Terrestrial Heat and Geothermal Resources in Hungary *

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The Hungarian basin is a part of the Alpine geosyncline system. The basin is surrounded by the Carpathians and the Dinarics. The territory of the present basin in the Mezozoic was characterized by thin sediments, and the sequence of rocks is incomplete, but in some places, especially in the mid-Hungarian Mountains, the thickness of the Mezozoic deposits is considerable. At this time the Carpathians and the Dinarics Alps, owing to intensive subsidence, were zones of thick deposition. In the Tertiary period the Hungarian basin began to subside intensively and was filled up especially by Pliocene sediments. The zones of the Carpathians and Dinarics were uplifted simultaneously with the subsidence of the Hungarian basin. In the Neogene period, in connection with the mountain risings, great volcanic activity took place. While the Alpine mountain ranges are folded and fractured, within the Hungarian basin owing to small scale tectonic movements no folded structrures are to be found.

Geologic Structure of the Hungarian Basin

Intensive exploration for oil deposits in the Tertiary sediments of the Hungarian plain has revealed the subterranean surface of the Paleozoic-Mezozoic bedrocks and supplied reliable figures on virgin rock temperature. The Hungarian plain is in the center of the Carpathians. The Paleozoic-Mezozoic bedrocks are elevated along a SW-NE fracture line forming the mid-Hungarian Mountains rising up to 1000 m above sea level. These elevated, mostly Mezozoic strata divide the Hungarian plain into two basins, a smaller in a NW- and a greater

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in a SE-direction. The depression are filled with Tertiary porous sediments; about half of their thickness consists of Lower Pliocene (Pannonian) strata. The maximum depth of the depressions is about 5000 m below sea level; the average depth of the Tertiary basins is about 2000 m. The porous and permeable sandstone strata contain immense quantities of water and up to now oil and gas deposits of commercial value have been located in about 50 traps.

Discovery of Heat Flow Anomaly

A surprisingly high heat flow was measured in 1956 (BOLDIZSÁR, 1956). A figure of 3.035 μcal/cm^{2}sec was found, and there was some doubt among the experts in accepting a value so much higher than the average (1.2 μcal/cm^{2}sec). Other investigators in England (BULLARD and NIBLETT, 1951), Canada (MISENER, 1955), Japan (UYEDA and HORAI, 1960) and Australia (NEWSTEAD and BECK, 1953) have also found considerably higher values than the average, but it may be doubted whether all these high values, including the Hungarian, represent the regional heat flow of greater areas.

The high heat flow published in 1956 was measured in the SW part of Hungary in the Liassic coal mine district of Komló. The mine district is in the Mecsek Mountains consisting chiefly of Permian, Triassic and Liassic sediments. The measurement refers to the heat flow in vertical direction of two large shafts of 7 m diameter, 90 m distant from each other. Further sinking of the twin shafts allowed measurements to be extended to a depth of over 600 m. The result has confirmed the earlier high heat flow and the new value is more exact, containing more virgin rock temperature and conductivity data. The average heat flow in Komló in the twin shafts is 3.34 ± 0.04 μcal/cm^{2}sec (BOLDIZSÁR, 1964/a).

Similar measurements were made in Hosszuhetény a distance of 5 km from Komló. The Hosszuhetény coal mines being opened up, two shafts with the same dimensions and the same distance from each other as in Komló were sunk to a depth of 530 m. In the same Middle Liassic strata as in Komló, the average heat flow was 2.49 ± 0.02 μcal/cm^{2}sec (BOLDIZSÁR and GÓZON, 1963). Rock conductivity is about the same as in Komló, the decreased heat flow is the consequence of the smaller temperature gradient. The gradient of temperature in Komló is 47 deg/km, whereas in Hosszuhetény it is 36 deg/km, both values are quite high compared with areas outside the Carpathians. Taking the average value from the two measurements mentioned above, it gives a heat flow in the NE region of the Mecsek Mountains of about 2.9 $\mu cal/cm^2 sec$.

Heat-flow measurements in the Nagylengyel oilfield near the Austrian border revealed 1.9 to 2.0 $\mu cal/cm^2 sec$ (Boldizsár, 1959). While the dense rocks in Komló and Hosszuhetény made it possible to ascertain rock conductivity with precision, in Nagylengyel the Tertiary rocks of high porosity presented difficulties. The samples were saturated with water before the conductivity was measured.

Recent Investigations

My further measurements of heat flow indicated in the Pliocene sediments of the Hungarian plain at Hajduszoboszló a heat flow amounting to 2.4 to 2.6 $\mu cal/cm^2 sec$. At the edge of the mid-Hungarian Mountains near Szentendre in Oligocene sandstone 2.0 $\mu cal/cm^2 sec$ has been found, further in the southern part of the Mecsek Mountains in Permian sandstone near Hetvehely and Bakonya the heat flow amounted to about 2.4 $\mu cal/cm^2 sec$. The papers relating to these heat flows are being prepared for publication.

In the Czechoslovakian part of the Hungarian basin at Selmecbánya (Banska Stiavnica) in Tertiary andesite and dacite rocks 2.66 $\mu cal/cm^2 sec$ heat flow was observed (Boldizsár, 1965). All heat flow values are shown in Figure 1. The distribution of high heat flow values over the whole Hungarian basin without any exception suggest that this tectonic structure is somehow connected with this geophysical phenomenon.

More than 400 carefully controlled temperature measurements were made in boreholes to ascertain virgin rock temperature of the rocks of th Tertiary basin and the bottom rock. Points of measurement are well distributed over the whole country and iso-temperature-gradient lines were constructed as shown in Figure 1. The average value of the temperature gradient is 54.2 deg/km, but over big territories (about 3500 km^2) the temperature gradient is over 70 deg/km. The highest measured temperature gradient at Lakitelek is 165 deg/km in Pliocene sediments with no indication of volcanic activity. This territory of about 50 sq.km suggests an extremely hot water or steam deposit suitable for electrical power generation (Fig. 2).

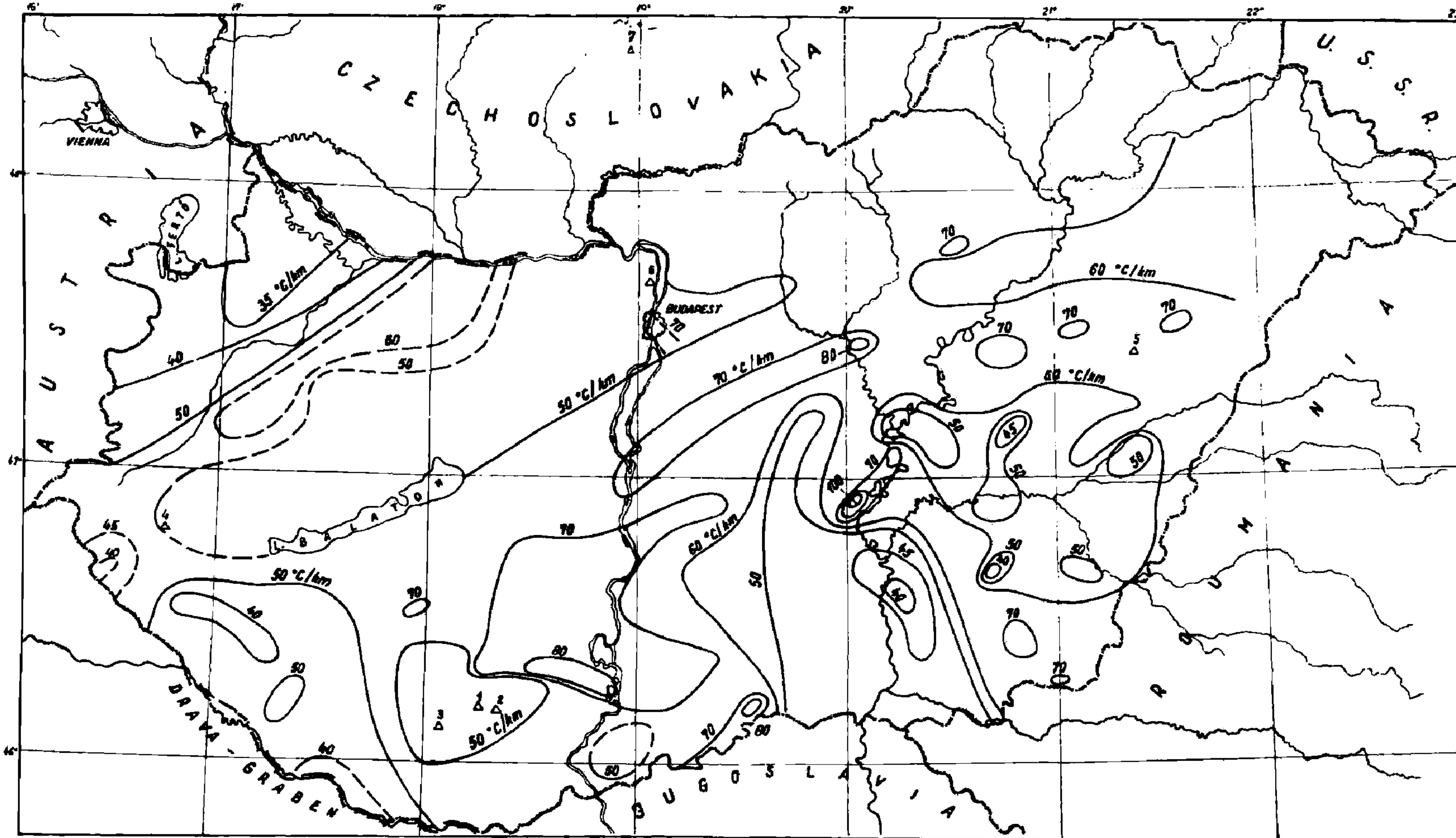

FIG. 1 - Temperature gradients and measured heat flow values in Hungary.

▲ Places of heat flow measurement		3 Bakonya	2,4	6 Szentendre	2,0
1 Zobak	3,3	4 Nagylengyel	1,9 - 2,0	7 Banska Stiavnica	2,6
2 Hosszuhetény	2,5	5 Hajduszoboszló	2,2 - 2,6		

Heat flow values are given in μcal/cm² sec unit.

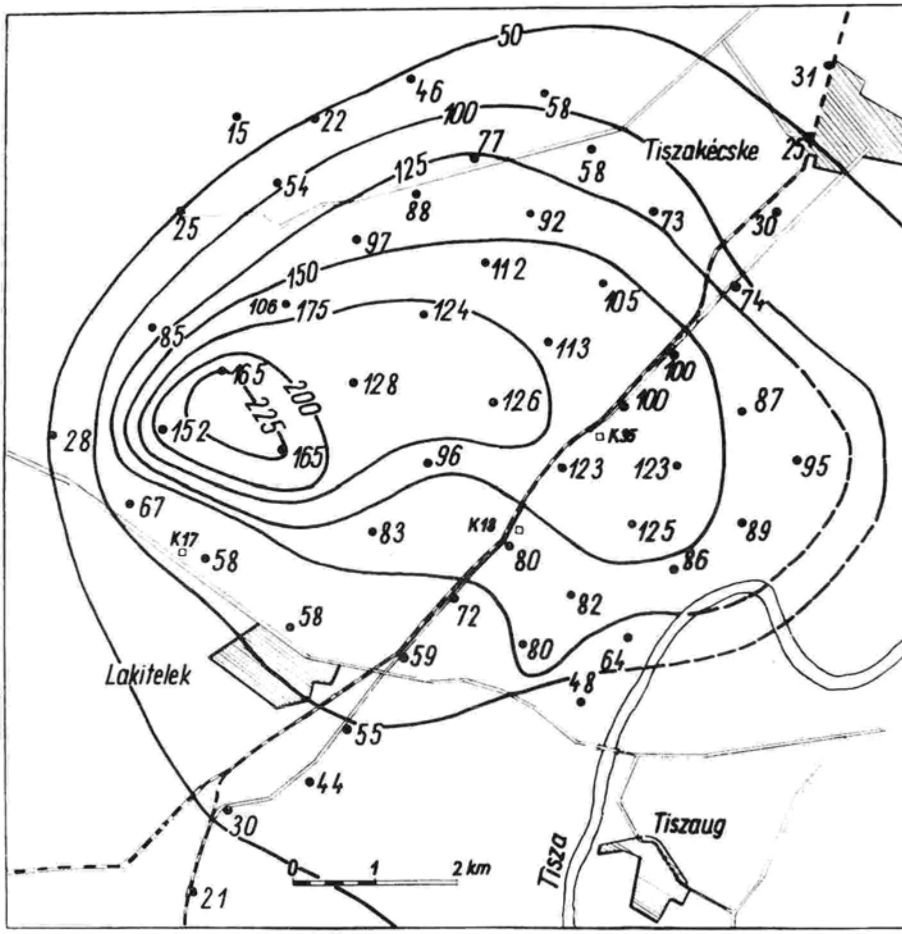

FIG. 2 - The geothermal anomaly of Lakitelek. (Number at the black dots indicate measured surface temperature gradients in deg/km. Numbers on the iso-gradient lines indicate temperature gradients relating to the conductivity of of the deep formation. Surface gradients were measured between 20 and 50 m depth.

Economic Value of the Hot Water Deposits

The volume of Tertiary and younger rocks is about 160,000 km^3. The volume of porous rocks with porosity over 10 % is about 20,000 km^3. Over 4,000 km^3 hot water of 60° to 200°C temperature, is stored in the pores of the rocks below 1000 m deep; most of it can be mobilized by making boreholes everywhere to create hot water wells with capacities of 1 to 3 m^3/min. This immense quantity of stored heat dropping the temperature down to 40°C amounts to 2.3×10^{19} cal, which is about 50 % of the calorific value of the known petroleum deposits in the entire world at the end of 1963.

According to my proposition, the hot water is now being exploited in a great scale for heating and industrial purposes since the geothermal heating is more economic than any other alternative. Wells 1000 to 2000 m deep can produce 1 to 3 m^3/min hot water of 60° to 100°C for decades. The newly discovered Lakitelek steamfield may possibly be used for power generation. Preliminary estimates show 10^{11}kWh recoverable energy reserve.

Heat Flow and Tectonics

I believe that the ultimate cause of the tectonic processes are thermal phenomena in the subcrustal regions of the earth. The terrestrial heat may be primary or radioactive or both; the direction of the heat flow may be upward, downward, or a combination of them, but there is no thermal equilibrium and that is why heat flows within the mass of the earth causing displacement, plastic flow of the subcrustal rocks and therefore the oscillatory movement of the crust. The heat flow within the earth is a non-stationary phenomenon, which tends in time to get nearer to the stationary state and in some parts of the earth the thermal state may already be quasi-stationary. If this is so, a reasonable explanation is offered of the observation that the amplitude of the tectonic activities are decreasing with time and also that great parts of the earth, the « nuclei » of the continents, are tectonically inactive, while great tectonic activities take place in the active belts, in the geosynclines.

The uniform high heat flow in the Hungarian basin can be explained by the fact that the Hungarian basin is a part of the Alpine orogenic system. The orogenic cycle was induced by radioactive heat production which caused the dilatation of the crust. The decreased remains of the high heat flow which have caused this orogenic cycle, can now be measured along the Alpine system. Few heat flow measurements are available, but high temperature gradients in the Pyrenees (Lacq gas-field), in the Appenines, in the Alps and measured high heat flow in the Carpathian basin support this view. On the contrary, north and northeast of the Alps and Carpathians measured temperature gradients are between 30-10°C/km. In the Ukrainian Precambrian shield heat flow measurements show values between 0.62-0.74 μcal/cm²sec (LUBIMOVA, 1964). These low heat flow and geologic evidence show that the Russian platform was inactive during the Alpine period.

At Lakitelek, where heat flow increases to 9.1 μcal/cm²sec, the maximum temperature gradient is about 225°C/km. The bottom of the Tertiary basin is assumed at about 1500-2500 m. Recent investigations show that the Alpine flysch, which covers the Mesozoic bottom rocks is present under Tertiary sediments. The situation is somewhat similar to that of Larderello except that at Larderello the flysch is not buried under thick cover rocks. According to my measurements at Larderello (BOLDIZSÁR, 1963) the maximum heat flow value is 13.7 μcal/cm²sec compared to 9.1 μcal/cm²sec at Lakitelek. The cause of the exceptional high heat flow in both case may be an unknown intrusive body in the depth. This intrusion has heated up the fractured Mesozoic rocks; in connection with the hydraulic system, hot water up to perhans 374°C at Lakitelek and superheated steam at Larderello have been found. It is also possible that at Lakitelek a superheated steam deposit exists.

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