The Aeolotropy of Thermal Conductivity in Rock

A. V. Pegler
Department of Mining Engineering
Queen's University at Kingston, Ontario

ABSTRACT

The conductivity of heat through rock materials is one of Earth's least understood geophysical properties. A more complete understanding of thermal conductivity in rocks would be a significant advance which could be utilized by industry, and government agencies of civil defense and subterranean environmental and working conditions.

It has been stated that "one of the most remarkable facts about the earth's heat is the extreme slowness with which it travels through the soils and rocks by conduction" (Jacobs, Russel and Wilson, 1959). However, the statement appears to be mainly concerned with the conduction of the earth's internal high temperatures to surface, and the penetration of surface temperatures by seasonal change into the earth.

This paper is primarily concerned with studying the differential directional components of heat flow in naturally occuring rock formations, and to consider directional heat flow effects of induced temperature increases of surface and underground origin.

A preliminary feasibility study indicated the possibility that thermal conductivity from an induced source is not an isotropic property of rock. Further investigations of available literature has not indicated that research has been conducted into this subject using internal point heat sources. Present research just being commenced is at the stage of developing an instrumentation and measurement system.

INTRODUCTION

Although it appears to be generally accepted that heat flow, as a product of temperature gradient and thermal conductivity, is "reasonably constant," i.e., the average value is about 1.2×10^{-6} cal/cm^2 - sec, it is also recognized that the mean heat flow varies regionally (Jacobs, Russel and Wilson, 1959). Though the greatest heat flow range shown in the reference is only between 0.87 to 2.24 ($\times 10^{-6}$) cal/cm^2 - sec., greater individual measurements have been made in countries other than those cited. Similarly, it has been frequently shown that the change is not necessarily linearly related to depth below the earth surface.

It is also hypothesised that, of the total "observed" heat flow, at least 80% is derived from inherent radioactivity in rocks, and no more than 20% can come from a central heat flow. It is similarly recognized that the distribution and concentration of radioactive materials in rocks must seriously complicate the problems of measurement of this phenomenon. It is on such a theme that the thermal history of the earth is discussed (Jacobs, Russel and Wilson, 1959), but in this paper, the writer will attempt to provide a basis for discussion and further research in which it is proposed that parallel to the radioactivity distribution theory, physical aeolotropy and its links with other rock properties is also an important consideration of the directional bias of thermal conductivity in rocks.

Heat flow may be accomplished by conduction, radiation and convection mechanisms along certain temperature gradients. If an ideal material can be imagined then it would be quite reasonable that heat flow in a unit direction in it should equal the heat flow in any other direction. Thermal conductivity,

$$(k) = \frac{\text{Heat Flow}}{\text{Temperature Gradient}}$$

$$= \frac{\dfrac{\text{Calories}}{\text{Time} \times \text{distance}}}{\text{Temperature change}}$$

As there are very few materials which even approach a state of true isotropy and homogeniety, the heat flow in real solids should depend upon a complex summation of the heat flow by the agencies of all mechanisms, any one or all of which may in turn be biased by some other non-isotropic property of the material.

Rock is mostly an aeolotropic and heterogeneous material, and by its structural arrangements is an extremely difficult one to work with. Studies of rock indicates a number of directional properties. It is not unreasonable to postulate that directional characteristics might influence transference of heat through rocks.

Preliminary feasibility tests were conducted to study the possibility of detecting the difference in heat transference in various directions in rock. The first was to determine if heat transfer was influenced by shear plane orientations. This test showed that it is possible to detect heat transfer in a sample of rock, but extensive refinements of the procedure and testing equipment would be necessary to determine (a) if there is a preferred heat transfer direction in a rock, (b) what properties are directionally compatible with the conductivity, (c) if results can be statistically validated and correlatable, and (d) if an economical rapid method of examination and analysis may be developed.

There must also be a method of insulation devised by which test work on a laboratory sample may be rationally compared with conditions in-situ; i.e., little to no interference fr ambient currents and no temperature transfer from sample to air takes place.

Work carried out in laboratory and field experiments of significant interest has demonstrated the effects of cyclic steam injection for the stimulation of fluid flow in oil sand reservoirs. However, no attention was paid to any directional effect on conductivity. Steady radial heat flow was assumed (Boberg and Lanz, 1966).

Linear thermal expansion of mine rock was studied by Hardy and McLean (1966). The work was conducted to determine the effects of temperature changes on samples of rock during load measurement tests.

Starfield (1966) suggests formulae for the development of heat flow tables, but mainly for a consideration of heat transfer and diffusivity for ventilation air calculations in mines. No consideration has been required or discussed, dealing with the possibility that the thermal conductivity of a rock may be an aeolotropic property. Further considerations of conductivity and diffusivity have recently been completed at Queen's University (Akbar, 1967). The study was undertaken with the terms of reference of mine ventilation problems. It was suggested that granular lineation and grain size in rocks have some influence on directional conductivity.

Thomas (1965), from an investigation of the effects of overburden pressure in Oil Shale during underground retorting reported that:

1. Massive thermal fracturing did not occur in shale when it was reduced to a friable material when being retorted in-situ.
2. In shale beds perpendicular to the maximum principal stress, the magnitude of induced permeability is stress dependent.
3. In beds parallel to the maximum principal stress, induced permeability is essentially pressure invariant.
4. Induced porosity is essentially temperature invariant above 850°F under overburden pressure of 2,500 psi or less.
5. Above 1,000 psi pressure the minimum temperature required to create pore structure decreases as overburden pressure increases.
6. Thermal conductivities of "raw and spent" shale probably vary by no more than 13% under stress conditions in excess of 1,000 psi.

The above conclusions, abbreviated, offer no assistance to any consideration of directional bias.

Gray (1965) investigated surface spalling of rocks due to high temperature fluctuations by the examination of a surface stress distribution in a completely constrained rock mass.

Loofbourow (1966) in discussion of depth and rock temperatures supported general geophysical statements that: ". . . low rock temperatures as well as low gradients are found in rocks of high thermal conductivity." . . . heat flow at all elevations in a vertical column of rock should be uniform. . . . masses having high thermal conductivity, providing that they have been stable for a sufficient time, have low gradients . . . some rocks conductivities are affected by variations in density and intense fracturing or porosity." Many shales, sandstones and limestones have a broad range of densities and degrees of saturation and their upper and lower measured conductivities may differ by a factor of 8.

Birch and Clark (1940) showed that—the conductivities of the common rocks tend to approach equality at high temperatures. The range of conductivity of five common igneous rocks of 4.2 to 11.1 metric units at 0°C, reduced to 4.5 to 7.5 at 300°C.

In the petroleum production fields of research, investigators are more concerned with improving conductivities of fluid saturated porous media, and therefore any importance of anisotropy or aeolotropy in the thermal conductivity of a rock matrix is considerably diminished (Lanz, 1967).

Melton and Cross (1967) have carried out investigations into the fracturing of shales by electrical currents. In the tests, the location of electrodes influenced the orientation of a fracture. It was noticeable that less current was required to create a fracture along bedding planes than across them. It was considered that this may only have been due to a more uniform distribution of the electrical conducting materials. However, it is also possible, and is to be investigated, that another rock material having some lineal characteristic could also be more easily fractured in a specific direction than any others by electrode location. This appeared to recommend to the writer that thermal conductivity may be associated with preferred electrical conductivity as well as some other rock property. Melton and Cross, did not indicate that their formations had any preferred direction of electrical conductivity, merely a planar preference.

Birch, Shairer and Spicer (1942), in a table of "Thermal Conductivity and Diffusivity of Rocks," list the variation in the conductivity, between bedding planes and foliation planes of some materials. The thermal conductivity of Pelham granite gneiss parallel to the foliation was 7.42 cal/sec. cm. deg., while perpendicular to the foliation and at the same temperature, the measurement was 5.17. Similarly, Pennsylvania carboniferous limestone parallel to bedding was 8.2 and perpendicular to bedding was 6.1. It was also noted that for less heterogeneous materials such as Proctor Vermont chalk the difference was negligible (7.36:7.2). For quartzite sandstone the comparison was 13.6:13.1. Similarly, Pennsylvania Slate, with a more pronounced bedding showed a 4.6:3.7 relationship. From the information shown, there is no doubt that differences exist between perpendicular to bedding and parallel to bedding in some materials, but it is not known what significance this may have by numbers of tests.

In summary from the information available it appears the planar variations of thermal conductivity of rock vary inversely with apparent homogeniety and/or structural similarity. This bears some correlation with the work done by Melton and Cross (1967). However, neither of the summations suggested have any reference to directional bias within a plane or to any other structural comparison, other than that of materials of pronounced bedding and/or linear characteristics.

It appears from the table below that increased temperatures have no significant effect on the differences between the conductivity properties (i.e., parallel or perpendicular to structural planes).

Birch showed that results of experiments on holocrystalline rocks of all types (generally covering all igneous) were erratic. By the method of measurement stated this is not surprising. Irreversibility of procedure and variation with temperature in the sedimentary groups could not be equitably compared with igneous groups. This may have been caused by variations between groups of materials. What is noticeable in the paper

Ratio of Conductivity parallel/Conductivity perpendicular to Bedding (B) and/or Foliation (F)

	Materials				
Temperature	Granite Gneiss (F)	Pennsyl. carb Lst (B)	Chalk (B)	Quartzitic S.Stn (B)	Penns. Slate (B)
0°C	1.44	1.34	1.02	1.04	1.13
100°C	1.36	1.30	1.05	1.03	1.12
200°C	?	?	1.02	1.035	?

is that there is no reference to numbers of samples in each group, statistical validity and/or method of correlation, but there is a stated qualification "mass of data very considerable."

Thermal conductivity of porous materials.

Somerton (1958) has shown that the thermal conductivity of a porous rock material is seriously influenced by the type of fluid content, and there is a measurable difference between gases and liquids. Secondly, confining and/or fluid pressure has a significant effect of increasing the conductivity at higher pressures. Measured at 90° F and in BTU/Hr. sq. ft. °F/Ft. the thermal conductivity of a sandstone in air = 0.507. In oil it measured 0.781, and in water 1.592. In a mixture of oil and water, 1.425. Other materials such as silty sandstone showed similar changes.

It was shown that thermal conductivity increase was related to the conductivity of the saturating fluid. An approximate correlation was developed by Asaad (1955),

$$\frac{K}{k_1} = (k_2/k_1)^m$$

where

- K = thermal conductivity of fluid saturated rock.
- k_1 = thermal conductivity of rock solids.
- k_2 = thermal conductivity of saturating fluid.
- m = an empirical exponent = $c\phi$ where ϕ is a fractional porosity c is a correlation factor $\cong 1.0$.

Sample testing.

In test work on porous materials by the previously named researchers most measurements appear to have been made by single repetitive linear propagative techniques. It is possible that any one measurement could cause some physical change in the materials in the traverse path of the heat flow. If this is a problem there is the possibility that all successive measurements may be influenced by the initial measurement and also interfere with each other even if only differences were measured. It is now considered by the writer that a series of measurements to determine the validity of hypotheses should be made to record propagative rates simultaneously in different planned directions from one heat source. It is not certain in this approach how one must account for the natural heterogeniety of the sample and existing structural discontinuities. It may be possible even in a "small" sample that a central heat probe may have its propagative rates influenced by structural changes, which may be important in a small sample, and yet unimportant when considering the mass conductivity trajectories.

At this stage, when other rock properties are required to be determined from the same samples tested for thermal conductivity, it is important to conduct all work at temperature ranges which are not likely to cause any structural or mineralogical deterioration in the samples.

Two basic measurement methods have been determined, (a) steady state, and (b) nonsteady state.

Steady State: Equipment involved in this technique is supposedly more exact, but a considerable time lapse is required to attain temperature equilibrium. Somerton (1958) describes a comparator device using crown glass as a standard. Wechsler and Claser used a single guarded cold plate. Another similar method is described by Kunii and Smith (1961).

Nonsteady State: Components of such a system provide a fast determination, thereby less likely to produce a nonuniform distribution in partially saturated rocks. Somerton and Mossahebi (1967) employed a ring heater detector with a point probe operating over a prepared surface contact of a rock. Woodside and Messmer (1961) used a linear heat probe and detector on surfaces, Edmondson (1968) used an internal tube heater for a "semi-infinite" sample.

No researchers yet appear to have used an internal point heat source, which might enable simultaneous measurements of thermal transfer in different directions.

In the method proposed for this initial investigation a point heater is inserted into a sample, and thermocouples are placed around the heater at known distances to enable measuring of a thermal flow response in selected directions.

The heater.

For a continuous point heat source located in an infinite homogeneous medium, the temperature rise at a radius r from the point is given by Carslaw and Jaeger (1962).

$$T = \frac{q}{4\pi r k} \quad \text{erfc} \quad \frac{r}{(4\alpha t)^{1/2}}$$

- T - Temp. rise in rad. r. at time t (°C).
- q - heat liberated by heater (cal/sec).
- r - radius (cm)
- k - thermal conductivity of test material. cal/sec/cm.
- α - thermal diffusivity of test material (cm^2/sec).
- t - time (sec).
- erfc - complementary error function.

To produce a change of temperature, heating power is required. For copper-constantan thermocouples a temperature change of 25°C causes a change of thermoelectric force of about lmV, which is satisfactory for measuring. For r = 2cm and k = 0.02/0.002 cal./sec./cm°C a heating power of about 10W is required.

The heater is constructed from Karma resistance wire, which has very low temperature coefficient of resistance. It is wound on the tip of a thermocouple, which will measure temperature of the heater (see Fig. 1). To obtain a good temperature contact between the heater and the sample a pool of mercury is maintained in the heater hole. The current passing through the heater is used to measure heating power (its resistance will be known and constant).

Heat losses from the system (conduction losses to the lead wire of the heater and thermocouple and to the insulation) are ascertained by calibration in known samples.

Thermocouples.

The extremely small diameter of these units necessitated special construction. One unit was combined with a heater, to be described later, the others were used as temperature sensors in the prepared rock sample. Figures 2 and 3.

The thermocouples are of copper constantan premium grade. The wires are 30 AWG and the junctions were formed using electrical solder to maintain minimum junction diameters. The thermocouple rods were sealed in at the hole collars. Insulation of the units is teflon and enameled coated fibre glass. All reference junctions were kept at room temperature and well insulated. Figure 1.

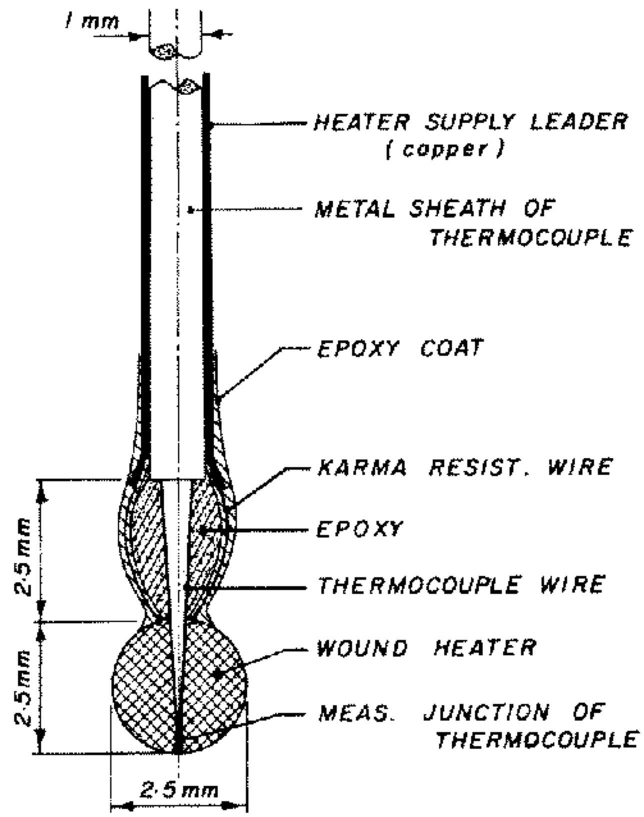

Figure 1. Heather with Thermocouple.

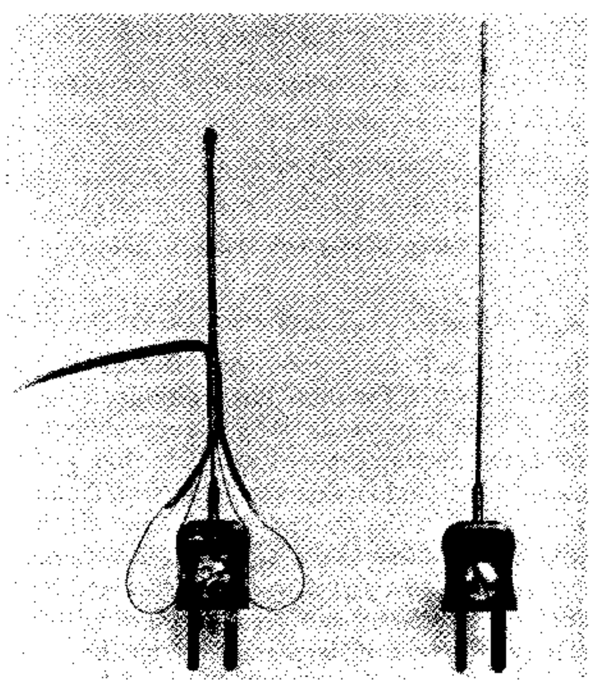

Figure 2.

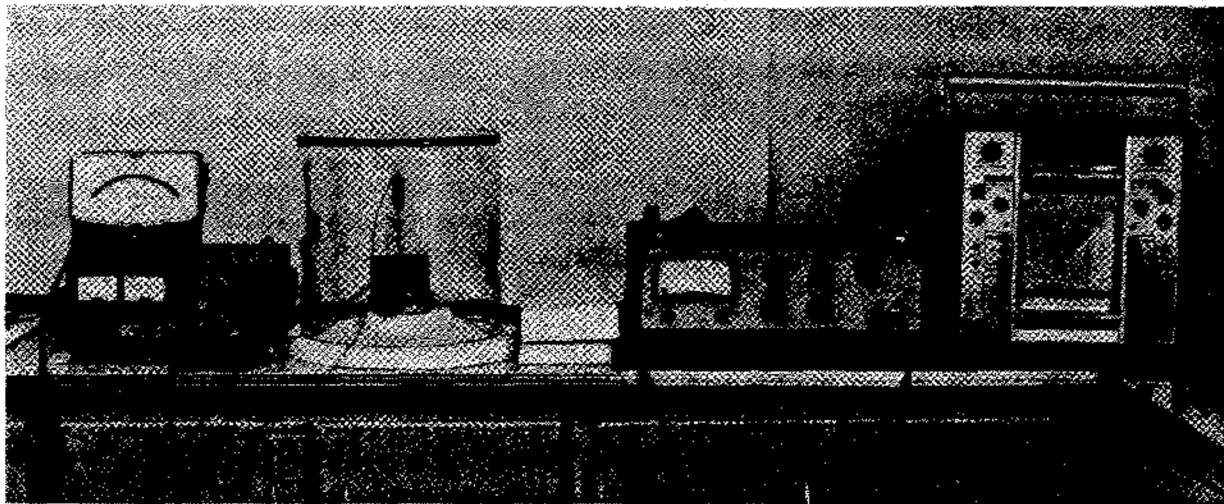

Figure 3.

The heater.

This main unit was constructed around a thermocouple as described above. For the coil about the tip of the thermocouple, Karma resistance wire was wound. It has a resistance of 107.0 ohms per foot, and a low temperature resistance coefficient of 0.00002 per degree C. It is heavily enameled with an O.D. of 0.00275 inches. The initial heater has a total resistance of 308 ohms. The final shape of the coil is approximately spherical and both ends of the heater leads are soldered to copper leads.

The thermocouple on which the heater wire is wound, is made of 0.04 inch ceramo. The wires, slightly heavier than the sensor thermocouples, are of 36 AWG. It has a ceramic insulation with a stainless steel sheath, which was removed just from the end. After the junction was made, a thin coat of epoxy resin was applied. The layer was then built up by successive coats to act as an insulation to minimize thermal losses through the metal sheath (Fig. 1).

As it was important to minimize permanent changes of the rock material during testing, a heating power of 1-2 watts only was applied, to produce a maximum temperature at any time of 100°C.

A finished heater and thermocouple are shown in Figure 2. The copper constantan thermocouple wire is exhibited alongside a scale in Figure 12. Instruments recording temperatures are shown in Figure 3, together with a sample fitted with heater and sensors under a bell jar mounted on a polystyrene insulating sheet.

Preliminary circuitry.

Heating temperatures were monitored by a Mosely Model 7001AM Recorder, and the temperature changes at the sensor thermocouples amplified through two Keithly Nanovoltmeters, Model 148. Total current flow to the system was monitored through a Triplet milliampmeter Model 800 type 2 (Fig. 3).

TABLE I

Fig.	Heater	R (ohms)	I (milliamps)
4	1	308	60.5
5	2	345.5	49.8
6	2	345.5	49.3
7	2	345.5	50.1

Note: Figure 4 in the second experiment (Line 1_2, 2_2) a slightly higher pressure was exerted on the thermocouples to make better contact in their holes. Vertical axes units are time in seconds. Horizontal axes units are microvolts from thermocouples. One microvolt corresponds to 0.025°C.

Present Problems.

1. Thermal equilibrium is most difficult to maintain while temperature changes of less than 0.025°C are required. An air conditioned room and better ambient control will be established.
2. Heater hole influence on the total sample must be studied.
3. Losses of heat from the heater through the thermocouple wires must be monitored.
4. Little is yet known of the effect of thermocouple tip mass difference.
5. Additional equipment is required by which to more accurately monitor time—micro second digital readout. To determine if thermocouple differences created bias, we reversed thermocouples.

Test 1—Figures 4 and 5

2—Figures 6 and 7

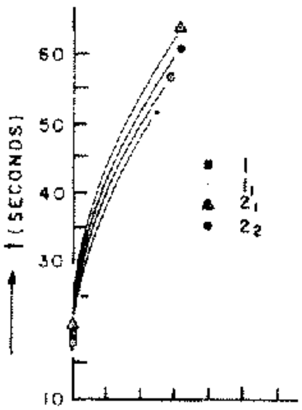

Figure 4.

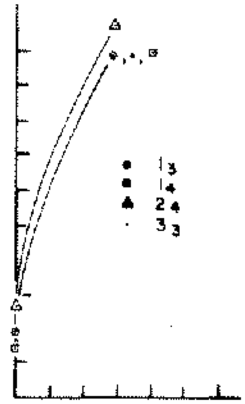

Figure 5.

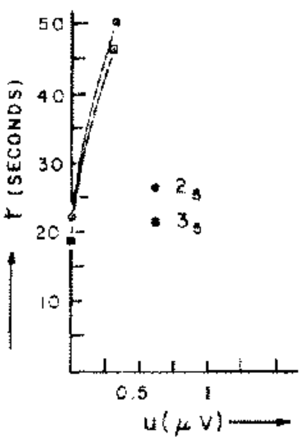

Figure 6.

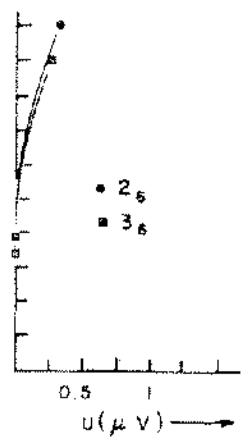

Figure 7.

6. Thermal flow reaches thermocouples in 18 to 20 secs. in the test sample. When the flow reaches the sample perimeter we no longer have an infinite sample, even though it is well insulated.

To determine preliminary calibration factors, small discs were cut from the samples, and K values were measured at the Department of Seismology, Energy Mines and Resources, Ottawa, Ontario by Dr. Jessop. Values of 0.01076 in cgs units in a direction perpendicular to bedding planes, and 0.0118, cgs units parallel to the bedding were determined. These values were compared with the thermocouple readings from two separate tests in which conductive distances of 15 m.m. and 30 m.m. respectively were measured. This produced values of 5.675 μv, equivalent to .01076 cal/cm. sec. and 0.284 μv, equivalent to .01076 cal/cm. sec. resp.

Measurement errors of ± 10% produced corresponding K value variations of ∓ 10%. Table 2 shows the values obtained for the 2 samples in which distances of 30 m.m. and 15 m.m. were used. Figures 8 to 15 show the recorder values of

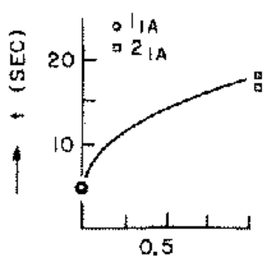

Figure 8.

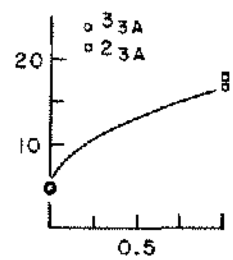

Figure 9.

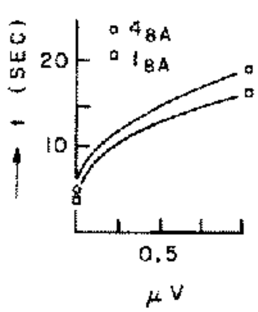

Figure 10.

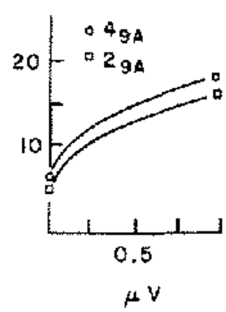

Figure 11.

15 mm

heating times compared with thermocouple readings in microvolts (μv). The following is a description of the column readings in Table 2.

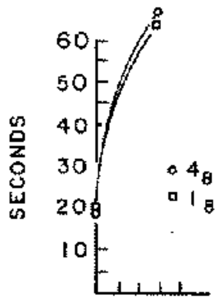

Figure 12.

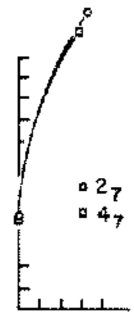

Figure 13.

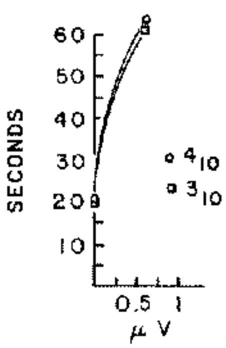

Figure 14.

30 mm

Figure 15.

Th	30 sec.	temperature of the heater, 30 sec. after switch-on.
I_h		current through the heater.
T_{rj}		temperature of ref. junctions of the heater.
L		left channel on Sanborn Recorder.
R		right channel on Sanborn Recorder.
T_0		time in which temperature starts to change.
t_1		time in which the voltage from temperature sensor reaches $1\mu v$.
V_{Jo}		reading from thermocouples in 50 sec. after start.
K		thermal conductivity (relative).

CONCLUSIONS

As this is an interim paper primarily intended to show progress, no conclusions are yet available.

REFERENCES

Akbar, S., "Experimental Determination of the Thermal Parameters of Some Rocks," unpublished M.Sc. Thesis, Queen's University, Kingston, Ontario, 1967.

Asaad, Y., "A Study of the Thermal Conductivity of Fluid Bearing Porous Rocks," Ph.D. Thesis, University of California, (June, 1955).

Birch, F., and Clark, H., "Thermal Conductivity of Rocks and Its Dependence on Temperature and Compositions," Am. Jour. of Sc., v. 238, p. 529-558, 1940.

Birch, F., Schairer, J.F., Spicer, H.C., Eds. Handbook of Physical Constants Publ. by Geol. Soc. Am., January 31, 1942, p. 251-258.

Boberg, T.C., and Lanz, R.B., "Calculation of the Production Rate of a Thermally Stimulated Well," SPE 1578 Soc. of Pet. Engr. 41st Annual Fall Meeting, Dallas, Texas, October, 1966.

Carslaw, H.S., and Jaeger, J.C., "Conduction of Heat in Solids," Oxford University Press, 2nd ed. 1962.

Edmondson, T.A., "Thermal Diffusivity of Sedimentary Rocks Subjected to Simulated Overburden Pressure." Thesis for M.Sc. University of California.

Gray, W.M., "Surface Spalling by Thermal Stresses in Rock," 3rd Canadian Symposium on Rock Mechanics, University of Toronto, January, 1965.

Hardy, H.R., and MacLean, M.J., "Measurement of the Coefficient of Linear Thermal Expansion of Mine Rock," Fuels and Mining Practice Division, Divisional Report FMP 66/99-P, Ottawa, 1966.

Kunii, D., Smith, J.M., "Thermal Conductivities of Porous Rocks Filled with Stagnant Fluid," Society of Petroleum Engineers Journal, March, 1961.

Lanz, R.B., and Boberg, T.C., personal correspondence 1967.

Loofbourow, R.L., "Depth and Rock Temperatures," Soc. of Min. Engr., Mining Engineering, January, 1966.

Marovelli, R.L., Chen, T.S., and Veith, K.F., "Thermal Fragmentation of Rock," 7th Symposium on Rock Mechanics Proceedings Penn. State Univ., June, 1965 and Engr. Index 1966, p. 142.

Melton, N.M., and Cross, T.S., "Fracturing Oil Shale with Electricity," Quarterly of the Colorado School of Mines, v. 62, no. 3, July, 1967, and personal correspondence, (November, 1967).

Somerton, W.H., and Mossahebi, M., "Ring Heat Source Probe for Rapid Determination of Thermal Conductivity of Rocks." The Review of Scientific Instruments, v. 38, no. 10, October, 1967.

Somerton, W.H., "Some Thermal Characteristics of Porous Rocks." Trans. AIME, 1958, Techns. note 2008.

Starfield, A.M., "Tables for the Flow of Heat into a Rock Tunnel with Different Surface Heat Transfer Coefficients." Jour. S. Afr. Inst. Min. and Met., July, 1966, p. 692-694.

Thomas, C.W., "Some Effects of Overburden Pressure on Oil Shale During Underground Retorting," SPE 1272, Soc. Pet. Engr. Denver, Colorado, October, 1965.

Wechsler, A.E., and Glaser, P.E., "Thermal Properties of Powdered, Vesicular, and Solid Rocks."

TABLE 2

Sample 1												Hole Distances: 30 ± 0.1 m.m.					
Exper. No.	Date	Heater No.	I_h (MA)	30 sec T_h (°C)	T_{RI} (°C)	Chann L Hole No.	t_0 (sec)	t_1 (sec)	Chann R Hole No.	t_0 (sec)	t_1 (sec)	Hole	VSO (μv)	K (cgs) $\times 10^{-3}$	Hole	VSO (μv)	K (cgs) $\times 10^{-3}$
1	7.1V	1	60.5			1	19.0	65.0	3	20.5	68.5	1	0.46		3	0.35	
2	8.1V	1	60.5	96		1	17.8	62.2	3	18.8	65.0	1	0.52		3	0.45	
3	9.1V	2	49.8	93	23.8	1	18.4	72.9	3	19.7	74.0	1	0.35	.825	3	0.31	.977
4	9.1V	2	49.8	93	25.0	1	19.4	72.0	2	24.0	77.7	1	0.34	.863	2	0.27	1.13
5	10.1V	2	49.3	91	24.1	3	19.0	73.5	2	22.5	77.0	3	0.34		2	0.30	
6	10.1V	2	50.1	95	25.0	3	19.5	73.5	2	21.0	76.0	3	0.32	.94	2	0.29	1.053
7	11.1V	2	50.3	95	25.6	4	21.0	75.2	2	22.0	76.5	4	0.29	1.053	2	0.30	1.015
8	13.1V	2	49.9	92	24.0	4	18.5	80.5	1	19.0	73.0	4	0.28	1.091	1	0.34	.863
9	14.1V	2	49.9	91	23.0	4	25.0	80.5	1	19.0	72.8	4	0.28	1.091	1	0.34	.863
10	17.1V	2	50.3	95	22.5	4	21.0	75.2	3	20.5	74.5	4	0.285	1.072	3	0.32	.94
11	18.1V	2	51.1	90	12.2	1	18.5	72.0	2	20.0	72.7	1	0.38		2	0.36	
12	18.1V	2	25.2	40	21.5	1	21.0	14.40	2	19.0	14.40	1			2		
Sample No. 1A												Hole Distances: 14.9 ± 0.05 m.m.					
1	23.1V	2	51.1	88	21.1	1	5.5	17.8	2	5.5	17.6	1	6.4	.938	2	6.75	.872
2	23.1V	2	51.4	88	21.1	1	4.5	17.2	3	5.0	17.2	1	6.55	.91	3	6.7	.88
3	24.1V	2	51.3	89	22.2	2	4.8	16.9	3	4.8	17.0	2	6.9	.843	3	6.7	.88
4	24.1V	2	51.7	89	21.6	1	5.0	17.3	4	5.5	19.9	1	6.55	.91	4	5.2	1.166
5	24.1V	2	51.3	90	22.7	1	5.1	17.5	4	5.6	20.2	1	6.55	.91	4	5.2	1.166
6	25.1V	2	51.1	91	23.3	1	4.9	17.3	4	5.1	20.0	1	6.55	.91	4	5.2	1.166
7	25.1V	2	51.1	89	22.7	2	5.0	17.0	4	5.5	20.0	2	6.9	.843	4	5.2	1.166
8	29.1V	2	50.9	88	25.0	1	4.6	16.7	4	4.9	19.2	1	6.8	.862	4	5.6	1.09
9	30.1V	2	51.0	89	26.3	2	5.2	16.8	4	5.4	19.0	2	6.85	.852	4	5.65	1.082
10	30.1V	2	50.9	90	27.6	3	5.0	17.5	4	5.1	18.9	3	6.45	.929	4	5.7	1.072
11	1.V	2	51.2	90	26.6	4	5.6	18.6	1	5.0	16.5	4	5.75	1.062	1	6.9	0.843
12	1.V	2	51.6	87	25.7	4	5.0	18.5	1	4.4	16.4	4	5.75	1.062	1	6.9	.843
13	1.V	2	51.6	87.5	26.4	4	5.0	18.8	1	4.2	16.4	4	5.7	1.072	1	6.9	.843
14	1.V	2	51.1	87	26.9	4	5.6	18.9	1	4.4	16.6	4	5.5	1.11	1	6.7	.88
15	5.V	2	26.75	43	25.0	4	6.5	34.8	1	6.1	30.5	4			1		