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HEAT FLOW IN THE BOSS DEPOSIT OF MISSOURI

BY

DON STAINBROOK

A

THESIS

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Approved by

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James J Scott

ABSTRACT

Values of heat flow through a Precambrian mineral deposit were determined in the Boss area of Missouri, where 350 meters of Paleozoic sedimentary rocks overlie a complex series of rhyolite flows which have been altered and contain a copper bearing magnetite deposit. Geothermal data were obtained from a closely spaced grid of 17 diamond drill holes penetrating to depths of 1000 meters below ground surface. Temperature measurements were made at 5 meter intervals in the Precambrian section of all holes. These and thermal conductivity measurements made on representative core samples from 300 to 400 meters below the top of the Precambrian gave a regional heat flow of 1.3 microcalories/cm^{2}sec. Core from one hole was sampled at approximately 5 meter intervals from 350 to 1000 meters. Comparison of the regional flux with the vertical components of heat flow in the deeper portions of the intensively sampled hole indicated the presence of a low conductivity zone with a flux 25 percent below the regional and a high conductivity zone with a flux 10 percent above the regional. The calculated attitudes of these zones led to an interpretation of the geologic structure that, previously, had not been considered. The low conductivity corresponds to a tabular zone of prophyllitic alteration dipping 72 degrees, and the high conductivity corresponds to a granite dike dipping 50 degrees.

TABLE OF CONTENTS

LIST OF ILLUSTRATIONS

Figures

Tables

INTRODUCTION

The thermal state of the earth is a postulate to many basic geologic hypotheses. Accumulation of geothermal data has taken place slowly because of the difficulty in measuring temperature gradients and thermal conductivities. The approximately 2000 individual heat flow observations collected world-wide through 1964 present only a hint of the global picture. It is the purpose of this study to present additional data in order that a more complete understanding might be realized; and specifically to investigate the geothermal properties relative to a specific mineral deposit. The deposit, although selected partially for convenience, was particularly amenable to this survey because of the concentration of many drill holes in a relatively small area and their great depth of penetration.

ACKNOWLEDGEMENTS

I gratefully acknowledge the assistance of Dr. Robert Roy, director of the Harvard Heat Flow Project. It was through association with him that my interest in geophysics was stimulated, and the opportunity for this study was provided. Equipment for the measurement of bore hole temperatures was furnished from the research facilities of Hoffman Laboratory, Harvard University, by Dr. Roy.

My special appreciation goes to Dr. Paul D. Proctor, Dean of the School of Science, University of Missouri at Rolla, for recommending the specific study area and for his substantial assistance in obtaining financial support and permission for access to private information and property. My thanks to Dr. James Maxwell who introduced the writer to Dr. Roy, and for his sincere criticisms and patience as thesis advisor.

A debt of gratitude goes to the American Zinc, Lead, and Smelting Company for allowing access to their drill logs and holes; and providing a truck, office space, and financial assistance. The V. H. McNutt Memorial Fund of the University of Missouri at Rolla provided additional financial support.

LOCATION AND DESCRIPTION

The mineral deposit studied is located near the town of Boss on the Iron-Dent County line in southeast Missouri. Figure 1 shows the location of the study area and of additional heat flow determinations from Missouri. Figure 2 shows the arrangement of drill holes in the Boss area. Areal geology consists of 1200 feet of Paleozoic sedimentary rocks overlying a complex series of Precambrian rhyolite flows which have been altered and contain a copper-bearing magnetite deposit. Drilling interest was aroused by a large double-domed aeromagnetic anomaly. Little is known about the Precambrian geology as most previous exploration endeavors have been in search of lead deposits in the Paleozoic rocks. Because of the competitive nature of exploration in this area, geologic logs which were studied by the investigator can be described only in brief outlines.

The drill holes range in depth from 740 to 1200 meters. All depths, unless otherwise specified, are measured in meters below the top of the collar. Casing in the holes was set through the sedimentary rocks to the top of the Precambrian rock surface. All holes are water filled and the static water level averages about 40 meters below the ground surface.

Intermittent uplift of this area during Paleozoic time and subsequent erosion has produced a plateau highly dissected by streams. Relief of the area is about 60 meters. Surface elevations range from 355 to 375 meters above sea level.

FIGURE 1. Missouri heat flow determinations in $\mu cal/cm^2 sec$

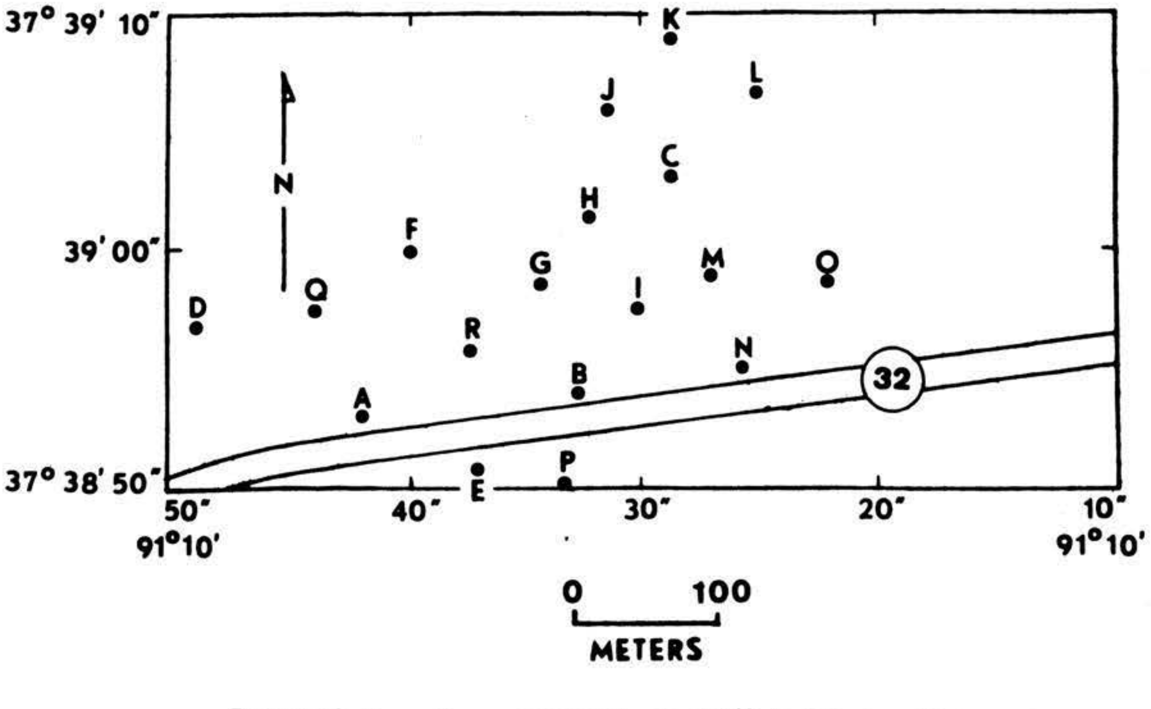


FIGURE 2. Arrangement of drill holes in Boss area Southeast Missouri

THEORY OF TERRESTRIAL HEAT FLOW

To determine the terrestrial heat flow in any area the temperature gradient $\frac{\partial T}{\partial Z}$ and the thermal conductivity K of the rocks in that area must be measured. The heat flow Q, which is the heat flow towards the earth's surface, is $K\left(\frac{\partial T}{\partial Z}\right)$, where the Z axis is taken as vertically downward. The geothermal gradient $\frac{\partial T}{\partial Z}$ is the rate of increase of temperature with depth.

In an ideal uniform medium, two measurements of temperature and a measurement of conductivity would suffice to determine Q. In practice there are many effects which affect underground temperatures and which have to be allowed for in determining Q. The temperature distribution at depth reflects the calculated heat flow. The amount depends on whether the temperature measurement is free from the flow of mass such as circulating water, whether the measurement is free of transient disturbances, and whether the thermal conductivity of the rocks is homogeneous. Irregularities in the heat flow can result from the geologic history of the area: uplift, erosion, glaciation, oxidation or reduction, or from irregular topography. The area of this investigation is assumed to have a nearly constant temperature gradient over a long period of time and to be in a steady-state thermal condition with the deeper portion of the crust.

For reduction of observations in drill holes, a linear steady-state equation in one dimension is used.

$$Q = K\left(\frac{\partial T}{\partial Z}\right) \tag{1}$$

The quantity of energy flowing across a unit surface area normal to Z in a unit of time is Q. $\frac{\partial T}{\partial Z}$ is the temperature gradient taken in the Z direction and K the thermal conductivity of material representative of the interval ΔZ.

FIELD AND LABORATORY PROCEDURE

Temperature Measurement

Temperatures were determined using a portable Wheatstone bridge. The temperature sensing elements were thermistors encased in a pressure proof aluminum probe. The probe and the cable used for lowering it into the bore hole were connected in the unknown branch of the Wheatstone bridge electrical circuit. A modification of the bridge allowed the use of a 3-conductor cable for lead wire compensation. A reversing switch was used with a 1.5 volt power supply to eliminate thermally induced voltages. Bridge null was detected with a battery operated vacuum tube voltmeter. About 3 minutes equilibration time was required for the probe to reach the temperature of its surroundings.

Measurements were always taken as the probe was lowered into the drill holes in order to avoid errors caused by convection cells within the water. The probe was allowed to partially equilibrate at a point a few meters above the depth where a temperature measurement was to be taken and then lowered into position and another 2 minutes allowed for thermal equilibrium. Insulation resistance of the cable was checked daily.

In the first part of this investigation 5 holes were measured from a depth of 100 to 740 meters, at 10 meter intervals. For reasons to be explained later, measurements obtained to a depth of 400 meters were not considered for heat flow determinations. Later seven additional holes were measured from 400 to 740 meters in 5 meter increments. Near the end of the investigation, a longer cable enabled temperatures in 3 holes to be measured at 5 meter intervals down to an 1100 meter depth. Data were collected from a total of 17 holes.

Two holes were re-measured with another probe as a calibration check. Differences between temperatures measured at the same depth varied as much as 0.1°C but the gradients remained the same. One hole was re-measured with the same probe to check on the drift of the thermisters. Drift was less than 0.02°C.

Figure 3 shows a simplified schematic of the apparatus used for measurement of bore hole temperatures.

Thermal Conductivity

Thermal conductivity of core samples was measured by a transient method using an apparatus described by Birch (1950) and modified by Roy (1963). Measurements were made at the facilities of Hoffman Laboratory, Harvard University. The sketch in figure 4 shows the basic components of the apparatus.

Samples of representative rocks were selected from core obtained from each hole from 200 to 300 meters below sea level. The complexity of the geology dictated the number of samples collected from each interval. Six to 12 specimens were considered adequate. From one hole 130 specimens were selected to represent the Precambrian from 400 to 1100 meters in depth.

Much of the core had been split for purposes of chemical analysis. Where circular pieces were available, they were selected. Conductivity discs were then sawed from these samples and their surfaces ground flat

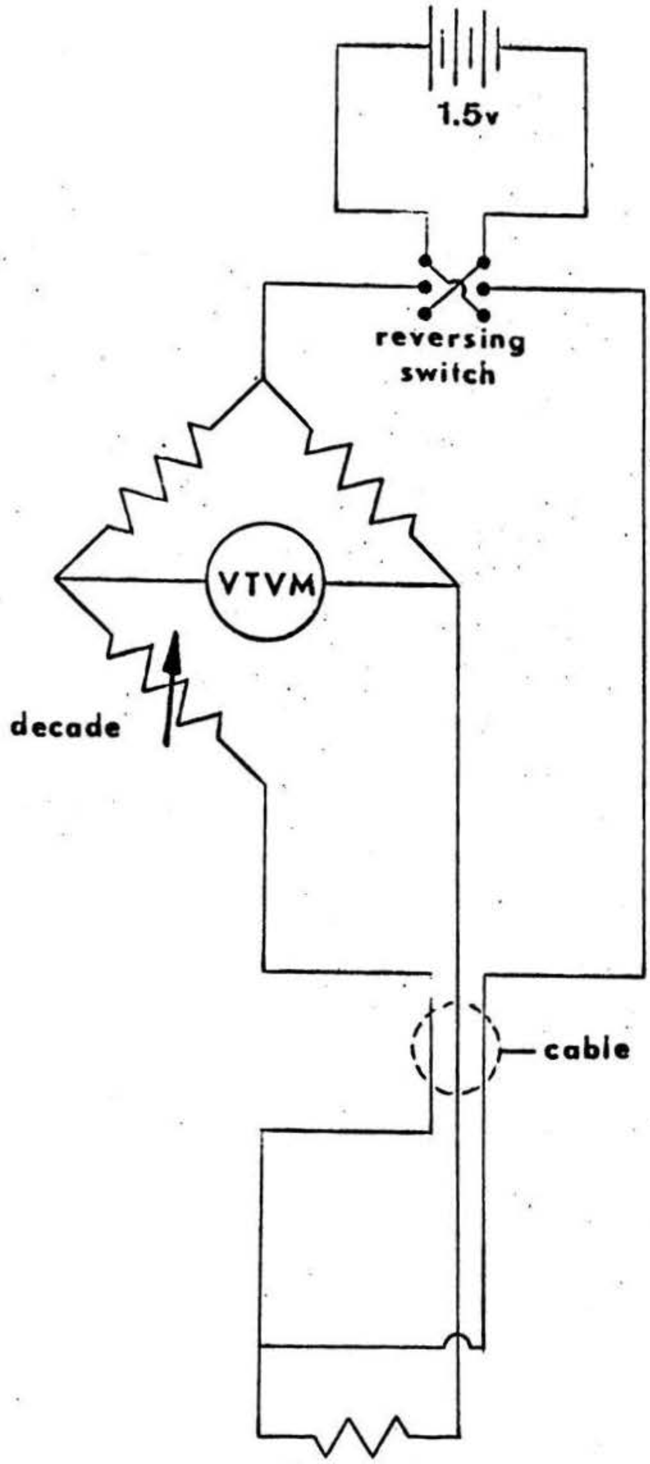


FIGURE 3. Sketch of bridge used for measurement of bore hole temperatures

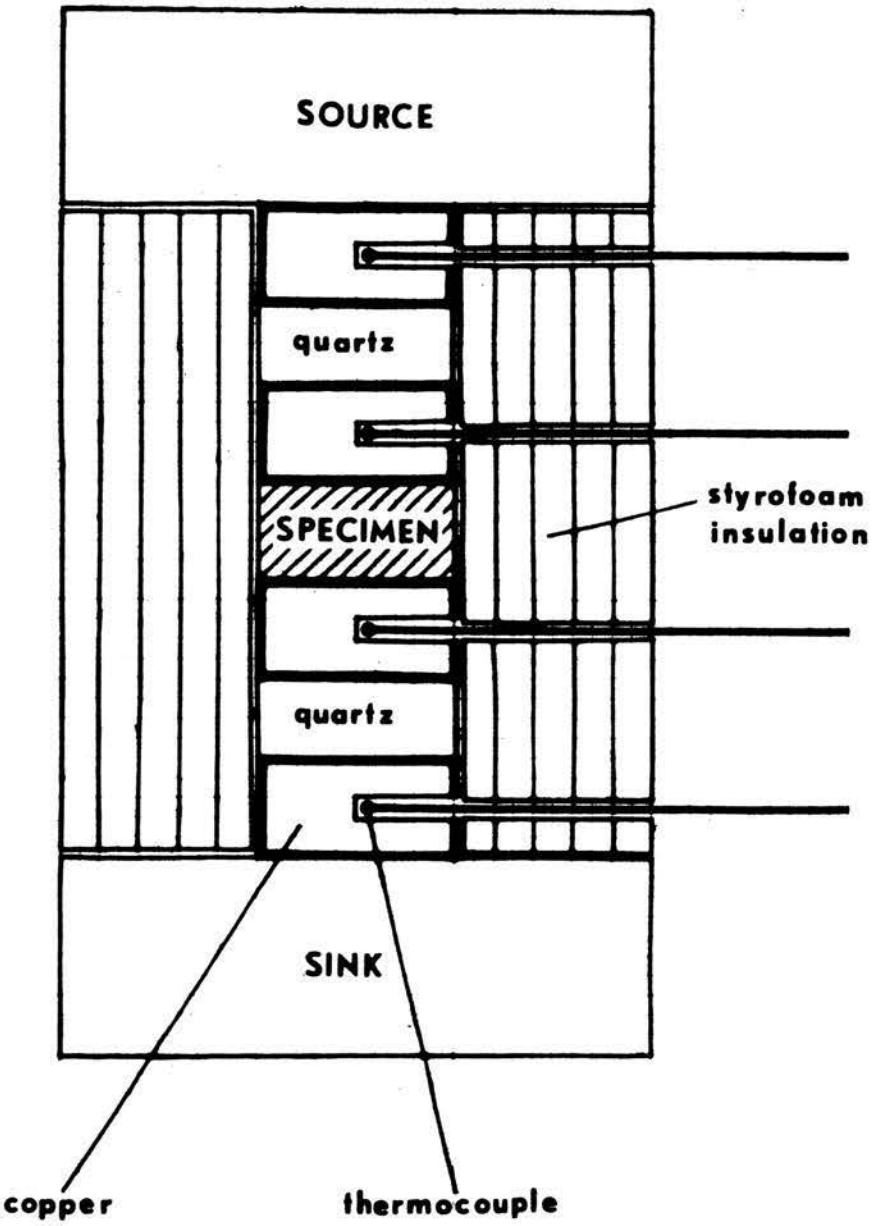


FIGURE 4. Sketch of apparatus for measurement of thermal conductivity

and parallel to ± 0.001 in. tolerance. Thicknesses were either 0.250 or 0.375 in. and the diameters were about 1.18 inches. When it was necessary to sample split core, discs were ground to 0.875 in. diameters and 0.250 or 0.375 in. thicknesses while maintaining the ± 0.001 in. tolerance. In a few instances, it was found necessary to epoxy two halves of core together.

Conductivities were measured relative to those of quartz and silica glass as determined by Ratcliffe (1959).

Thermal conductivity is dependent upon temperature, pressure, moisture content, and rock type. The experimentally determined relationship between conductivity and these factors will be refered to as temperature, pressure, and saturation coefficients.

Conductivities were measured at temperatures of 13°C to 14°C which is 4°C to 11°C lower than the in-place temperatures. No correction was made for temperature coefficient. Specimens were measured in a dry condition. Each was run with axial pressures of 100 and 200 bars. A mean pressure coefficient of 0.8%/100 bars was found. Conductivities calculated under 200 bars of pressure are within the limits of reproducibility of those same conductivities which would be calculated under their appropriate lithostatic pressure. Therefore, conductivities determined at 200 bars of pressure were used for all heat flow calculations. Seven specimens were re-measured a second and third time. Reproducibility was always less than or equal to 2.00 percent. Seventeen samples were saturated with water and re-measured. The saturation coefficient was found to be less than or equal to 1.5 percent. Discs were coated with a film of petroleum jelly to assure uniform contact with the reference discs. The application of axial pressure to the ends of the discs and the control of the machining of the surfaces aided in the elimination of thermal contact resistance.

CALCULATION OF HEAT FLOW

A mean gradient and conductivity were determined in each hole from 200 to 300 meters below sea level. The product of the gradient and conductivity, as shown in equation (1), determined the value of heat flow in each hole. The mean of the values found in 13 holes was taken as a value for the area.

Roy (1963) uses an alternative method of calculating the heat flux in a single hole. Integrating equation (1) gives

$$Q = \left(T_2 - T_1\right) \Big/ \int_{Z_1}^{Z_2} \frac{dZ}{K} \qquad (2)$$

where T_1 and T_2 are the temperatures at the depths Z_1 and Z_2. The integral in (2) may be approximated by

$$\int_{Z_1}^{Z_2} \frac{dZ}{K} \approx \sum_{i=1}^{n} \frac{Z_i}{K_i} \qquad (3)$$

where K_i is the conductivity representative of the interval Z_i. Substituting (3) into equation (2) and re-arranging gives

$$Q = \left(\frac{T_2 - T_1}{Z_2 - Z_1}\right)\left(\frac{Z_2 - Z_1}{\sum_{i=1}^{n} \frac{Z_i}{K_i}}\right) \qquad (4)$$

The first term is a mean temperature gradient over an interval and the second is an average conductivity for the same interval.

This alternative method shows any variations of heat flow with depth. Heat flow in one hole was determined using this method. The heat flow so determined was compared with the average heat flow for the area. Significant variations are explained in the results.

Metric units are used for all calculations in this paper. Temperature gradients were measured in °C/kilometer, thermal conductivity in millicalories/cm.sec°C, and heat flow in microcalories/cm^2sec.

POSSIBLE ERROR IN MEASUREMENT AND ANALYSIS

Error may occur in measurement of both temperature and conductivity. The error term following each heat flow value in this paper is the sum of all anticipated errors in the measurement of temperature and conductivity accumulating unfavorably.

The low relief of the topography and the compensating effect of alternating hills and valleys eliminated the need for a topographic correction. No correction was deemed necessary for geologic history such as uplift, erosion, or glaciation in the area. Because the ore was observed to be magnetite with negligible amounts of sulphides, oxidation or reduction of the deposit is believed to be so small that correction for it would be of no consequence. Sufficient time had elapsed since the drilling of the holes that no correction was necessary for thermal disturbances caused by drilling. The effects of water movement and variation in thermal conductivity are discussed under the results obtained in drill holes A and I.

RESULTS

Few temperature determinations were made in the sedimentary rocks. In the first 5 holes, (see Appendix I, holes A, F, G, J, M), measurements were made every 10 meters from a depth of 100 to 740 meters. All depths, unless otherwise specified, are measured in meters below the top of the collar. The surface of the Precambrian rocks is approximately 400 meters below ground surface.

Two good aquifers exist in the area and one was being pumped for drilling purposes. In hole A, which was located only a few decameters from a pumping well, the effect of flowing water upon temperature is most readily seen (see figure 5). The large bulge in the temperature versus depth curve is created by an aquifer whose vertical temperature distribution does not conform to the normal increase of temperature with depth. The gradients swing rapidly negative indicating a cooling with depth and then a rapid recovery to the normal. Temperatures in the sedimentary formations varied as much as 0.1°C because of circulating water. Because no core were available and disturbances caused by the movement of water were present, no heat flow determinations were made in the sedimentary formations overlying the Precambrian rocks.

Movement of water caused by earth tides was considered neglible. The Precambrian rocks are dense and impermeable with porosities less than 1 percent. The overlying sedimentary rocks are highly porous and permeable. The investigator believes that any tidal effect would be compensated for by the ready transmission of water in the sedimentary rocks.

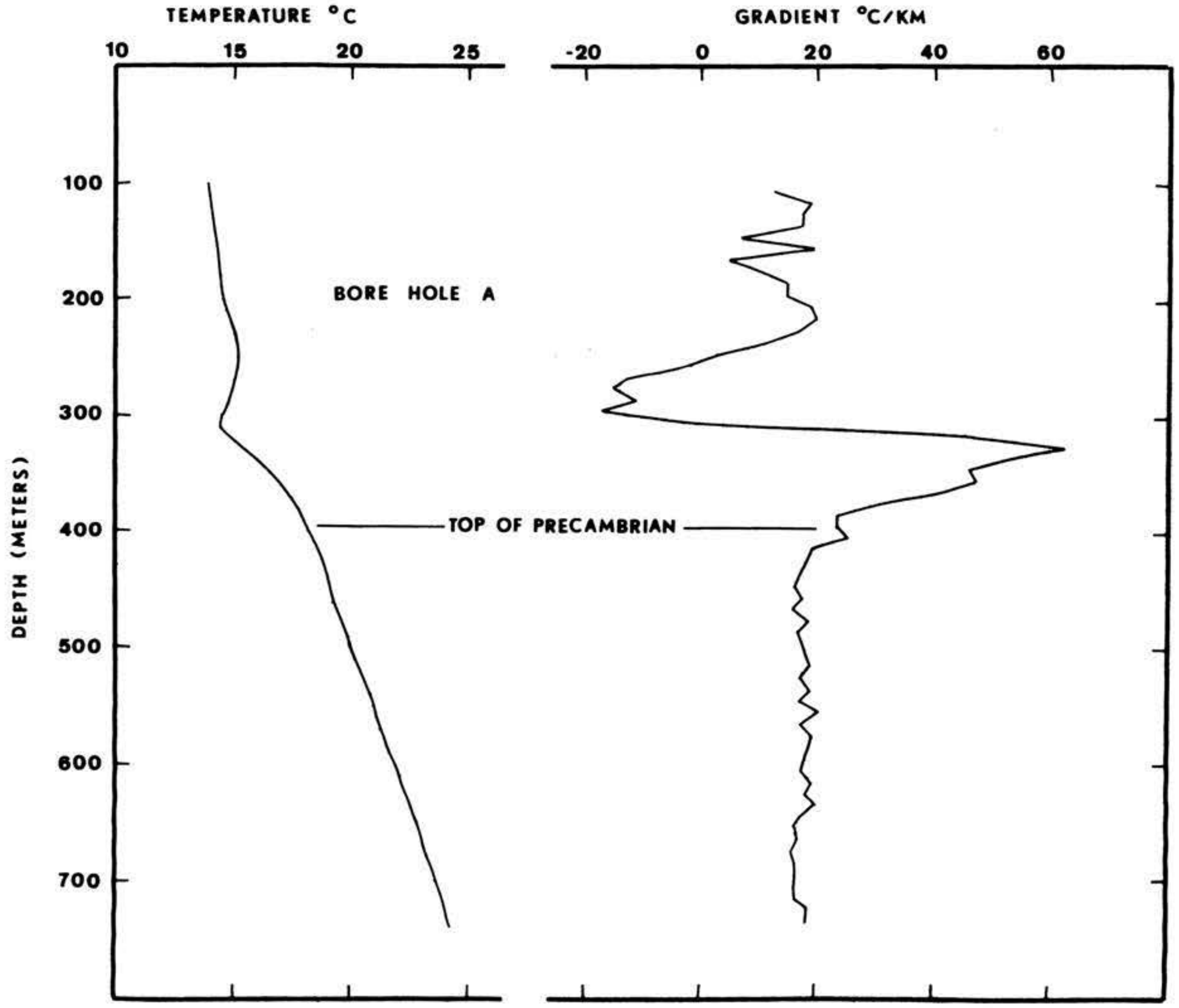


Figure 5. Geothermal data for bore hole A, Boss deposit, southeast Missouri

Graphs of temperature and temperature gradient versus depth for all holes revealed no apparent correlation with the geologic logs of the bore holes. Broad zones of geophysically similar rock types were indicated when thermal conductivity versus depth was plotted for each hole. A conductivity of nearly 9 millicalories/cm.sec°C corresponded to a granite dike. Conductivities of 7.62, 6.00, and 6.44 millicalories/cm.sec°C showed no apparent correlation to recognized rock types. Heat flow versus depth for all holes showed the same relationship to the rocks as thermal conductivity.

Heat flow values for each of 13 holes were calculated using the mean gradient and mean conductivity from 200 to 300 meters below sea level in each hole. A mean of these values gave a regional heat flow of 1.34 ± 0.05 microcalories/cm^2sec. Table 1 gives the necessary data for calculation of the regional heat flow.

Figure 6 shows the geothermal data from drill hole I. Table 2 gives the necessary data for calculation of heat flow in hole I. One hundred and thirty conductivity samples represented the Precambrian section of the hole from 400 to 1100 meters.

The thermal conductivity and heat flow versus depth curves suggest a subdivision of the rocks into three rock types: one with a heat flow of 1.35 microcalories/cm^2sec , another with a flux of 1.09, and a third type with a flux of 1.42. It should be noted that changes in the conductivity curve correspond to changes of the same sign in the heat flow curve. If heat flow is assumed constant up the bore hole, the products of gradient and conductivity in each interval would be equal if the rocks were not dipping. If the rocks were dipping, variations in the heat flow curve would follow variations in the conductivity curve. Because this latter effect is observed in hole I, this investigator

TABLE 1

DATA NECESSARY FOR CALCULATION OF REGIONAL HEAT FLOW

Hole	A	B	C	D	G	H	I
T_{200}	21.32	21.34	21.17	21.21	21.27	21.21	21.35
T_{300}	23.13	23.14	23.03	23.07	23.12	23.08	23.15
$\Delta T/KM$	18.5	17.9	18.4	18.6	18.6	18.7	18.0
K_{ave}	7.36	8.04	8.08	7.29	7.94	5.95	7.04
N	6	6	2	4	8	7	19
Q_i	1.36	1.44	1.49	1.35	1.48	1.11	1.27

Hole	J	K	L	M	N	O
T_{200}	21.29	21.20	21.18	21.25	21.37	21.33
T_{300}	23.13	23.04	23.03	23.06	23.15	23.11
$\Delta T/KM$	18.2	17.3	18.4	18.4	17.8	17.8
K_{ave}	6.47	6.72	7.20	7.54	7.71	8.07
N	8	7	8	8	8	12
Q_i	1.18	1.16	1.32	1.39	1.37	1.44

T_{200}	temperature 200 meters below sea level
T_{300}	temperature 300 meters below sea level
N	number of thermal conductivity samples
Q_i	calculated heat flow in each bore hole

Regional heat flow, $Q_{ave} = 1.34 \pm 0.05$ microcalories/cm^{2}sec

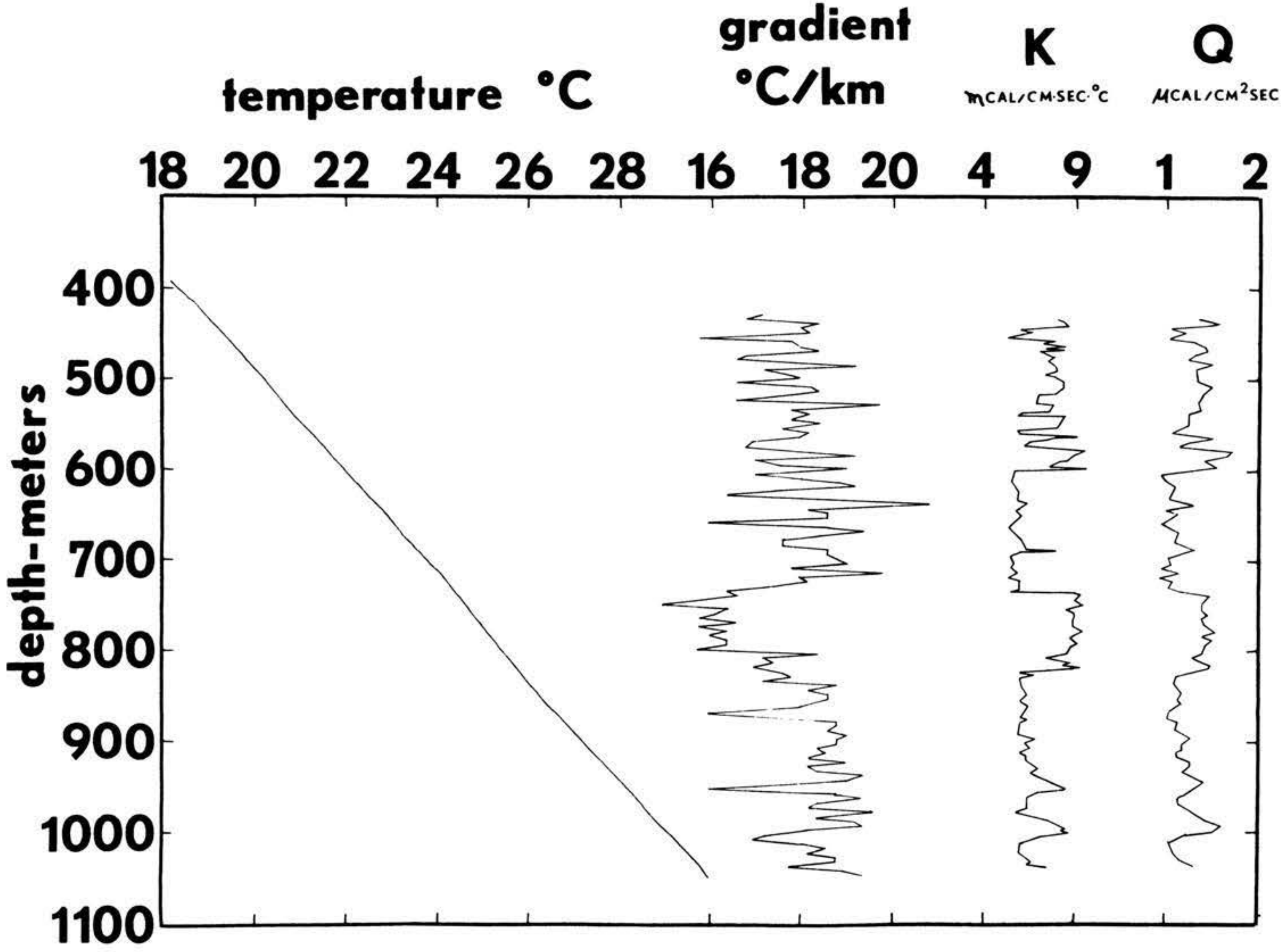


Figure 6. Geothermal data for bore hole I, Boss deposit, southeast Missouri

TABLE 2

GEOTHERMAL DATA FOR BORE HOLE I

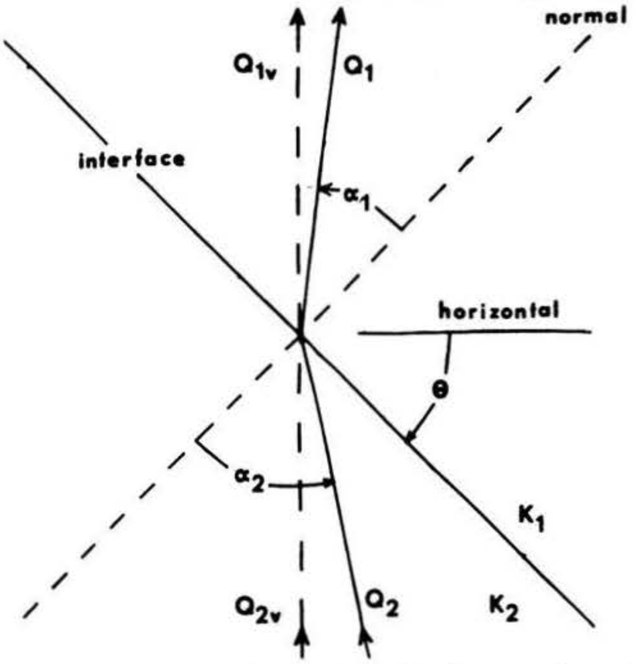
DEPTH	T	ΔT/KM	K_{ave}	N *	Q_v **	ROCK TYPE ***
400	18.34	18.32	7.62	51	1.35	Rhyolite
600	21.98					
600	21.98	18.1	6.00	21	1.09	Altered Rhyolite
735	24.43					
735	24.43	16.0	8.90	21	1.42	Granite
825	25.87					
825	25.87	18.3	6.40	21	1.17	Altered Rhyolite
940	27.98					
940	27.98	18.8	8.00	2	1.50	Granite and Rhyolite
960	28.36					
960	28.36	18.9	6.13	3	1.16	Altered Rhyolite
980	28.74					
980	28.74	18.2	8.18	5	1.49	Granite and Rhyolite
1010	29.28					
1010	29.28	18.3	6.58	6	1.20	Altered Rhyolite
1040	29.83					

* number of thermal conductivity samples

** mean vertical component of heat flow

*** rock type as determined from geophysical data feels the most reasonable explanation for the three different heat flows is a structural interpretation consisting of three mutually dipping rock types.

The refraction of heat flux at an interface between two mediums has been investigated by several persons. Bullard <u>et al.</u> (1965, page 16) review this effect. A plane surface separating two uniform mediums of conductivities K_1 and K_2 have heat flux values in them of Q_1 and Q_2 respectively. These heat flux values are inclined at angles α_1 and α_2 respectively, to the normal to the plane of separation.



Continuity of normal components of heat flux and continuity of temperature are the boundary conditions at the interface, and they lead to the tangential law of refraction.

$$K_2 \tan\alpha_1 = K_1 \tan\alpha_2 \tag{5}$$

A straight bore hole in the plane of Q_1 and Q_2 will make an angle θ with the normal. If Q_{1v} and Q_{2v} are the components of heat flow measured along the drill hole in the two mediums, it can be shown that

$$\frac{Q_{2v}}{Q_{1v}} = \frac{\cos\alpha_1 \cos(\theta - \alpha_2)}{\cos\alpha_2 \cos(\theta - \alpha_1)} \tag{6}$$

The dips of the three rock types in the Boss area can be found by proper application of this equation. Roy (1963, p. 18) makes a simplifying assumption that the isothermal surfaces, which are normal to the heat flow vectors, in the upper medium are horizontal. In equation (6) if the drill hole is in the direction of Q_1, then $\theta = \alpha_1$, and (6) can be shown to be

$$\sin^2\alpha_1 = \left(\frac{Q_{2v}}{Q_1} - 1\right) \Big/ \left(\frac{K_2}{K_1} - 1\right) \tag{7}$$

where α_1 is the dip of the interface.

The ratio of the flux densities in the two mediums is

$$\frac{Q_1}{Q_2} = \frac{\cos\alpha_2}{\cos\alpha_1} \tag{8}$$

Figure (6) reveals an interface existing at a depth of 600 meters. If the vertical heat flow values of 1.35 and 1.09 from Table 2 are substituted into equation (7) for Q_1 and Q_{2v} respectively, and if 7.62 and 6.00 are substituted in for the values of K_1 and K_2, a dip of 72° is calculated for the interface.

The zone from 735 to 830 meters in hole I is known to be a granite dike. It is the most easily correlatable unit in the area and its dip can be calculated geometrically. Because the angle of dip is known, the attitudes of the isotherms and heat flow vectors in the granite dike and the rocks above and below it can be calculated. Continuity of normal components of heat flow and continuity of temperature are the mathematical boundary conditions at the interface. It can be shown that

$$\tan\alpha_1 = \left(1 - \frac{Q_{2v}}{Q_{1v}}\right) \Big/ \left(\frac{Q_{2v}}{Q_{1v}} - \frac{K_2}{K_1}\right) \qquad (9)$$

where α_1 is the angle of refraction of Q_1, the heat flow vector in medium 1; Q_{1v} and Q_{2v} are the vertical components of heat flow in mediums 1 and 2; K_1 and K_2 are the thermal conductivities; and θ is the dip angle. This equation is valid only for heat flow vectors incident between the normal and dip. For heat flow vectors incident on the other side of the normal, the sign of the denominator is changed.

The dip of the upper surface of the granite, assumed to be a planar surface, was geometrically calculated from geologic logs using the depth to the top of the granite from the following holes: A, B, H, I, N, R. A mean of six values yielded a dip of 51°. Substituting values from Table 2 into equation (9) yields $\alpha_1 = 53.8°$. Therefore, Q_1 is inclined 2.8° from the vertical. From Table 2, $Q_{1v} = 1.09$, thus, the magnitude of $Q_1 = Q_{1v}/\cos 2.8° = 1.09$. From equation (5) $\alpha_2 = 63.7°$ and is thus inclined 12.7° from the vertical. The magnitude of Q_2 is $Q_{2v}/\cos 12.7° = 1.45$.

The dip of the interface at the lower boundary of the granite was calculated geometrically to be 47°. Substituting values from Table 2 into equation (9) yields $\alpha_1 = 57.3°$. Thus, Q_1 at the lower interface is inclined 10.3° from the vertical and its magnitude is $Q_{1v}/\cos 10.3° = 1.44$. From equation (5) $\alpha_2 = 48.2°$ and Q_2 is thus inclined 1.2° from the vertical. The magnitude of Q_2 is $Q_{2v}/\cos 1.2° = 1.17$. The relationship of the heat flow to the structure is exhibited in figure 7.

Using the calculated attitudes of the granite-rhyolite boundaries, the geologic logs of the bore holes were re-examined; and interpretation

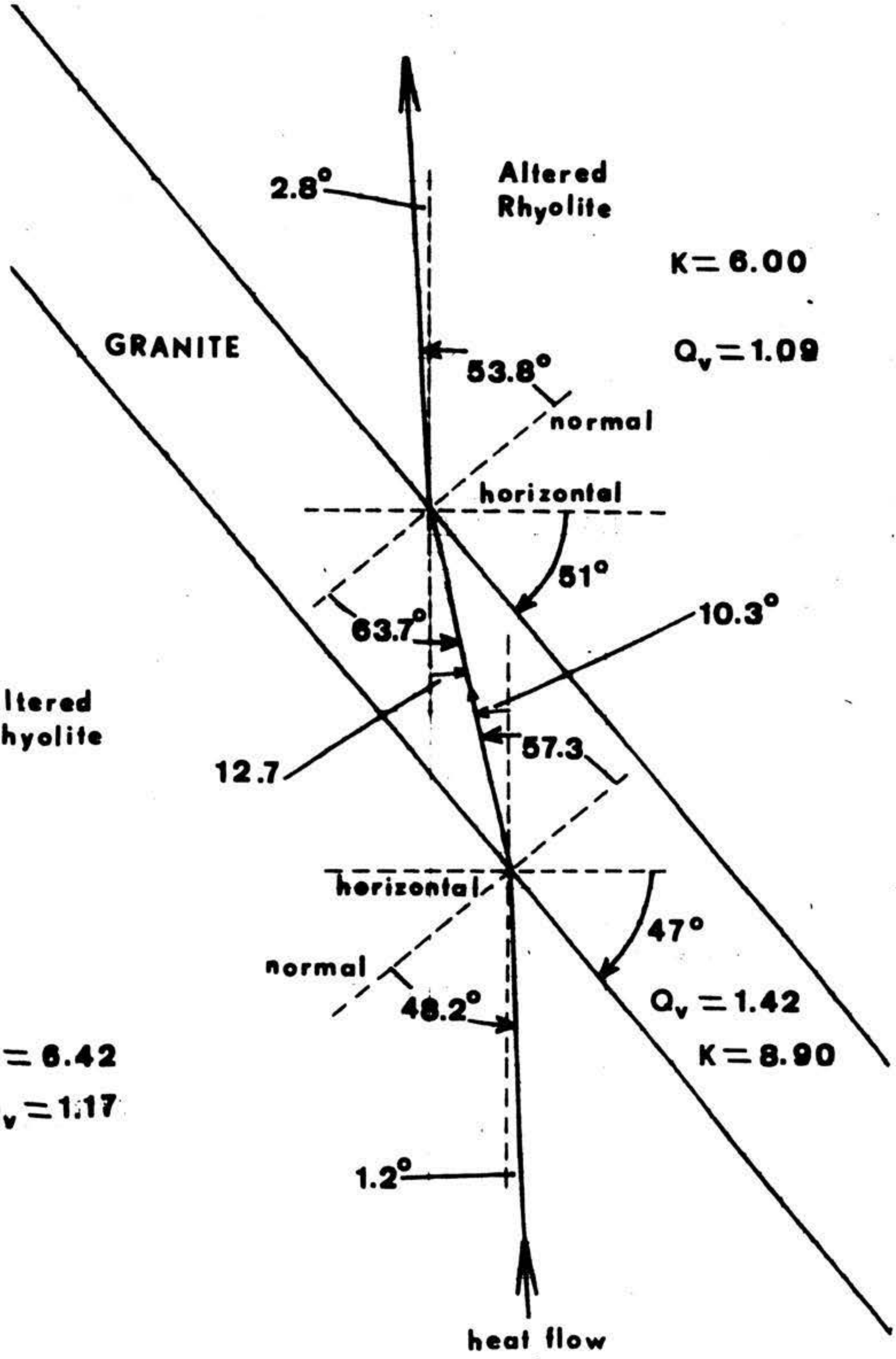


FIGURE 7. Relationship of heat flow vectors to granite. Section is perpendicular to strike of granite. Boss deposit, Southeast Missouri

was arrived at which had not previously been considered. All rocks were classified as rhyolites, altered rhyolites, or granite depending upon the characteristic heat flow measured or anticipated within them.

From figure 6 it can be seen that a zone exists from the top of the Precambrian surface down to a depth of 600 meters which has a calculated mean vertical heat flow of 1.35 microcalories/cm^{2}sec. Although several varieties of unaltered rhyolitic rocks were present in this zone, the entire zone, along with other rocks of similar nature in other bore holes, will be refered to as a rhyolite. The heat flow in the rhyolite is the same as the calculated regional value, so the rhyolite is considered to be the country rock.

In figure 6 the zone from 600 to 735 meters has a mean heat flow of 1.09 ± 0.05. Rhyolitic rocks are also present within this zone with the exception that there was abundant development of chlorite and epidote along with minor amounts of calcite. The mineralogy suggests a prophyllitically altered series of rhyolites. Because of the characteristic heat flow and the type of alteration present, all rocks of this type will be refered to as altered rhyolites.

From 735 to 830 meters in hole I, there is a dike of very fresh granite with a heat flow of 1.42 ± 0.05. The granite can be traced easily from one hole to another through the use of the geologic logs.

Below the granite in bore hole I the rock is predominately altered rhyolite. Two small zones of a rhyolite-granite mixture exist at depths from 940 to 960 meters and again from 980 to 1010 meters. The number of conductivity specimens from these zones was too small to permit a reasonable calculation of their attitudes, but the data available do indicate steep dips associated with them.

Shown in figure 8 is a north-south geologic cross-section based upon the above geophysical subdivision of the rocks. The section is perpendicular to the strike of the granite which dips northward, and is also perpendicular to the strike of the altered rhyolite which dips southward. The southward dip of the altered rhyolite was realized only after the geophysical subdivision of the rocks was made. Planar geologic maps were drawn at various depths within the deposit and then viewed superimposed. The contact between the rhyolite and altered rhyolite is irregular in nature, and - unlike the granite- does not permit an exact geometric verification of its attitude.

Figure 9 is an east-west geologic cross-section based upon the same subdivisions as figure 8.

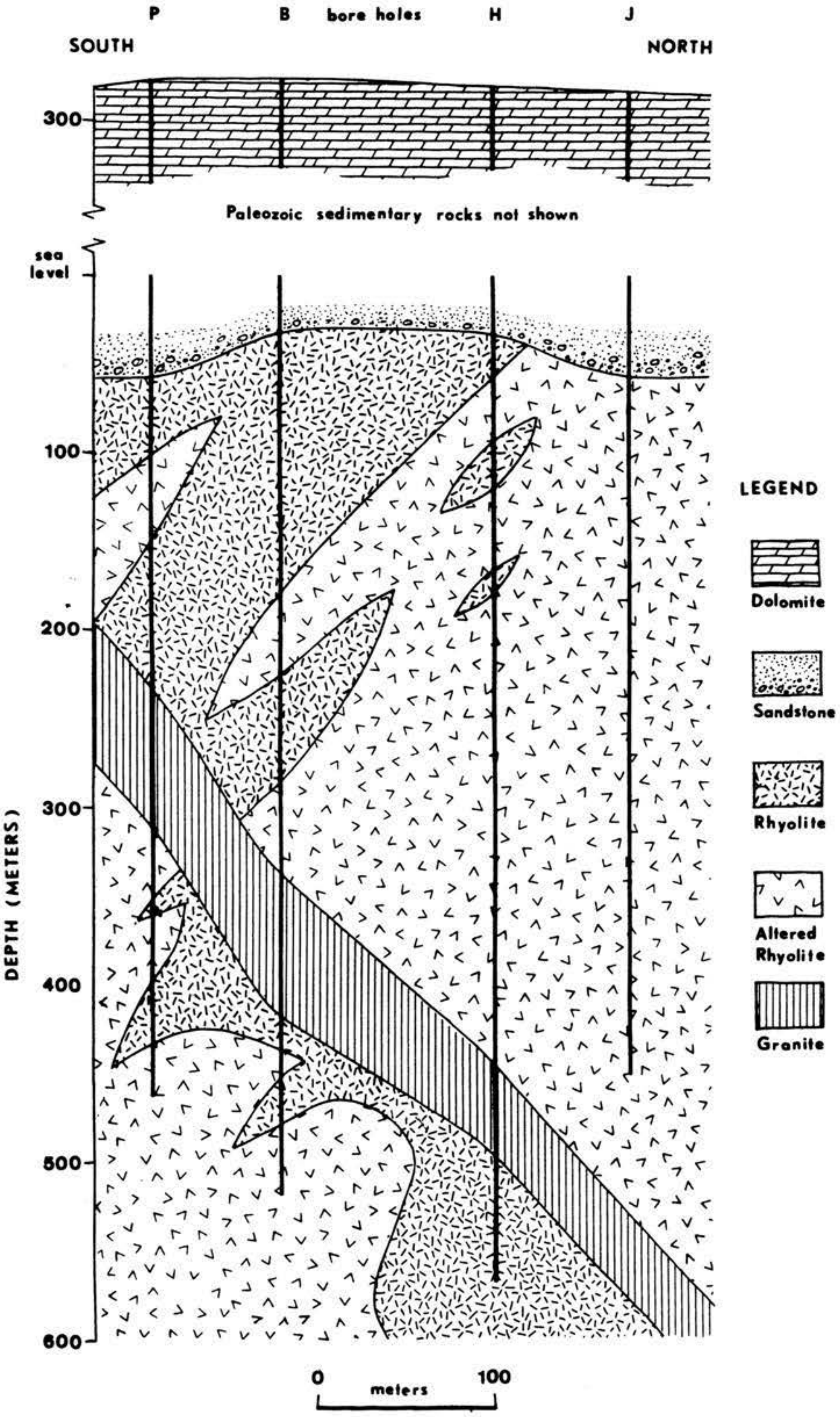


Figure 8. North-south geologic cross-section, Boss deposit, Southeast Missouri

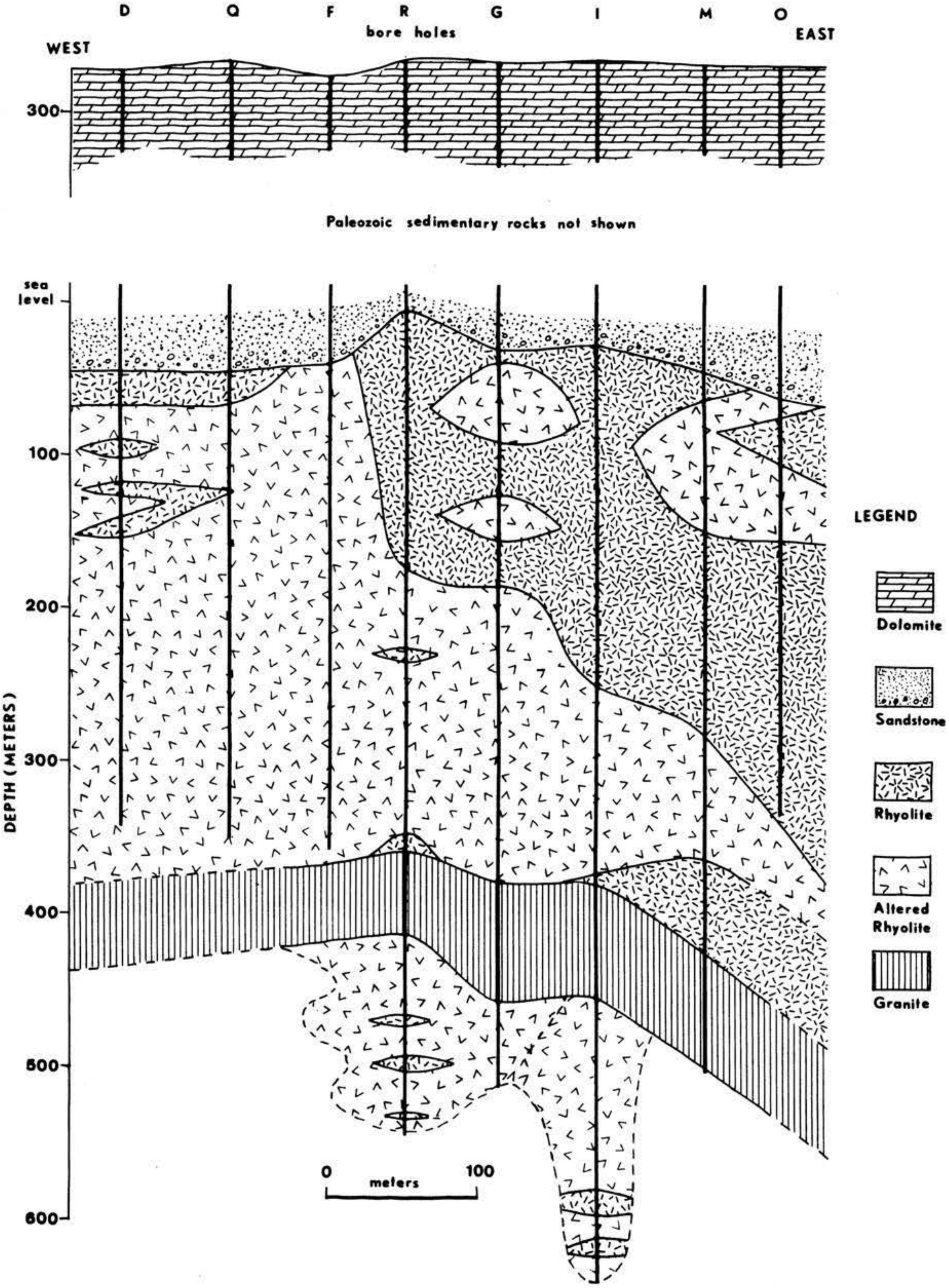


Figure 9. East-west geologic cross-section, Boss deposit, Southeast Missouri

CONCLUSIONS

A regional heat flow value for the area surrounding Boss, Missouri was calculated using a mean temperature gradient and mean thermal conductivity from measurements in an interval 200 to 300 meters below sea level in 13 drill holes. Temperatures were determined at 5 or 10 meter intervals in all bore holes and were combined with 217 measurements of conductivity. The regional heat flow is 1.34 ± 0.05 microcalories/cm^{2}sec and is confirmed by a value of 1.29 ± 0.05 obtained by Roy (1963) about 3 kilometers northeast of Boss. The area to which the 1.34 heat flow determination could be extended is speculative. At Bourbon, Missouri, situated 40 kilometers north of the Boss area, Roy (1963) determined a regional value of 1.22. This value from Bourbon differs less than 10 percent from the Boss value. Because of geologic considerations, it is not unreasonable to assume that the Boss value is correct to 10 percent for a radius of 40 kilometers. This investigator feels, however, that the Boss value is correct to 20 percent as a value for the entire state.

The Boss mineral deposit was found to consist of three rock types based upon geothermal evidence. One type was labeled a rhyolite and had associated with it a mean conductivity of near 7.5 millicalories/cm.sec^{o}C and a heat flow of 1.34 microcalories/cm^{2}sec. It was considered to be the host rock because its mean vertical component of heat flow was the same as the regional value. Another rock type was termed an altered rhyolite and had associated with it a conductivity of near 6.0 and a heat flow of about 1.1. It was characterized by propyllitic alteration. A third unit was a very fresh granite dike and had associated with it a conductivity of near 8.9 and a heat flow of near 1.4.

Assuming the heat flow vectors were vertical in the rhyolite, the dip of the interface separating the rhyolite from the altered rhyolite was calculated to be 72 degrees. The total heat flow vector in the altered rhyolite was calculated to be 1.1 and was inclined about 4.5 degrees from the vertical.

Because the dip of the granite dike was known, the attitudes of the heat flow vectors within the dike and in the rocks above and below it could be calculated. Within the dike the total heat flow vector was calculated as 1.45 and inclined about 13 degrees from the vertical. The total heat flow vectors in altered rhyolites above and below the granite were 1.1 and were inclined about 2 degrees from the vertical.

Using the calculated dips of the rock units, the geologic logs of the bore holes were re-examined and an interpretation of the geology was arrived at which previously had not been considered. The most reasonable interpretation consisted of three dipping rock types. Two geologic cross-sections were drawn based upon geophysical evidence. One cross-section was drawn parallel to the strike of the granite and altered rhyolite and another was drawn perpendicular to the strike.

This geothermal survey proved useful in the interpretation of the geologic structure of the Boss mineral deposit. This investigator concludes that similar surveys would be useful in evaluating other mineral deposits provided proper precautions are taken for correcting temperature disturbances within them. There are certain prerequisites which a deposit should have in order that a geothermal survey might provide the most useful information. These are that a thermal conductivity contrast between the host rocks and the deposit be sufficient to differentiate between them, that oxidation or reduction of the deposit is sufficiently small as to not effect underground temperatures appreciably, and the deposit be free from circulating water.

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VITA

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APPENDIX I

TEMPERATURE MEASUREMENTS

Following are the symbols and abbreviations used in this appendix:

DEPTH	depth in meters below collar of bore hole
T	temperature at the indicated depth
ELEV.	elevation of the collar in meters above sea level
B	bottom of bore hole

CONTENTS

BORE HOLE * page

* For location, see figure 2

DRILL HOLE A (ELEV. 369)

DEPTH	T	DEPTH	T	DEPTH	T	DEPTH	T
100	13.804	270	14.976	430	18.820	590	21.700
110	13.868	280	14.826	440	18.994	600	21.881
120	13.963	290	14.715	450	19.158	610	22.057
130	14.056	300	14.448	460	19.336	620	22.249
140	14.148	310	14.440	470	19.498	630	22.433
150	14.185	320	14.899	480	19.628	640	22.631
160	14.283	330	15.523	490	19.854	650	22.804
170	14.308	340	16.059	500	20.029	660	22.968
180	14.361	350	16.523	510	20.212	670	23.134
190	14.436	360	16.994	520	20.399	680	23.294
200	14.511	370	17.398	530	20.575	690	23.455
210	14.606	380	17.710	540	20.765	700	23.620
220	14.806	390	17.949	550	20.940	710	23.783
230	14.977	400	18.188	560	21.142	720	23.951
240	15.088	410	18.443	570	21.318	730	24.134
250	15.116	420	18.639	580	21.510	740	24.315
260	15.100						

DRILL HOLE B (ELEV. 372)

400	18.306	435	18.828	470	19.558	505	20.177
405	18.367	440	18.904	475	19.651	510	20.265
410	18.418	445	18.989	480	19.733	515	20.356
415	18.487	450	19.081	485	19.822	520	20.435
420	18.566	455	19.198	490	19.912	525	20.530
425	18.651	560	19.290	495	19.994	530	20.617
430	18.726	565	19.444	500	20.083	535	20.708

DRILL HOLE B (continued)

DEPTH	T	DEPTH	T	DEPTH	T	DEPTH	T
540	20.795	595	21.793	645	22.683	695	23.581
545	20.885	600	21.884	650	22.770	700	23.664
550	20.975	605	21.978	655	22.861	705	23.747
555	21.064	610	22.066	660	22.955	710	23.828
560	21.152	615	22.154	665	23.044	715	23.909
565	21.248	620	22.245	670	23.142	720	23.993
570	21.336	625	22.333	675	23.229	725	24.071
575	21.426	630	22.422	680	23.316	730	24.154
580	21.520	635	22.509	685	23.404	735	24.237
585	21.610	640	22.594	690	23.489	740	24.320
590	21.701						

DRILL HOLE C (ELEV. 357)

340	17.782	405	18.524	470	19.614	535	20.820
345	17.845	410	18.608	475	19.706	540	20.907
350	17.920	415	18.695	480	19.795	545	20.998
355	17.956	420	18.772	485	19.887	550	21.086
360	18.008	425	18.850	490	19.982	555	21.171
365	18.059	430	18.927	495	20.080	560	21.260
370	18.107	435	19.013	500	20.168	565	21.354
375	18.153	440	19.095	505	20.258	570	21.447
380	18.198	445	19.181	510	20.352	575	21.535
385	18.262	450	19.263	515	20.444	580	21.620
390	18.309	455	19.352	520	20.543	585	21.718
395	18.369	460	19.438	525	20.632	590	21.810
400	18.443	465	19.527	530	20.727	595	21.903

DRILL HOLE C (continued)

DEPTH	T	DEPTH	T	DEPTH	T	DEPTH	T
600	22.002	640	22.754	675	23.388	710	24.009
605	22.091	645	22.848	680	23.478	715	24.099
610	22.187	650	22.939	685	23.569	720	24.197
615	22.285	655	23.031	690	23.661	725	24.290
620	22.377	660	23.120	695	23.745	730	24.384
625	22.477	665	23.214	700	23.829	735	24.478
630	22.573	670	23.297	705	23.917	740	24.581
635	22.661						

DRILL HOLE D (ELEV. 357)

390	18.290	470	19.611	550	21.115	630	22.604
395	18.332	475	19.704	555	21.210	635	22.698
400	18.390	480	19.801	560	21.303	640	22.792
405	18.443	485	19.892	565	21.396	645	22.885
410	18.497	490	19.990	570	21.491	650	22.979
415	18.555	495	20.092	575	21.585	655	23.069
420	18.652	500	20.183	580	21.679	660	23.161
425	18.764	505	20.274	585	21.767	665	23.256
430	18.865	510	20.363	590	21.866	670	23.353
435	18.957	515	20.458	595	21.959	675	23.453
440	19.051	520	20.550	600	22.053	680	23.546
445	19.142	525	20.645	605	22.145	685	23.637
450	19.238	530	20.739	610	22.234	690	23.716
455	19.332	535	20.839	615	22.328	695	23.795
460	19.426	540	20.931	620	22.417	700	23.873
465	19.517	545	21.022	625	22.515	705	23.951

DRILL HOLE D (continued)

DEPTH	T	DEPTH	T	DEPTH	T	DEPTH	T
710	24.032	720	24.188	730	24.349	740	24.512
715	24.112	725	24.267	735	24.428		

DRILL HOLE E (ELEV. 369)

400	18.350	480	19.740	560	21.156	635	22.527
405	18.451	485	19.828	565	21.251	640	22.623
410	18.533	490	19.914	570	21.348	645	22.713
415	18.639	495	20.002	575	21.440	650	22.804
420	18.709	500	20.089	580	21.532	655	22.883
425	18.794	505	20.173	585	21.618	660	22.964
430	18.877	510	20.255	590	21.703	665	23.041
435	18.964	515	20.335	595	21.790	670	23.124
440	19.047	520	20.414	600	21.879	675	23.204
445	19.137	525	20.508	605	21.968	680	23.285
450	19.218	530	20.595	610	22.062	685	23.365
455	19.304	535	20.689	615	22.156	690	23.447
460	19.390	540	20.781	620	22.252	695	23.527
465	19.477	545	20.873	625	22.350	700	23.612
470	19.564	550	20.985	630	22.433	B	23.662
475	19.657	555	21.063				

BORE HOLE F (ELEV. 360)

100	13.578	130	13.896	160	14.254	190	14.695
110	13.690	140	14.021	170	14.376	200	15.031
120	13.790	150	14.126	180	14.515	210	15.432

BORE HOLE F (continued)

DEPTH	T	DEPTH	T	DEPTH	T	DEPTH	T
220	15.725	350	17.504	480	19.806	600	22.007
230	16.024	360	17.604	490	19.983	610	22.186
240	16.362	370	17.765	500	20.169	620	22.379
250	16.544	380	17.929	510	20.356	630	22.539
260	16.675	390	18.087	520	20.534	640	22.733
270	16.795	400	18.283	530	20.724	650	22.910
280	16.861	410	18.494	540	20.907	660	23.092
290	16.844	420	18.700	550	20.097	670	23.274
300	17.010	430	18.885	560	21.277	680	23.461
310	17.173	440	19.063	570	21.465	690	23.650
320	17.292	450	19.249	580	21.650	700	23.779
330	17.380	460	19.427	590	21.830	B	23.779
340	17.437	470	19.631				

BORE HOLE G (ELEV. 364)

390	18.173	450	19.172	510	20.244	570	21.356
395	18.244	455	19.264	515	20.315	575	21.449
400	18.295	460	19.352	520	20.431	580	21.537
405	18.388	465	19.446	525	20.531	585	21.629
410	18.482	470	19.540	530	20.622	590	21.725
415	18.572	475	19.634	535	20.704	595	21.806
420	18.662	480	19.720	540	20.799	600	21.905
425	18.745	485	19.809	545	20.891	605	22.002
430	18.835	490	19.899	550	20.985	610	22.100
435	18.914	495	19.983	555	21.076	615	22.196
440	18.999	500	20.070	560	21.174	620	22.298
445	19.085	505	20.156	565	21.269	625	22.387

BORE HOLE G (continued)

DEPTH	T	DEPTH	T	DEPTH	T	DEPTH	T
630	22.484	660	23.028	690	23.586	720	24.151
635	22.578	665	23.120	695	23.679	725	24.241
640	22.672	670	23.214	700	23.770	730	24.333
645	22.766	675	23.310	705	23.864	735	24.423
650	22.852	680	23.400	710	23.956	740	24.515
655	22.938	685	23.494	715	24.053		

BORE HOLE H (ELEV. 360)

400	18.354	490	19.936	580	21.580	670	23.256
405	18.422	495	20.025	585	21.672	675	23.350
410	18.508	500	20.121	590	21.766	680	23.438
415	18.594	505	20.220	595	21.859	685	23.535
420	18.690	510	20.308	600	21.950	690	23.628
425	18.776	515	20.389	605	22.040	695	23.721
430	18.863	520	20.490	610	22.140	700	23.812
435	18.953	525	20.582	615	22.242	705	23.900
440	19.042	530	20.671	620	22.344	710	23.991
445	19.129	535	20.762	625	22.436	715	24.085
450	19.214	540	20.850	630	22.530	720	24.179
455	19.305	545	20.936	635	22.621	725	24.270
460	19.399	550	21.024	640	22.712	730	24.362
465	19.490	555	21.123	645	22.804	735	24.454
470	19.582	560	21.213	650	22.892	740	24.546
475	19.671	565	21.306	655	22.983		
480	19.757	570	21.399	660	23.075		
485	19.846	575	21.490	665	23.165		

BORE HOLE I (ELEV. 366)

DEPTH	T	DEPTH	T	DEPTH	T	DEPTH	T
390	18.218	520	20.542	650	22.884	780	25.113
395	18.265	525	20.625	655	22.977	785	25.193
400	18.340	530	20.724	660	23.057	790	25.275
405	18.431	535	20.813	665	23.149	795	25.357
410	18.547	540	20.904	670	23.246	800	25.436
415	18.666	545	20.993	675	23.338	805	25.528
420	18.772	550	21.085	680	23.426	810	25.614
425	18.869	555	21.173	685	23.514	815	25.701
430	18.955	560	21.264	690	23.607	820	25.786
435	19.039	565	21.354	695	23.700	825	25.874
440	19.131	570	21.439	700	23.794	830	25.963
445	19.221	575	21.523	705	23.889	835	26.049
450	19.312	580	21.613	710	23.978	840	26.143
455	19.391	585	21.709	715	24.077	845	26.234
460	19.480	590	21.794	720	24.167	850	26.327
465	19.570	595	21.882	725	24.258	855	26.420
470	19.662	600	21.977	730	24.345	860	26.511
475	19.746	605	22.062	735	24.427	865	26.601
480	19.829	610	22.151	740	24.510	870	26.681
485	19.925	615	22.245	745	24.552	875	26.766
490	20.010	620	22.341	750	24.627	880	26.860
495	20.098	625	22.428	755	24.709	885	26.954
500	20.188	630	22.510	760	24.790	890	27.047
505	20.271	635	22.604	765	24.869	895	27.142
510	20.362	640	22.700	770	24.952	900	27.236
515	20.454	645	22.791	775	25.031	905	27.330

BORE HOLE I (continued)

DEPTH	T	DEPTH	T	DEPTH	T	DEPTH	T
910	27.422	945	28.076	980	28.735	1015	29.372
915	27.515	950	28.163	985	28.827	1020	29.465
920	27.606	955	28.263	990	28.923	1025	29.556
925	27.701	960	28.357	995	29.020	1030	29.650
930	27.792	965	28.454	1000	29.111	1035	29.744
935	27.884	970	28.546	1005	29.197	1040	29.832
940	27.981	975	28.637	1010	29.282		

BORE HOLE J (ELEV. 357)

100	13.873	270	14.807	430	18.898	590	21.851
110	13.927	280	14.905	440	19.081	600	22.044
120	13.971	290	14.964	450	19.261	610	22.250
130	14.027	300	15.774	460	19.448	620	22.410
140	14.141	310	16.845	470	19.627	630	22.593
150	14.133	320	17.443	480	19.808	640	22.771
160	14.199	330	17.660	490	20.004	650	22.943
170	14.217	340	17.795	500	20.198	660	23.131
180	14.229	350	17.921	510	20.384	670	23.305
190	14.217	360	18.017	520	20.573	680	23.490
200	14.239	370	18.110	530	20.762	690	23.677
210	14.301	380	18.188	540	20.936	700	23.858
220	14.338	390	18.273	550	21.124	710	24.041
230	14.420	400	18.371	560	21.299	720	24.222
240	14.494	410	18.500	570	21.491	730	24.410
250	14.615	420	18.752	580	21.671	740	24.593
260	14.720						

BORE HOLE K (ELEV. 356)

DEPTH	T	DEPTH	T	DEPTH	T	DEPTH	T
400	18.247	490	20.010	575	21.567	660	23.123
405	18.289	495	20.105	580	21.655	665	23.215
410	18.352	500	20.196	585	21.755	670	23.306
415	18.550	505	20.295	590	21.850	675	23.396
420	18.698	510	20.379	595	21.943	680	23.488
425	18.815	515	20.460	600	22.033	685	23.586
430	18.905	520	20.562	605	22.130	690	23.666
435	19.007	525	20.655	610	22.216	695	23.761
440	19.094	530	20.737	615	22.307	700	23.850
445	19.191	535	20.837	620	22.395	705	23.924
450	19.286	540	20.929	625	22.488	710	24.024
455	19.382	545	21.020	630	22.585	715	24.112
460	19.469	550	21.108	635	22.674	720	24.208
465	19.556	555	21.202	640	22.762	725	24.299
470	19.643	560	21.289	645	22.855	730	24.394
475	19.734	565	21.381	650	22.946	735	24.483
480	19.830	570	21.479	655	23.036	740	24.580
485	19.915						

BORE HOLE L (ELEV. 362)

400	18.369	430	18.807	460	19.399	490	19.929
405	18.417	435	18.932	465	19.472	495	20.022
410	18.503	440	19.032	470	19.574	500	20.116
415	18.576	445	19.110	475	19.645	505	20.201
420	18.695	450	19.210	480	19.750	510	20.292
425	18.762	455	19.284	485	19.842	515	20.376

BORE HOLE L (continued)

DEPTH	T	DEPTH	T	DEPTH	T	DEPTH	T
520	20.466	580	21.529	635	22.544	690	23.552
525	20.551	585	21.613	640	22.640	695	23.643
530	20.636	590	21.702	645	22.731	700	23.738
535	20.724	595	21.799	650	22.823	705	23.827
540	20.816	600	21.901	655	22.916	710	23.925
545	20.906	605	21.990	660	23.030	715	24.014
550	20.994	610	22.080	665	23.109	720	24.105
555	21.078	615	22.174	670	23.198	725	24.196
560	21.177	620	22.272	675	23.284	730	24.282
565	21.271	625	22.367	680	23.378	735	24.372
570	21.354	630	22.458	685	23.466	740	24.368
575	21.441						

BORE HOLE M (ELEV. 362)

100	13.553	220	15.180	340	17.653	460	19.438
110	13.578	230	15.256	350	17.814	470	19.625
120	13.686	240	15.417	360	17.954	480	19.803
130	13.851	250	15.478	370	18.075	490	19.996
140	13.970	260	15.690	380	18.185	500	20.180
150	14.066	270	15.999	390	18.288	510	20.362
160	14.311	280	16.341	400	18.390	520	20.546
170	14.368	290	16.620	410	18.534	530	20.722
180	14.447	300	16.853	420	18.715	540	20.897
190	14.542	310	17.051	430	18.899	550	21.075
200	14.664	320	17.209	440	19.077	560	21.254
210	14.914	330	17.437	450	19.256	570	21.429

BORE HOLE M (continued)

DEPTH	T	DEPTH	T	DEPTH	T	DEPTH	T
580	21.614	630	22.511	670	23.247	710	23.973
590	21.791	640	22.702	680	23.431	720	24.151
600	21.970	650	22.883	690	23.611	730	24.325
610	22.151	660	23.060	700	23.793	740	24.499
620	22.332						

BORE HOLE N (ELEV. 367)

390	18.388	485	19.946	580	21.635	675	23.336
395	18.466	490	20.034	585	21.724	680	23.428
400	18.519	495	20.122	590	21.815	685	23.520
405	18.572	500	20.210	595	21.906	690	23.606
410	18.624	505	20.299	600	21.997	695	23.690
415	18.677	510	20.388	605	22.081	700	23.773
420	18.735	515	20.480	610	22.163	705	23.857
425	18.805	520	20.568	615	22.251	710	23.942
430	18.893	525	20.655	620	22.341	715	24.025
435	18.993	530	20.743	625	22.430	720	24.108
440	19.091	535	20.832	630	22.523	725	24.191
445	19.190	540	20.921	635	22.161	730	24.273
450	19.288	545	21.008	640	22.709	735	24.353
455	19.386	550	21.101	645	22.801	740	24.436
460	19.477	555	21.185	650	22.890	745	24.475
465	19.577	560	21.275	655	22.979	750	24.554
470	19.676	565	21.367	660	23.066	755	24.634
475	19.768	570	21.459	665	23.153	760	24.721
480	19.861	575	21.546	670	23.240	765	24.813

BORE HOLE N (continued)

DEPTH	T	DEPTH	T	DEPTH	T	DEPTH	T
770	24.893	825	25.885	875	26.772	925	27.680
775	24.978	830	25.963	880	26.863	930	27.770
780	25.066	835	26.055	885	26.955	935	27.862
785	25.160	840	26.141	890	27.044	940	27.950
790	25.250	845	26.230	895	27.136	945	28.039
795	25.338	850	26.319	900	27.227	950	28.129
800	25.428	855	26.408	905	27.317	955	28.223
805	25.519	860	26.500	910	27.411	960	28.312
810	25.606	865	26.591	915	27.498	965	28.402
815	25.697	870	26.683	920	27.588	B	28.433
820	25.786						

BORE HOLE O (ELEV. 362)

400	18.540	465	19.620	530	20.793	595	21.941
405	18.592	470	19.709	535	20.892	600	22.028
410	18.645	475	19.801	540	20.972	605	22.127
415	18.705	480	19.891	545	21.069	610	22.209
420	18.775	485	19.987	550	21.153	615	22.301
425	18.875	490	20.088	555	21.239	620	22.388
430	18.976	495	20.175	560	21.330	625	22.481
435	19.065	500	20.264	564	21.415	630	22.566
440	19.150	505	20.349	570	21.501	635	22.658
445	19.246	510	20.451	574	21.588	640	22.749
450	19.341	515	20.538	580	21.678	645	22.836
455	19.430	520	20.627	585	21.767	650	22.927
460	19.525	525	20.708	590	21.854	655	23.026

BORE HOLE O (continued)

DEPTH	T	DEPTH	T	DEPTH	T	DEPTH	T
660	23.107	670	23.286	680	23.466	B	23.585
665	23.198	675	23.387	685	23.551		

APPENDIX II

THERMAL CONDUCTIVITY MEASUREMENTS

Following are the symbols and abbreviations used in this appendix:

DEPTH	depth in meters below collar of bore hole
K	thermal conductivity, millicalories/cm.sec°C
ELEV.	elevation of collar in meters above sea level

CONTENTS

* For location, see figure 2

BORE HOLE A (ELEV. 369)

DEPTH	K	DEPTH	K	DEPTH	K	DEPTH	K
579	6.10	610	7.60	635	8.06	648	6.88
587	7.34	624	8.20				
BORE HOLE B (ELEV. 372)							
573	6.99	610	7.39	641	7.74	646	8.72
585	8.40	628	8.97				
BORE HOLE C (ELEV. 357)							
574	7.00	637	9.16				
BORE HOLE D (ELEV. 357)							
618	6.05	628	6.56	641	7.80	643	8.68
BORE HOLE G (ELEV. 364)							
565	7.63	585	8.58	595	8.40	626	8.76
568	8.00	591	8.08	598	6.14	645	7.95
BORE HOLE H (ELEV. 360)							
563	6.15	584	5.21	610	6.67	635	5.57
569	5.97	592	6.10	623	5.80		
BORE HOLE J (ELEV. 357)							
558	6.18	589	6.16	610	5.72	636	6.99
575	6.00	600	6.89	624	7.82	647	6.03
BORE HOLE K (ELEV. 356)							
559	5.86	590	6.01	630	5.79	653	6.23
569	9.48	617	7.49	644	6.15		
BORE HOLE L (ELEV. 362)							
564	5.59	585	8.19	591.5	5.79	630	8.32
575	7.77	591	8.78	609	7.12	632	6.05

BORE HOLE I (ELEV. 366)

DEPTH	K	DEPTH	K	DEPTH	K	DEPTH	K
413	8.00	538	5.95	708	5.56	860	6.6
419	7.92	539	8.31	713	5.89	866	6.4
423	6.45	552	8.08	718	5.38	8.72	6.1
426	6.47	555	5.83	722	6.05	872.5	6.6
432	8.10	559	5.98	730	6.11	878	6.1
433	8.39	561	9.21	733	5.64	890	6.0
440	8.72	562	7.77	734	8.99	896	6.9
443	6.08	566	7.62	735	9.3	904	6.4
446	6.74	566	7.80	742	9.1	906	6.6
452	5.42	569	6.62	748	9.5	912	6.1
455	7.90	572	6.31	754	8.7	915	6.4
458	7.42	574	7.64	756	8.99	918	6.4
462	8.47	578	9.57	759	9.1	924	6.7
466	8.42	582	8.79	765	9.0	930	7.1
469	7.23	589	8.68	772	9.0	935	6.7
475	7.85	590	8.29	777	9.5	952	8.7
478	7.59	596	7.60	784	8.8	955	7.3
484	7.85	596.5	9.72	790	9.3	963	6.5
487	7.95	602	5.71	795	8.9	973	6.5
490	7.99	610	5.63	803	8.7	979	5.4
494	7.42	624	6.01	803.5	8.0	986	7.7
494.5	7.89	633	5.94	808	7.6	995	8.6
501	8.35	637	6.36	811	8.9	997	8.5
501.5	7.37	644	5.67	811.5	8.4	1000	8.8
507	11.98	650	6.17	815	9.3	1005	7.3
508	8.36	663	5.51	818	8.8	1012	6.2

BORE HOLE I (continued)

DEPTH	K	DEPTH	K	DEPTH	K	DEPTH	K
516	7.88	676	6.13	820	8.8	1023	6.1
517	7.19	687	6.25	824	6.3	1024	6.3
526	6.94	688	7.96	830	6.2	1031	6.7
527	7.69	689	6.24	839	6.3	1033	6.6
535	7.61	696	5.60	848	6.5	1036	7.6
536	6.08	701	5.70	854	6.2		

BORE HOLE M (ELEV. 362)

573	7.89	597	7.02	613	8.75	652	8.28
585	8.15	610	7.14	641	6.65	661	6.45

BORE HOLE N (ELEV. 367)

573	7.75	604	10.35	634	6.53	655	5.75
585	7.85	614	9.36	646	6.85	664	7.27

BORE HOLE O (ELEV. 362)

564	8.67	589	9.02	612	7.37	637	7.14
574	7.38	600	9.68	621	7.96	647	8.95
582	7.83	606	7.86	629	8.07	659	6.94