrestrial heat flow caused by FCL (q=2. 9HFU) is higher than Tezcan's (Tezcan & Turgay, 1989) data calculated by assuming a constant thermal conductivity of Neogene clayey formations.

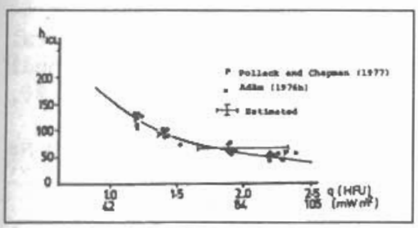

Fig. 6: The h(q) empirical curve and regional heat flow for the treated region estimated from the depth of conductive layer in the upper mantle, i. e. the astheno - sphere, and the other data taken from central Europe (Adàm, 1976; Pollack & Chapman, 1977). Our data situated with the bars corresponds to depth h_{ICL}=60.0 ± 15.0 km.

It can be suggest that as the physical parameters of the asthenosphere (high - attenuation of S_n i. e. low Q, higher electric conductivity) are due to partial melting, a increase of the temperature (or of the heat flow) in the Earth's interior causes a thickening of the lithosphere.

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