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7. *Studies of the Thermal State of the Earth. The Eighth Paper: Terrestrial Heat Flow Measurements in Kanto and Chubu Districts, Japan.*

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Abstract

Eight sets of new data on the terrestrial heat flow have been added to the existing five sets of data in Kanto and Chubu Districts, or the central part of Japan. Of the eight new localities, seven are in metal mines and one in a natural gas field.

Expressing the geothermal gradient $\Delta T/\Delta Z$ in $°C/100\,m$, and the heat flow in $10^{-6}\,cal/cm^2\,sec$, the present data can be summarized as:

Mobara:	$\Delta T/\Delta Z=1.85$,	$Q=0.54$	
Ashio:	$\Delta T/\Delta Z=3.57$,	$Q=2.23$	
Chichibu:	$\Delta T/\Delta Z=1.90$,	$Q=1.34$	
Kamioka:	$\Delta T/\Delta Z=2.77$,	$Q=1.80$	
Nakatatsu:	$\Delta T/\Delta Z=2.90$,	$Q=1.95$	
Kune:	$\Delta T/\Delta Z=1.97$,	$Q=1.60$	(Honzan)
	$\Delta T/\Delta Z=2.17$,	$Q=1.44$	(Nako)
Minenosawa:	$\Delta T/\Delta Z=2.82$,	$Q=1.79$	

Combined with previous data, the above figures indicate the following facts: a) Heat flow on the Pacific coast side of Kanto District is, without exception, small ($Q<1.00$); b) High heat flow region, known on the Japan Sea coast side of Tohoku District ($Q>2.00$) extends to the north-western part of Kanto District and possibly down to the Izu-Mariana Arc. This high heat flow region apparently coincides with that of Tertiary volcanism of Japan. c) Heat flow in Chubu District is higher than the world's average ($Q=1.2\sim1.4$) but not very much. This high value may be accounted for by the relatively thick crust of the District.

1. Introduction

During the period 1960–1962, a systematic survey of terrestrial heat flow in Japan was undertaken. Due to financial difficulties, drilling holes at desired localities specifically for the present purpose was beyond hope from the beginning, and it was necessary to make use of existing boreholes which were drilled for different purposes, mainly for prospecting natural resources.

Following the suggestions given by the Japan Mining Industry Association, Coal Association and Natural Gas Mining Association, a letter of inquiry as to the feasibility of carrying out a measurement of geothermal gradients and availability of rock specimens for thermal conductivity measurement was sent to some 40 metal mines, 20 coal mines and 100 oil and/or natural gas fields over the Japanese Islands. As a result of this inquiry, it was found that, out of these, about 30 metal mines, 10 coal mines and 15 oil and/or gas fields have deep boreholes, left untouched for a time long enough for dissipation of artificial thermal disturbances, and relevant rock specimens.

Up to the present, geothermal studies have been made at 45 localities, most of them producing useful data. As a result of the present survey, it seems that the general distribution of the terrestrial heat flow in Japan has been determined. A series of papers, the first of which is the present one, will describe the results of the measurements of terrestrial heat flow conducted in the course of the above project.

Terrestrial heat flow can be obtained from two separate quantities, namely thermal gradient $\Delta T/\Delta Z$ and thermal conductivity K of the strata in which thermal gradient was measured. Thermal gradient $\Delta T/\Delta Z$ was determined applying the method of least-squares to the temperature data on the assumption that the underground temperature increases linearly downward. Deviation of individual temperatures from the average temperature-depth relation which could be caused by numerous factors in the strata was regarded here as an inevitable disturbances to the average thermal field.

There are no definite way of estimating the composite thermal conductivity of the strata from the conductivities of individual rock samples. In the present study, an average thermal conductivity was substituted for the composite one. Substantial amount of errors will probably accompany with this method, especially when the thermal conductivities of individual rock samples differ greatly from each other.

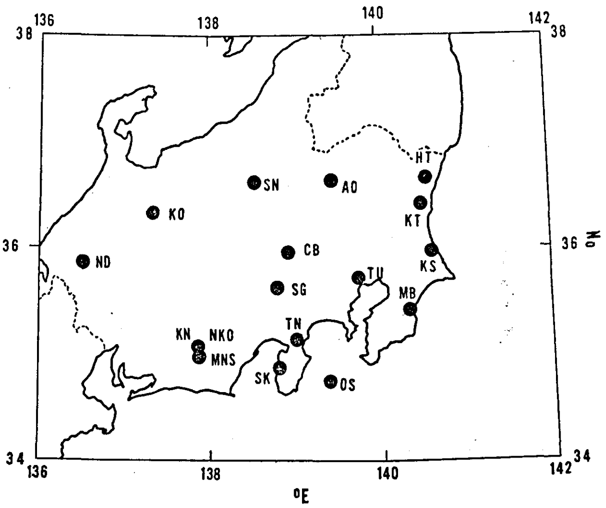

Fig. 1. Localities of heat flow measurement.

HT	:	Hitachi	TN	:	Tanna
KT	:	Katsuta	SK	:	Seikoshi
KS	:	Kashima	OS	:	Oshima
TU	:	Tokyo University	KO	:	Kamioka
MB	:	Mobara	ND	:	Nakatatsu
AO	:	Ashio	KN	:	Kune
KTSN	:	Kusatsu-shirane	NKO	:	Nako
CB	:	Chichibu	MNS	:	Minenosawa
SG	:	Sasago			

To illustrate the situation, consider an example that the heat flow $Q=1.5\times10^{-6}\,cal/cm^2\,sec$ was obtained from a set of data i. e., the mean thermal gradient $\frac{\Delta T}{\Delta Z}=2.5°\text{C}/100\,m$ and the average thermal conductivity $K=6\times10^{-3}\,cal/cm\,sec\,°\text{C}$. If the probable error of the thermal gradient obtained from the same data applying the method of least squares was 0.2 °C/100 m, it is easy to see that the deviation of thermal conductivity must be less than $1.52\times10^{-3}\,cal/cm\,sec\,°\text{C}$ in order to settle the possible errors of heat flow valves within 33 % i. e, $0.5\times10^{-6}\,cal/cm^2\,sec$. These figures will afford a certain indication regarding the accuracy of heat flow determinations.

In the following description, half the range of thermal conductivity, i, e., $\frac{R}{2}=\frac{max\,K-min\,K}{2}$ will be attached to the average thermal conductivity value for reference. When the strata was composed of rocks of different types, *max K* and *min K* were taken as the maximum and the minimum of the mean thermal conductivity of rocks belonging to the same rock type in the strata concerned.

There had been five sets of data relative to terrestrial heat flow in Kanto and Chubu Districts[1,2,3]. In the present paper, eight sets of new data will be presented: The localities are (see Fig. 1) Mobara Gas Field, Ashio Mine, Chichibu Mine, Kamioka Mine, Nakatatsu Mine, Kune Mine (Honzan Mine and Nako Mine) and Minenosawa Mine.

2. Mobara

The area around Mobara City, Chiba Prefecture, (Figs. 1 and 2) is well developed for natural gas production. We made temperature measurements in three boreholes owned by Aioi Kogyo Co., i. e. No.

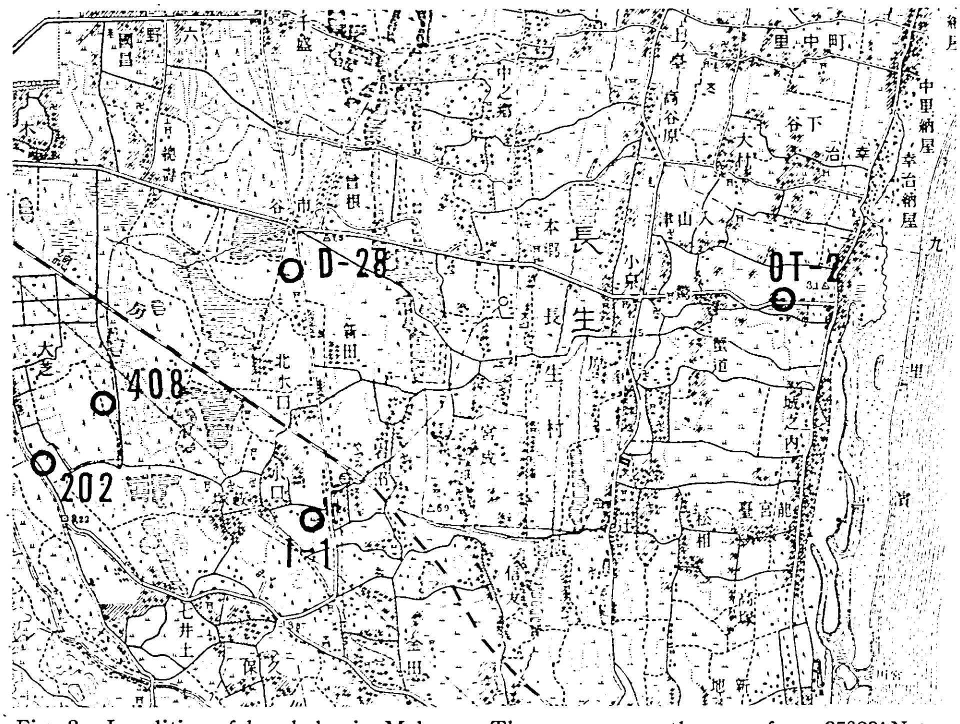

Fig. 2. Localities of boreholes in Mobara. The map covers the area from 35°23′ N to 35°26′ N in latitude and from 140°19′10″4 E to 140°24′10″4 E in longitude.

1) S. UYEDA, T. YUKUTAKE and I. TANAOKA, *Bull. Earthq. Res. Inst.*, **36** (1958), 251-273.
2) K. HÔRAI, *ibid.*, **37** (1959), 571-592.
3) S. UYEDA and K. HÔRAI, *ibid.*, **38** (1960), 421-436.

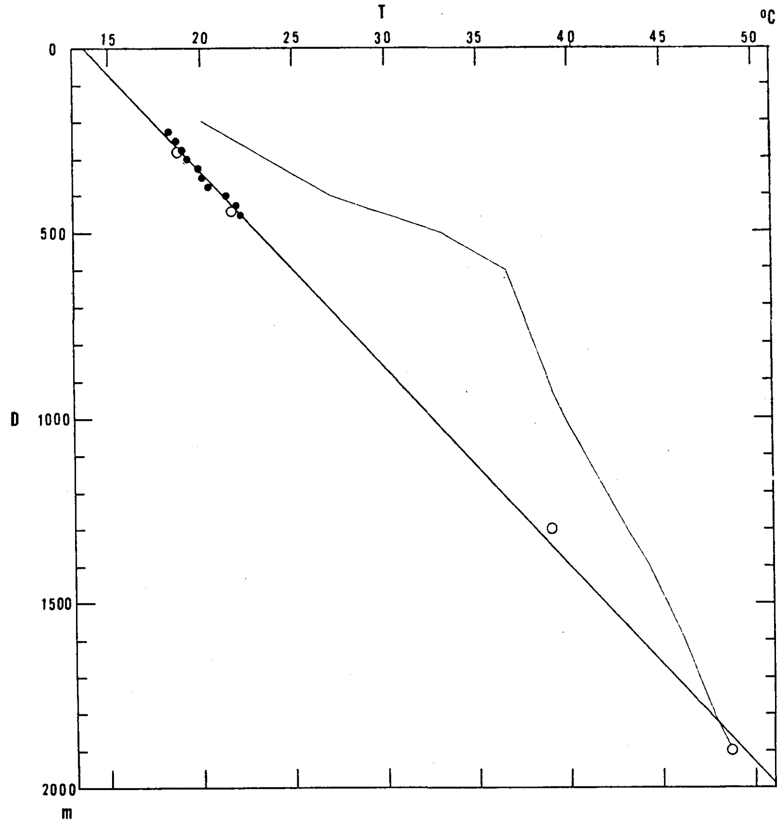

Fig. 3. Temperature—depth relation in Mobara gas field.
Hollow circles are the bottom temperatures of, from left to right, boreholes I-1, 202, D-28 and OT-2.
Full circles are the temperatures in the borehole No. 408.
Thin line is the temperature-depth curve for the borehole OT-2.
(Data for the boreholes D-28 and OT-2 are given by Kanto Natural Gas Development Co.)

408 (depth $d=470\,m$), No. 202 ($d=450\,m$) and I-1 ($d=275\,m$).

Approximate position coordinates of these boreholes are 35°24′-25′ N, 140°19′~23′E. Out of these three boreholes, gas was being drawn from No. 202 and I-1 until several hours before the temperature measurement, so that the temperature data is regarded as less reliable. It may be considered, however, that the bottom temperatures would be close to the actual temperature and are plotted in Fig. 3. The borehole No. 408, drilled in June, 1956, had been kept at rest for three months before the measurement (on 14, Feb. 1961) and the temperature-depth relation was obtained as shown in Fig. 3. There are two other underground temperature data records of the area; these are the bottom temperatures of nearby deep test wells OT-2 and D-28 owned by Kanto Natural Gas Development Co. (Fig. 2). The measurements were conducted by the company by means of an Amerada-type thermometer. It may be observed that these four sets of data lie on a straight line as in Fig. 3. The geothermal gradient obtained by the method of least squares for the area is $\Delta T/\Delta Z=1.85\pm0.02°C/100\,m$.

The geological formation concerned is an interbedding of sand and siltstone of Quaternary and Tertiary ages. Some siltstone specimens were given by Kanto Natural Gas Development Co. to the authors for thermal conductivity measurements. They are from 700 *m*, 100 *m*, 1400 *m* and 1700 *m* levels of the borehole OT-2 and the thermal conductivity was measured by the divided-bar method in the water-saturated state[4] to give the value listed in Table 1. The average of the measured

Table 1.

Specimen	Rock type and spot of collection	Thermal conductivity ($\times10^{-3}$ *cal/cm sec °C*)	Temperature duriug measurement (*°C*)	Water content by weight (*%*)
MB I	Siltstone 700m	2.50	24.2	19.7
II	Siltstone 1000m	3.14	24.3	11.0
III	Sandstone 1000m	2.18	24.4	11.5
IV	Sand 1400m	3.32	23.2	9.8
V	Siltstone 1700m	3.28	23.2	17.0
VI	Sandstone 1700m	3.21	22.5	6.7

values is $K=2.94\times10^{-3}\,cal/cm\,\text{sec}\,°\text{C}$. ($\frac{R}{2}=0.57\times10^{-3}\,cal/cm\ sec\ °C$) and thus the heat flow can be obtained as $Q=0.54\times10^{-6}\,cal/cm^2\,sec$.

A temperature-depth curve was obtained by the Kanto Natural Gas Development Co. for the borehole OT-2 as indicated by a thin curve in Fig. 3. Although the measurement was done after five months' quiescence, it was necessary to reduce the gas pressure from 30 kg/cm^2 to 25kg/cm^2 to lower the apparatus. This may have caused some thermal disturbance in the hole since the sharp kink at the depth of 600 *m* can hardly reconcile the continuity of heat flow unless thermal conductivity is about 4 times as small in the upper stratum as in the stratum lower than 600 *m*. Such a great change in the thermal conductivity is unlikely.

4) K. HÔRAI and S. UYEDA, *Bull. Earthq. Res. Inst.*, **38** (1960), 199-206.

3. Ashio

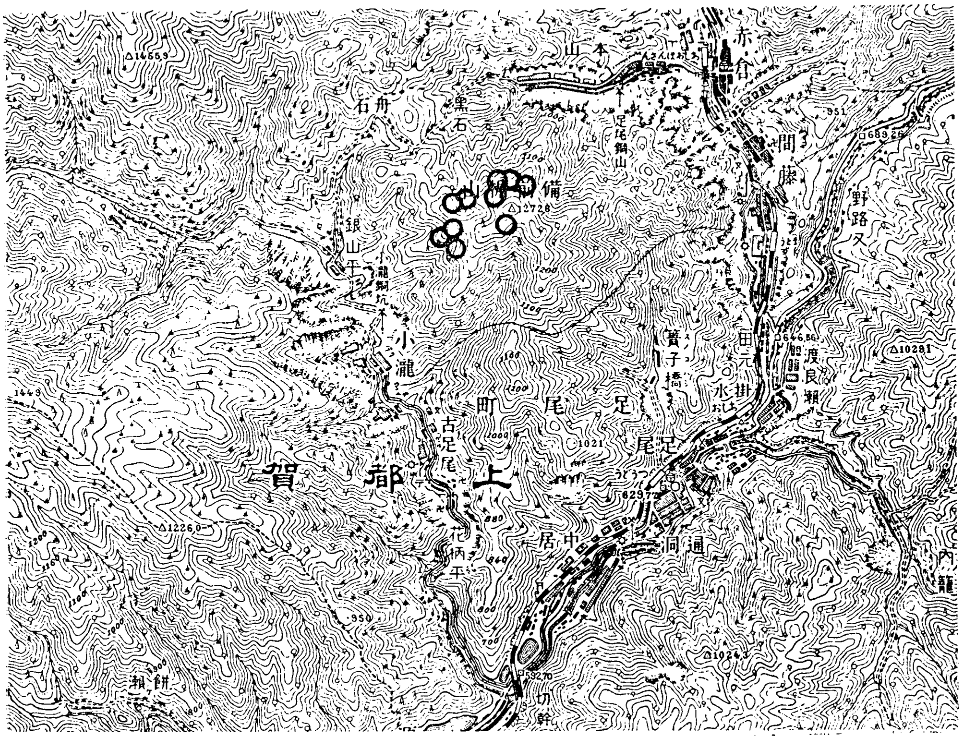

Fig. 4, a. Localities of temperature stations in Ashio Mine. The map covers the area from 36°37′ N to 36°40′ N in latitude and 139°23′10″4 E to 139°28′10″4 E in longitude.

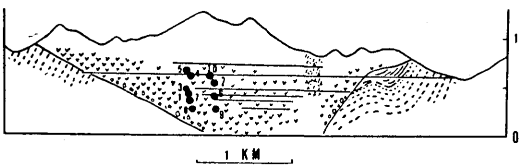

Fig. 4, b. NS section passing the peak of Mount Bizendate.

.... rhyolite
.... palaeozoics

Underground temperature measurement was conducted using ten short boreholes in drifts and galleries at various depths (0 *m* to 400 *m* from the surface) in Ashio Mine (36°39′N, 139°27′E), Tochigi Prefecture (Fig. 1 and Fig. 4). Drifts of Ashio Mine are developed in the body of a mountain called Bizendate, which is made of a rhyolite mass of the Miocene age. Copper ore veins are mainly in the rhyolite and "Kajika"

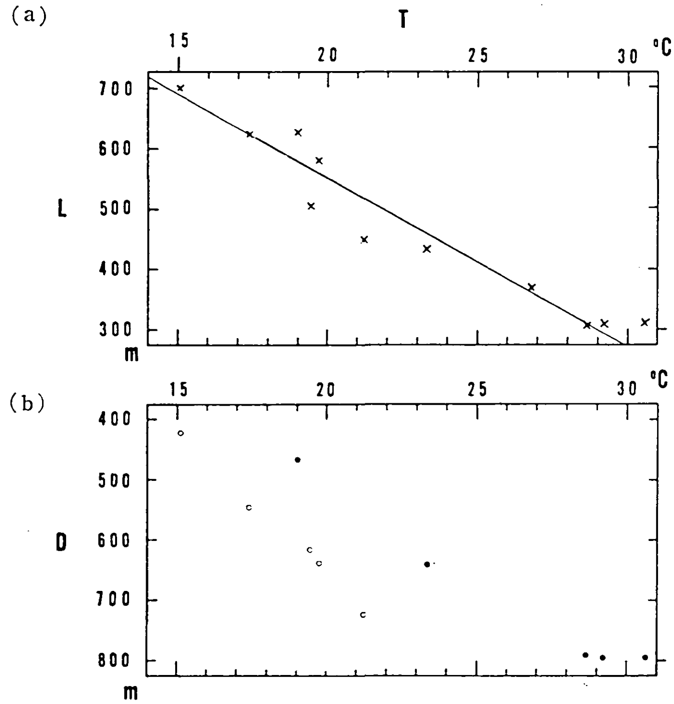

Fig. 5. (a) Temperature plotted against the altitude of the stations, Ashio. (b) Temperature plotted against the depth of the stations, Ashio.

ores are found in the surrounding paleozoics.[5] The rocks concerned with the present study are exclusively rhyolite (Fig. 4, b).

The temperature measurements were made throughout the length of each borehole and the asymptotic approach of temperature to the undisturbed rock-temperature was ascertained in each case.[6][7]

The results of the temperature measurements are shown in Fig. 5, a, b. It may be noticed in these diagrams that the temperature data

Table 2.

Specimen	Rock type	Thermal conductivity ($\times 10^{-3}$ *cal/cm sec °C*)	Temperature during measurement (°*C*)	Density (*gr/cm*^{3})
AO Ia	Rhyolite	6.54	29.4	2.60
Ib	Rhyolite	5.95	29.3	2.58

5) T. NAKAMURA, *Jour. Inst. Polytechnics, Osaka City Univ.*, Ser. G., **4**, (1961).
6) A. D. MISENER, *Trans. Amer. Geophys. Union*, **36** (1955), 1055.
7) K. HÔRAI, *Bull. Earthq. Res. Inst.*, **37** (1959), 571.

Table 3. Temperature stations in Ashio Mine.

No.	Name of the station	Altitude of site (m above sea level)	Depth of site (m)	d* (m)	Undisturbed rock temperature (°C)
1	Hotei-shita, No. 6 drainage drift	448	724	22.6	21.2
2	Hotei-shita No. 2 drift, Yoko No. 2, hanging wall.	581	639	8.6	19.7
3	Hotei-shita, No. 4 drift, Yokomabu 530 feet vein, shita 2 W3 bore, north cross cut.	505	616	17.3	19.4
4	Adit level, Yokomabu E6, foot wall, north cross cut	626	544	22.6	17.4
5	Ue, No. 2 drift, Hotei W4 bore	699	422	13.1	15.1
6	Yoko 3, shita No. 6 drift, Shinsei foot wall vein W8.	433	643	16	23.3
7	Yoko 3, shita No. 8 drift, vein No. 11 W16.				
	No. 1	369	767	15	26.8
	No. 2	369	767	5	26.8
8	Yoko 3, shita No. 10 drift, vein No. 12 W12,				
	No. 1	310	796	10	30.6
	No. 2	310	796	0	29.2
9	Yoko 3, shita No. 10 drift, platform for shaft	307	791	10	28.6
10	Ginsei adit level, 350 feet vein W16.	627	467	12	19.0

* d=Distance of the position of thermometer in a borehole from the drift wall.

Remark: Water was flowing out of borehole No. 2 of station No. 8 and borehole at station No. 9.

shows more consistency when plotted against the altitude rather than against the depth from the surface overhead. Implications of this fact will be treated elsewhere.[8] The geothermal gradient thus determined by the method of the least squares in Ashio Mine is 3.57 ± 0.31°C/100 m. The mean thermal conductivity of the rhyolite was determined as 6.25 $\times 10^{-3}$ $(\frac{R}{2} = 0.29 \times 10^{-3})$ $cal/cm\,sec°C$ (Table 2), so that the terrestrial heat flow value is $Q = 2.23 \times 10^{-6}\, cal/cm^2\, sec$.

The description of the temperature stations is as shown in Table 3, (Fig. 4 and 5).

4. Chichibu

Temperature measurements in two boreholes were made in Chichibu Mine (36°01′N, 138°48′E), Saitama Prefecture (Fig. 1 and Fig. 6). The site of the boreholes was the Base No. 3 in Doshinkubo Mine, where the altitude is 1024 m above sea level and the altitude of the surface

8) K. HÔRAI, *Bull. Earthq. Res. Inst.* (to be published).

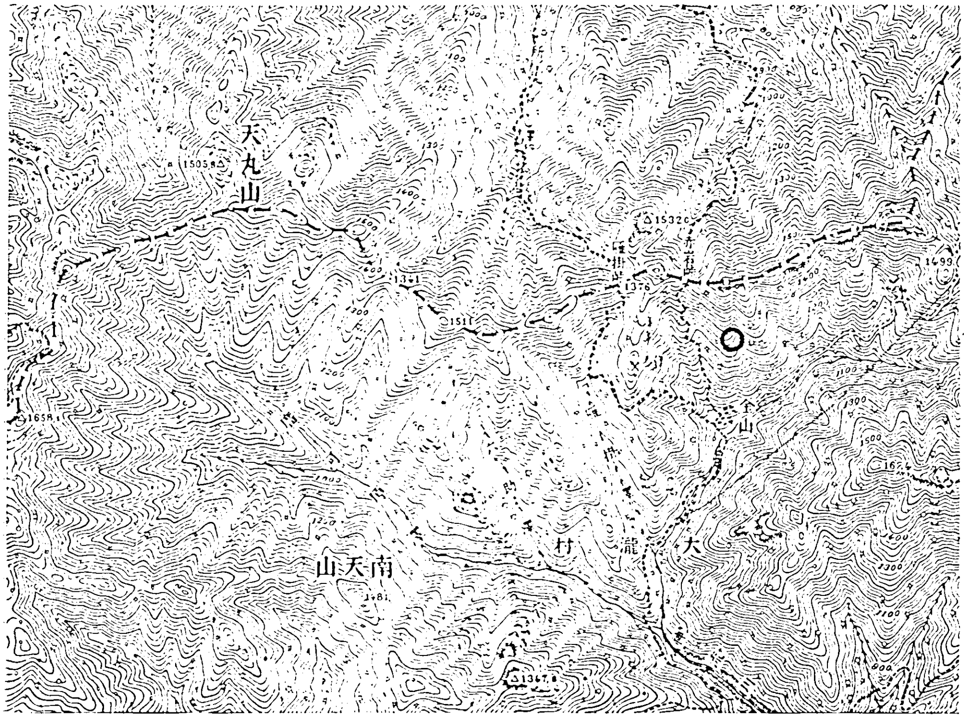

Fig. 6. Locality of boreholes in Chichibu Mine. The map covers the area from 36°00′ N to 36°03′ N in latitude and from 138°45′10″4 E to 138°50′10″4 E in longitude.

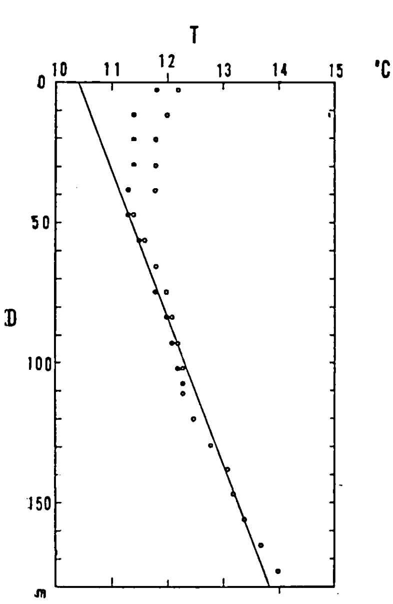

Fig. 7. Temperature-depth relation in Chichibu Mine. The ordinate is the vertical depth in boreholes regardless of surface topography.

Table 4.

Specimen	Rock type	Termal conductivity ($\times 10^{-3}$ *cal/cm sec °C*)	Temperature during measurement (°*C*)	Density (*gr/cm³*)
C B I	Limestone	6.56	29.4	2.67
II	Magnetite	6.54	29.4	4.25
III	Pyrrhotite	8.62	29.3	4.05

overhead is 1250 *m* above sea level. The depth of the site therefore is 226 *m*. The holes were test bores No. 560 (vertical depth=107.5 *m*) and No. 554 (vertical depth=174.5 *m*). The angles of declination and inclination of the boreholes were 215°, −65° and 180°, −65° respectively.

The results of temperature measurements in the two holes show more consistency when plotted against the altitude regardless of the surface topograpy rather than against the depth, just as in the case of Ashio Mine. In Fig. 7, the ordinate is the vertical depth from the site of the bore, which is essentially the altitude, and the least square geothermal gradient is $1.90\pm0.07°C/100\,m$.

As shown in Fig. 6, Chichibu Mine is located amidst the Chichibu Mountainland. Magnetite and Pyrite ores are developed in skarn and limestone in association with the Miocene intrusives.[9]

The rock specimens were limestone, magnetite and pyrite ore, whose thermal conductivities were found as shown in Table 4. From consideration of the geological section of the concerned area, these measured thermal conductivities were averaged with the weight of 2:1:1 and the mean thermal conductivity thus obtained was $K=7.06\times10^{-3}$ $(\frac{R}{2}=1.04\times10^{-3})$ *cal/cm sec°C*. The amount of heat flow then is $Q=1.34\times10^{-6}$ *cal/cm² sec*.

5. Kamioka

In Kamioka Mine, Gifu Prefecture, temperature measurements were made in two long boreholes and one short hole in Tochibora Mine (36°21′ N, 137°19′ E) (Fig. 1 and 8). The boreholes are listed in Table 5.

The effective or vertical depths of the long boreholes were 388 *m* (*XH* 94) and 221 *m* (*XH* 78). Just as in the two cases mentioned in the earlier sections, the temperature data in Kamioka Mine is also more consistent when plotted against the altitude than against the depth as shown in Fig. 9, and the least square geothermal gradient is $2.77\pm0.04°C/100\,m$.

9) M. KANEDA, private communication.

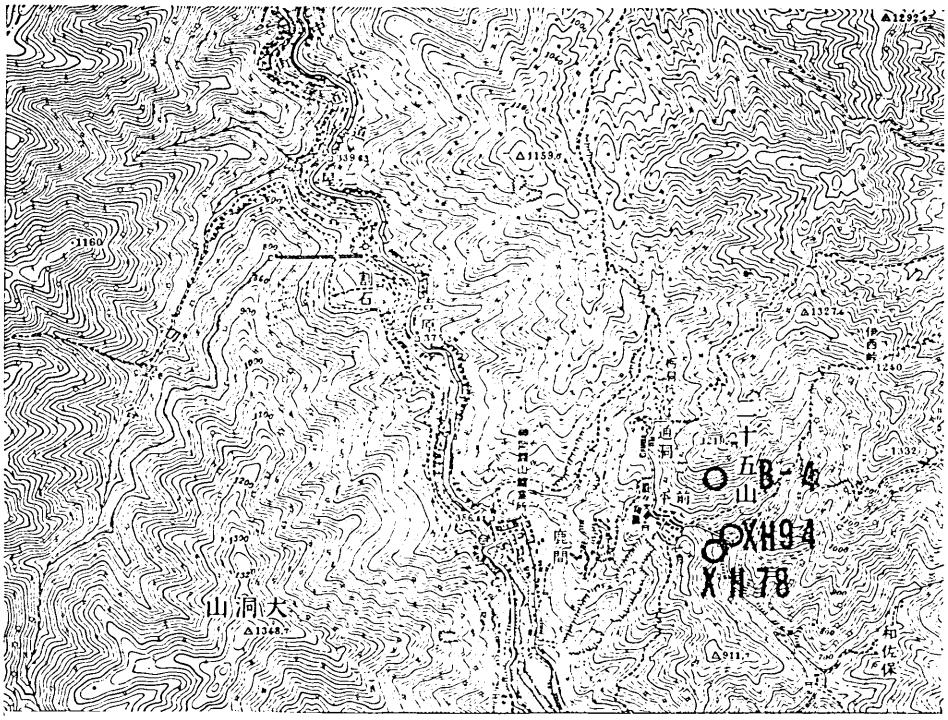

Fig. 8. Localities of boreholes used in Kamioka Mine. The map covers the area from 36°20′ N to 36°23′ N in latitude and from 137°15′10″4 E to 137°20′10″4 E in longitude.

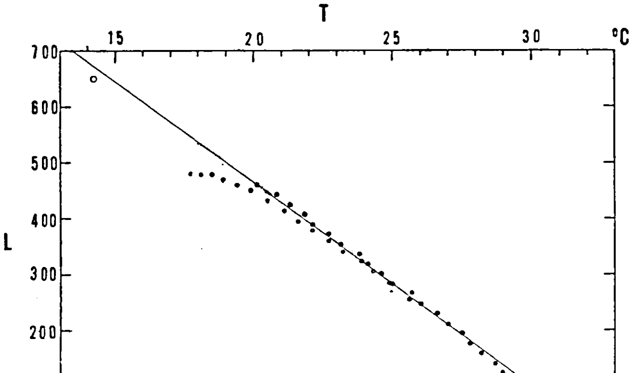

Fig. 9. Temperature-altitude relation in Kamioka Mine. Hollow circle at the upper left corner: Borehole B-4, Hollow circles: Borehole *XH* 78, Full circles: Borehole *XH* 94.

Kamioka Mine is located high up in the Hida Plateau (Paleozoics). Zinc and lead ores are formed in skarns which are considered as being formed in connection with the intrusion of granite-porphyry in the Mesozoic age into gneiss and limestone.[10] The rock specimens for thermal conductivity determination are diopside-gneiss, limestone, mela-

10) S. TONO, private communication.

Table 5. Temperature stations at Kamioka Mine

Name of borehole	Altitude of boring site (*m* above sea level)	Depth of boring site (*m*)	Declination of bore	Dip of bore	Length of bore (*m*)
No. XH 94	480	398	217°	−61°	446
No. XH 78	480	363	0°	−60°	287
B-4	650	325	106°	−14°	8

Table 6.

Specimen	Rock type	Thermal conductivity ($\times 10^{-3}$ *cal/cm sec °C*)	Temperature during measurement (°*C*)	Density (*gr/cm*^{3})
KO I	Diopside gneiss	5.22	29.1	2.80
II	Limestone	5.52	28.8	2.66
III	Mela-gneiss	4.16	29.0	2.71
IV	Granite porphyry	5.62	28.9	2.54
V	Hedenbergite skarn	5.49	28.8	3.25
VI	Hedenbergite skarn	8.78	28.6	3.27
VII	Andradite	8.90	28.9	3.66

gneiss, granite-porphyry, hedenbergite-skarn, garnet (andradite). The conductivity values measured are listed in Table 6 and the average value is $K=6.49\times10^{-3}$ *cal/cm sec* °*C* ($\frac{R}{2}=2.37\times10^{-3}$*cal/cm sec* °*C*). The value of the heat flow is thus $Q=1.80\times10^{-6}$ *cal/cm*^{2} *sec.*

6. Nakatatsu

In Nakatatsu Mine (Fig. 1 and Fig. 10), Fukui Prefecture, temperature measurements were made using one vertical borehole and two horizontal boreholes in Nakayama Mine (35°52′ N, 136°35′ E). The boreholes used are described in Table 7.

In the present case again, the subterranean temperatures are better lined up when plotted against the altitude than against the depth from the surface overhead (Fig. 11), and the "least squares" geothermal gradient is 2.90 ± 0.06°*C*/100 *m*.

Nakatatsu Mine is a contact metasomatic ore of zinc and lead, developed in skarn bands in Paleozoic limestone in association with late-Mesozoic or Tertiary intrusives.[11]

Rock specimens used for conductivity estimation were garnet skarn,

11) K. WAKABAYASHI, private communication.

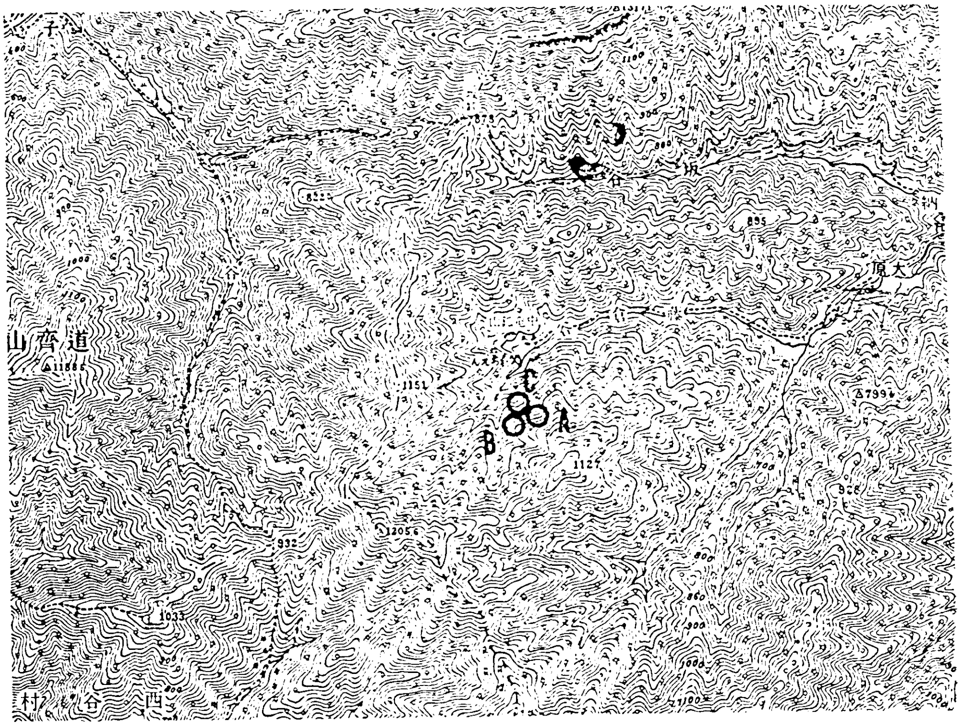

Fig. 10. Localities of boreholes in Nakatatsu Mine. The map covers the area from 35°51′ N to 35°54′ N in latitude and from 136°32′10″4 E to 136°37′10″4 E in longitude.

A: $-160m$ level downward vertical bore.
B: $-200m$ level No. 4 horizontal bore.
C: $0m$ level No. 275 horizontal bore.

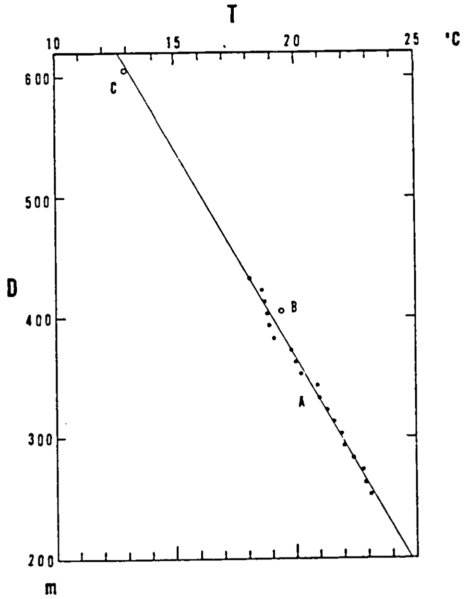

Fig. 11. Subterranean temperature vs. altitude in Nakatatsu Mine.

A: $-160m$ level downward vertical bore.
B: $-200m$ level No. 4 horizontal bore.
C: $0m$ level No. 275 horizontal bore.

Table 7. Temperature stations at Nakatatsu Mine

Name of berehole	Altitude of boring site (*m* above sea level)	Depth of site (*m*)	Length of borehole (*m*)
−160 m level downward vertical.	435	460	180
−200 m level No. 4 horizontal.	405	440	22.6
0 m level No. 275 horizontal.	605	180	8.6

Table 8.

Specimen	Rock type	Thermal conductivity ($\times 10^{-3}$ *cal/cm sec °C*)	Temperature during measurement (°C)	Density (gr/cm^3)
ND I	Garnet skarn	7.68	29.1	3.41
II	Porphyrite	5.50	29.0	3.20
III	Hedenbergite skarn	6.38	28.9	3.40
IV	Limestone	5.16	28.8	2.68

hedenbergite skarn, and porphyrite. From the geological column concerned the conductivities of these rocks (Table 8) were averaged with relative weights of garnet skarn: hedenbergite skarn: porphyrite $=82:49:52$. The weighted mean of the thermal conductivity is $K=6.71 \times 10^{-3}\, cal/cm\, sec\, {}^\circ C$ ($\frac{R}{2}=1.26\times 10^{-3}$). The amount of terrestrial heat flow, then, becomes $Q=1.95\times 10^{-6}\, cal/cm^2\, sec$.

7. Kune

In Kune Mines, Shizuoka Prefecture (Fig. 1 and Fig. 12), geothermal measurements were made using 14 horizontal boreholes and one vertical borehole drilled from drifts at various levels of Honzan Mine (35°05′ N, 137°50′ E), and 7 horizontal boreholes at various levels of Nako Mine (35°03′ N, 137°52′ E). The vertical distance covered by the above measurements was about 500 *m* in Honzan Mine and 400 *m* in Nako Mine. The descriptions of the temperature stations (Fig. 12) are as listed in Table 9.

In all cases, temperature was measured at a distance of 13 *m* from the mouth of the hole. The temperature data is as shown in Fig. 13 and Fig. 14. The results from Kune (Honzan) Mine are rather scattered and the geothermal gradient determined by the method of the

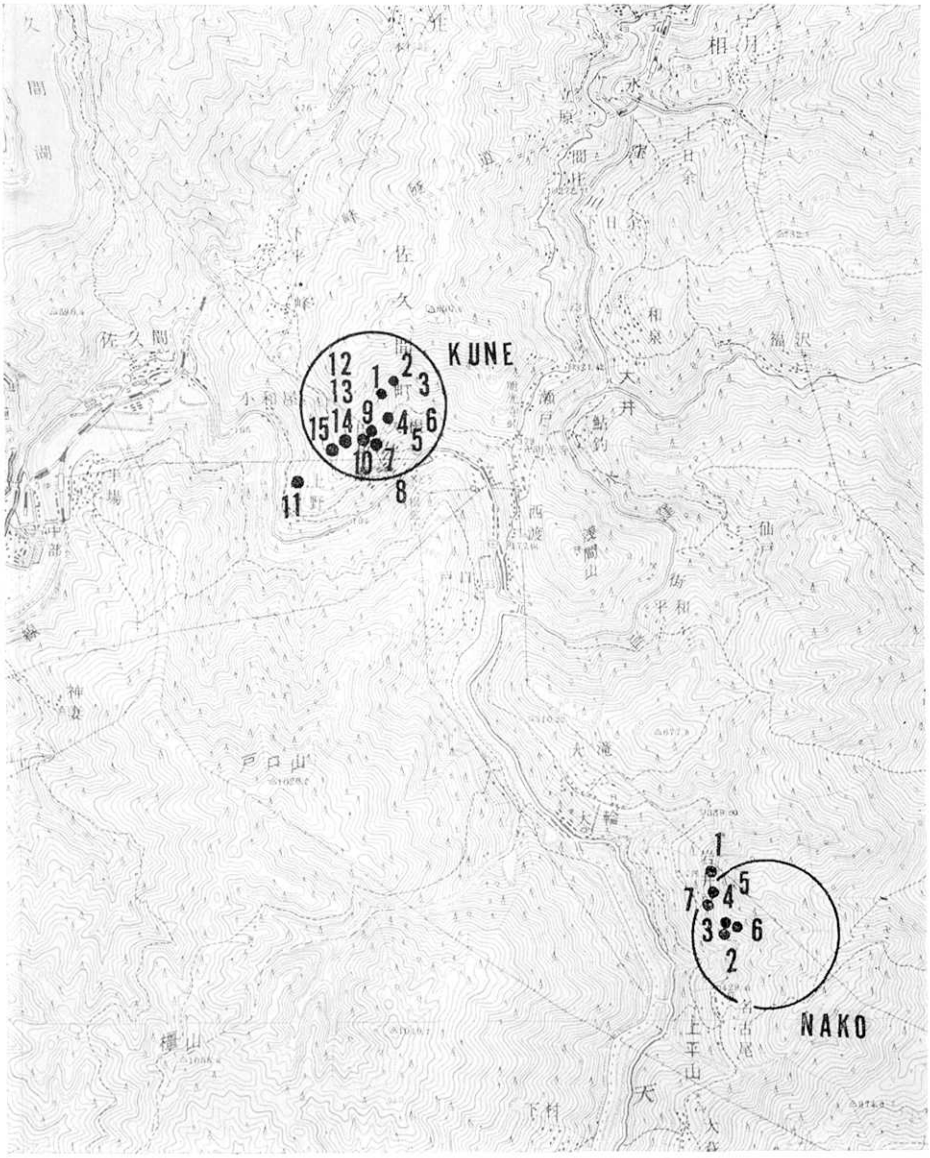

Fig. 12. Localities of boreholes in Kune (Honzan) and Nako Mines. Numbers to the circles refer to those in Table 9. The map covers the area from 35°02′ N to 35°07′ N in latitude and from 137°48′ E to 137°53′ E in longitude.

least squares is $1.97 \pm 0.31\ °C/100\ m$, while that from the data in Nako Mine is $2.17 \pm 0.12\ °C/100\ m$.

Ores in the Kune Mines belong geologically to so-called Kieslager-type

Table 9. Temperature stations at Kune Mine.

No.	Altitude of site (*m* above sea level)	Depth of site (*m* from ground surface)	Rock temperature (°*C*)
Honzan Mine 1	146	319	19.7
2	146	267	19.5
3	146	267	19.8
4	262	168	21.3
5	262	178	18.0
6	262	183	21.4
7	237	191	21.9
8	237	188	22.1
9	176	284	22.5
10	176	269	23.6
11	−210∼−282	488∼560	24.4∼27.2
12	−4	464	26.0
13	−4	461	29.1
14	−4	461	29.1
15	−70	372	28.4
Nako Mine 1	−105	639	24.9
2	133	369	19.8
3	133	375	19.4
4	134	381	19.8
5	134	381	19.3
6	285	245	16.0
7	285	209	15.9

Table 10.

Specimen	Rock type	Thermal conductivity ($\times 10^{-3}$ *cal/cm sec* °*C*)	Temperature during measurement °*C*)	Density (*gr/cm*³)
KN I*	Crystalline schist	6.36	33.9	2.93
II		8.93	33.9	2.99
III		9.59	33.9	2.69
IV		7.69	33.9	2.69
KN V**	Crystalline schist	6.40	33.6	2.91
VI		6.28	33.6	2.86
VII		6.29	33.6	2.91
VIII		6.42	33.7	2.91
IX		6.00	33.5	2.86
X		7.15	33.5	2.88
XI		8.02	33.4	2.96

* Collected in Honzan Mine.

** Collected in Nako Mine.

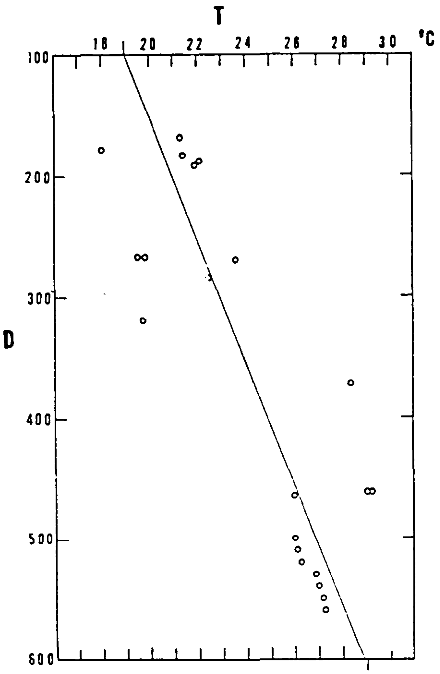

Fig. 13. Subterranean temperature in Kune (Honzan) Mine, plotted against the depth of stations from the land surface overhead.

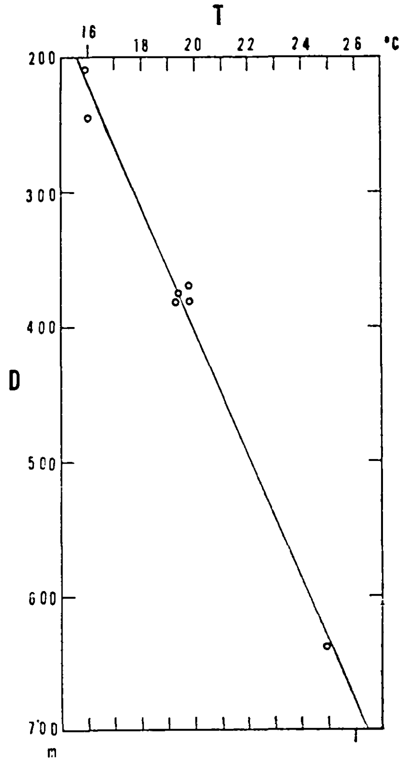

Fig. 14. Subterranean temperature in Nako Mine, plotted against the depth of stations from the land surface overhead.

bedded cupriferous pyritic deposits in Sambagawa crystalline shists.[12][13] Specimens (four from Honzan Mine, and seven from Nako Mine) of crystalline shists were sampled for the estimation of the thermal conductivity. Table 10 shows the measured conductivity values. The mean thermal conductivity obtained from these measurements is $K=8.14\times10^{-3}$ $(\frac{R}{2}=1.62\times10^{-3})$ $cal/cm\,sec\,°C$ for Kune (Honzan) Mine, and $K=6.65\times10^{-3}$ $(\frac{R}{2}=1.01\times10^{-3})$ $cal/cm\,sec\,°C$ for Nako Mine respectively.

The heat flow values are, thus,

$$Q=1.60\times10^{-6}\,cal/cm^2\,sec \text{ (Honzan Mine)},$$
$$Q=1.44\times10^{-6}\,cal/cm^2\,sec \text{ (Nako Mine)}.$$

12) T. KAMIYAMA, *Journ. Mining and Metallurgical Inst. Japan*, **75** (1959), 715.
13) T. KAMIYAMA and N. YAMAE, *Mining Geology*, **11** (1961), 136.

8. Minenosawa

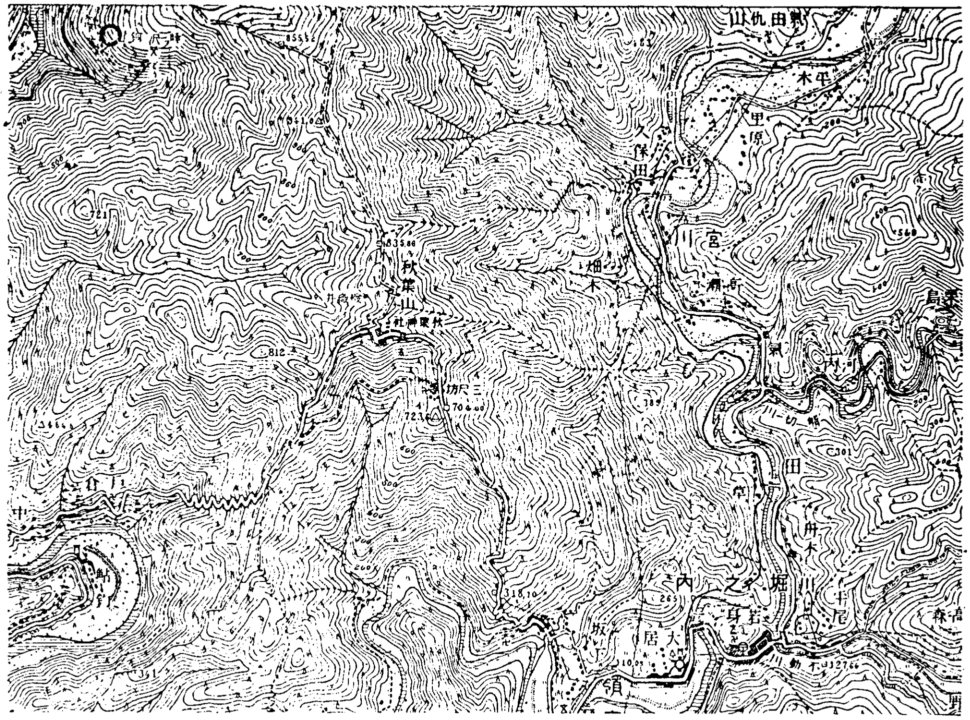

Fig. 15. Locality of the boreholes (upper left corner) in Minenosawa Mine. The map covers the area from 34°57′ N to 35°00′ N in latitude and from 137°50′10″4 E to 137°55′ 10″4 E in longitude.

A borehole dipping −57° (No. 1) and a vertical borehole (No. 2) were used for the estimation of the underground temperature gradient in Minenosawa Mine (35°00′ N, 137°51′ E), Shizuoka Prefecture, (Fig. 1 and Fig. 15).
However, as the temperature measurement was made when borehole No. 1 was under the operation of drilling, it was considered that only the bottom temperature would be close to the real undisturbed temperature.[14)15)]

Borehole No. 2 is a 97 m long vertical hole from a drift 90 m below the land surface, and the result of temperature measurement is shown in Fig. 16 by full circles. The geothermal gradient from this data is 2.92 ± 0.15 °C/100 m.

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14) S. R. COOPER and C. JONES, *Geophys. Journ. Roy. Astr. Soc. London* (1959), 116.
15) S. UYEDA and K. HÔRAI, *Bull. Earthq. Res. Inst.*, **38** (1960), 421.

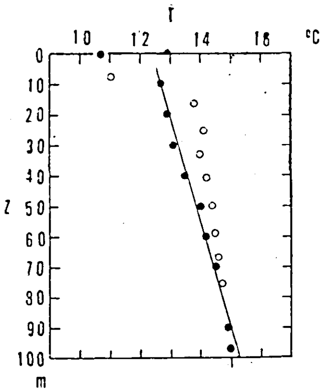

Fig. 16. Temperature depth relation in Minenosawa Mine. Full circles: Borehole No. 2. Hollow circles: Borehole No. 1, which was being drilled at the time of measurement.

Table11.

Specimen		Rock type	Thermal conductivity ($\times^{-3}$ *cal/cm sec °C*)	Temperature during measurement (°C)	Density (*gr/cm³*)
MNS	I	Crystalline schist	6.24	34.7	2.99
	II		5.82	34.7	2.98
	III		5.18	34.8	3.03
	IV		7.27	34.8	2.93

In the same figure, the temperature data from bore No. 1 is also shown by hollow circles, taking the common ordinate as the altitude. It may be stated that the measured bottom temperature, in accordance with expectation, coincides approximately with the undisturbed temperature.

Minenosawa Mine, being located about 5 *km* south of Nako Mine described in the preceding section, belongs geologically to the so-called Kieslager-type mines and the rocks dominating the area are all Sambagawa shists[16]. The average value of the thermal conductivity for four specimens of shists (Table 11) is $K=6.13\times10^{-3}$ $(\frac{R}{2}=1.05\times10^{-3})$ *cal/cm sec °C*, so that the heat flow of this area may be estimated as $Q=1.79\times10^{-6}$ *cal/cm² sec*.
Since the depth of the borehole was only 97 *m*, it must be mentioned that the geothermal gradient estimated here has less reliability compared with other cases in the present report.

9. Seikoshi

In Seikoshi Mine (34°54′N, 138°49′E), Shizuoka Prefecture (Fig. 1), 6 boreholes at various depths were used for temperature measurements. It was hoped that important data would be obtained from the measurements because the location of Seikoshi Mine is on the possible extension of the zone of high heat flow (see Fig. 1).

However, the underground temperature in the mine was found to be badly scattered. The effect of circulation of underground water was suspected as causing this.

16) T. WATANABE. Ed., *Progress in Economic Geology* (Fuzanbo, Tokyo, 1956.)

10. Tanna Basin

Two boreholes, drilled for the geological survey of Tanna Basin by Japan National Railways, were made available for temperature measurement.

The boreholes were located in Tanna Basin (Fig. 1) under which the New Tanna Tunnel was being constructed, and were about 150 *m* and 180 *m* deep.

In both cases, it was found that there is no observable temperature gradient (Fig. 17). Again, the effect of underground water is considered to be responsible for this.

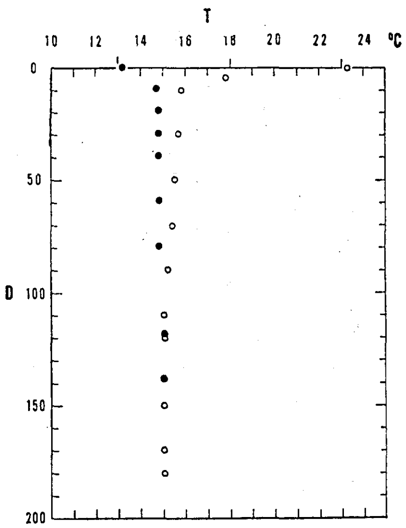

Fig. 17. Temperature depth relations in Tanna Basin.
Full circles: Naga, No. 1, 1958
Hollow circles: Takizawa No. 1,

11. Conclusion and Acknowledgement

Data on terrestrial heat flow in Kanto and Chubu Districts is summarized in Table 12. In this table, data already published is also included. Table 12, together with Fig. 1, seems to indicate the following facts. 1) Heat flow is invariably small ($Q<1\times10^{-6}$ *cal/cm*^{2} *sec*) on the Pacific coast side of Kanto District. 2) Zone of relatively high ($Q>2\times10^{-6}$ *cal/cm*^{2} *sec*) heat flow known on the Japan Sea coast of Tohoku District[15][17] seems to extend down to the northwestern part of Kanto District. This zone, being coincident with that of the Tertiary volcanism in Japan, is suspected to continue farther south to the Izu-Mariana Island Arc. 3) West of the area mentioned in 2), i. e. the main part of Chubu District has heat flow higher than the world's average but not as high as 2×10^{-6} *cal/cm*^{2} *sec*.

In the region treated in the present report, the heat flow at Kusatsu-Shirane geothermal area was found to be anomalously high. It was found, however, that the geothermal gradient in Volcano Mihara, Oshima Island, measured in several deep wells is almost nil[18]. Such a case was encountered in three other localities in the present area, i. e. Hokota, Tanna, and Seikoshi. In all these cases, the temperature variation with

17) S. UYEDA, T. YUKUTAKE and I. TANAOKA, *Bull. Earthq. Res. Inst.*, **36** (1958) 251.
18) S. UYEDA, *Bull. Earthq. Res. Inst.*, **39** (1961), 579.

Table 12. Terrestrial heat flow in Kanto and Chubu Districts, Japan

Locality	Abbreviation	Site	Latitude (N)	Longitude (E)	Geothermal gradient (°C/100m)	Thermal conductivity (10^{-3} cal/sec cm °C)	Terrestrial heat flow (10^{-6} cal/sec cm^2)	Remarks
Hitachi	HT	Cu mine	36° 38′	140° 38′	0.94 1.21	6.73-7.08 6.51-7.43	0.63-0.67 0.79-0.90	Northern part(19) Southern part(19)
Katsuta	KT	Gas field	36° 24′	140° 30′	3.01	3.02	0.91	(20)
Hokota	HK	Sandy coast	36° 12′	140° 27′	—		—	(21)
Kashima	KS	Gas field	35° 57′	140° 41′	2.1	3.57	0.76	(20)
Mobara	MB	Gas field	35° 24′	140° 20′	1.85	2.94	0.54	
Tokyo	TU	Tokyo University	35° 42′	139° 46′	2.20	3.36	0.74	(20)
Ashio	AO	Cu mine	36° 39′	139° 27′	3.57	6.25	2.23	
Kusatsu-Shirane	KTSN	Geothermal area	36° 37′	138° 34′	24.2	4.48	10.8	(21)
Chichibu	CB	Fe mine	36° 01′	138° 48′	1.90	7.06	1.34	
Sasago	SG	Railway tunnel	35° 37′	138° 48′	2.71	7.61	2.06	(21)
Tanna	TN	Tanna basin	35° 13′	139° 00′	—		—	
Seikoshi	SK	Au mine	35° 54′	138° 49′	—		—	
Oshima	OS	Volcano	34° 45′	139° 25′	—		—	(22)
Kamioka	KO	Zu, Pb mine	36° 21′	137° 19′	2.77	6.49	1.80	
Nakatatsu	NT	Zu, Pb mine	35° 52′	136° 35′	2.90	6.71	1.95	
Kune	KN	Cu mine	35° 05′	137° 50′	1.97	8.14	1.60	
Nako	KNO	Cu mine	35° 03′	137° 52′	2.17	6.65	1.44	
Minenosawa	MNS	Cu, Zn mine	35° 00′	137° 51′	2.92	6.13	1.79	

(19) K. HÔRAI, *Bull. Earthq. Res. Inst.*, **37** (1959) 571
(21) S. UYEDA, T. YUKUTAKE and I. TANAOKA, *Bull. Earthq. Res. Inst.*, **66** (1958) 251.
(20) S. UYEDA and K. HÔRAI. *Bull. Earthq. Res. Inst.*, **38** (1960) 421.
(22) S. UYEDA, *Bull. Earthq. Res. Inst.*, **39** (1961) 579.

depth showed some strange features, such as nil gradient or negative gradient, and it has been suspected that undergound water movement is causing these.

The authors would like to thank many people at the heat flow stations, whose kind assistance made the present series of work possible. Only a few names of these people will be mentioned in the Japanese abstracts of each paper. We are also indebted to Prof. T. Rikitake for his kind supervision on the whole project.

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7. 地球熱学第8報 関東および中部地方における地殻熱流量測定結果

地震研究所 上田誠也
東京大学大学院数物系研究科
地球物理学専門課程 宝来帰一

1. 1957年以来，地震研究所においては，日本全土における地殻熱流量分布の決定が試みられてきた. 1961年以降には，日本鉱業協会，日本石炭協会，天然ガス鉱業会，帝国石油株式分社，東京大学地質学教室の渡辺武男教授，久野久教授他の大きな御協力を得て，全国の鉱山，炭礦，油田，ガス田等においてやや組織的な地熱測量が行なわれた. 地球熱学第8報乃至第12報は，その結果の報告である，この仕事では，樋口重雄氏，山川一郎氏(日本鉱業協会)，佐久洋氏，佐野孝一氏(石炭協会)，橋爪義雄氏(天然ガス鉱業会)，柴宮博氏(帝国石油株式会社)，他多くの方々，並びに，各現場での数多の方々の御指導，御援助を得た. 記して深甚の謝意を表明する. 岩石熱伝度測定のための試料研磨については，地震研究所渡辺佐技官に多大のお世話になつた. なお，この研究は地震研究所力武常次教授の全面的御援助の下に終始したものである.

従来，関東地方，中部地方には，信頼し得る地殻熱流量，Q，の測定は5個であつた. すなわち，Q を $10^{-6}\,cal/cm^2\,sec$ で表して，日立 ($Q=0.94\sim1.21$)，鹿島 ($Q=0.76$)，勝田 ($Q=0.91$)，東京大学構内 ($Q=0.74$)，笹子トンネル ($Q=2.06$)，である. 今回は，新たに，8個の測定が加えられた，その結果概要は以下の通りである.

千葉県茂原:	$Q=0.54$
栃木県足尾:	$Q=2.23$
埼玉県秩父:	$Q=1.34$
岐阜県神岡:	$Q=1.80$
福井県中竜:	$Q=1.95$
静岡県久根:	$Q=1.60$, (久根坑)
	$Q=1.44$, (名合坑)
静岡県峰之沢:	$Q=1.79$

本文，第1図を参照しつつ，上記結果を検討すると，以下のことが明らかである.

a) 関東地方太平洋側では，地殻熱流量は例外なく小さい ($Q<1.0$).

b) 従来察知されていた，東北地方日本海側の地殻熱流量の大きい地域 ($Q>2.0$) の延長が，関東地方西北部にもみられ，所謂，第三紀火成活動帯と一致している. この地域は，更に南にのび，伊豆マリアナ弧につながる可能性がある.

c) 中部地方の大部分は，世界的平均熱流量 ($Q=1.2\sim1.4$) よりは大きい値を示すが，$Q=2.0$ には至らない程度である.

なお，この地方では，既報，草津白根地熱地帯での結果のごとく，熱流量が局地的異常を示した

例もあるが，伊豆大島火山，丹那盆地，清越鉱山等，おそらくは地下水の流動のために，信頼するに足る地温勾配の得られない場合もあつた．

各測点での記録は以下のごとくである．

2. 茂原： 千葉県茂原市周辺は，関東堆積盆地での天然ガス産地で，このための試錐孔が多い．今回は，相生工業株式会社所有の試錐 No. 408 (深さ 470 *m*), No. 202 (深さ 450 *m*), および I-1 (深さ 275 *m*) について，温度測定を行つた．このうち， No. 408 以外は，測定当日まで作業中であり，孔底温度以外は信頼度がすくない．この地区 (35°24-25′ N, 140°19-23′ E) では，この他に，関東天然ガス開発株式会社所有の深井 OT-2, D-28 中での温度測定結果がある．それは，同社，茂原鉱業所調査課によるもので，上記結果と総合すると，地温勾配は，1.85 °*C*/100 *m* となる．(第2図，第3図)．また，上記深井 OT-2 中での深度 700 *m*, 1000 *m*, 1400 *m*, 1700 *m* でのコア試料の，水飽和状態での平均熱伝導率は，2.94×10^{-3} *cal/cm sec* °*C* であつた．これらの値から，地殻熱流量は，0.54 $\times10^{-6}$ *cal/cm² sec* となる．茂原地区では，相生工業八積工場（千葉県長生郡長生村）相原勇夫氏，後藤哲雄氏，関東天然ガス開発，茂原鉱業所（茂原市）品田芳二郎氏他各位の御援助を受けたので，ここに深謝する．

3. 足尾： 栃木県上都賀郡足尾町の古河鉱業足尾鉱業所では，同社，大須賀友三郎氏他の御協力を得て，備前楯山 (36°39′ N, 139°27′ E) を中心に分布する流紋岩類中の坑道内で温度測定を行なつた．測定は，地表よりの深度 0～400 *m* での各深度での 10 個のボーリング孔によつて行ない，その結果は，第5図のごとくである．すなわち，地表からの深さに対してではなく，測点の標高に対して温度を図示する方がより整然たる地温分布を示し，地温勾配は 3.57°*C*/100 *m* となる．足尾銅山は，中新世に流紋岩類が秩父古生層中に噴出して作つた漏斗状岩体に生じた裂罅充填鉱脈と，流紋岩類中および古生層中に胚胎する不規則塊状の河鹿鉱床からなる．地温測点に関連ある地層は，流紋岩のみであり（熱伝導度$=6.25\times10^{-3}$ *cal/cm sec* °*C*），熱流量は，2.23×10^{-6} *cal/cm², sec.* となる．

4. 秩父： 埼玉県秩父郡大滝村にある，日窒鉱業秩父鉱業所 (36°01′ N, 138°48′ E) では，同所，金田光弘氏他各位の御協力によつて，道伸窪坑内第3ベース試錐 No. 560 (深度$=108$ *m*), No. 554 (深度$=175$ *m*) 中での温度測定を行なつた（第6図）．これ等試錐孔の孔口は，標高 1024 *m* であり，その地点での地表標高は 1250 *m* である．測温結果は，地表からの深さに対してではなく，標高に対して温度を図示する方が，両孔での測定値はよい一致を示す．地温勾配は，1.90 °*C*/100 *m* である．秩父鉱山は，秩父山地深くにあり，鉱床は，中新世の貫入岩に伴なつて，スカルンおよび石灰岩中に発達している．岩石試料は，石灰岩，磁鉄鉱，磁硫鉄鉱であり，その量比は，地質構造から，2:1:1 であるので，平均熱伝導率は，7.06×10^{-6} *cal/cm sec* °*C* となつた．したがつて，熱流量は，1.34×10^{-6} *cal/cm² sec* となる．

5. 神岡： 岐阜県神岡町 (36°21′ N, 137°19′ E) にある．三井金属鉱業神岡鉱業所では，同所，栃洞坑，戸野昭氏他各位の御協力によつて， No. *XH* 94 (垂直有効深度 $d=388$ *m*) および *XH* 78 ($d=221$ *m*) の二つの坑内ボーリング内で温度測定を行つた．これらの孔口標高は 480 *m* (海抜) であつた．また，標高 650 *m* の地点では，長さ 8 *m* の短ボーリング内で岩石温度を求めた，地下温度は，深さに対してよりも，標高によつて図示した方が，より一致を示し（第9図），地温勾配は，2.77°*C*/100 *m* である．神岡鉱山は，飛弾山地深く，地表は海抜 900 *m* 級の標高を示す．亜鉛，鉛，鉱床は，中生代末期の花崗斑岩の貫入に関連して，片麻岩，石灰岩中に生じたスカルン鉱床である．岩石試料としては，透輝石片麻岩，石灰岩，優黒質角閃岩片麻岩，花崗斑岩，杢地，足長杢地，柘榴石等について熱伝導率が測定された．平均熱伝導率として，6.49×10^{-3} *cal/cm sec* °*C* が得られ，熱流量は 1.80×10^{-6} *cal/cm² sec* となつた．

6. 中竜： 福井県大野郡和泉村にある，日本亜鉛株式会社中竜鉱業所 (35°52′ N, 136°35′ E) では同所，若林健介氏他各位の御協力を得て，中山坑内で，-160 *m* レベル（孔口標高海抜 435 *m*）よりの垂直ボーリング ($d=180$ *m*) および，それぞれ 0 *m* レベル（標高 605 *m*），-200 *m* レベル（標高 405 *m*）での水平ボーリング内の温度から，温度標高関係（第11図）が求められた．地温勾配は，2.90°*C*/100 *m* である．中竜鉱山は，石炭紀一デボン紀地層中に貫入した中生代末もしくは，第三紀の貫入岩による亜鉛，鉛の接触交替鉱床である．岩石試料は，ガーネットスカルン，ヘデンベルグスカルン，斑岩であり，その存在比を地質断面から推察して，平均的熱伝導率としては，6.71×10^{-3} *cal/cm sec*

°C が得られた．したがつて，熱流量は，$1.95\times10^{-6}\,cal/cm^2\,sec$ である．

7. 久根： 静岡県磐田郡佐久間町の，古河鉱業久根鉱業所の本山坑と，その支山名合坑の坑道を利用して地下温度測定を行なつた．附近の地層は，三波川変成帯に属する結晶片岩から成つている．本山坑 (35°05′ N, 137°50′ E) では，利用した坑道の高低差は約 500 m，地温勾配は 1.97 °C/100 m (第13図)，名合坑 (35°03′ N, 137°52′ E)，では高低差約 400 m，地温勾配は 2.17°C/100 m (第14図) であつた．両坑から採集された結晶片岩試料の平均熱伝導率は，$8.14\times10^{-3}\,cal/cm\,sec$ °C (本山坑)，$6.65\times10^{-3}\,cal/cm.\,sec$ °C (名合坑)であつた．地殻熱流量は，それぞれ $1.60\times10^{-6}\,cal/cm^2\,sec$，$1.44\times10^{-6}\,cal/cm^2\,sec$ となる．調査にあたつて，久根鉱業所探査係，福本博美氏他各位のお世話になつた．

8. 峯之沢： 静岡県磐田郡竜山村の日本鉱業峰之沢鉱業所 (35°00′ N, 137°51′ E) の坑道内の垂直試錐孔を利用して，地温勾配 (=2.92 °C/100 m) を求めた．峰之沢鉱山は，久根鉱業所名合坑の南方約 5km にあたり，附近の地質は，三波川変成帯に属する結晶片岩である． 結晶片岩試料 4 ケの熱伝導率の平均は $6.13\times10^{-3}\,cal/cm\,sec$ °C で，地殻熱流量は $1.79\times10^{-6}\,cal/cm^2\,sec$ となる．しかし，この場所での，試錐孔の深さが 97 m にすぎぬことから，上の推定値の信頼度は他に比べてやや落ちる可能性がある．調査にあたつては，峰之沢鉱業所の笹倉健一郎氏，塚田靖氏にお世話になつた．

9. 清越： 静岡県田方郡天城湯ケ島町にある中外鉱業清越鉱業所 (34°54′ N, 138°49′ E) では，同社，田中万吉氏，帆足祀夫氏等の御協力により，6 個の試錐孔中で温度測定を行なつた．同鉱山の位置は，東北日本西部の高熱流量地域がフォッサマグナ地域を経て，南にのびる地域中にあるので，その熱流量測定結果には，期待がもたれたが，信頼すべき値が得られなかつた，おそらく，地下水の流動のために，地下温度が大きく攪乱されていたためと思われる．

10. 丹那： 静岡県丹那盆地も，上記清越と同じく高地熱流量地域の延長とみられる地域にあり，重要な地点である．国鉄新幹線のための新丹那トンネルくつさくにあたり，同盆地では，地質調査用の試錐孔が掘鑿された．国鉄技術研究所，宮崎政三氏等の御協力によつて，同盆地内の二つの試錐孔 (名賀 1 号，(1958)，および滝沢 1 号) について測温が行なわれた．しかし結果は，第17図のごとくで，地温勾配はみとめられなかつた．このことは，盆地の水理学からみて，地下水の流によるものと解される．