GEOPHYSICAL INVESTIGATIONS IN DENİZLİ GEOTHERMAL FIELDS, TURKEY

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ABSTRACT. — Resistivity and gravity surveys were carried out in Denizli region as a part of exploration and development of geothermal energy program conducted by MTA. The surveys covered Tekke Hamam, Kızıldere, Tosunlar, Bölmekaya, Yenice, Gölemezli, Karahayıt and Pamukkale geothermal fields which are located along the edges of Menderes and Gediz Graben. The surface manifestations of thermal activity in the area are in the form of hot springs recording temperatures from 34°C to 98°C, fumarol, hydrothermal deposits and thermal alterations. Gravity survey was applied for reconnaissance survey of geothermal resources. The data reduced to the complete Bouguer anomaly and second order derivative gravity maps, gave the general topography of the basement and horst-graben tectonics in the area. Resistivity survey was carried out using Schlumberger electrode configuration. Maximum electrode separation ranged from 2000 m to 6000 m. More than 500 resistivity soundings were made and approximately 500 square kilometers were investigated. Interpretations of resistivity data using model curves and computer techniques has furnished important data related to the setting and extensions of the geothermal areas. Exploratory drillings over the interpreted geothermal anomalies in Kizildere, Tosunlar, Bolmekaya, Yenice, Gölemezli, Karahayıt and Pamukkale fields are suggested for the future assessment of geothermal energy in the region on an industrial and scientific scale.

INTRODUCTION

It is known that an area may have a geothermal power deposition only if the following four main factors occur at the same place simultaneously

1. A source of natural heat of great output such as cooling magma,
2. An adequate water supply,
3. An «aquifer» or permeable reservoir,
4. An impermeable cap rock.

In Turkey, there are many localities with such properties mentioned above. Particularly Western Anatolia is exceptionally rich in the number of geothermal energy potential fields. Denizli geothermal field is one of the most important example to these fields. It forms a part of geothermal system situated on the Eastern end of Menderes and Gediz grabens. It includes Kızıldere, Tosunlar, Bölmekaya, Yenice, Gölemezli, Karahayıt and Pamukkale geothermal fields. Hot springs and other thermal manifestations are widespread through this region (Fig. 1).

The multidisciplinary exploration program aimed at developing geothermal steam for electrical power generation in Denizli have been conducted by the Mineral Research and Exploration Institute (MTA) of Turkey since 1965.

Standard geological, geochemical and geophysical exploration techniques have been used. Combined geophysical studies including gravity and electrical resistivity started in the region in 1965. Gravity survey covered approximately 1500 km^2 (Tezcan, 1967). Resistivity survey was first carried out in Kızıldere and Tekke Hamam fields and 40 km^2 were covered. Sixteen deep wells were opened between 1968-1974 and six of which had the potential for electricity generation. A 20 MW power station is under construction to go into service by 1984.

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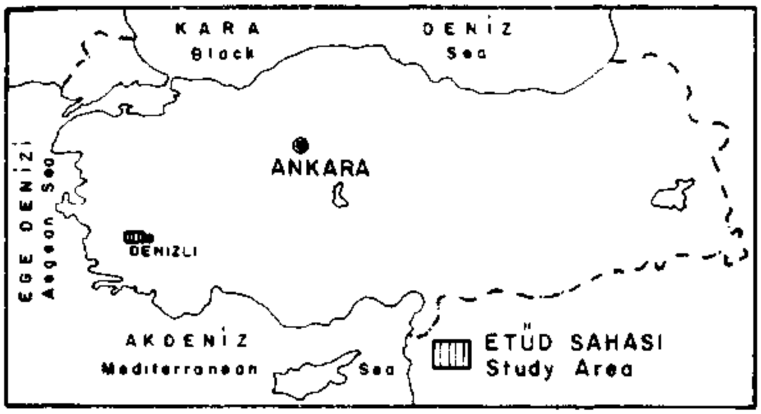

Fig. 1 - Location map of the study area.

Following the positive results obtained in Kızıldere, resistivity studies were extended to cover all the geothermal fields such as Tosunlar, Bölmekaya, Yenice, Gölemezli, Karahayıt and Pamukkale to identify new specific target areas and to lay the reconnaissance groundwork for future assessment of geothermal energy in Denizli region on an industrial and scientific scale. These studies started in 1978 and completed in 1979 and approximately 1500 km^2 were covered (Turgay, Özgüler and Şahin, 1979).

This paper presents the results of resistivity studies in detail and the summary of other works carried out to establish the extend of the geothermal fields in the area.

GEOLOGY

Denizli geothermal fields are located on the Pliocene filled basin surrounded by high topographic level metamorphics of Menderes massif. Stratigraphic units from old to young in the area are;

Paleozoic metamorphics: They form the basement and consist of augen gneiss, gneiss schist, guartzite, micaschist and marble from the base upwards.

Pliocene sediments: Continental and lacustrine Pliocene sediments overlie the metamorphics and include conglomerate, sandstone, claystone, limestone, marl and siltstone alternations.

Quaternary sediments: They include alluvium and hydrothermally altered rocks (Şimşek, 1982) (Fig. 2).

Menderes massif has been uplifted after Pliocene, E-W grabens has been formed by tensional forces. Total slip of step faults on both sides of the graben is about 2000 m. Magma is intruded under the massif and grabens and earth crust is thinned. Thus, geothermal fields are naturally occurred along the grabens. From S to N, Babadağ Horst, Menderes Graben, Buldan Horst, Gediz Graben and Yenice Horst are the major structures in the area.

Pliocene limestone is the first, and Paleozoic marbles, schist and quartzite intercalations are the second reservoir in the area. The impermeable clayey sediments of Pliocene form the cap rocks in the region.

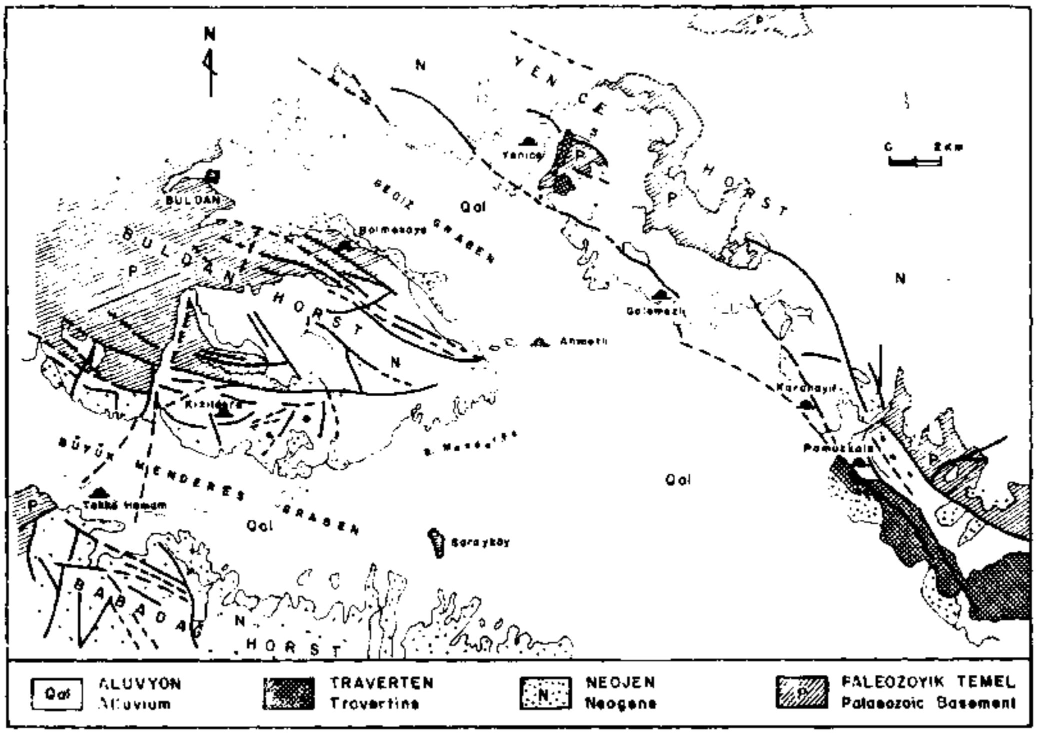

Fig. 2 - Geological map of the study areas.

Thermal activity in the area is characterised by a variety of surface manifestations such as hot springs (34°C - 98°C). The nature, magnitude and location of the heat source remains unknown. The field is not associated with present or recent volcanic activity nor with young magmatic intrusions. However, magmatic emanations along the faults show that the heat source is that of a deap seated magmatic origin.

The geochemical thermometers such as SiO_2 content and Na/K ratio define the reservoir temperature approximately as 200°C. Generally reservoir temperatures more than 150°C indicate at least the presence of hot water dominated geothermal systems.

GEOPHYSICAL INVESTIGATIONS

In the geothermal areas geophysical methods are generally used to construct the deep structural situation, hydrogeological conditions and the thickness of cap rock as well as the regional and local thermal situation. Because geothermal reservoirs or their immediate surroundings have certain specific physical characteristics which are susceptible to detection and mapping by geophysical methods.

GRAVITY SURVEY

Gravity survey is a method where by to understand underground structures such as undulation and depth of bedrock, location and size of deep seated intrusive rocks and presence of tectonic lines by studying changes in gravity values resulting from the difference in density among geological formations and it is very useful in making a rough tectonic view of an entire geothermal region.

The gravity measurements were reduced to Bouguer anomaly and second order derivative maps (Tezcan, 1963) (Fig. 3 and 4).

The contourlines of Bouguer anomaly map (Fig. 3) are in conformity with the topography. The high topographic level formations which are uplifted metamorphics of Menderes massif raise the Bouguer values considerably with respect to the low level Neogene and Quaternary formations. Therefore the Bouguer values reflect the metamorphic topography. Any Bouguer anomaly variations in the area of Neogene cover can easily be attributed to the topographic variations ofthe underlying metamorphic substratum. All the Bouguer anomaly values tend to decrease towards a gravity low in the central part ofthe map where Menderes and Gediz Grabens meet. This part is correlated with the thickest Neogene cover over the basement.

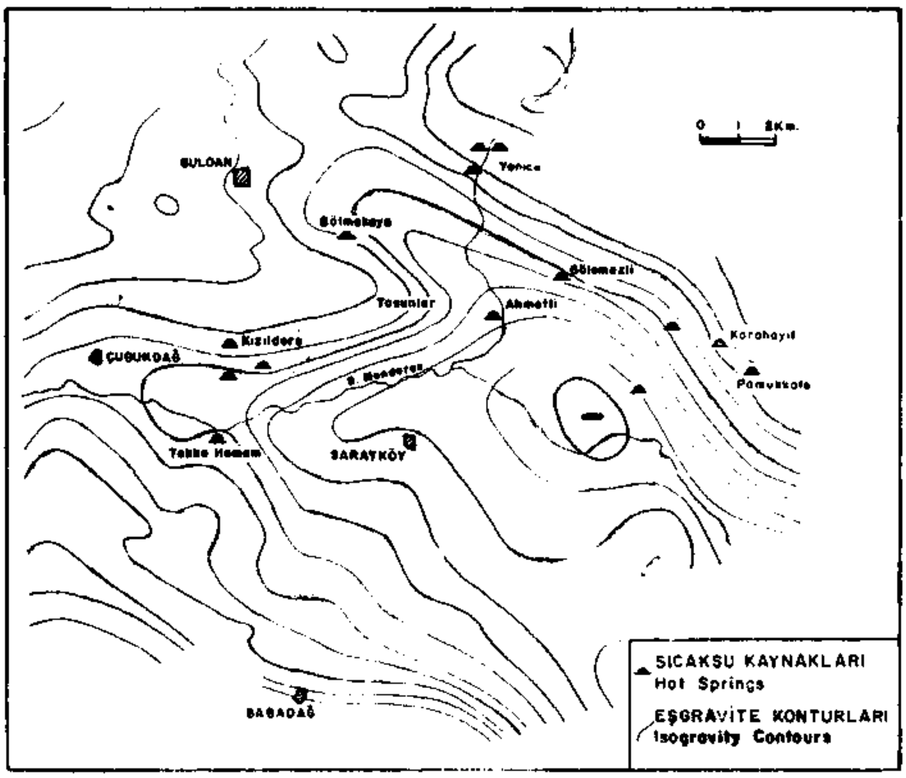

Fig. 3 - Bouguer anomaly map of Denizli-Sarayköy-Pamukkale-Buldan geothermal fields.

The strip of Bouguer contours with steep gradient along E-W and SE-NW directions are correlated with major faults at the boundaries of horsts and grabens.

There are three large clearly identifiable highs (positive) outstanding in the second-order derivative map (Fig. 4). The first one lies between Kızıldere and Buldan with an E-W trend, the second one is in the S also with an E-W trend and the third is in the NE with a NW-SE trend. These are correlated with Buldan Horst, Babadağ Horst and Yenice Horst respectively. The gravity lows (negative) are correlated with grabens.

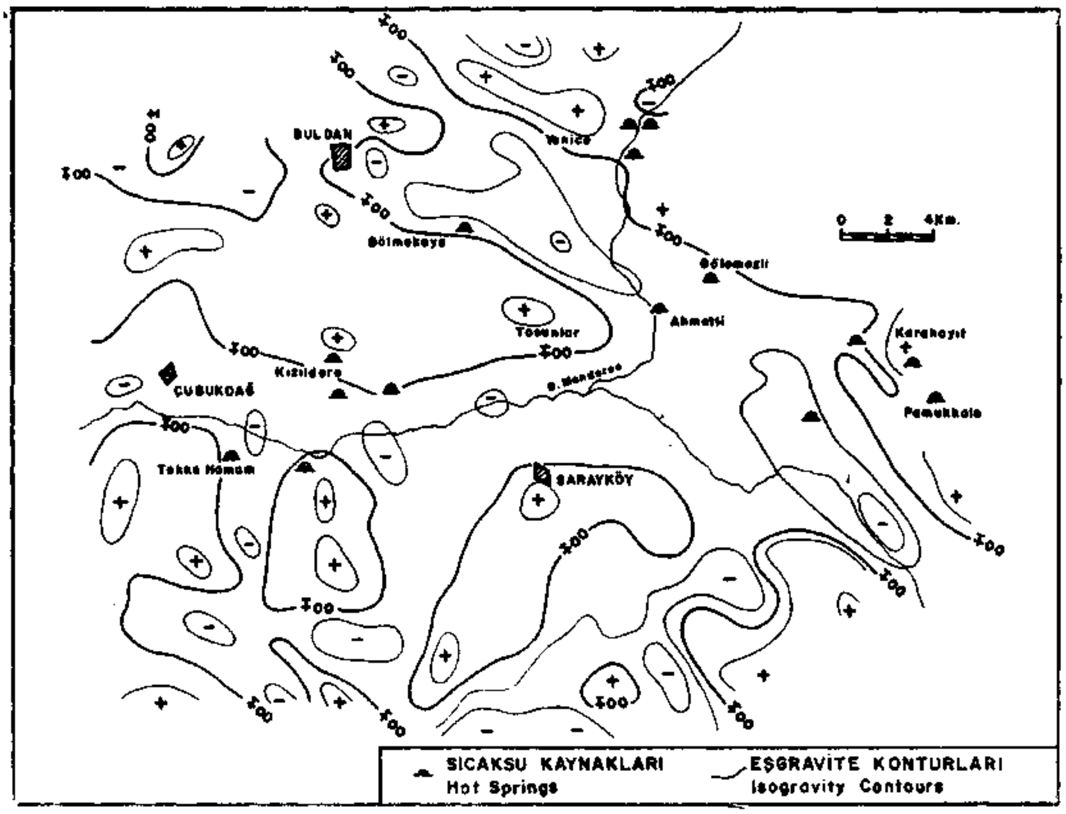

Fig. 4 - Second order derivative gravity map of Denizli-Sarayköy-Pamukkale-Buldan geothermal fields.

All of the geothermal surface manifestations are located along the boundaries of negative and positive anomalies. This fact shows that the geothermal system in the area must be associated with horst-graben boundaries.

RESISTIVITY SURVEY

Electrical resistivity method is one of the most important techniques in geothermal energy exploration because resistivity is a strong function of some of the properties which are most likely to vary in geothermal fields, that is temperature, fluid salinity and porosity. For example, the hot and cold zones within an area can be located by the decrease of the electrical resistivity as a result of an increase in the temperature and salt concentration in the geothermal reservoir.

The survey was planned on a mesh of network with 250-1000 m between the adjacent points. Approximately at 500 points resistivity deep sounding (RS) was made with a MTA - made direct current resistivity instrument (Model DR-9) using Schlumberger electrode configuration. Maximum current electrode spacing ranged from 2000 m to 6000 m. The effective probing depth used in this work for Schlumberger electrode array is the half of the distance between current electrodes (d= AB/2).

RS curves were interpreted by curve matching procedures using albums of theoretical curves and auxiliary point diagrams. The graphical interpretations were checked for accuracy by computer modelling.

Generally most of the RS curves showed the existence of three different electrostratigraphic units (Fig. 5 and 6).

1. A resistant cover (30-2000 Ohm.m): This includes alluvial sand beds, hydrothermal deposits (e.g. travertine) and coarse grained sediments and pyroclastic rocks generally seen on the flanks of uplifted blocks.

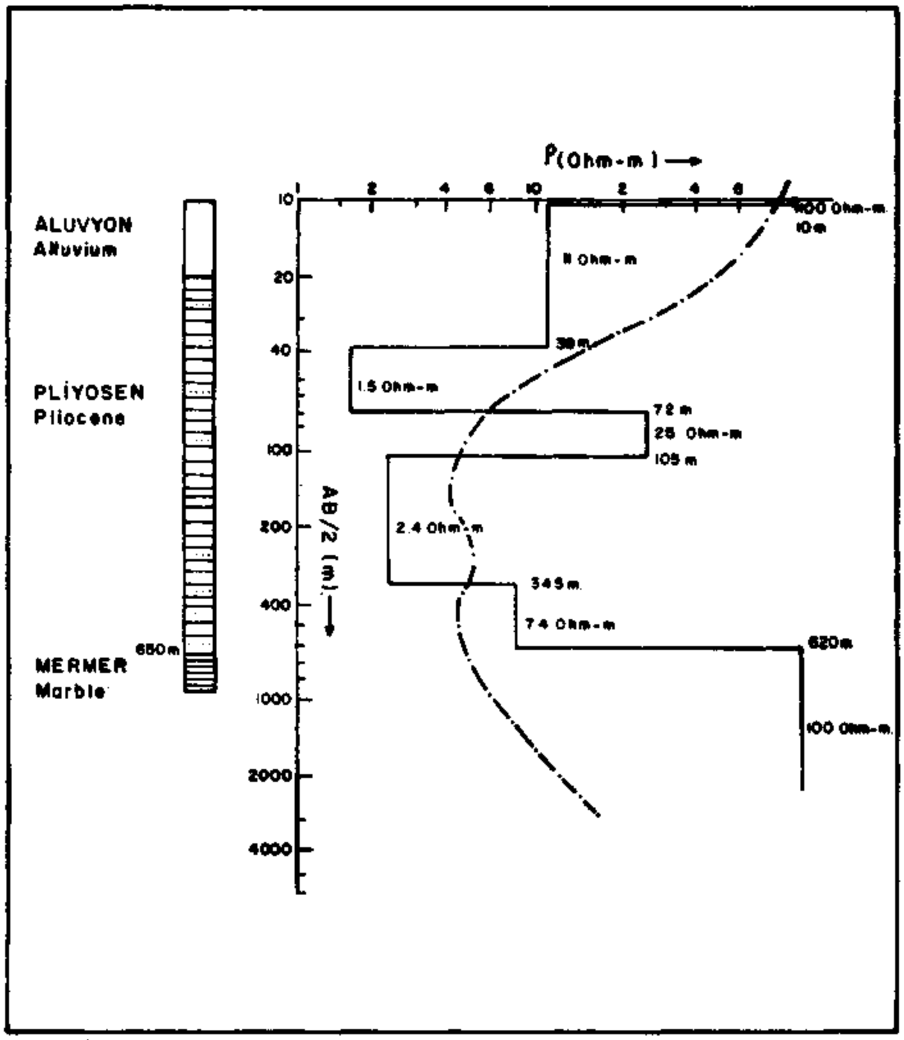

Fig. 5 - Well log data and interpreted results of RS curve at the producing well Kızıldere KD-6.

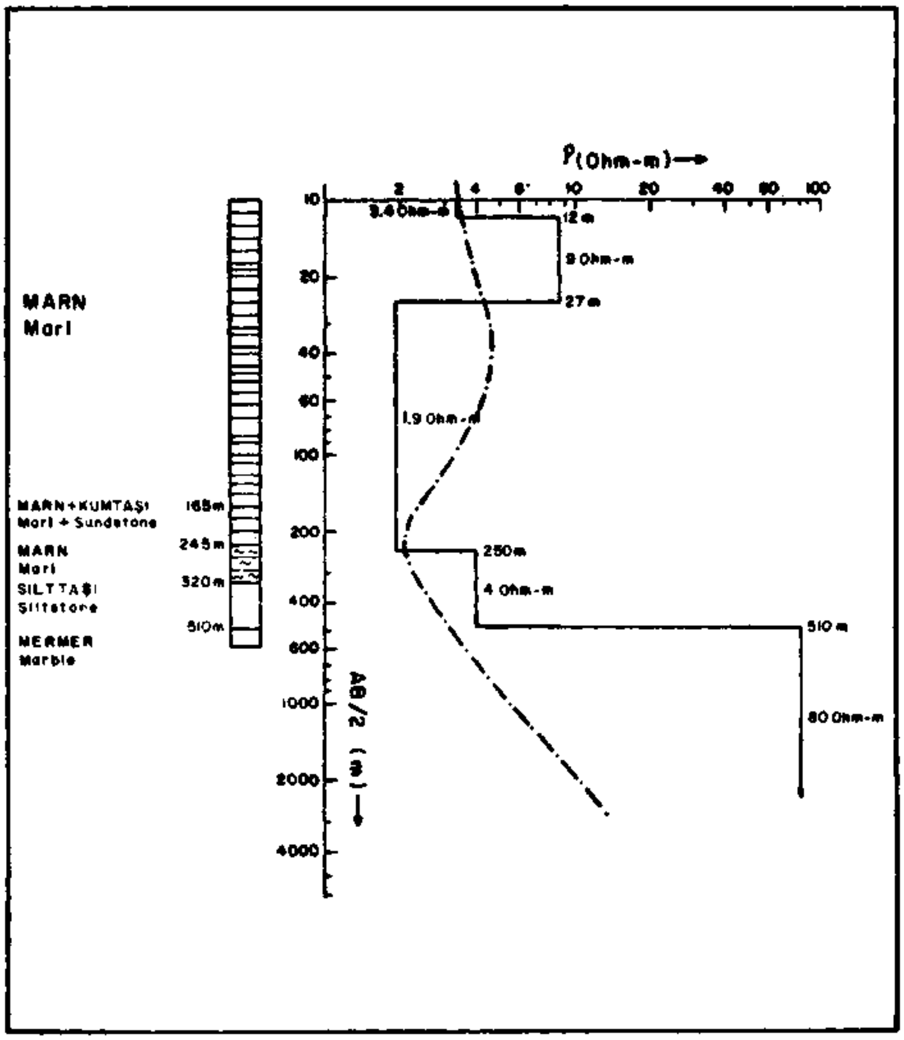

Fig. 6 - Well log data and interpreted results of RS curve at the producing well Kızıldere KD-8.

2. A conductive complex (2-30 Ohm.m): These are represented by Pliocene sediments. The ones with less than 10 Ohm. m are correlated with heated or hot water bearing Pliocene series which lie just over geothermal reservoir.

3. A resistant substratum (50-1000 Ohm. m): They correspond to Paleozoic complex which consist of metamorphic schist, gneiss, marble and quartzite.

RS curves obtained over the production wells KD-6 and KD-8 in Kızıldere are shown in Figures 5 and 6. The interpretation of these curves and well log data are also depicted on the same figures. Quaternary and Pliocene sediments and metamorphic basement are well reflected on the curves and the electrostratigraphic layers appear to be in a perfect agreement with the well log data.

Figure 7 shows an apparent resistivity map plotted for half electrode distance equal to 300 m. The map shows very strong resistivity contrasts. Despite the generally contrasting features. It can be noted that the resistivity values increase dramatically in the N, NE, E and SW part of the area forming very distinct resistive ridges extending from E-W and SE to NW. These ridges reflect the boundaries of horst and graben structures. Another contrasting feature which can be noted is the central part of the area which is characterised by resistivity values less than 30 Ohm. m. Resistivity highs and resistivity lows are correlated with metamorphics of horsts and Pliocene sediments of grabens respectively.

The most outstanding feature on the map is the presence of some areas in the central part where the resistivity drops to less than 10 even 5 Ohm.m which are below the background resistivity. These zones are located in the vicinity of Kızıldere, Tosunlar, Bölmekaya, Yenice, Gölemezli, Karahayıt and Pamukkale areas where geothermal surface manifestations are wide-spread. They are also characterised by being distinctly parallel to the major tectonic lineaments.

These resistivity lows are correlated as they are the imprints of geothermal reservoir in metamorphics on the overlying Pliocene sediments.

Figure 8 shows an apparent resistivity map plotted for half electrode distance equal to 500 m. This map approximately identical with 300 m map (Fig.7). Only the area of resistivity lows decrease in a small scale due to the approachment to the basement.

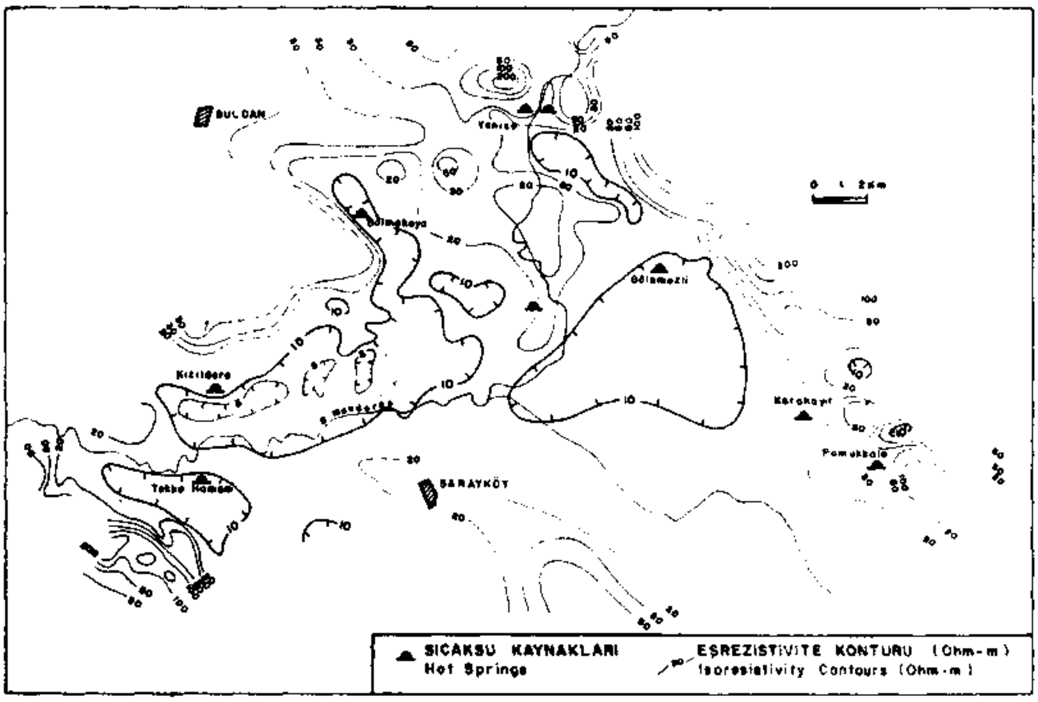

Fig. 7 - Apparent resistivity map of Denizli-Sarayköy-Pamukkale-Buldan geothermal fields (Schlumberger, AB/2=300 m).

Apparent and interpreted vertical geoelectric cross-sections of traverse lines G-160, 0-0 and K-80 are shown in Figure 9-11. Although there are some complexity of the resistivity patterns which emphasizes the lateral heterogeneity of the formations in the graben. The structure of step-faulted basement, Pliocene and Quaternary cover can be clearly seen on these sections. The resistivity lows in Pliocene just over the step faulted basement were interpreted as they are the results of resistivity drop caused by the superheated geothermal fluid in the reservoir. These zones were classified as geothermal anomalies for exploratory drilling. The resistivity values increase away from the stepfaulted basement. Therefore vertical and horizontal distributions of these mediums define the boundaries of geothermal activity in the basement reservoir.

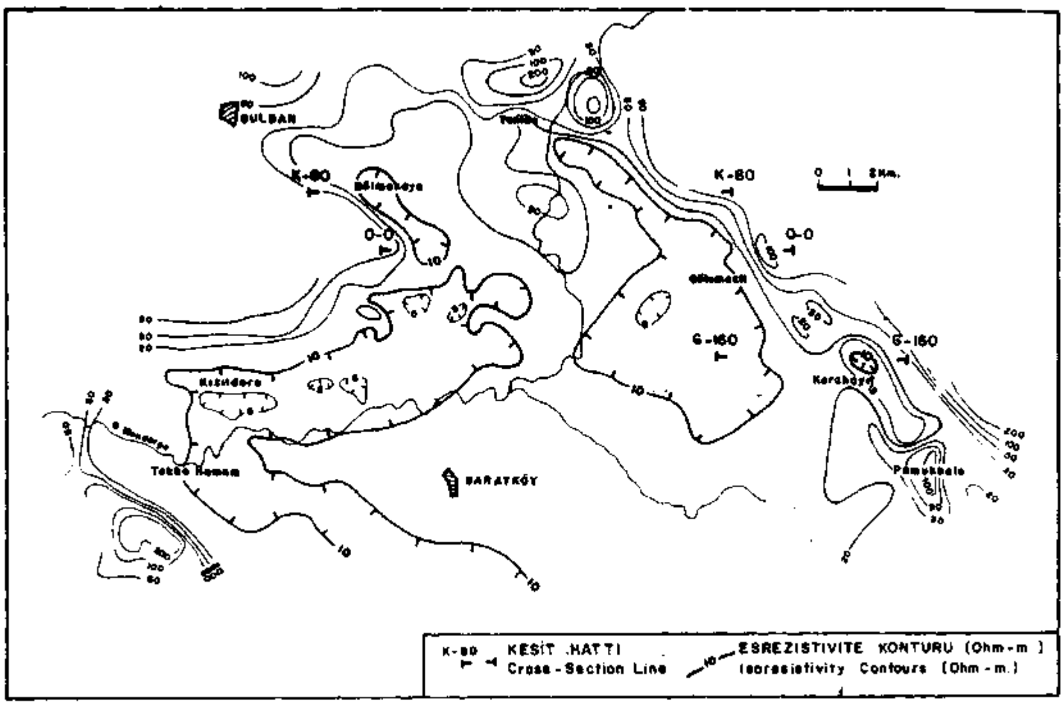

Fig. 8 - Apparent resistivity map of Denizli-Sarayköy-Pamukkale-Buldan geothermal fields (Schlumberger, AB/2= 500 m).

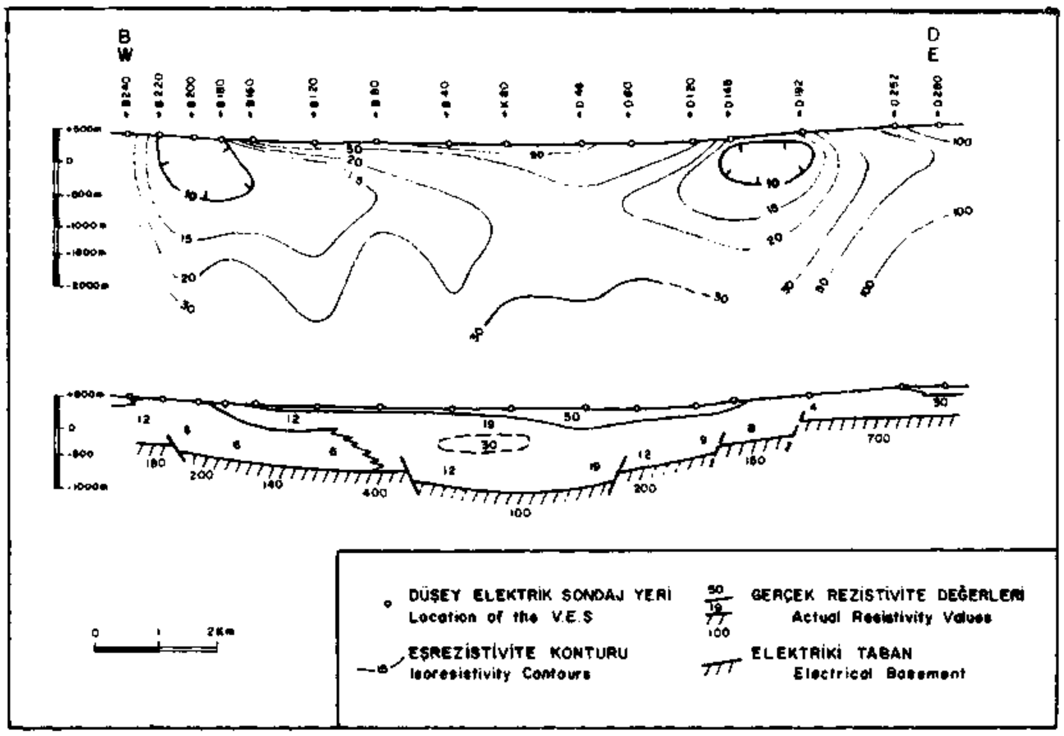

Fig. 9 - Apparent resistivity and geoelectric cross-section through the profile K-80.

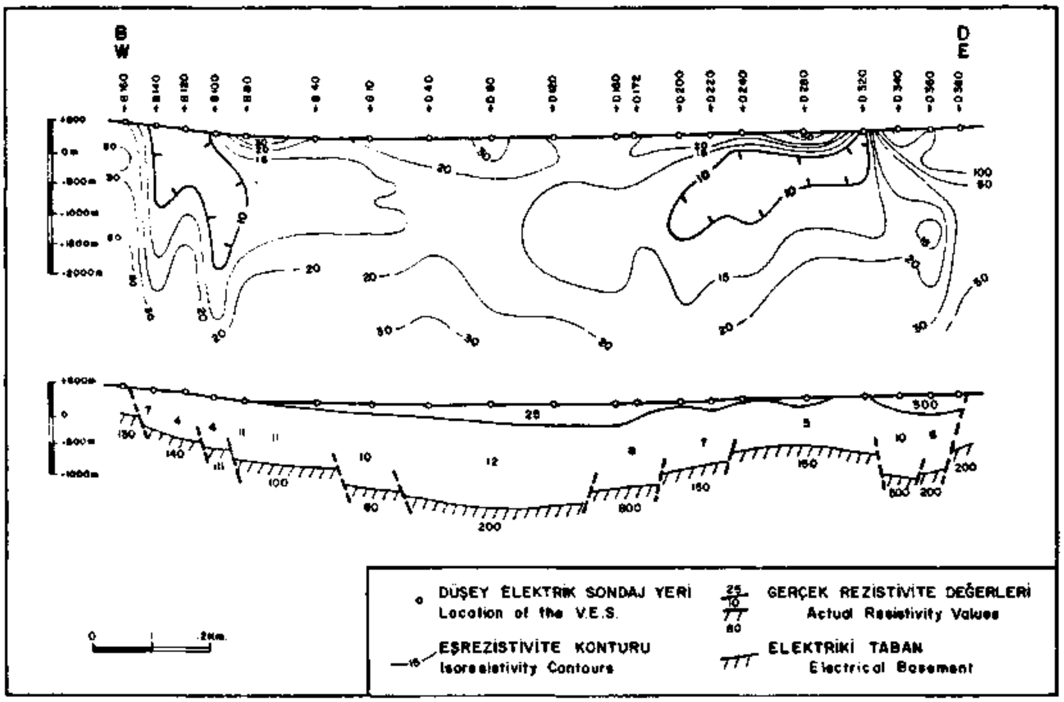

Fig. 10 - Apparent resistivity and geoelectric cross-section through the profile 0-0.

The depth, delineation and structure of the basement can be seen from its contour map which was prepared from the interpretation of RS curves (Fig. 12). It reflects horst and graben tectonics of the region and their boundaries. The data suggests the total throw of the faults to be about 2000 m.

CONCLUSION

Geophysical surveys furnished very important data relating to the setting and extensions of geothermal aquifiers in Denizli geothermal fields. Gravity studies revealed the tectonic structure of the region.

Application of resistivity survey has made contributions to the exploration work in two ways.

1. To outline the low resistivity mediums (geothermal anomalies) which are the imprints of the basement geothermal reservoir in Pliocene sediments and classified as the target zones for the exploration of the steam.

2. To define and delineate the depth of the basement and its structure to minimize the cost of drilling.

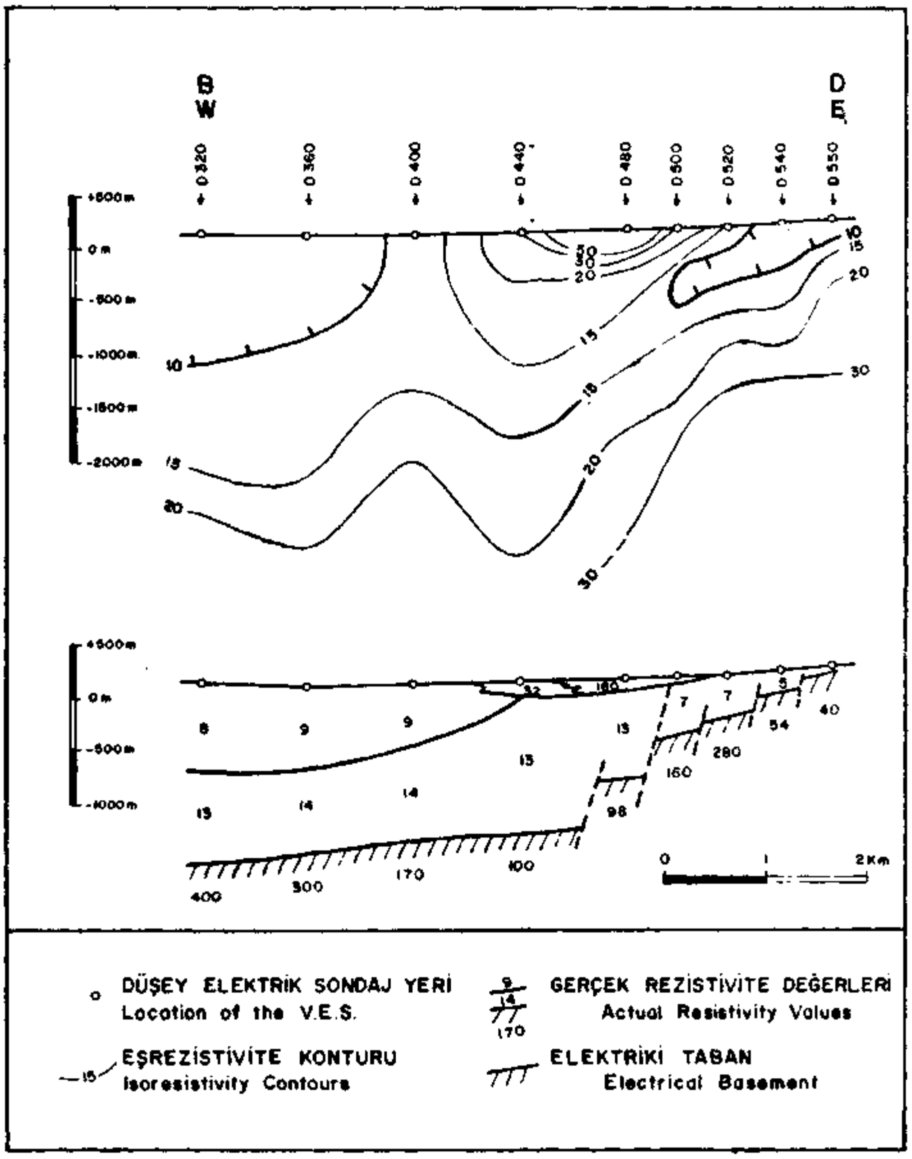

Fig. 11 - Apparent resistivity and geoelectric cross-section through the profile G-160.

The anomalies found in Kızıldere, Tosunlar, Bölmekaya, Yenice, Gölemezli, Karahayıt and Pamukkale field are found to be closely associated with the major faults and fracture systems developped at the interface of horsts and grabens. Exploratory drillings just over these geothermal anomalies are suggested for future assessment of geothermal energy in the region on an industrial and scientific scale.

With this study the total area of the low resistivity mediums where geothermal energy production are expected were found to be about 20 km^2. Geological, geochemical and geophysical evidences show that geothermal systems developped in these areas are similar to that of Kızıldere geothermal field. If it is considered that 20 MW of electric energy is generated from less than 1 km^2 and it makes only ten percent of thermal energy in Kızıldere, then the electric and thermal energy power of Denizli region may be around 400 MW and 4000 MW respectively.

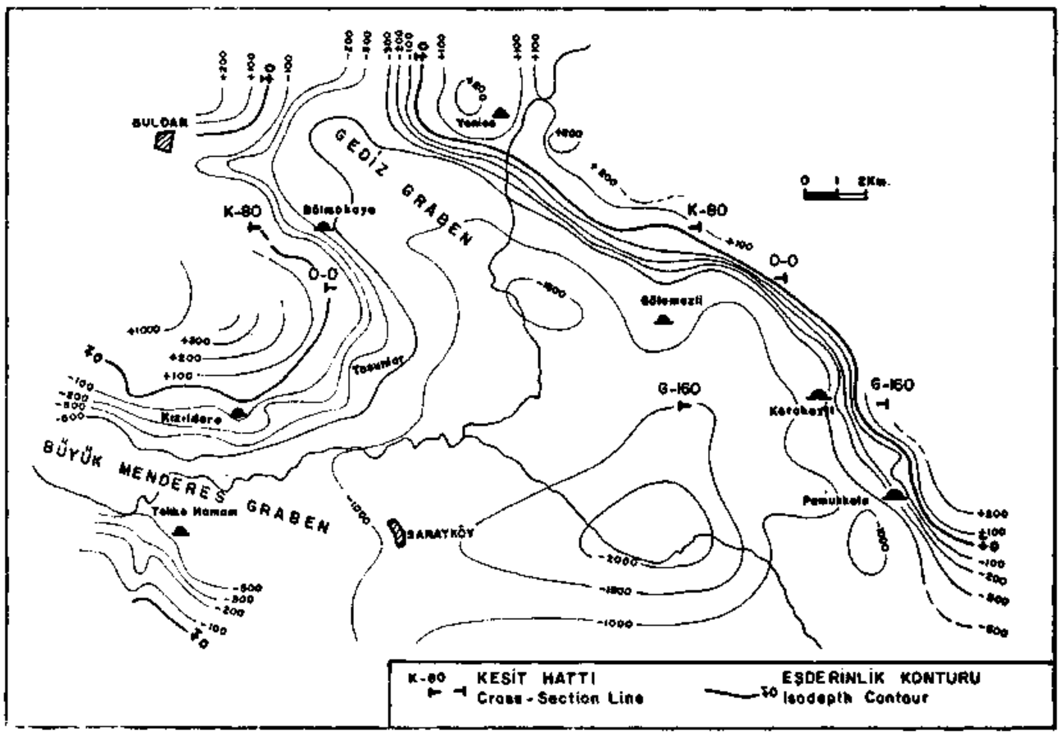

Fig. 12 - Isodepth contour map of resistive basement in Denizli-Sarayköy-Pamukkale-Buldan geothermal fields.

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