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LECTURES ON GEOTHERMICS IN HUNGARY

Peter Ottlik

UNU Geothermal Training Programme
Reykjavík, Iceland
Report 11, 1989

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Publication of the
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PREFACE

Since the foundation of the UNU Geothermal Training Programme in Iceland in 1979, it has been customary to invite annually one geothermal expert to come to Iceland as a UNU Visiting Lecturer. The UNU Visiting Lecturers have been in residence in Reykjavik from one to eight weeks. They have given a series of lectures on their speciality and held discussion sessions with the UNU Fellows attending the Training Programme. The lectures of the UNU Visiting Lecturers have also been open to the geothermal community in Iceland, and have always been very well attended. It is the good fortune of the UNU Geothermal Training Programme that so many distinguished geothermal specialists with an international reputation have found time to visit us. Following is a list of the UNU Visiting Lecturers during 1979-1989:

1979	Donald E. White	United States
1980	Christopher Armstead	United Kingdom
1981	Derek H. Freeston	New Zealand
1982	Stanley H. Ward	United States
1983	Patrick Browne	New Zealand
1984	Enrico Barbier	Italy
1985	Bernardo S. Tolentino	Philippines
1986	C. Russel James	New Zealand
1987	Robert Harrison	United Kingdom
1988	Robert O. Fournier	United States
1989	Peter Ottlik	Hungary

The UNU Visiting Lecturer of 1989, Mr. Peter Ottlik, has during the last decade written several review articles on geothermal utilization and development in his home country, Hungary. It is of great value for the participants of the UNU Geothermal Training Programme to learn about the geothermal work in Hungary, which is the leading user of geothermal water from sedimentary basins in the world. The world potential for harnessing geothermal waters in the sedimentary basins is vast. It is therefore very important to learn from the experience of the Hungarian geothermal community. We are grateful to Mr. Peter Ottlik for giving us an insight into Hungarian geothermics in his five lectures in Reykjavik in September 1989, and for preparing the lecture notes that are presented here.

Ingvar Birgir Fridleifsson,
Director,
United Nations University
Geothermal Training Programme.

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(P. Ottlik[1])

Introduction

Hungary is a small country in the Eastern part of Middle Europe. It has favourable geothermal conditions.

The whole territory of the country is 90.000 sq km, within the Carpathians, in the so called Pannonian Basin.

The surface of the land is mainly flat, crossed by the Hungarian Central Range. Two rivers flow across the country. One of them is the Danube, the biggest river of this part of Europe. The other river is a smaller one called Tisza. It springs from the Eastern side of the Pannonian Basin and it flows into the Danube in the Southern part of the Basin.

The territory, the area of the country consists of the following geographical regions: Transdanubian region is on the Western part of the country. The Small Hungarian Plain which is on the Northern part in the Transdanubian region. The Great Hungarian Plain is divided into the region between the Danube and Tisza rivers, and East of the Tisza is the Trans-Tisza region.

The crust of the Earth was active during the tercier geological epoch. There have been several tectonic phases of the Alp-Carpathian orogenetic cycle.

The volcanism is related to the orogenetic-tectonic periods and started in the Eocene age and came to its peak point during the Miocene. This volcanism produced mainly andesitic rocks.

The youngest volcanoes are found north of Lake Balaton and are separate basaltic cones. (Figure 1)

In the Hungarian Central Range there are mainly mezozoic formations on the surface. The major part of the total mass of the Central Range consists of carbonatic rocks, limestone and Triassic dolomite.

These rocks are fractured, fissured, faulted by tectonic forces. Triassic limestones and dolomites were on the surface for several geological ages and became carstified.

The geological data show that on a big, extended part of the Pannonian Basin these Triassic carbonates form the bedrock of the young pliocene basin.

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[1] EGI Contracting and Engineering, Budapest

Beside Triassic formations older metamorphic rocks such as shists and gneises are also found in the basement.

The Earth crust had been elevated at the end of the tertiary age so the area of Pannonian Basin became a part of the continent.

Geothermal background

In the Hungarian Plain quite dynamic drilling activity was carried out in the past 40-45 years with the purpose of exploration and opening up of oil reserves. In the frame of this work several thousands of wells were drilled with 1500-4500 m depth. Geophysical exploration was made also by the oil industry.

Long seismic profile were measured in international cooperation along the Alp-Carpathian Chain-mountain to explore the root zone of the mountain. Deep magnetotelluric measurements were also done by Hungarian geophysicists.

By the interpretation of seismic and magnetotelluric data they obtained as a result that the Mohorovicic discontinuity surface is in a greater depth below the mountains, but it is in an elevated position under the basin area.

The Mohorovicic surface is the bottom of the lithosphere. The geological section based on geophysical data shows that the mountains have roots corresponding to the Wegener theory and to the suggestions concerning plate tectonics. (Figure 2)

Besides the structural information the section has the key to the explanation why geothermal conditions are more favourable in the basin within the arc than outside it.

The thickness of lithosphere is in average 30-33 km under the continent. This value is only 18-24 km under the Pannonian Basin.

Consequently the average value of heat flow is about 50 mW/sqm on the continent but in the Pannonian Basin it is 80-100 mW/sqm. These are measured values and isolines which are shown in Figure 3, 3/a.

Corresponding to the heat flow also the value of geothermal gradient is better than the continental average. The normal value of this parameter is usually a temperature increase of 35 °C on each 1000 m. In Hungary according to the small map on Figure 4 in 1000 m depth temperature reaches even 70 °C.

Hydrological systems, geothermal aquifers

The structure of the Earth crust ensures the favourable geothermal condition of the Pannonian Basin. An energy bearer is needed too to utilize this condition, by which geothermal energy can be exploited. This media is the water stored in sedimentary strata. So hydrological, hydrogeological conditions are also of a great importance concerning utilization of geothermal energy.

In Hungary there are two big hydrological systems. One, the more significant, is in the Upper-Pannonian (Pliocene) series. The second one is in the fractured, carbonatic formations.

During the Pliocene-Pannonian age the Pannonian Basin was a sinking area. The trend of subsidence was continuous but the movement itself was oscillating with a rather short periodicity.

The result of this epirogenetical, oscillating subsidence took place in the Lower Pannonian age, a series of sedimentary beds consisting of clay and marble strata with only a few sandy-clay strata imbedded. The character of the whole series is clayey and impermeable.

On the contrary the series developed during the Upper Pannonian age shows a 'sandwich'-like picture by the alternation of loose sand, clayey-sand and clay beds. These beds are rather thin. The thickness varies between 1-25 m but the most frequent value is between 2-5 m.

The measure of sinking and of filling up by sedimentation had been in equilibrium during this time. This fact is evident from the whole thickness of the series which is over 1.000 m at several locations. (Figures 5, 5/a).

The paleogeographical lacustrine, swampy conditions have remained during the period of sedimentations. So within these aquifers there is fresh water with a salt content between 1.000-12.000 mg/l. The solved salt is alkaline-hydrocarbonate.

The stored water is syngenetic with the bed. CO_2 and CH_4 content come to the surface with the produced water. These gases are the results of disintegration of organisms which had lived in the lakes and swamps. The presence of gasses is independent from the temperature of the water.

The specific permeability of these sandy aquifers varies according to the granulometry and clay content of the bed. This variation can be observed both in the horizontal and in the vertical directions.

There is no method to predict the value of this parameter so it is the most severe risk factor in opening up and utilizing of geothermal energy in Hungary. The risk may be reduced by perforating more aquifers into one borehole.

The porosity of the best, i.e. of the loose sand aquifer is about 30%. The value of good porosity comes from the fact that bed and water are syngenetic so compaction, consolidation rate of these aquifers were small. Because of their origin these beds are more or less extended lenses.

The temperature of the aquifers depends on their depths. The deepest part of the Pannonian Basin is on the SE. Therefore here are the best conditions for producing geothermal energy. The main part of exploited water has been produced from these aquifers.

In the last 5-10 years they observed that the flow rate of free outflowing wells decreased and the measurements showed the pressure drop of aquifers too. (Figure 6.) Decrease of pressure is 0.1-0.2 bar/year, that means that the total pressure loss is still now 2-5 bars.

Most of the wells in this region of the country are operated by pumps.

Measurement carried out in observation wells proved that pressure decrease almost reaches aquifers near to the surface, connected with the big amount of exploited thermal water.

This phenomenon shows on the one hand that the exploited quantity of thermal water aquifers is more than the recharge and the recharge comes from the aquifers situated above the tapped strata. On the other hand these data made evident that the Upper Pannonian, and the covering younger strata operate as one big hydrological system.

The porosity of these sandy aquifers has a statistical distribution, from a hydrological point of view they are homogeneous and isotropic.

Locating wells to avoid interaction there is only the distance between the wells to be taken into account, the direction can be chosen freely.

The dimensions of pores are small so the speed of flowing water is very slow because of the big hydraulic resistance of the bed. This is only 1-10 cm/year under undisturbed conditions. By tapping the aquifer - under disturbed conditions - this value increases.

The other big hydrological system exists into carbonatic, fractured, fissured formations, which are carstified on the upper 15 m part. The most significant of these rocks are the limestones and dolomites of Upper Triassic age. The thickness of these formations is several thousand meters, and can be even over 4.000 m. At places where it is in a direct contact with the covering Jurassic, Cretaceous and Eocene limestones it forms a uniform hydrological system with them. The biggest mass of the Central Range consists of these formations. These are on a very extended area on the surface. Because the conditions of percolation, infiltration are very good, the recharge of this system comes from this area. The infiltrating atmospheric water has a cooling effect on the upper part of these rocks. Through deep faults the percolating water reaches big depth where the temperature is high and the water is heated by the rock.

The chemical character of carstic waters is usually very hard because of the big quantity of solved Ca CO_3. The gas content is usually low and consists of CO_2 only.

This hydrological system differs in two points from the system which exists in the Pliocene series.

First of them is that the dimensions of secondary porosity formed by fractures, fissures are bigger than the pores in sandy layer. By this fact there is a smaller hydraulic resistance in such rocks and the speed of flowing water is higher in natural conditions 1-10 m/year.

The other difference is that secondary porosity arise from tectonic forces which acted from a certain direction so the direction of fractures is determined by their origin. The distribution of these is not statistical, but they occur in zones, therefore these aquifers are not homogeneous and unisotropic. When locating - for example - a production and a reinjection well, besides the distance the direction of the location has to be taken into account as well. Locating two wells on the same fault zone they are in a direct hydraulic contact so the interaction between them appears in a short time.

The water into the carstic system is much younger than the aquifer itself. The rocks of mezozoic age are of marin origin so the syngenetic water would be brine, but is fresh water in fact.

To sum up, in Hungary there are two big hydrological systems with quite different properties. But both of them are heated only by the terrestrial heat flow. The temperature increases with the depth in normal cases regularly. The value of heat flow is relatively high in the Pannonian Basin but low from an industrial, economic point of view so geothermal energy is not or hardly renewable.

Geothermal investigation and resources in Hungary

In the following we are going to give a brief summary about the investigation carried out by VITUKI (Scientific Research Center for Water Management).

The targets of geothermal investigations carried out "in situ" and in laboratories were essentially to determine the reserves. However to achieve this theoretical calculations and practical observations were necessary in a number of fields of this topic as follows:

- Heat loss during production of thermal water.
- Heat conductivity tests were made in laboratory and field conditions.
- Plotting of geothermal gradient maps.
- A method was worked out to determine hydrologic character of aquifers.
- Application of geochemical thermometer: suitable for the Hungarian conditions.
- Determination of the amount of geothermal energy stored in the Pannonian Basin.

Theoretical and practical field and laboratory research was done about the heat loss potential of the rocks.

In working out the method the basic assumption was that convective horizontal heat flow is taking place in the formation.

Further assumptions were used to arrive at the mathematical description:

- the flow is plain and normal to the axis of the well,
- the water production is constant,
- the total thickness of the tapped aquifer layers is known,
- during the time of production the heat exchange is insignificant between the aquifer and the boundary strata,
- the parameters of thermal conductivity (K) and heat density ( ) during the test are constant both in location and time,
- the convective heat flow and flow of the fluid are stabilized immediately.

With the assumptions above the equation of relative temperature was derived

$$T^{x} = (T - T_{k})\ (T_{o} - T_{K})$$

where:

T^{x} = relative temperature
T = measured temperature
T_{k} = initial temperature of water reservoir
T_{o} = constant temperature of the produced or reinjected water

With the recorded and measured data a curve is plotted under the formula which is related to the series of master curves.

In determining the heat conductivity of the impermeable covering layer of the aquifer the well was taken into account as a line-shaped heat source and in its environment only conductive heat transfer was assumed. The measurement can be carried out in case of a stationary heat space.

From the investigation it became clear that the hot water rising in a well provides more significant heating for a relatively small region around the well only. A practically related result is also that the thermal balance of the cooled wells (with drilling mud etc.) is restored only over a longer period of time, that is several months. (Figure 7).

Laboratory heat conductivity tests were made on sediments and artificial samples with the instrument developed at the Geophysical Department of the University in Budapest (ELTE), (Figure 8) with the aim of clarifying the correlation between the thermal conductivity and water content of rocks and to make these measurements, results suitable for extrapolation for field conditions too.

Measuring the dielectric constant (ϵ) of the sample proved the best way to determine its water content. This is so for the good reason that this is the way which causes the least physical damage to the sample. The equipment suitable for this purpose has been designed in the VITUKI (Figure 9).

From the tests the following conclusions can be drawn:

- the K-p% when the sample is dry (p=0%) approaches the value 1 $mcal.cm^{-1}\ .\ S^{-1}\ .\ {}^{\circ}C^{-1}$, with small deviation.
- Until the saturation value $p \simeq 10\%$ is achieved the K value grows relatively quickly.

- From the previous saturation value to the full saturation which is 1.5 to 2.5 times the K value belonging to $p \simeq 10\%$, the K value rises in a linear way depending on the rock type (Figures 10, 11, 12).

The most important is this second part of the curve from the aspect of the interpretation of measurements. This shows that there is a linear correlation between thermal conductivity and the water content percentage. The rise of the curve in this linear stage depends on the rock samples, although the difference is not large.

The significance of the above results is great for the practice because the "in situ" thermal conductivity determination is greatly facilitated therewith.

The water content of the sample core is to be determined just after taking it and before and after measuring its heat conductivity in the laboratory. If the water content does not differ significantly from the "in situ" value, the heat conductivity determined in the laboratory corresponds to the "in situ" value too. In case of the deviation of moisture content the "in situ" heat conductivity can be obtained with the help of model-curves through the extrapolation of moisture content.

In the course of these investigations it became clear that the average heat conductivity of clays and marles is $3x10^{-3}$ cgs while in case of sands this value is $6x10^{-3}$ cgs in water saturated condition. Accordingly, the average heat conductivity can be traced back to the geological construction

$$\frac{K_1}{K_2} = \frac{H_1}{H_2} + \frac{(1-H_1)\ a}{(1-H_2)\ a}$$

where H_1 and H_2 mean the % of sand thickness, and 'a' means the K_{H1}/K_{H2} quotient.

Having investigated many wells of 100 to 250 m depth it was found that the correct geothermal gradient value is obtained if the actual mean ground temperature is used as a starting point. The air temperature average values were also investigated and finally the result was obtained that the annual mean temperature of the ground is 12 °C.

The next task was plotting geothermal gradient maps for the territory of the whole sedimentary basin. The country was divided into squares of a size of 10x10 km. The network thus obtained provided surface elements of 100 km^2. Each such element was then described in terms of the data measured in their boreholes. In the case of elements where no holes were drilled they applied the procedure of interpolation.

In the first subject in the determination of the geothermal gradient the aim was the correction. If the max. error percentage of the determination is specified in 20%, in case of 50 °C/km gradient the surface mean temperature has to be known at the accuracy of 1 °C in order to keep the error below the permitted value. It was found that in the different regions of the country the difference between the values of annual mean temperatures on the surface can be even 2 to 3 °C, and the air temperature also differs from the soil temperature.

On the basis of the T_0 data of the soil temperature map the geothermal gradient map was corrected and replotted.

Calculating the values of temperatures measured in well 'T' those were taken into account in which the thermal equilibrium could be assumed.

New results were achieved in the field of determining the hydrogeological characteristics of the hot water containing aquifers. According to the experiences the electrical specific resistance of sandy strata is 2 to 3 times higher than that of impermeable clayey beds. Accordingly, the percentage of sand content was determined for each well.

A new process was worked out for the determination of seepage factor of the hot water aquifers on the basis of specific resistance measurements.

Electric conductivity was assumed to take place in the hydrate envelop on the surface of the grains in the porous rocks. Thus, the conductivity is related to the specific resistance.

The result of the calculation made with the classic assumption contradicted the empirical fact that the seepage factor is larger in the rock of higher specific resistance.

The correlations of the filtration factor and the specific electric resistance was further investigated in the porous rocks. It was found that in grainy rocks the electric conductivity is found on the surface of the grain even in water-saturated conditions.

A method was worked out in which the correlation could be determined as $K = a \times \sigma^2$ thus the formula in SI is as follows:

$$K = 10^{-7.03} \times \sigma^2$$

where

K ms^{-1}, σ is in ohm meter unit.

The hydraulic 'T' transmissivity calculated from the pressure rise and resistance measurement in wells and the geophysical T_q transmissivity values and their correlations are shown in Figure 13.

Further investigation of the application of the geochemical thermometer answered a question of geological nature as well. Namely, if data supplied on the geochemical thermometer shows a chemical composition of higher water temperature than what they actually found, it implies that the water in question is not syngenetic with its present aquifer. If this be the case they can expect hotter water deeper down.

After the evaluation of the relevant special literature they concentrated on the methods for the lower water temperature range in the country. So they made calculations using three formulas. These are as follows:

1) Si thermometer with adiabatic cooling

$$T_1 = 1315.5\ (5.202 - \log SiO_2)^{-1} - 273.15$$

2) Na - K - Ca, this method is actually identical with Na/K, but it considers the point that after cooling the equilibrium is also modified by the Ca-content of the solution. The dissolved material are given in mol/lit.

$$T_2 = 1648\ (2.24 + \log K')^{-1}$$

where log K' (Na/K = b.log (Ca/Na).

where b = 4/3, if Ca/Na_1 and T_6 100 °C

b = 1/3, if Ca/Na_1 or T_6 100 °C b= 4/3 mol

3) Na - K - Ca - CO_2 where the fact is taken into account that in waters below 75 °C temperature the partial pressure of CO_2 may also modify the Na/K value. For this the CO_2 contents or the HCO_3 amounts and the water pH are taken into account. If the dissolved materials are given in mol/lit,

$$T_3 = 1648\ (2.24 + \log K'')^{-1}, \text{ where}$$

$$\log K'' = \log (Na/K) + (4/3).\log (Ca/Na) - 1.36 - 0.253 \log P_{co2}$$

where

$$-\log P_{co2} = pH - \log HCO_3 + 7.699 + 4.22\times10^{-3}\ T_{water} + 3.54\times10^{5}\ T^2\ water$$

From the correlation investigations it is clear that for the warm waters in Hungary, the thermometers T_1, T_2 and T_3 are most applicable (Figures 14, 15).

And, finally, the work also aimed at the determination of the geothermal energy amount. The research of the previous years prepared the foundations for this task.

On the basis of this investigation the geothermal gradient map series of the country was plotted in 500 m depth intervals, one of which is shown in Figure 16 as an example for the depth between 1750 and 2250 m.

Thus, the geothermal reservoir formation maximum temperature map was plotted for the aquiferous sand on the boundary of lower and upper Pannonian sediments. (Figure 17.)

The stored heat quantity is calculated volumetrically. At that time the wells producing water above 35 °C were regarded as hot water wells (this has changed to 30 °C since that time). The map of the isotherm surface depth of 35 °C was plotted together with the isotherm map of the surface of lower-upper Pannonian boundary.

The thickness and extension of the porous water wells were calculated from the boreholes between the two levels of depth with the average porosity and cubic capacity. The total cubic capacity of the warm water holding formations in the basin is 35×10^3 km^3.

The regional geothermal gradient map calculated for the thermal water aquifer is shown in Figure 18.

The amount of thermal energy stored in the warm water formations was determined by columns of 100 km^2 base, where the amount of heat equals the volume multiplied by the specific heat and by the temperature difference.

The amount of heat is distributed as shown in the isocalory map. (Figure 19.) The isocalory lines are of 10^{16} value, that is along one line the full energy content of every sediment column of 100 km^2 basic area is 10^{16} kcal or 4.2×10^{19} Ws.

If only the water heat stored in the water is regarded exploitable and that of the rock is not, then the total heat content is $Q_{water} = 21.15 \times 10^{20}$ Ws.

If the conditions are modified by taking the average temperature instead of the bottom temperature, and this is 60 °C then

$$Q_{water} = 28 \times 10^{20} \text{ Ws.}$$

The work was continued by launching a subject "Geothermal Potential, Exploitable Thermal Water Reserves and Related Conditions in the Particular Regions of the Country". The title implies that for waters above 50 °C it is required to supply information besides the quantity of the water about its expected quality, its temperature, water recovery from one well and the depth of a well. And, finally, it was prescribed that the reserves exploitable till a depression of 200 m had to be taken into account.

The most significant quantitative question can be solved from the data of operating wells in such a way that the result is given in a fraction where the numerator stands for the already produced amount and the denominator indicates the still exploitable reserve in the 1000 m^3/day recovery value. The results are given in Table 1. The results of the last evaluation of reserves are shown in Table 2.

Utilization of the geothermal reserves

The distribution of the amount of thermal water produced in the country among the individual areas of utilization is shown in Table 3.

As it is shown in Table 3, about 72 per cent of the wells and a slightly larger share of the water produced are used in the field of balneology, agriculture and drinking water supply.

The most important area of utilization of geothermal energy is agriculture and to a much smaller extent the utility sector (domestic heating and household hot water supply).

Agricultural utilization. In the field of agriculture the horticultural branch is the largest geothermal energy consumer, primarily in the field of heating greenhouses and the plastic tents.

As a result of development, in 1970 there was a total area of 170 ha in Hungary covered with glass and plastic foils. Additionally there was a surface of about 1000 ha which could be temporarily covered with plastic foils in the country.

In about 25% of the green houses covered by glass and in 95% of houses covered by plastic foils vegetables are grown. The most important vegetables are pepper, tomato and cucumbers. The rest of the total area is used for nursing. On the largest surfaces of farm specialized on ornamental plants cut-flowers are grown. As far as efficiency is concerned growing ornamentals is more economical than growing vegetables.

Of the total area covered with glass houses about 70 ha is equipped with houses made in our country, the rest was imported. Hungarian green house production on a large scale started only in the sixties. The most extensively used model is PRIMOR I. which has a structure of galvanized steel and glass mounted on a 25 cm high concrete strip foundation. Sizes of houses manufactured in serial production are 3.2x6.4 m, that is with a ground floor space of 20.48 m^2. Of these units practically any required size can be assembled. The height of eaves ducts is more than the one used generally in Western Europe (2.7 m). The reason for this is to secure efficient ventilation even in case of crops of high growth.

Of the area covered with plastic foil houses about 600 ha is in the possession of large-scale farms, the rest is owned by small farmers. The supporting structure of these houses is usually plastic bent to shape or galvanized steel pipe with spacing of 1.5 m. Standard width is 7,5 m but there are structures manufactured with a width of 6,0 m and 4.5 m. Supporting piles are fixed into pipes hammered into the ground or concrete strip foundations made with stud-pipes placed in the liquid concrete. Spacings are 1.5 m.

Side foils are sealed by earth cover. Plastic foils are usually polyethilene made out of a thickness of 0.15 mm. In order to maintain good efficiency houses are built in a length of 50 m and ventilation is effected through the fronts.

The heating systems generally use the thermal water directly. Where the temperature of the thermal water is higher than 70 °C, the 3-stage greenhouse heating system is frequent. The incoming high temperature water heats the air through ribbed pipes at 1.8 to 2.0 m height. At this temperature the 80 °C heat drops to about 50 to 60 °C. The second stage is the vegetation heating where the heating pipes are located on the surface of the soil. These pipes are also frequently used as the lines for the harvesting trolleys. In the vegetation heating stage the temperature of the thermal water drops to 40 °C. The water of about 40 °C temperature enters the third stage, that is ground heating, and leaves the system after cooling from 25 to 30 °C. The heating pipes of the soil heating in most of the cases are made of plastic and are located in the soil at 20 to 60 cm depth. This is the highest efficiency system where the total useful cooling reaches 50 °C.

In the green-house systems set up 10 to 20 years ago the heating system is even simpler in several places and only one or two stages are used. The first is the already noted ribbed pipe design covering the top half of the interior. The other - and if this is the only heating system, then this one is used - the pipe coil of 2 or 3 threads running in 60 to 120 cm height from the soil surface bent in vertical plain.

There are two sites in the country where the geothermal heating system of green-house plants is fully computerized. In the larger plant the system heats a 20 ha greenhouse and a 30 ha plastic tent with the water of 11 thermal water wells. The system also has its own meteorological station measuring the outside temperature, the solar radiation and the wind speed. In the houses the temperature and the humidity are measured. These are the input data of the system, and the automatic unit controls the amount of water through controlling the operation and flow rate of the wells.

This heat supply system also takes care of geothermally heated egg hatcheries, broiler turkey and geese breeding houses.

The other automated system consists of 6 wells and 6 ha greenhouses. The measured input data are actually identical with the previous one but 50 per cent of the vegetation produced are flower and ornamental plants. This system also has a safety peak boiler which, however, has not yet been needed even in case of the coldest temperature recorded outside, which was below -20 °C.

The heating system of the plastic tents in actual fact is similar to that of the green-houses.

significantly more expensively and with more difficulty than in case of utilization for farming purposes. The direct household hot water supply was made impossible by the quality of the thermal water very much differing from the drinking water. These direct systems are very simple and therefore very cheap. The basic scheme is the same everywhere. From the well the water enters a basin of 200 to 400 m^3 capacity where at atmospheric pressure the free gas is discharged and in case of an appropriate staying time the physico-chemical equilibrium of the water is achieved, that is the scale depositing takes place in this pool. After leaving the pool the scale deposit in the heating system is practically negligible.

The indirect heat exchanger systems were started only in the last 5 to 10 years. In these systems the properties of the untreated thermal water may cause no problem whatsoever in the secondary heating circuit. In the primary circuit the reliability is ensured by keeping the pressure at the appropriate level or with the application of a reserve heat-exchanger.

Disposal of the thermal water after cooling down. The question of cooled water disposal is integrated in the utilization of the hot water resources.

Up to quite recently the aspects of the environment were of secondary importance for which reason water disposal has not been a problem.

The methods of water use and disposal is specified by the water authority in its licence for setting up and operating the well. According to the central specifications the temperature of water may not be above 40 °C if it is to be introduced into the sewer system or a live water body. The other criterion is the salt content which may not be above 1000 mg/liter. The bigger difficulty is the salt content because in most of the cases it ranges from 3000 to 5000 mg/lit. The Hungarian waters also contain Na-hydrocarbonate which also influences the possibility and the time of the disposal.

The reinjection is the most suitable solution from the aspect of environmental-protection and also of water management and resource depletion. By maintaining the formation pressure of production conditions are also satisfied. Water reinjection experiments have already been carried out. Its spreading is hindered by two main reasons. The first is that the system needs two wells instead of one, which significantly increases the investments costs to which the investment expenses of the filter-pump are added required for water reinjection as well as for the operational costs of water reinjection. The reinjected water may not contain more than 1 mg/l solids.

The difference is that in most of the plastic tents only one type of a system operates, that is the vegetation heating. This, with its heating elements located on the ground heats both the soil and the air. The simple plastic tents generally do not operate in the cold winter months.

Experiments have also been carried out with the plastic quilt heating. In these systems the water of relatively low temperature at max. 30 to 40 °C was running through a plastic quilt at low pressure in which holes with welded edges were made of a diameter which is optimal for the plants. The solution was satisfactory because it was partly heating and covering the ground through which its drying diminished and partly the 15 to 20 cm thick quilt provided appropriate temperature for the seedlings and finally the top surface of the quilt set also the temperature of the air.

The spreading of the solution was hindered by economic reasons. The plastic film has a relatively short service life because of the impact of light and heat and also the quilt is very sensitive to mechanical impacts, wherefore it had to be repaired or replaced more frequently than it would have been economical.

Drying produce is one way of using geothermal energy used in a few places. It makes the well more time efficient although it has not spread in the country as yet.

Another more significant area of using geothermal energy in the field of agriculture is animal husbandry, more specifically, the breeding of broiler chickens.

Its heating system in general consists of ribbed or normal pipes running over the floor by 15 to 20 cm along the walls. The number of the pipes primarily depends on the temperature of hot water. The heating system is complemented by the horizontal small surface plain radiators located horizontally also at low height, which are regarded as "artificial mother" as the young poultry have the tendency to lurk under or perch on top of them.

In the breeding of pigs and cattle geothermal energy of not significant amount is used with the solutions described for heating livestock and calf breeding facilities.

Home utilization. The geothermal energy utilization started with the heating of flats and household hotwater supply. At first these heating systems also used the thermal water directly and the impacts were directly felt in the system. One of the difficulties was that the temperature of the water was lower than what generally accepted in homes heating by Hungarian standards. The scale depositing tendency of thermal water was also a problem in the utilization of the water for homes purposes which led to damages in the heating system of a building which could be corrected

The other reason can be partly ascribed to the natural parameters. During reinjection in the domestic thermal water reservoirs of frequently lose sandy structure the phenomenon of suffosion is experienced. In actual fact this means that the water flowing with a high speed from the reinjection well drifts the smaller particles among the pores according to its kinetic energy in the medium of heterogeneous granular composition. As the speed and energy of the water discharged from the well decrease; the drifting particles settle down; with this the original permeability of the formation is diminished. Necessarily this process involves a growing excess pressure for the reinjection of an identical amount of water, resulting in the increased output of the reinjection pump, the power input and the price of energy. The process ultimately may lead to the bursting of the aquifer.

In order to solve the problem under Hungarian patents systems were established where according to the local usage the well was lined with a pipe of 7" to the formation to be tapped, e.g. 2300 m. The top part of the well was drilled and cased with a larger than usual diameter and this was perforated between 1600 and 1700 m. In such a way a double-function well could be established which produced through the 7" well and the cold water was reinjected into a higher layer through the annular clearance between the 7" and 9/8" pipes.

Although the drilling is about 30 per cent more expensive because of the bigger diameter drilled to a certain depth as compared to a usual production well, this system is significantly cheaper than having two wells in the system. The disadvantage of the system is that the fluid removed from the tapped formation is not reinjected in the same place, therefore, the water reserve and the formation pressure equally drop. A risk factor is that the water of a deep formation is mixed with the water of a higher water body so colmatation etc. may also occur which reduces the possibility and cost efficiency of the reinjection.

The difficulties in the utilization of geothermal energy

Salt content, scale deposit. The Hungarian thermal waters, generally the upper pliocene waters are chemically of the alkaline hydrocarbonate character. The salt concentration ranges widely from 1000 to 12.000 mg/l. The most frequent concentration is 3000 to 5000 mg/l. Their origin being shallow water or marshland also explains the presence of CH_4 and CO_2 and frequently N_2 gases deriving from the decomposition of organic matter.

About 30 per cent of the water of the Hungarian thermal water wells have the tendency for scale deposition. This partly depends on the dissolved salt content and partly on the CO_2 content.

Protection against scale deposit has been compulsory since the beginnings of the utilization of geothermal energy.

The inhibitors imported from the West were introduced in the mid seventies (Nalco, Hydrogel, Sago, Visco) permitted already long-term continuous operation.

By the 1980s already several Hungarian firms introduced inhibitors containing polyphosphate. In 1982 in well, where the incrustation increased daily by 1 to 1.5 mm, comparative measurements were carried out in such a way that 1 Hungarian made and 4 foreign made chemicals were added under completely identical conditions. Operation was carried on for one week with each of the inhibitors so the result was completely reliable. The experiment was started by adding 15 ppm and as an interesting out-come the lowest concentration was 6 ppm in all the 5 inhibitors, in case of which no scale deposit could be detected either in the top section of the well or in the surface pipelines.

In addition to the development of domestic inhibitors an automatic feeding system has also been devised which provides steady chemical concentration according to the flow rate of the water.

The magnetic water treating equipments are also applied with good results in the geothermal systems although they were not developed for geothermal waters. The advantage is that these systems are significantly cheaper and simpler than the inhibitor technology which in case of overdose makes the water aggressive. It requires no significant maintenance and is not very much sensitive to the water yield. Already a series suitable for different flow rates and pipe diameters is available from domestic sources.

A technical drawback is that in the present design this model may not be incorporated in the well structure therefore the well may not be protected with it. A series of experiments is to be carried out to determine the main parameters of the impact (time of stay, magnetic field, water type) in order to make the equipment plannable for the given system.

Gas content. In thermal water reservoirs of pliocene age and fresh water origin CO_2 and CH_4 are found.

The chemical investigation of the waters has been compulsory in the new wells for several decades now. However, these investigations indicate primarily the amount of the dissolved gases. However, over the last 11 years the analysis of the separated gas has been made compulsory. This can be of full or partial flow. Naturally, the full-flow analysis is more accurate. Where the water authorities specifies the installation of degasing unit, the implementation of the full-scope gas analysis is compulsory.

Methane (CH_4) in itself is chemically neutral.

It is to be noted that due to the identical genetical conditions these gases are also present in the water of top water holding formations used for drinking water supply. In the 1970s several explosions also occurred because the CH_4 discharged into the atmosphere in closed premises.

In order to prevent explosions the waters containing more than 5 Nl/m^3 methane must be degased. The max. allowed methane content in the water supplied through the network is 0.8 Nl/m^3. The regulations also apply to thermal water supply in case of direct systems. Where the thermal water supply in case of direct systems. Where the thermal water runs in a closed circuit without tapping possibilities the specifications are not so very strict. Ventilation is important in agricultural and horticultural systems to prevent CH_4 concentration which might lead to explosion.

CO_2 is a gas separated from the thermal water in large amounts. Its separation intensively influences the chemical balance of the water and it is the main factor leading to the separation of carbonates.

The CO_2 content varies widely in the waters.

Depletion of resources, decrease of formation pressure. The only heat source of the underground waters in Hungary is the terrestrial heat flow. Therefore, water of a temperature above 50 °C which can be used for energy purposes can be generally obtained from a depth below 1000 m.

Usually the precipitation and the percolation from the surface waters, rivers provide recharge for the water reserves. The water from the surface reaches the water storing formations at 1000 to 2000 m depth only indirectly, with a diminished extent and after a long period of time.

This phenomenon became more emphatic by the evolution of the regional depression presented by the large scale thermal water production in SE Hungary. This was primarily manifest after the end of 1960s with the diminishing water flow rate of the wells producing with out-flowing character, which naturally also indicated the reduction of aquifer pressure.

The pressure decrease of a few typical wells is shown in Fig. 6 made by Pál Liebe (VITUKI).

According to the hydrological assumptions 50% is the amount from the reservoir water and 50% from the amounts that can be recharged from the subsurface reserves. The increasing formation pressure drop in the high temperature water reservoirs at a greater depth indicates that consumption exceed recharge.

This is seen as one of the limiting factors of the development of the utilization of geothermal energy. Drinking water reserves would be endangered by this development.

In the territory a significant part of the wells has become negative and can be operated by pumping only. The clearly manifest reduction of the water reserves and the more expensive pumping operation lead to water economy and to the idea of a sounder water management.

The other method of water conservation is the enhancement of efficiency of utilization and the better heat utilization still offers a lot of technical developments. One of them is the installation of a heat pump in the utilization system. This operates in very few places in the country and its location must be based on economic calculations and conditions.

The better utilization of the heat content of thermal water brought to the surface is justified by the fact that the systems established up to now operate without reinjection, so they directly consume the water reserves.

Financial constraints. Regarding the financial questions of the production and utilization of the geothermal energy and the geothermal water disposal, it is convenient to start from the fact that in Hungary as a socialist country every natural resource under the surface is State owned. So a mine can only be State property therefore the expenditures of mining are covered by the State. This is naturally true for the production of fluids, oil and natural gas as well.

The water management law which answers all questions concerning the surface and sub-surface waters decrees that all water reserves are the property of the State but is also declared that every citizen has the right to have healthy drinking water which can be provided by himself. According to the law every citizen has the right to build wells to satisfy his own water demands and the law only regulates that under certain conditions license of the water authority is required for setting up the well.

The geothermal energy is carried by the geothermal water which is a special but integrated part of the water reserves of the country and the rules of the water law apply.

The financial question of the geothermal energy development and water utilization is determined by the legal situation outlined above. Starting a thermal water well requires a licence from the State and own financial funds. Under the domestic price conditions 40 to 60 per cent is the well construction cost, out of the total expenditure of the system consisting of a 1500 m deep thermal water well and the related utilization system.

It depends on the personal decision. This is unfavourable for the development of the geothermal energy utilization because the investor bears every mining risk involved in drilling which in other forms of energy is undertaken by the State.

The investment costs higher than the traditional project costs discourages the entrepreneur also from undertaking high-interest loans.

According to the Hungarian practice 50 to 55 kg per year fuel oil is needed for heating 1 m^2 green-house area. Related to the domestic oil prices the heating cost of the green-houses heated by geothermal energy is 1/4 part of the oil cost. From this situation is obtained that at present only those green-house complexes operated which are based upon geothermal energy.

The economic efficiency of the geothermal energy in concrete terms is hard to characterize because its investment cost is calculated in several ways so these data may not be compared. In a review under the information obtained from several operators the first-cost of 1 m^3 thermal water is a value between 7 and 20 Ft.

The complex utilization concerns the question of economic efficiency. Wherever it is possible efforts are made but not with full vigour; however, there are relatively few places where the multi-stage heat demand permitting complex utilization is localized on one site.

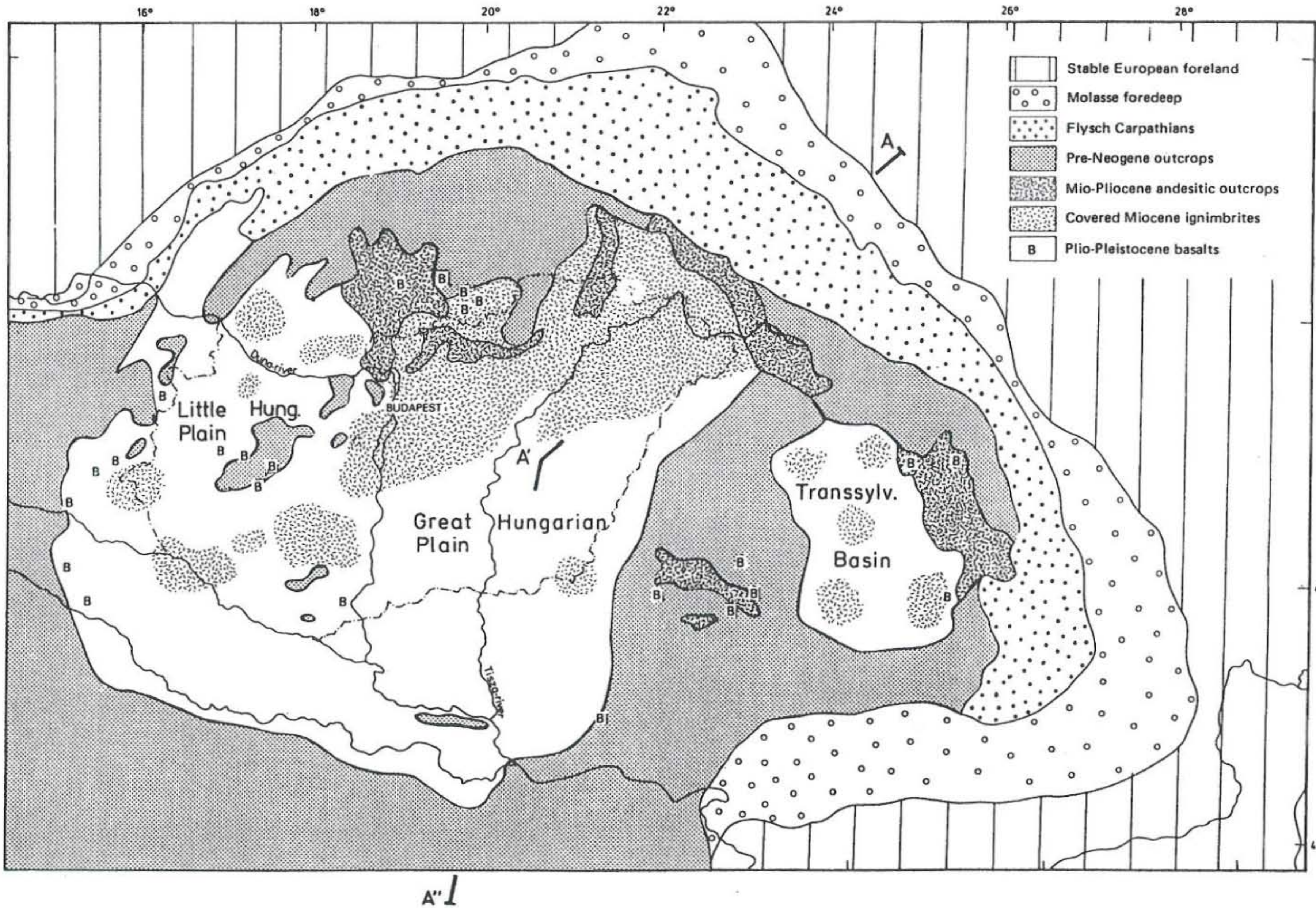

Figure 1. Neogene–Quaternary volcanism of the Carpatho-Pannonian region

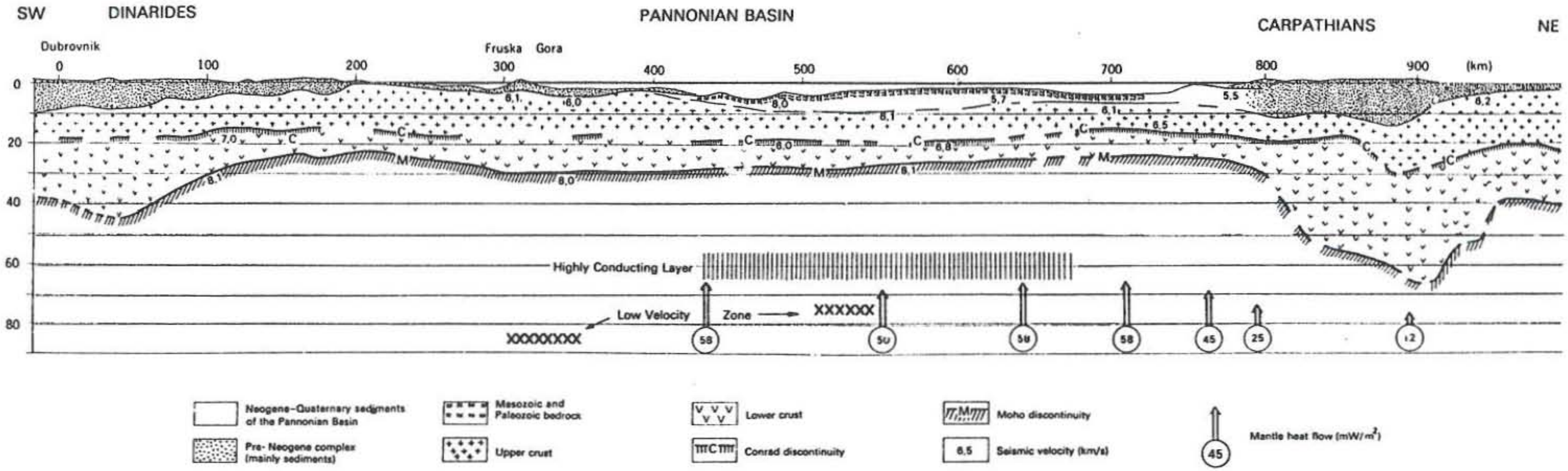

Figure 2. Crustal profile from the Carpathians to the Dinarides, with heat flow values calculated in mW/m^2 for the upper mantle (Buntebarth, 1976), with the position of the high conductivity layer (Ádám, 1976) and of the low velocity zone (Bisztricsány and Egyed, 1973). Geographical position of the profile see AA'A" in Figure 8.5. After Stegena et al. (1975)

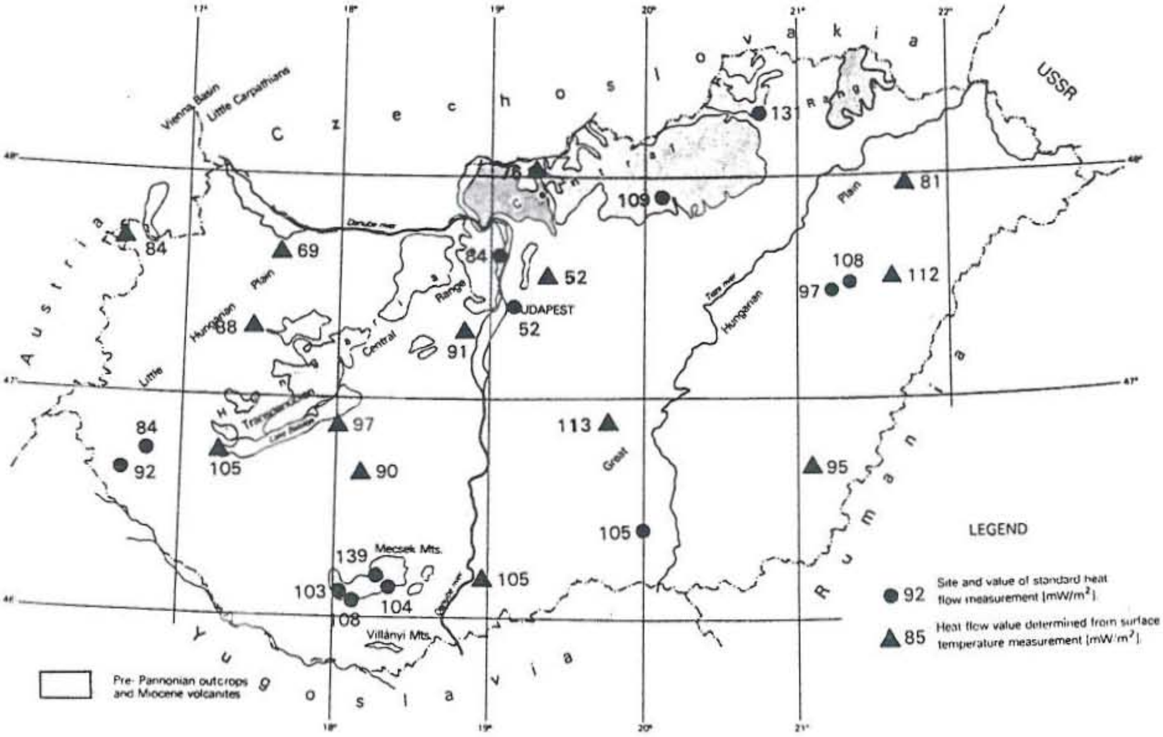

Figure 3. Heat flow data for Hungary, in units of mW/m^2

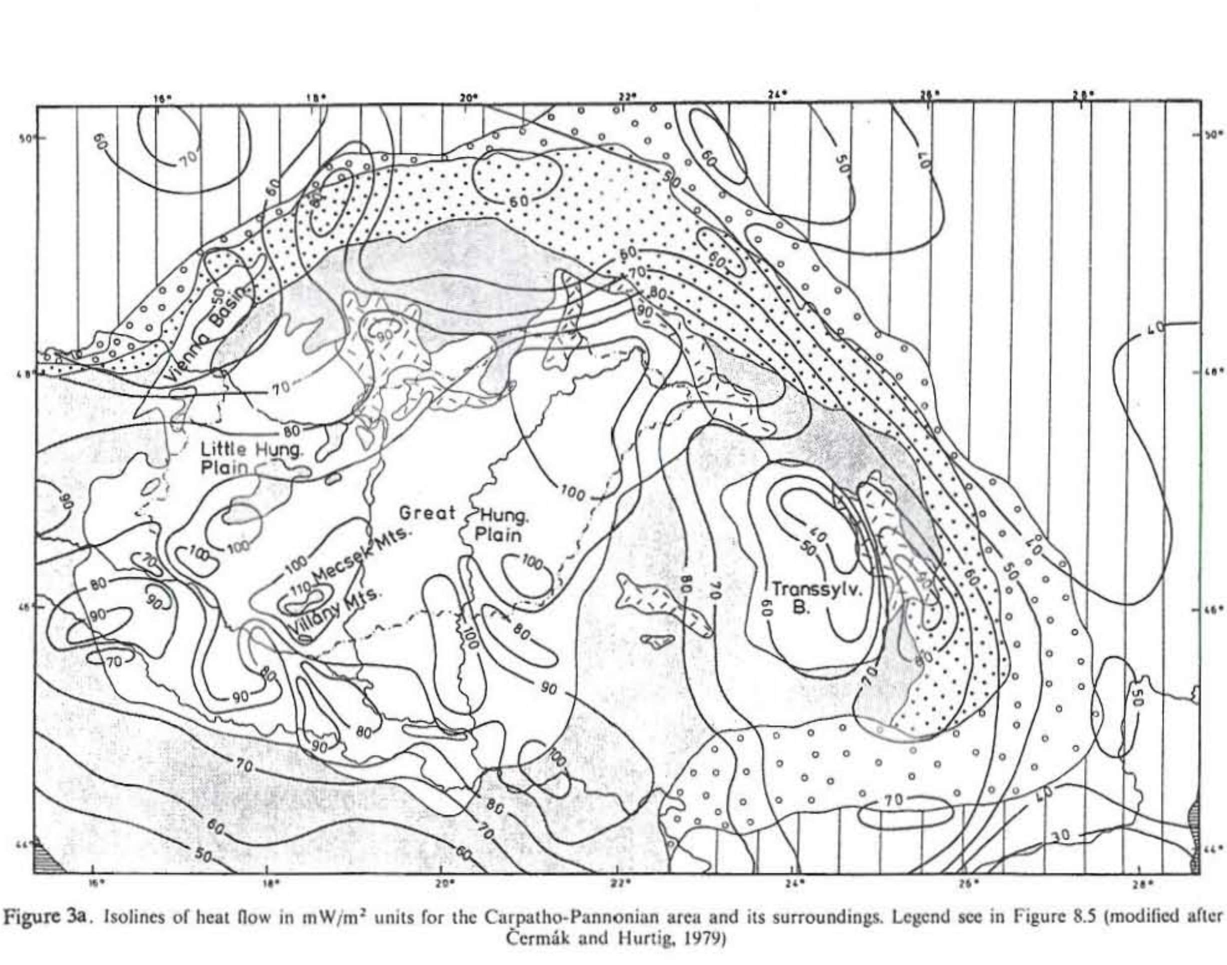

Figure 3a. Isolines of heat flow in mW/m^2 units for the Carpatho-Pannonian area and its surroundings. Legend see in Figure 8.5 (modified after Čermák and Hurtig, 1979)

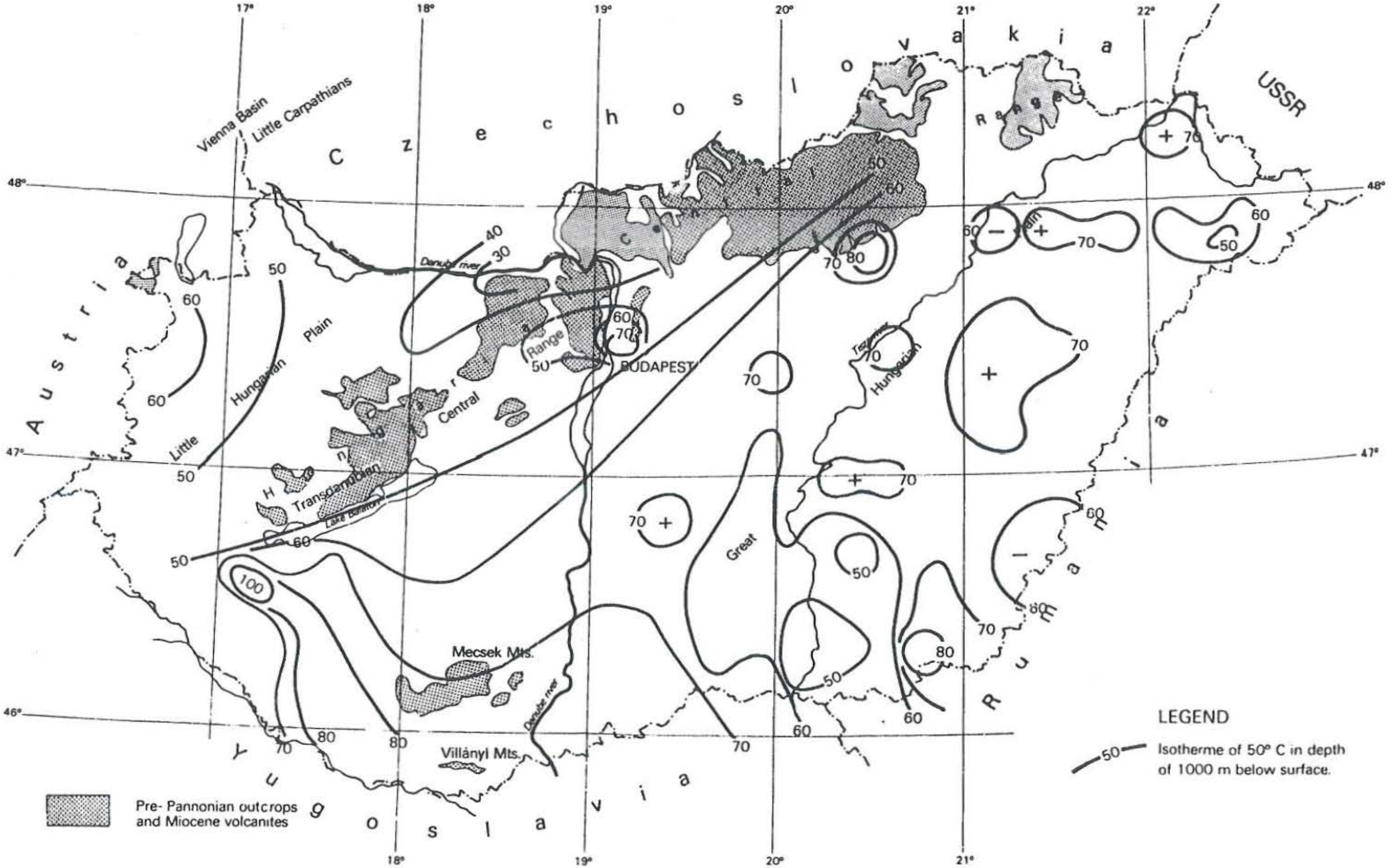

Figure 4. Geoisotherms for Hungary at 1000 m depth. Temperatures in °C

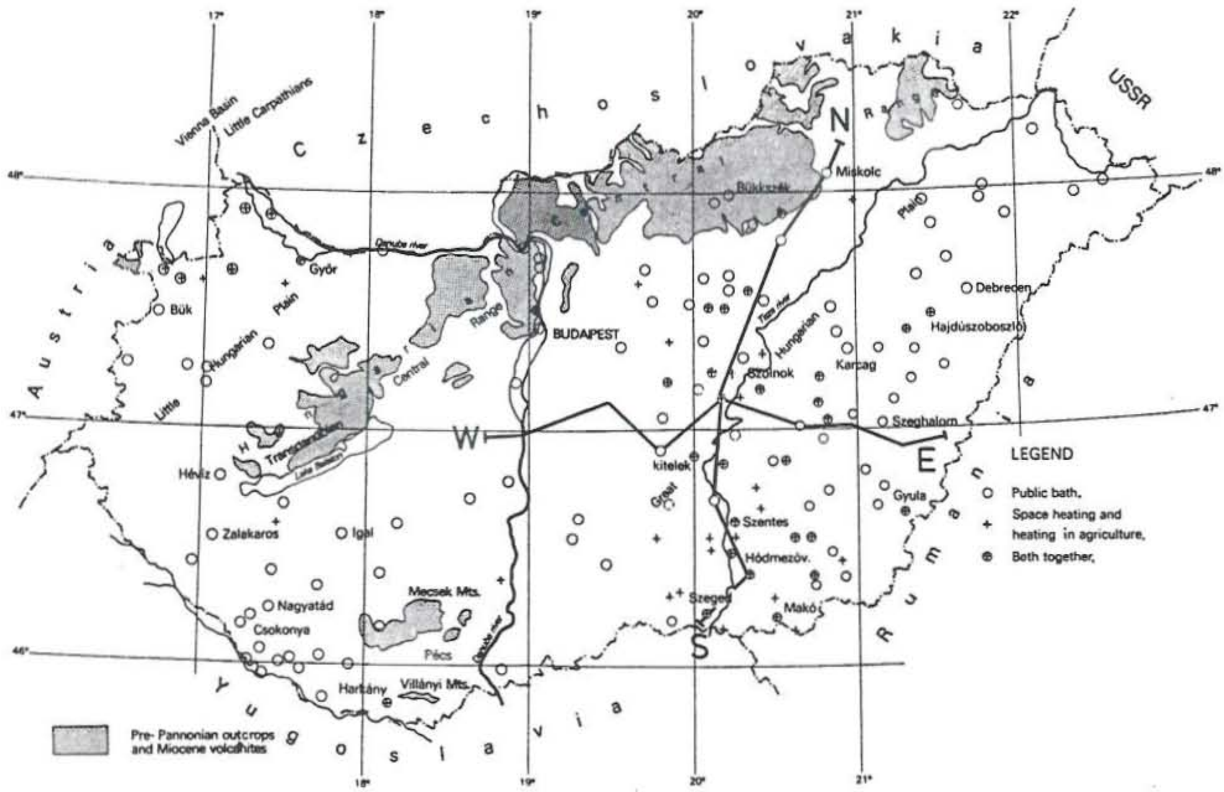

Figure 5. Sketch map showing the utilization of geothermal water in Hungary in 1977–78 (Korim, 1978)

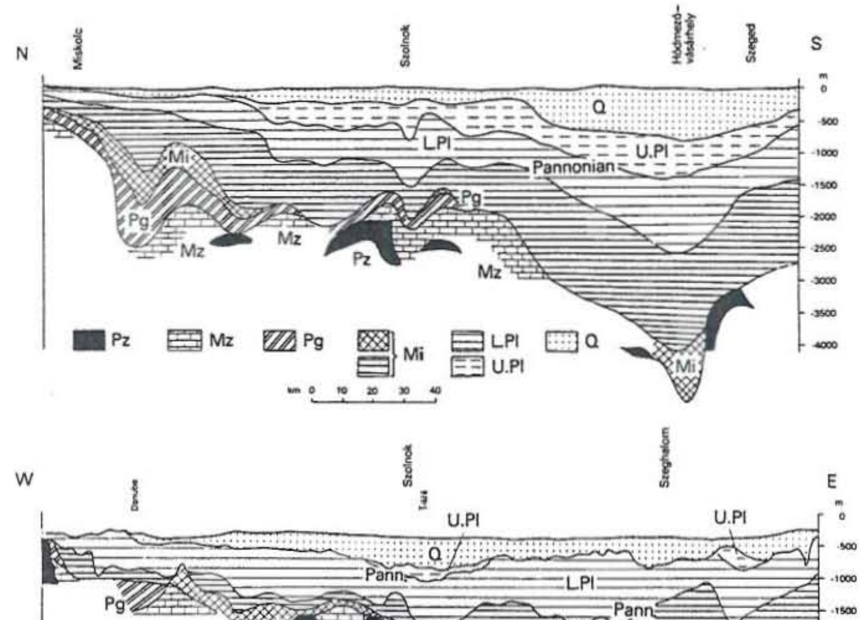

Figure 5a. Geological profiles of strike directions N–S and E–W across the Great Hungarian Plain (after Ronai, 1978). Geographical position of the profiles see in Figure 8.1. Pz: Paleozoic. Mz: Mesozoic. Pg: Paleogene. Mi: Miocene. Pl: Pliocene. Q: Quaternary

No. Hévizkat.szám	location Kút helye	opened intervall. Rétegnyitás (m-m)
5 - 75	Szentes, Árpád Tsz.2.	1640 - 1793
5 - 44	Szentes, Termál Tsz.	1829 - 2192
5 - 40	Szentes, Termál Tsz.	1850 - 1962
5 - 95	Mindszent, Lenin Tsz.	1800 - 1965
5 - 42	Hódmezővásárhely, Kerámiagyár	2112 - 2427
5 - 8	Makó, Strandfürdő	755 - 884
5 - 46	Makó, Kórház	1972 - 2060
5 - 43	Szeged, Felszabadulás MgTsz.	1602 - 1775
5 - 16	Szeged, Székelysor	1750 - 1866
5 - 17	Szeged, Haladás Tsz.	910 - 991
5 - 29	Szeged, Klinika	1727 - 1914
5 - 54	Szeged, Tiszasziget I.	1730 - 1920

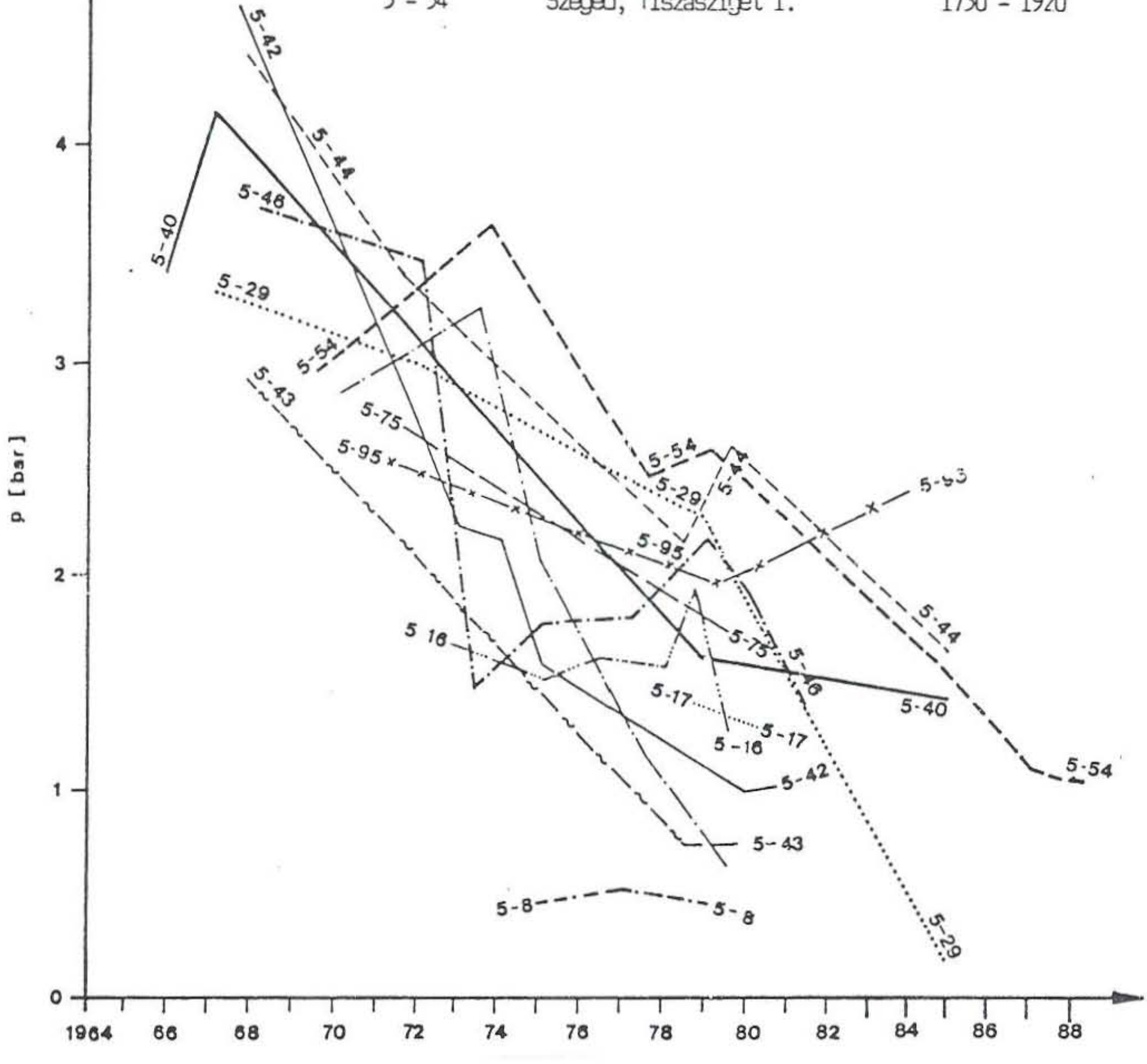

Figure 6. Decreasing of wellhead pressure on geothermal temperature of thermal wells on the S. Alföld

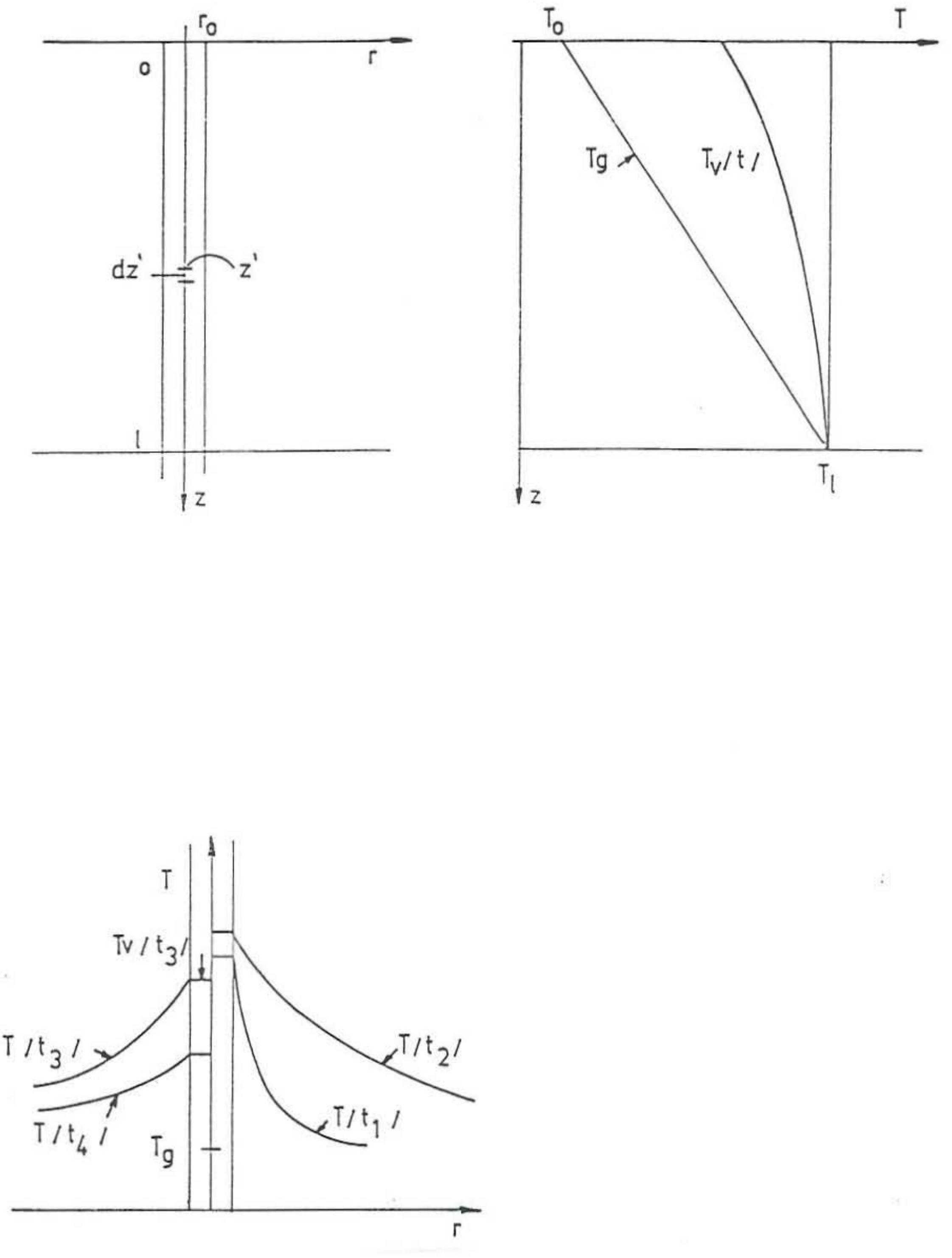

Figure 7. Physical model of heating on and cooling up of thermal water well

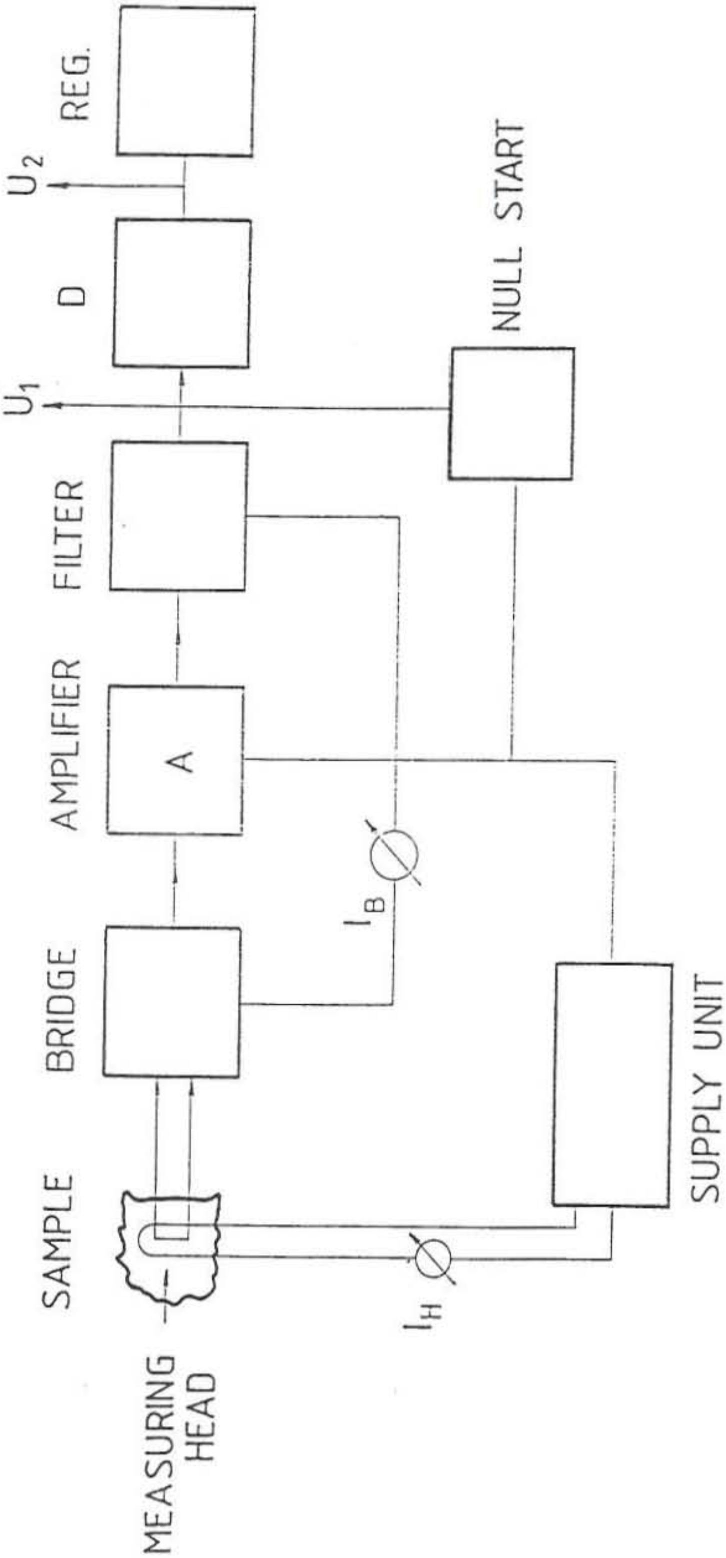

Figure 8. Scheme of heat conductivity measuring instrument

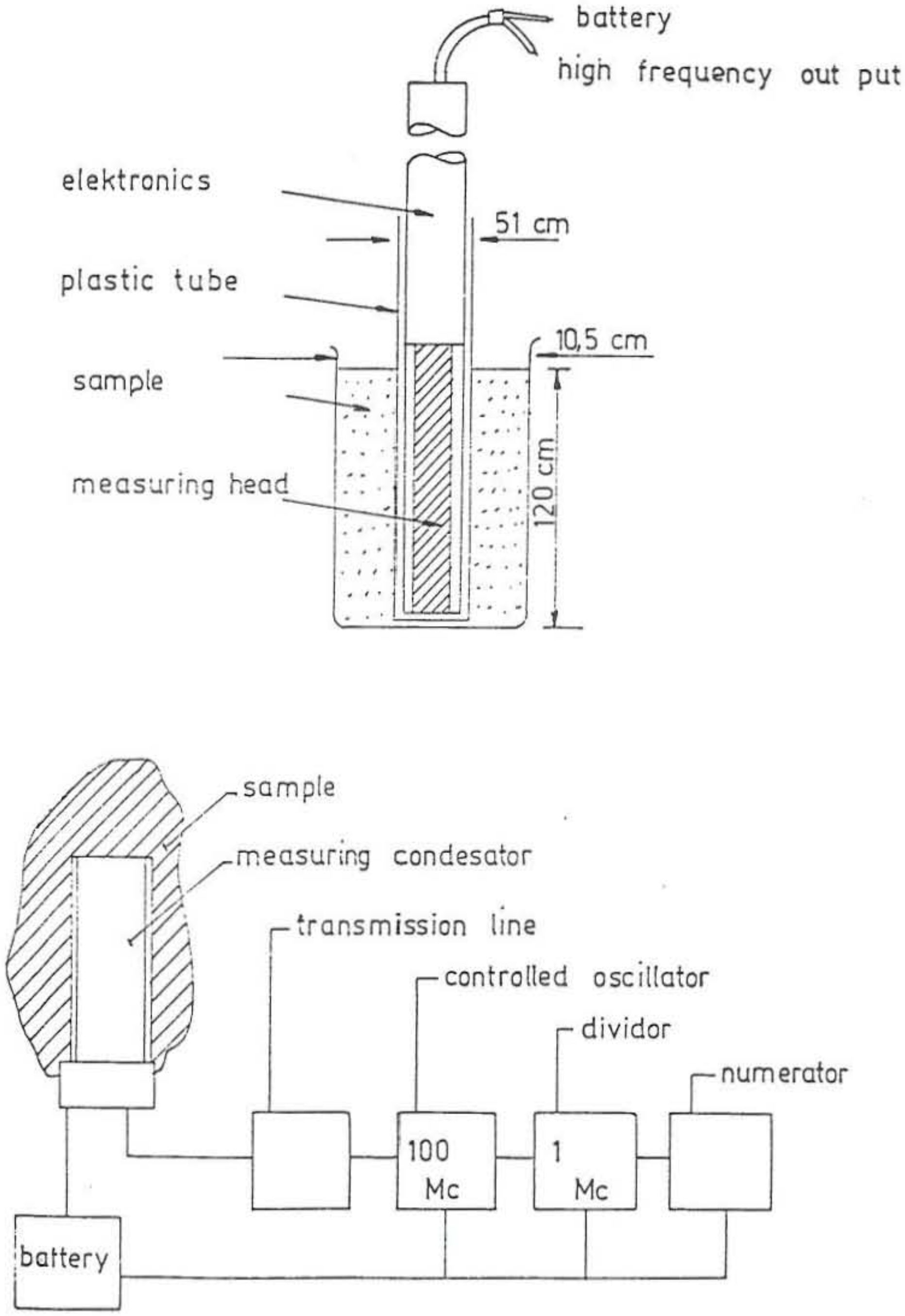

Figure 9. Scheme of permittivity measuring instrument

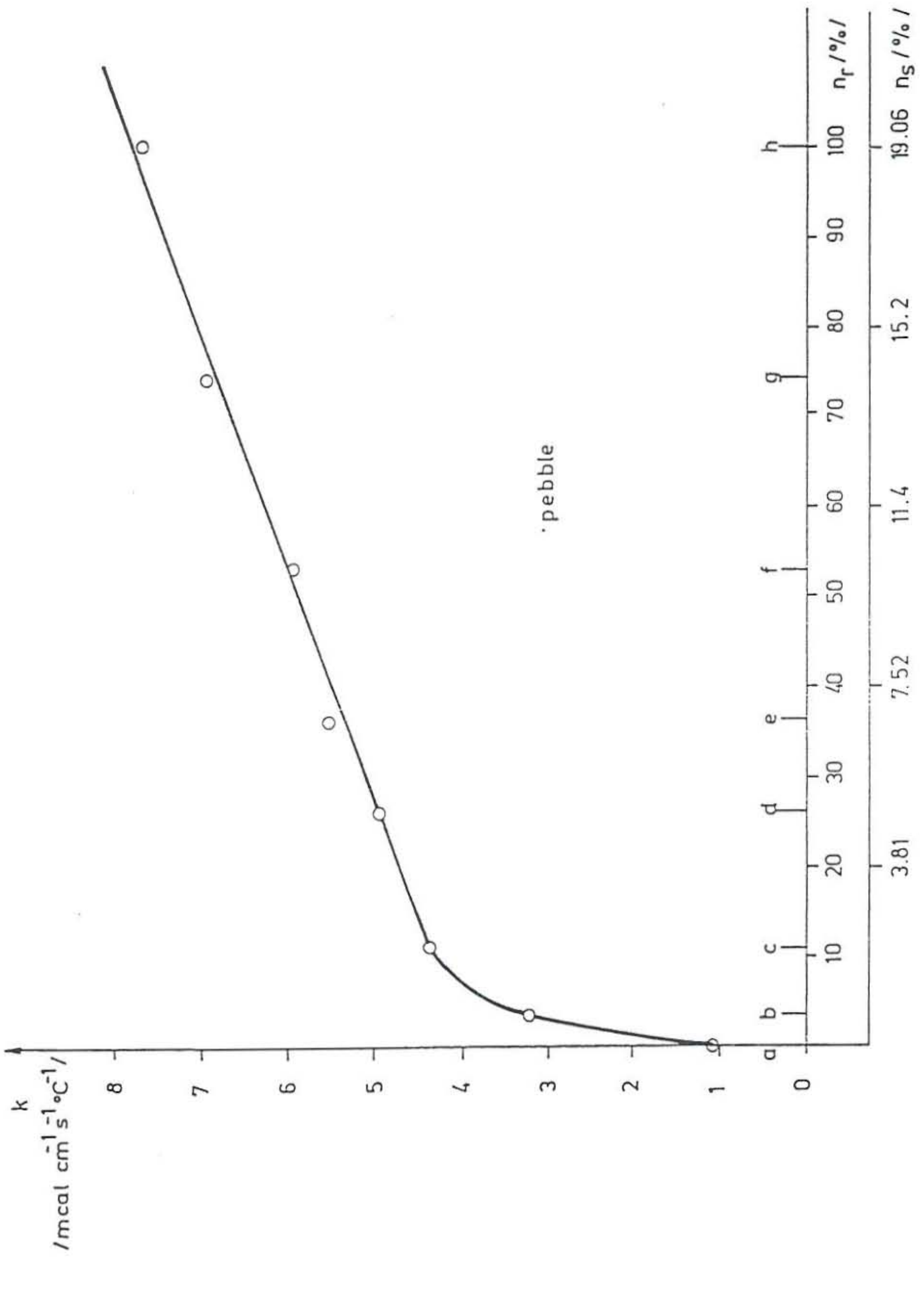

Figure 10. Relationship between heat conductivity and water saturation

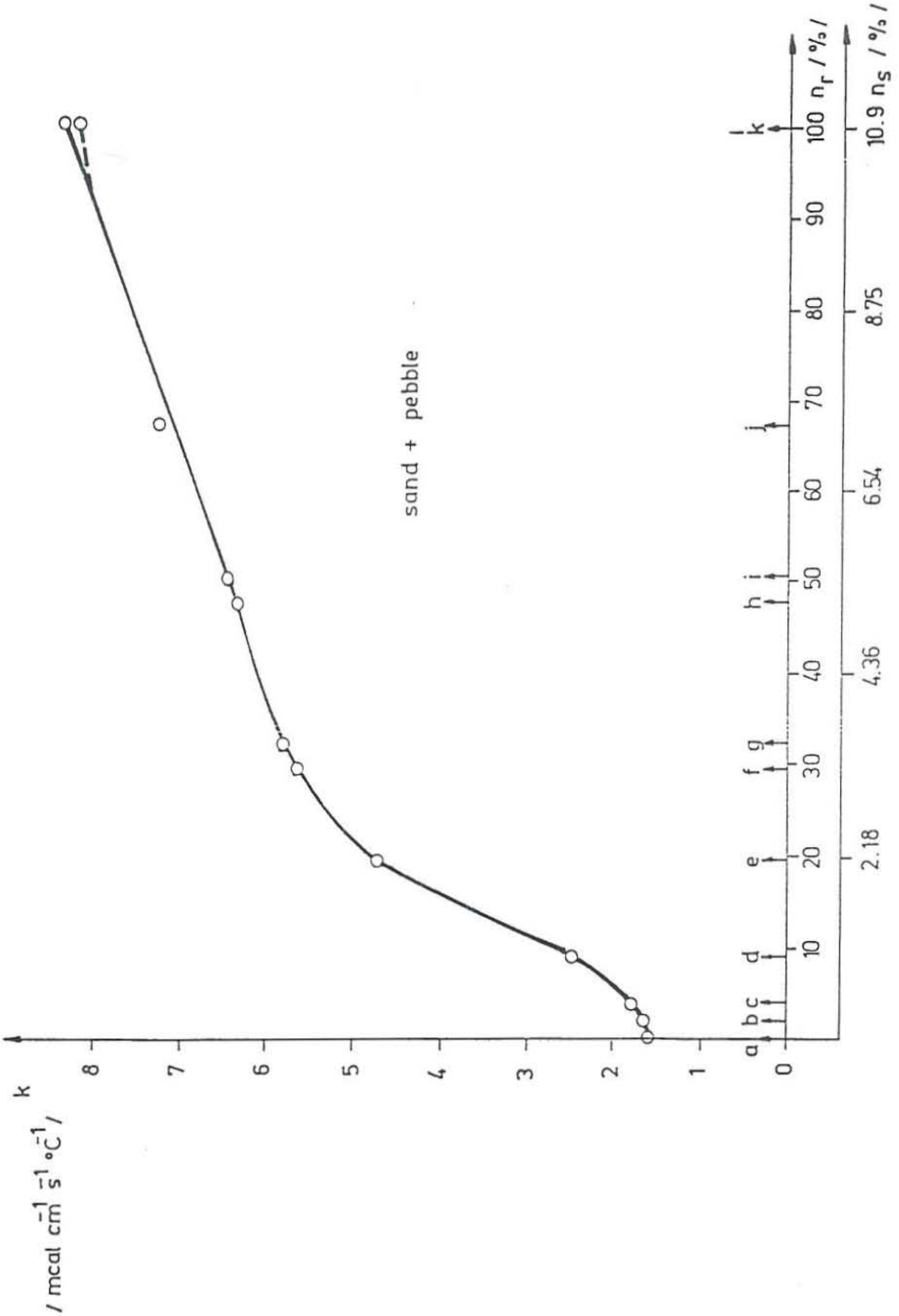

Figure 11. Relationship between heat conductivity and water saturation

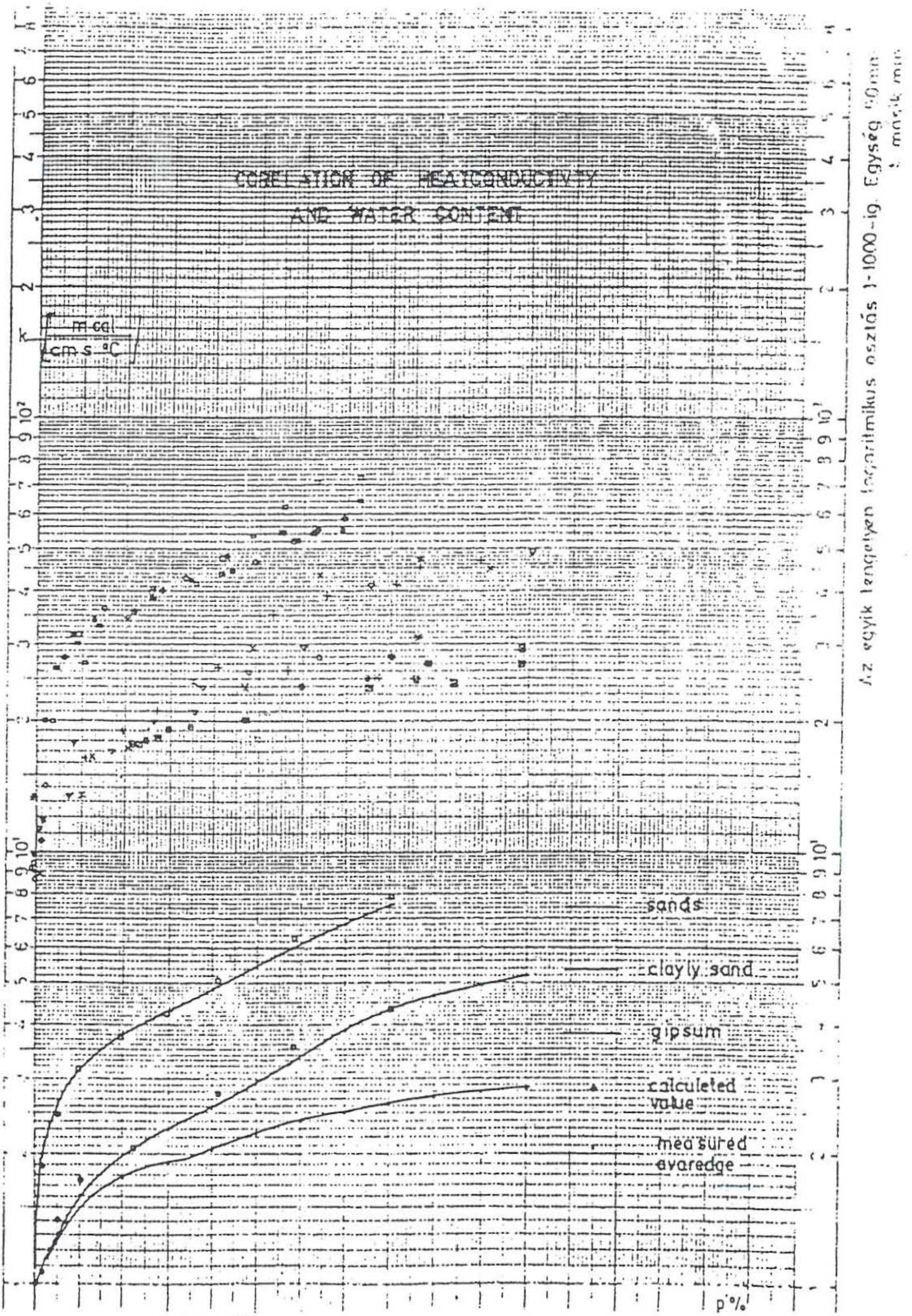
CORELATION OF HEATCONDUCTIVITY
AND WATER CONTENT
k [m cal / cm s °C]
sands
clayly sand
gipsum
calculeted value
measured avaredge
p %
Az egyik tengelyen logaritmikus osztás 1-1000-ig. Egység 50mm

Figure 12

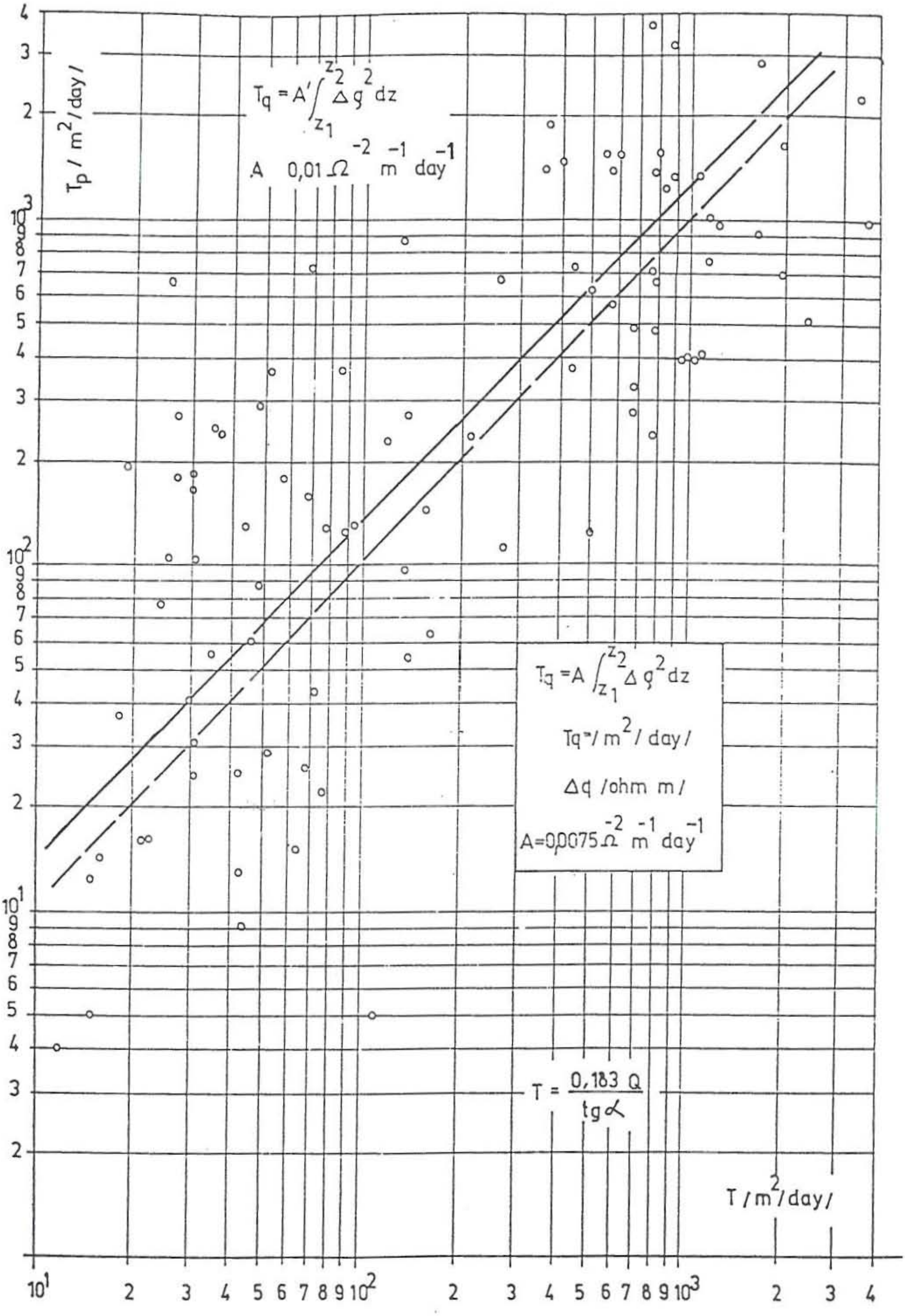

Figure 13 Draft of data of hydraulical transmissivity / T / calculated from pressure raising and resistivity loggings and gaind by geophysical measurements / Tq / for determining corelations

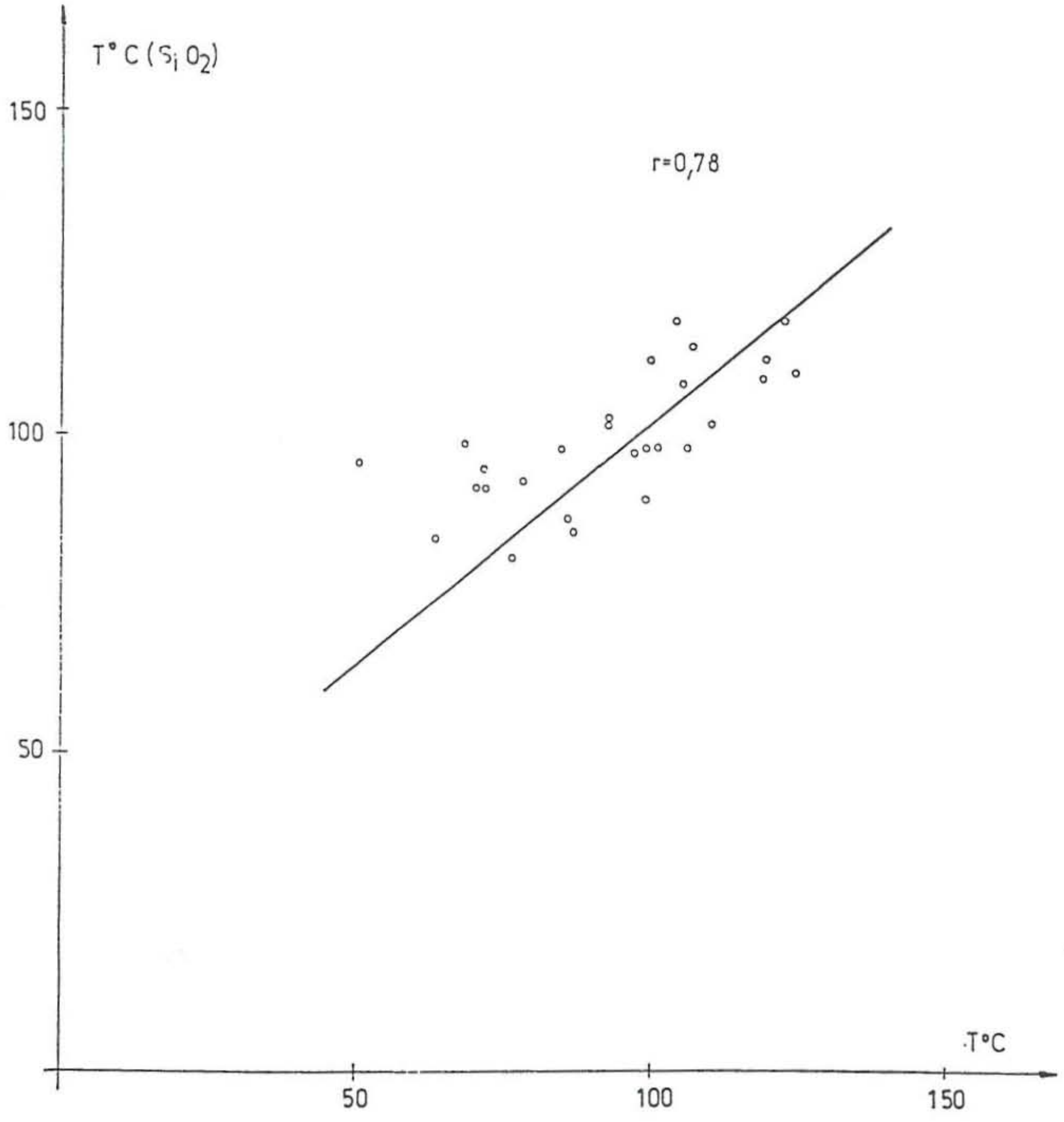

Figure 14 Correlation of temperatures measured by SiO thermo meter and the temperature data of aquifers.

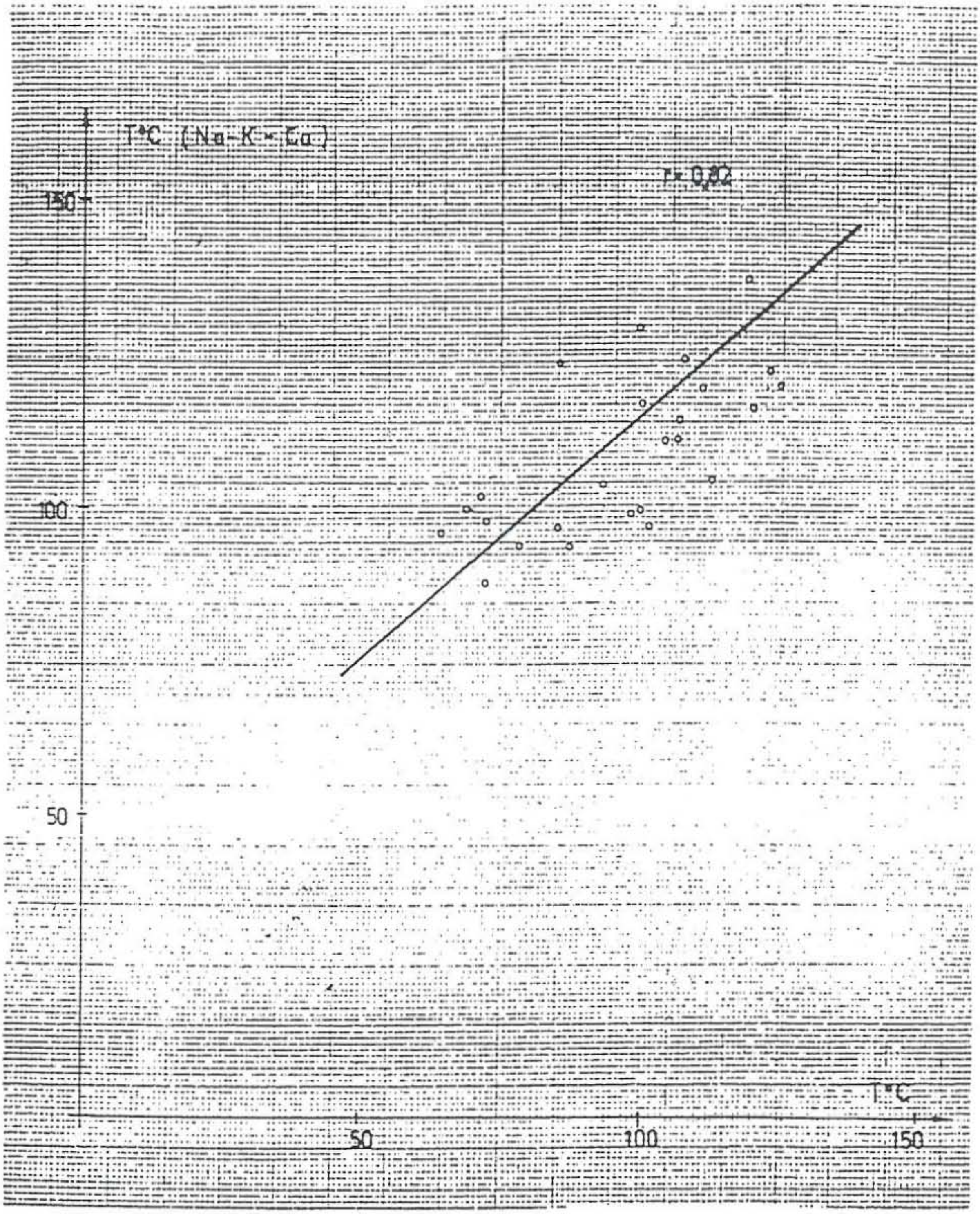

Figure 15 Correlation of temperatures measured by Na,K/Ca thermometer and the temperature data of aquifer

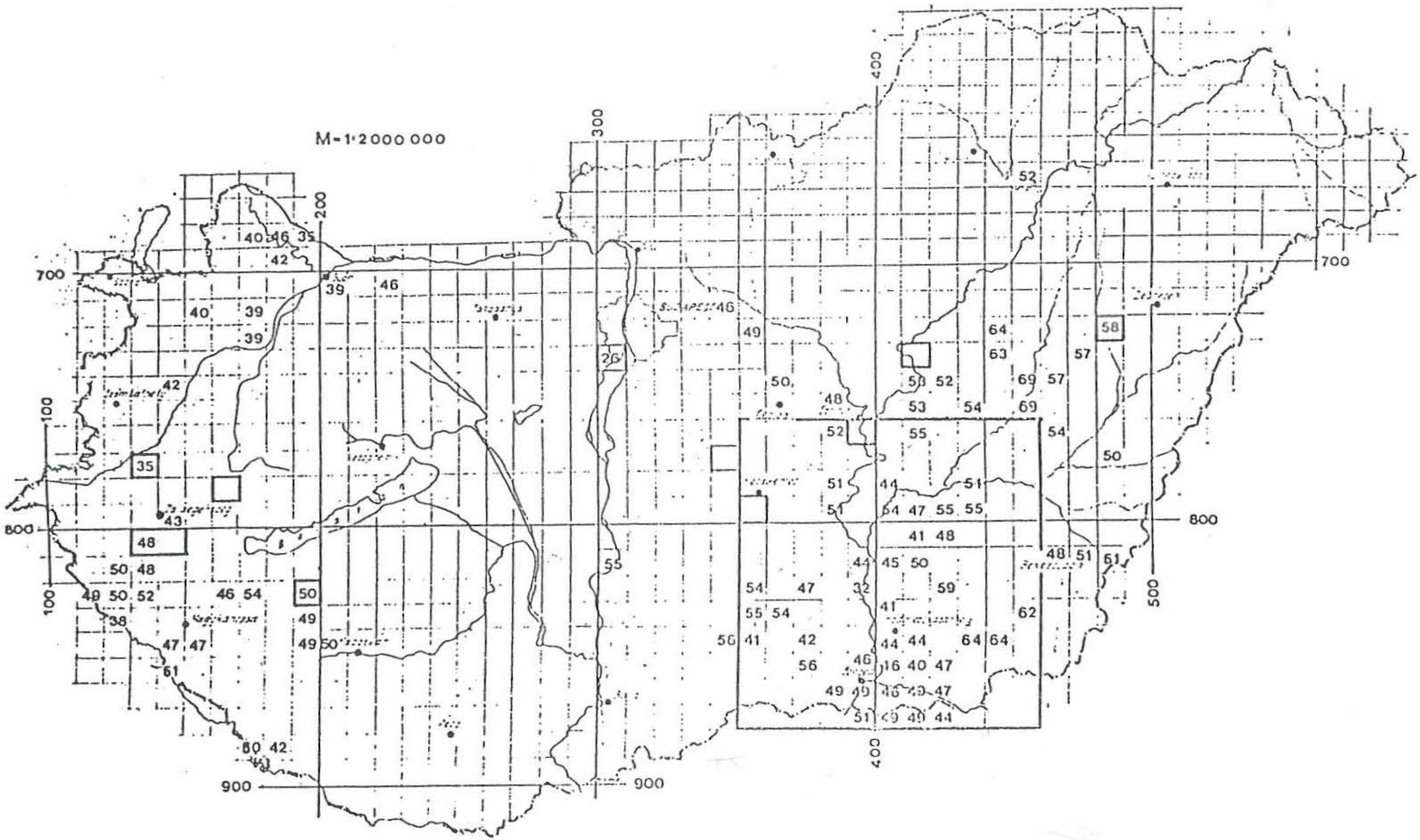

Figure 16 Geothermal gradient map of Hungary in depth interval 1750 – 2250 m

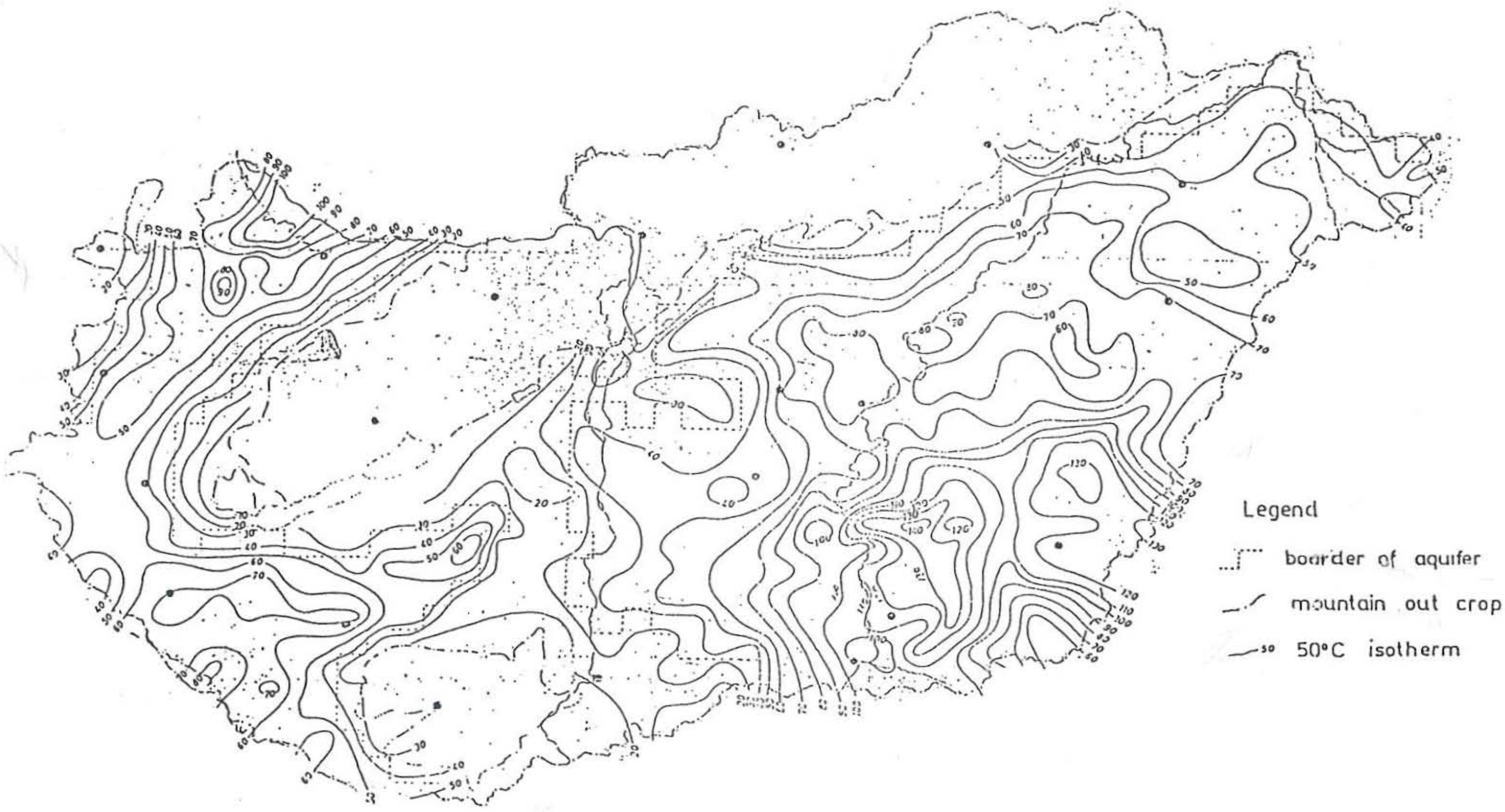

Figure 17. The max. temperature of the upper Pannonian aquifer

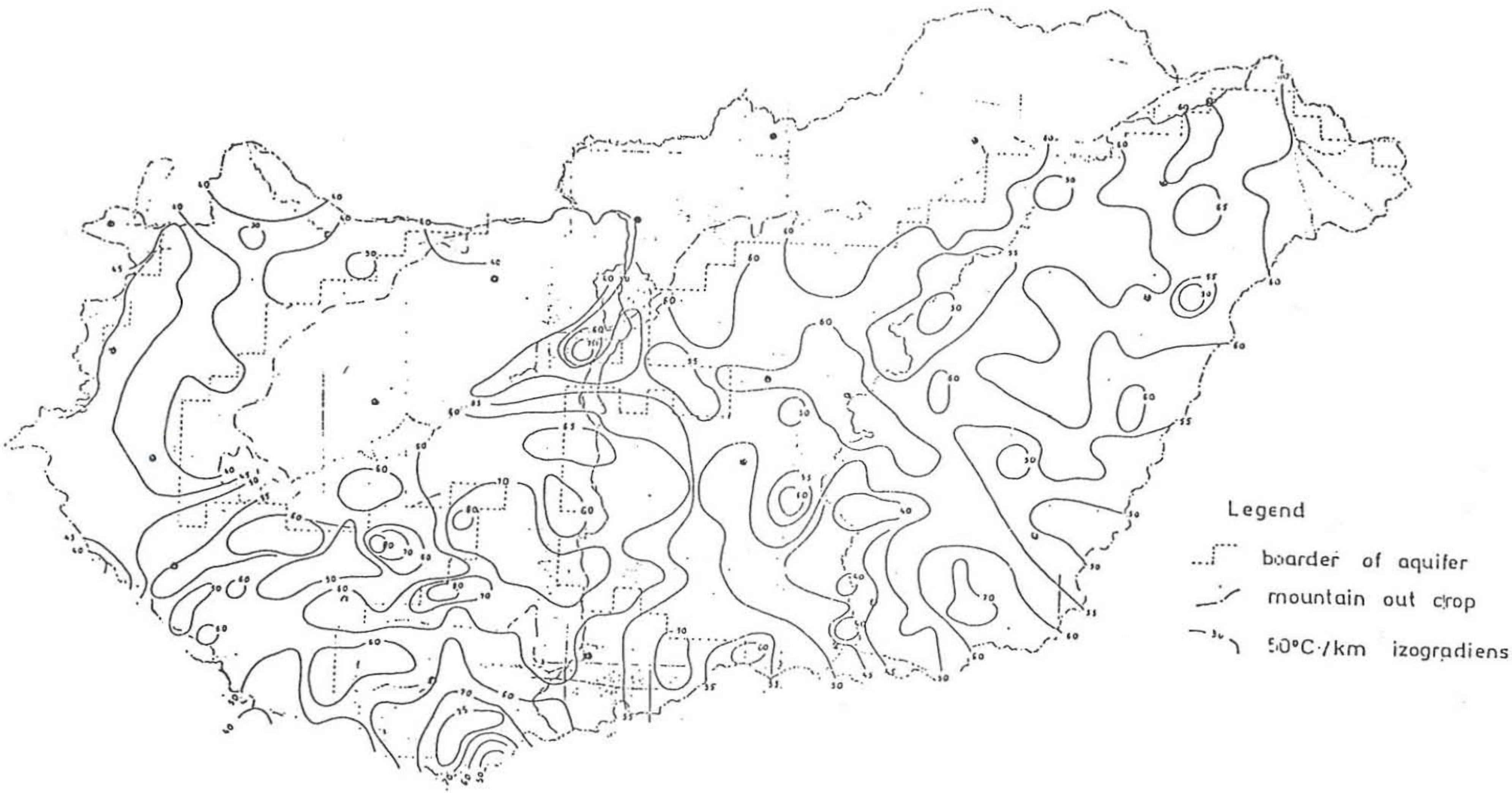

Figure 18. Regional geothermal gradient map concerning the aquifer

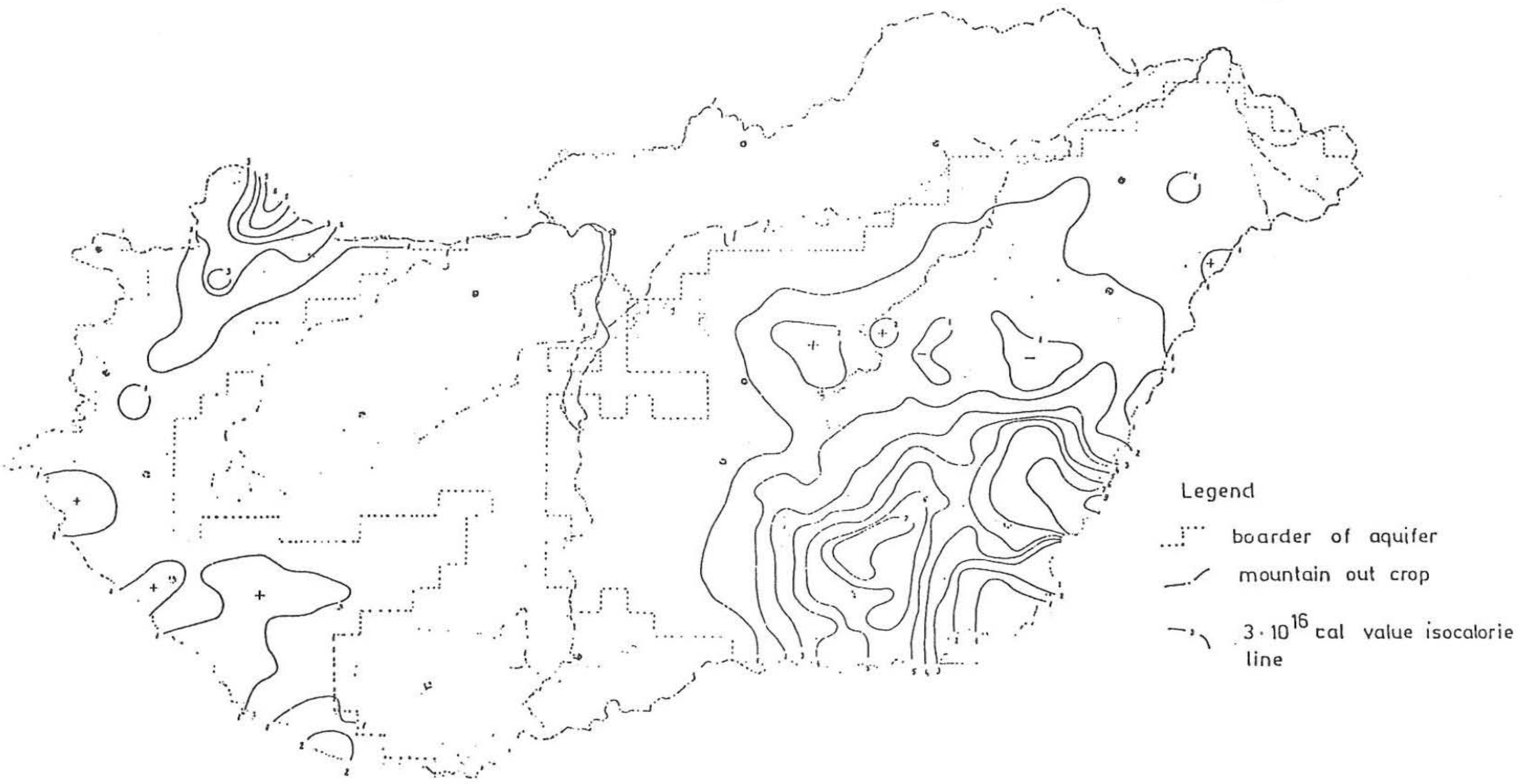

Figure 19. Map of thermalenergy distribution of aquifer

Thermalwater reserves of Pliocene sediments.
Exploited/Exploitable (by pumping 10^3 m^3/d)

Table 1.

Region	kif. viz hőmérséklet /°C/					
	5o-6o	6o-7o	7o-8o	8o-9o	9o-	Összesen
1. Kisalföld	o/38	1o/36	3/19	o/5	o/o	13/98
2. Lenti med.	o/5	o/2	o/o	o/o	o/o	o/7
3. Zala-Somogy	1/17	o/6	o/2	o/o	o/o	1/25
4. Drávavölgy	1/12	1/8	o/3	o/o	o/o	2/23
Dunántul	2/72	11/52	3/24	o/5	o/o	16/153
5. Szegedi ter.	12/28	8/24	6/12	12/15	7/12	45/91
6. Déltiszai süllyt.	12/92	7/7o	11/52	19/4o	26/3o	85/284
7. Délalföld	1/27	3/26	9/3o	7/2o	12/26	32/129
8. Békési sülly.	2/53	11/52	1/27	o/17	1/9	15/158
9. Jászság	22/88	12/73	o/24	o/o	o/o	34/185
1o. Középtiszai sülly, Nyirség	9/72	7/46	3/26	o/o	o/o	19/144
Alföld	46/36o	48/291	3o/171	38/92	46/77	2o8/991
	48/432	59/343	33/195	38/97	46/77	224/1144

Table 2.

Results of the information survey of thermal water resources of Hungary

Temp. of outflowing water °C	Aquifer Temperature °C	depth interval m-m	area 10^3 km^2	stored reserve 10^3 km^3	stored heat reserve 10^{15} KJ	present production 10^3 m^3/d	heat effect MW	Producted till now: total	Producted till now: from stored reserves
30 - 40	35 - 48	400 - 650	70	0,7	92	200	303	1,0	0,3
- 50	- 60	- 900	50	0,5	92	85	170	0,4	0,2
- 60	- 73	-1200	40	0,5	117	60	162	0,3	0,2
- 70	- 85	-1500	30	0,3	86	55	182	0,3	0,1
- 80	- 98	-1800	25	0,2	68	35	138	0,2	0,1
- 90	-110	-2100	20	0,2	78	35	158	0,2	0,2
-100	-123	-2400	15	0,1	40	30	138	0,2	0,2
				2,5	573	500	1250	2,6	1,3

Utilization of geothermal energy (datafrom Water Authority)

Table 3.

Utilization	1975.	1980.	1984.	1985.	Capacity m^3/h
		pc			1985.
Balneology	221	240	262	277	231,13
Drink water	351	416	386	236	186,14
Agri cult. heating	81	97	160	258	255,23
Flatheating+warm water	20	20	19	14	21,19
Industrial	15	21	64	70	61,94
Other	21	46	94	128	68,25
Closed	84	58	44	33	19,21
Summary	793	898	1029	1016	843,1