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8. *Studies of the Thermal State of the Earth. The Ninth Paper: Terrestrial Heat Flow Measurements in Kinki, Chugoku and Shikoku Districts, Japan.*

By Seiya UYEDA,
Earthquake Research Institute,
and Ki-iti HÔRAI,
Graduate School, The University of Tokyo.

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Abstract

10 measurements of terrestrial heat flow have been obtained in the western part of Japan, i.e. Kinki, Chugoku and Shikoku Districts. All except one of these localities are metal mines. Expressing the geothermal gradient $\Delta T/\Delta Z$ in °$C/100\,m$, and the heat flow Q in 10^{-6} $cal/cm^2\,sec$, the data are as follows:

Ikuno:	$\Delta T/\Delta Z = 1.88$,	$Q = 1.38$
Nakaze:	$\Delta T/\Delta Z = 3.35-3.43$,	$Q = 2.11-2.30$
Yanahara:	$\Delta T/\Delta Z = 1.92-2.14$,	$Q = 1.13-1.26$
Isotake:	$\Delta T/\Delta Z = 3.82-4.25$,	$Q = 3.30-3.68$
Tsumo:	$\Delta T/\Delta Z = 1.80$,	$Q = 1.09$
Kawayama:	$\Delta T/\Delta Z = 1.49-1.98$,	$Q = 0.86-1.14$
Naka:	$\Delta T/\Delta Z = 3.04$,	$Q = 1.79$
Hidaka:	$\Delta T/\Delta Z = 2.87$,	$Q = 2.12$
Kiwa:	$\Delta T/\Delta Z = 1.85$,	$Q = 1.31$
Besshi:	$\Delta T/\Delta Z = 2.49$,	$Q = 1.22$

The distribution of heat flow reported in the present paper indicates the following: 1) Japan Sea coast of Southwestern Japan has relatively high heat flow ($Q > 2.0\times10^{-6}$ $cal/cm^2\,sec$). This may be regarded as associated with the extension of the Tertiary volcanic zone from Northeastern Japan. The validity of this observation, however, should be treated with reserve, since the reliablity of geothermal data in Isotake is not high. 2) Absence of the area of low heat flow which was observed in the Pacific coast side of Northeastern Japan. With a few exceptions, heat flow data in the region suggests more uniform distribution than in Northeastern Japan. The zones of Mesozoic regional metamorphism, running through the region, show no indication of high heat flow.

1. Introduction

The present report is the second of a series of papers on a systematic survey of heat flow in the Japanese Islands undertaken by the Earthquake Research Institute.[1] In Kinki, Chugoku and Shikoku Districts there has been no data on the terrestrial heat flow. In the present work, 10 mesurements were made in these districts as shown in Fig. 1.

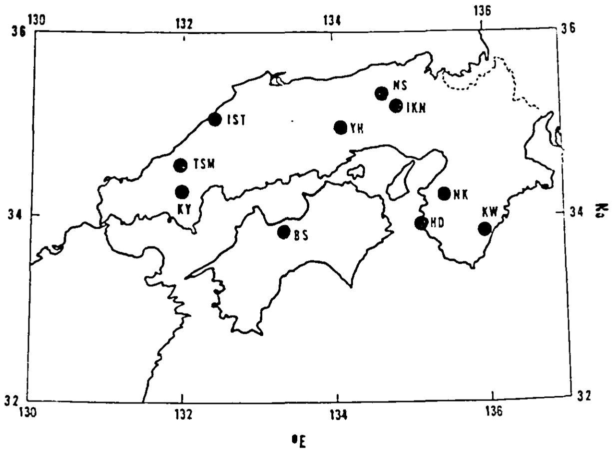

Fig. 1. Localities of heat flow stations in Kinki, Chugoku and Shikoku Districts.

IKN: Ikuno	NZ: Nakaze
YH: Yanahara	IST: Isotake
TSM: Tsumo	KY: Kawayama
NK: Naka	HD: Hidaka
KW: Kiwa	BS: Besshi

All the sites except Hidaka, which is a site for hot spring exploration, are metal mines of various kinds, i.e. Ikuno Cu–Zn Mine, Nakaze Au–Sb Mine, Yanahara Fe–S Mine, Iwami Pb–Zn Mine (Isotake), Tsumo Cu–Zn Mine, Kawayama Cu–S–Fe Mine, Iimori Cu–S–Fe Mine (Naka), Kishu Cu Mine (Kiwa) and Besshi Cu–S–Fe Mine.

2. Ikuno

In Ikuno Mine, Hyogo Prefecture (Fig. 1 and Fig. 2), 15 boreholes drilled from drifts at various depths (35°10′N 134°50′E) were used for

1) S. UYEDA and K. HÔRAI, *Bull, Earthq. Res. Inst.*, 41 (1963), 85.

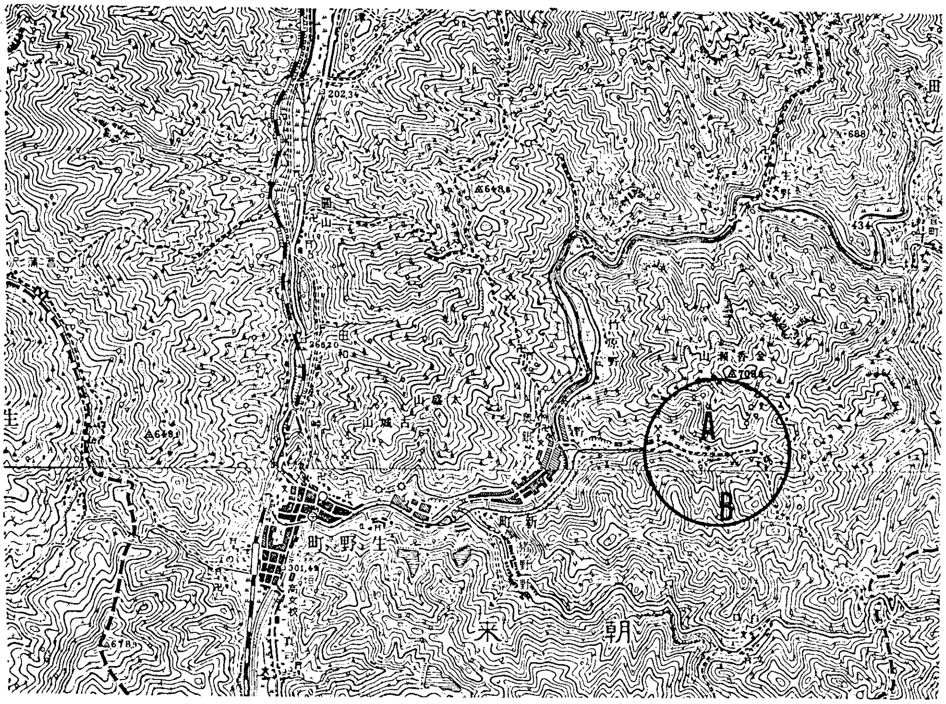

Fig. 2. Localities of temperature stations in Ikuno Mine. Around A; Stations 1, 4, 5, 6, 7. 8, 9, 10. Around B; Stations 2, 3, 11, 12, 13, 14, 15. The map covers the area from 35° 09′ N to 35°12′ N in latitude and from 134°46′10″4 E to 164°51′ 10″4 E in longitude.

Table 1. Temperature stations in Ikuno Mine

No.	Site	Altitude of site (m above sea level)	Depth of site (m)	Rock temperature (°C)
1	Kinsei-0L	367	50	13.9
2	Fukuju-0L	374	209	18.1
3	Fukuju-5L	251	297	21.1
4	Koei-5L	251	220	17.7
5	Keiju-21L	−97	568	23.8
6	Senju-21L	−95	528	25.1
7	Koei-13L	87	314	21.0
8	Koei-13L	103	340	21.1
9	Keiju-17L	3	486	22.6
10	Keiju-17L	4	446	23.7
11	Senju-29L	−306	880	31.6
12	Kinsei-27L	−257	868	30.2
13	Kinsei-25L	−207	786	29.1
14	Kinsei-25L	−207	799	29.2
15	Senju-23L	−156	758	27.2

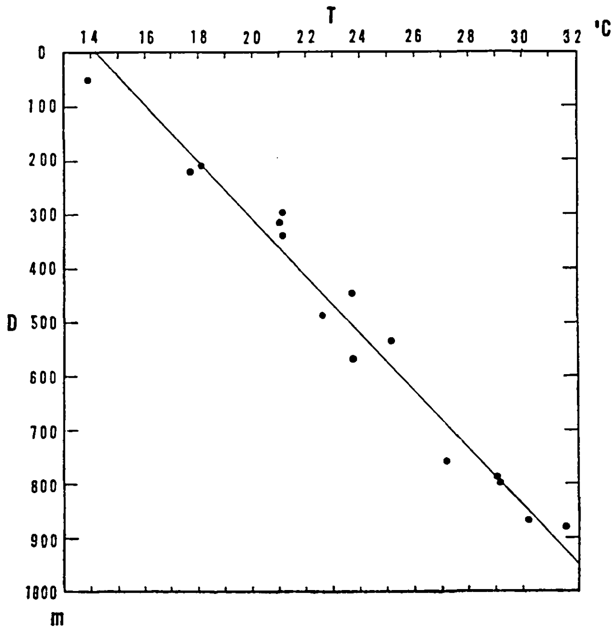

Fig. 3a. Temperature-depth relation in Ikuno Mine.

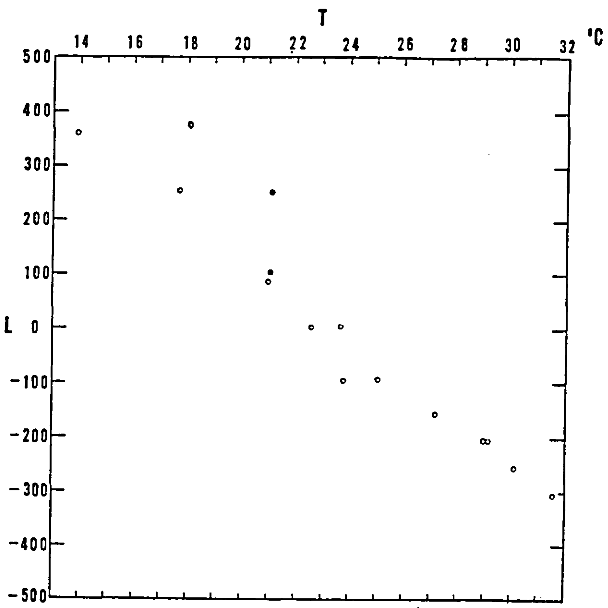

Fig. 3b. Temperature-altitude relation in Ikuno Mine.

Table 2

Specimen	Rock type	Thermal conductivity $(10^{-3}\ cal/cm\ sec\ °C)$	Temperature during measurement (°C)	Density (gr/cm^3)
IKN Ia	Liparite	6.48	33.6	2.57
Ib	Liparite	7.15	33.5	2.68
IIa	Tuff	8.68	33.1	2.48
IIb	Tuff	6.50	29.3	2.47
IIIa	Andesite	7.59	28.7	2.79
IIIb	Andesite	7.57	28.9	2.80

temperature measurements. Descriptions regarding the temperature stations are as shown in Table 1. When the measured temperatures are plotted against the depth as shown in Fig. 3 a geothermal gradient can be obtained as $1.88 \pm 0.09°C/100\ m$. (The temperature gradient in the present work is always obtained from the data by the method of least squares.) In Fig. 3 b, the temperatures are plotted against the altitude. It may be observed that the measured temperatures are better lined up in Fig. 3 a than in Fig. 3 b.

Since the temperature stations are scattered in the area, the fact that the measured temperatures line up when plotted against the depth may mean that the underground isotherms run more or less parallel to the surface topography.

Geology in the area is as follows[2]. The basement rocks belong to older Tertiary interbedding of sandstone and shale with tuff breccia. Acidic tuff, and tuff breccia are on the top of the basement and there are also extrusives of liparite, andesite and quartzporphyry. Thermal conductivity of liparite, tuff and andesite specimens was measured by the divided-bar device. The results are as listed in Table 2, and the mean value of the conductivities is $K = 7.33 \times 10^{-3}\ cal/cm\ sec\ °C$ $(\frac{R}{2} = 0.39 \times 10^{-3}\ cal/cm\ sec°C)$. The terrestrial heat flow of the area is thus obtained as $Q = 1.38 \times 10^{-6}\ cal/cm^2 sec$.

3. Nakaze

In Nakaze Mine (35°21′N, 134°57′E), Hyogo Prefecture (Fig. 1, Fig. 4), underground temperature measurements were made using one vertical and five horizontal boreholes drilled from drifts at various depths.

2) S. SAKAI, Private communication.

The area of the survey was divided into two mines, i.e. Manju Mine and Ishimabu Mine. The boreholes used are listed in Table 3. The temperature measurements were made deep in the boreholes so that the

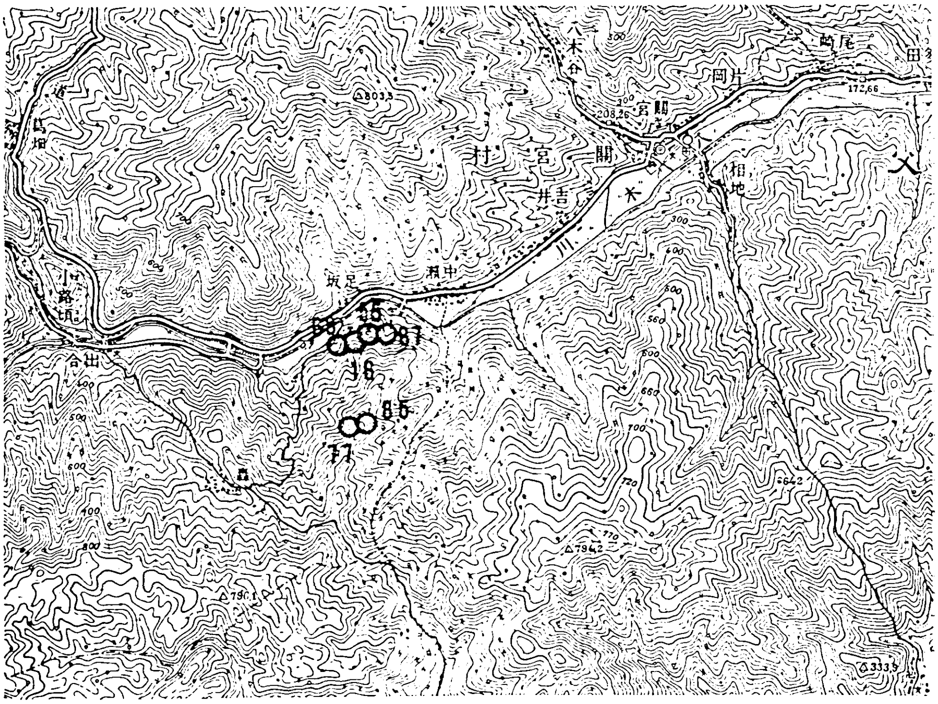

Fig. 4. Localities of the boreholes used in Nakaze Mines: Numbers attached to the circles correspond to those in Table 3. The map covers the area from 35° 20′ N to 35°23′ N in latitude and from 134°35′10″4 E to 134°40′10″4 E in longitude.

Table 3. Temperature stations in Nakaze Mine

Name	Depth of boring site (m)	Length of borehole (m*)	Rock temperature (°C)
Manju Mine:			
No. 85	265	100 (vertical)	(see Fig. 5)
No. 77	420	27 (horizontal)	22.0
Ishimabu Mine:			
No. 55	340	20 (horizontal)	24.0
No. 16	195	27 (horizontal)	18.1
No. 68	103	27 (horizontal)	15.7
No. 87	28	19 (horizontal)	13.2

* For horizontal boreholes, this represents the distance of thermometer in the borehole from the drift wall.

disturbance of temperature due to the existence of drifts was avoided.

The results of the measurement are plotted in Fig. 5. The data from the two mines seems to lie in different lines giving the geothermal gradient as $3.43 \pm 0.22°C/100\ m$ (Ishimabu), and $3.35 \pm 0.07\ °C/100\ m$ (Manju).

Prevailing rocks are Chichibu paleozoics in Ishimabu mine and Tertiary andesite tuff in Manju mine respectively. The ore (Sb, Sn, Au, Ag) is of fissure filling vein-type associated with Tertiary quartz porphyry intrusives.[3)]

Observed thermal conductivities of rock samples are listed in Table 4. The

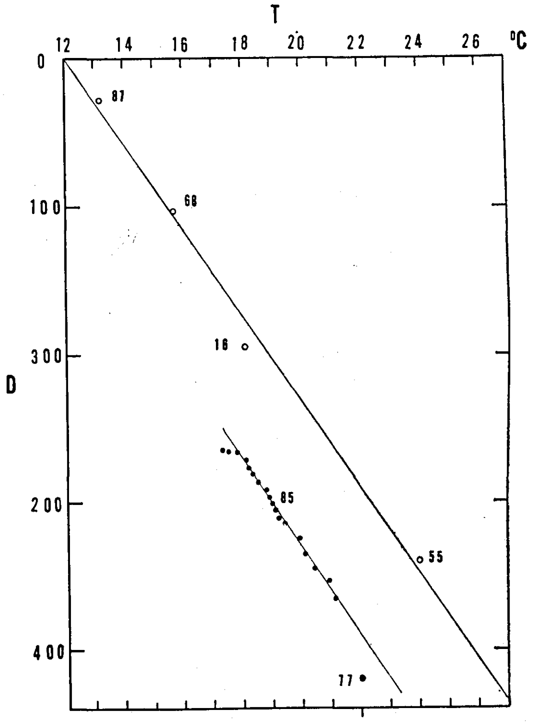

Fig. 5. Observed temperatures in Nakaze Mine plotted against the depth of stations from the land surface. The numbers specify the boreholes (Table 3, Fig. 4).

Table 4

Specimen	Rock type	Thermal conductivity ($\times 10^{-3}$ *cal/cm sec°C*)	Temperature during measurement (°C)	Density (*gr/cm*^{3})
NZ I *	Andesite	4.41	31.7	2.81
II	Green schist	7.44	31.7	2.69
III	Black schist	6.38	33.6	2.72
VIII	Schalstein	5.58	31.9	2.93
IX	Tuff	7.72	31.8	2.31
IV**	Black schist	8.95	31.7	2.50
V	Black semi-schist	5.07	33.3	2.72
VI	Green schist	7.41	33.0	2.76
VII	Schalstein	5.45	31.6	2.86

* Specimens collected in Manju mine.
** Specimens collected in Ishimabu mine.

3) G. YAMAMOTO, Private communication.

average values from the table are: $K=6.72\times10^{-3}\ (\frac{R}{2}=1.94\times10^{-3})\ cal/cm\ sec\ °C$ for Ishimabu and $K=6.31\times10^{-3}\ (\frac{R}{2}=1.66\times10^{-3})\ cal/cm\ sec\ °C$ for Manju.

The amount of heat flow is, then, estimated as,

$$Q = 2.30\times10^{-6}\ cal/cm^2\ sec \qquad \text{(Ishimabu)}$$
$$Q = 2.11\times10^{-6}\ cal/cm^2\ sec \qquad \text{(Manju)}.$$

4. Yanahara

Three deep boreholes drilled from the land surface were used for temperature measurements in Yanahara Mine (34°57′N, 134°04′E), Okayama Prefecture (Fig. 1, Fig. 6). The boreholes were No. 247 (depth $d=950\ m$), No. 248 ($d=200\ m$), and No. 166 ($d=200\ m$), but the temperature-depth relation in the borehole No. 166 was found to be abnormal, i.e. the thermal disturbance from the surface seems to penetrate down to a depth of some $150\ m$ by some unknown mechanism. Therefore, the temperature data from boreholes No. 247 and No. 248 only was used for the estimation of geothermal gradients (Fig. 7 a, b, c). The gradients in these boreholes are:

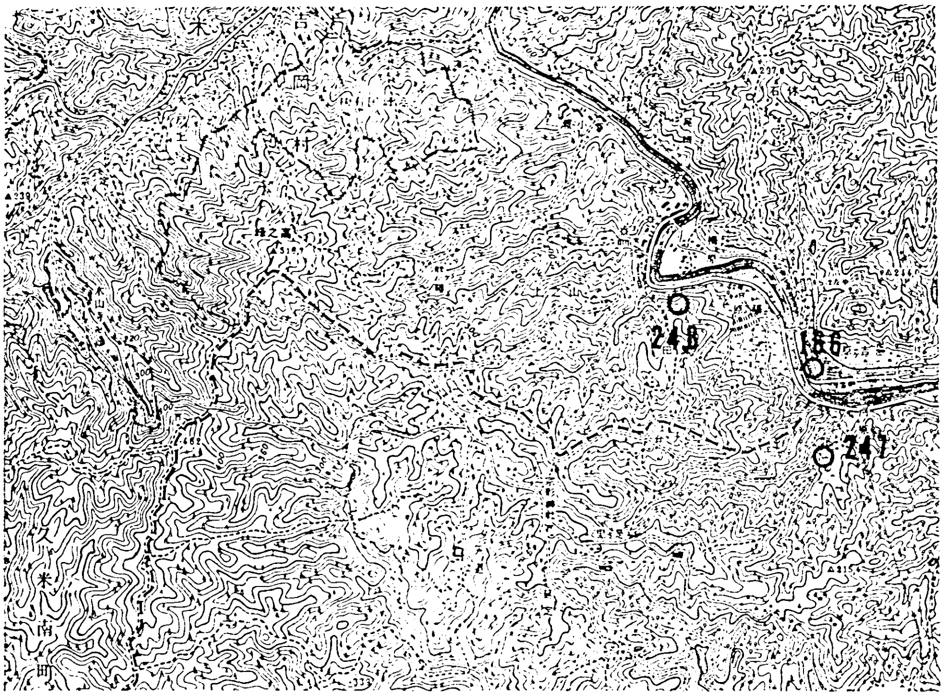

Fig. 6. Localities of boreholes used in Yanahara Mine. The numbers specify the boreholes (see text). The map covers the area from 34°55′ N to 34°58′ N in latitude and from 134°00′10″4 E to 134°05′10″4 E in longitude.

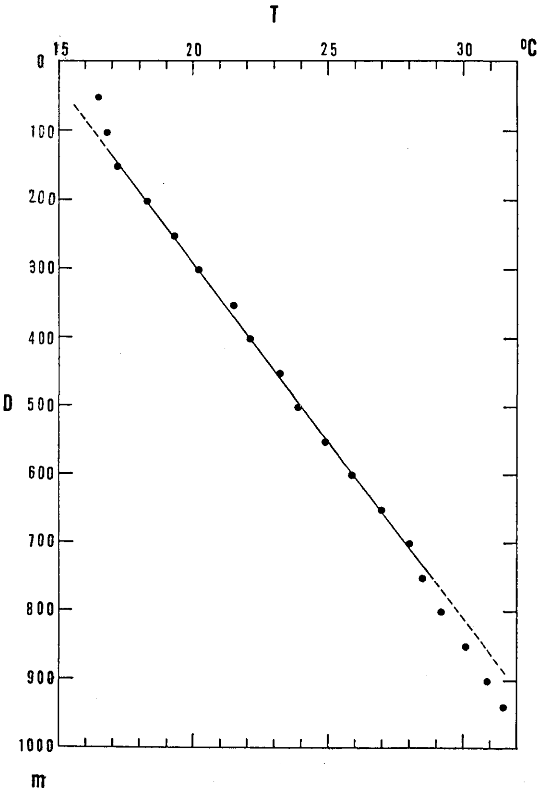

Fig. 7 a. Temperature-depth relation in borehole No. 247, Yanahara.

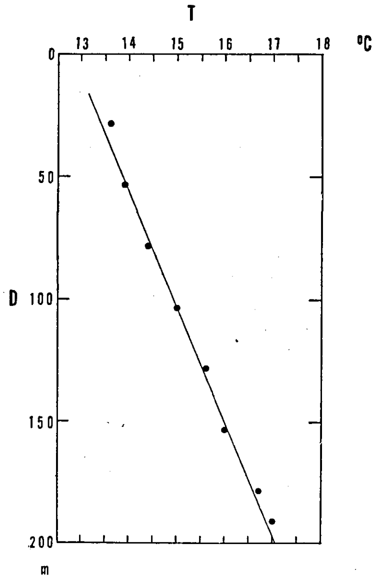

Fig. 7 b. Temperature-depth relation in borehole No. 248, Yanahara.

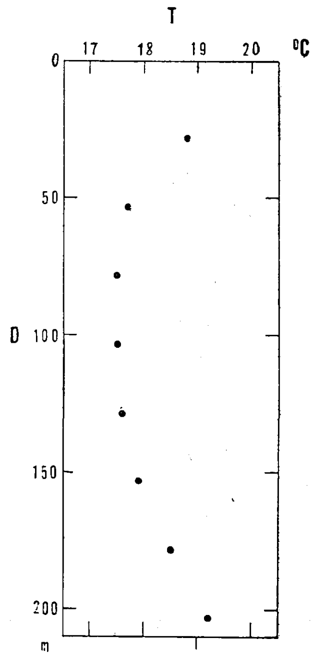

Fig. 7 c. Temperature-depth relation in borehole No. 166, Yanahara.

Table 5

Specimen	Rock type	Thermal conductivity (10^{-3} cal/cm sec °C)	Temperature during measurement (°C)	Density (gr/cm³)
YH I	Slate	5.04	26.3	2.73
II	Slate	5.93	26.2	2.71
III	Slate	5.97	26.3	2.83
IV	Slate	6.63	26.1	2.71
V	Slate	5.54	26.0	2.70
VI	Slate	6.22	26.0	2.73

$$\Delta T/\Delta Z = 1.92 \pm 0.02°C/100\,m \qquad \text{(No. 247)}$$
$$\Delta T/\Delta Z = 2.14 \pm 0.07°C/100\,m \qquad \text{(No. 248)}.$$

Geological column penetrated by these boreholes chiefly consists of Palaeozoic slates. In borehole No. 247, however, at a depth from 840 *m* to 930 *m* are old volcanics (pyroclastics) and below 930 *m* are granitic basement[4]. In Fig. 7, the temperature depth curve of borehole No. 247 seems to have a kink at about 750 *m* and this kink may be due to the difference in the thermal conductivity of these rocks and slates. The value of geothermal gradient cited above is from the data above 750 *m* level.

The average value of thermal conductivities determined for 6 slate specimens (Table 5) being $5.89 \times 10^{-3} cal/cm\,sec°C$ ($\frac{R}{2} = 0.80 \times 10^{-3} cal/cm\,sec$ $°C$), the heat flow values corresponding to the above two gradients are: $Q = 1.13 \times 10^{-6}\,cal/cm^2\,sec$ and $Q = 1.26 \times 10^{-6}\,cal/cm^2\,sec$.

5. Isotake (Iwami Mine)

In Iwami Mine, Isotake, Shimane Prefecture (Fig. 1 and Fig. 8), temperature measurements were possible only in two boreholes drilled from the land surface (35°11′N, 132°26′E). These holes, numbered as *R*1 and *R*2, were located at several metres from each other and the thermometer could be lowered down to a depth of only 160 *m* and 170 *m* respectively. Moreover, the results of measurements showed (Fig. 9) that the temperature above 110 *m* is much disturbed so that the data obtained from a depth greater than say 90 *m* or 110 *m* only was useful for geothermal gradient estimation. The gradients in this portion of the two holes are $3.82°C/100\,m$ and $4.25°C/100\,m$.

According to the geological column of the holes constructed by the

4) T. Nakano, Private communication.

Fig. 8. Locality of the boreholes used in Iwami Mine, Isotake. The map cevers the area from 35°10′ N to 35°13′ N in latitude and from 132°25′10″4 E to 132°30′10″4 E in longitude.

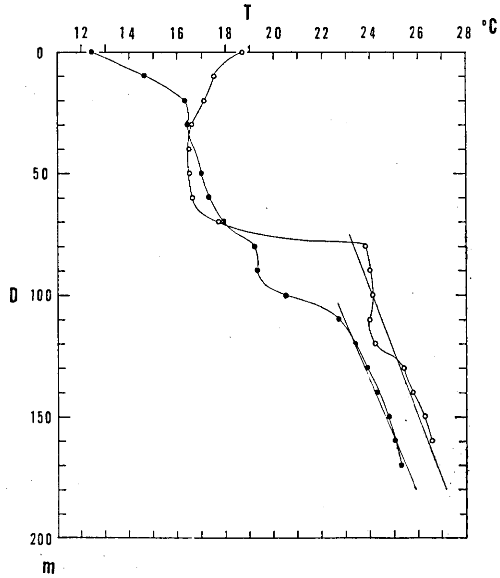

Fig. 9. Temperature-depth relations in Iwami Mine, Isotake. Full circles: $R2$, hollow circles: $R1$. Straight lines indicate the least square gradients for data below 110 m. and 90 m

Table 6

Specimen	Rock type	Thermal conductivity $\left(10^{-3}\ cal/cm\ sec\ °C\right)$	Temperature during measurement (°C)	Density (gr/cm^3)	Water content by weight (%)
IST II	Gypsum	2.86	33.5	2.28	
III	Clay	2.51	27.9		26.6
IV	Black ore	10.01	33.6	2.58	

Mine,[5] the portion from 110 m to 170 m consists of gypsum, clay and black ore in phyllite. The results of thermal conductivity measurement on the specimens of these rocks (Table 6) show that the conductivity of phillite is considerably greater than that of gypsum and clay.

The effective conductivity was obtained as the mean value with weight proportional to the abundance in the column as, $K=8.65\times10^{-3}$ $cal/cm\ sec\ °C$ $(\frac{R}{2}=3.75\times10^{-3}\ cal/cm\ sec\ °C)$. Combination of this K with the geothermal gradients gives the heat flow as $Q=3.30-3.68\times10^{-6}\ cal/cm^2\ sec$. Owing to the reasons stated above, the reliability of heat flow

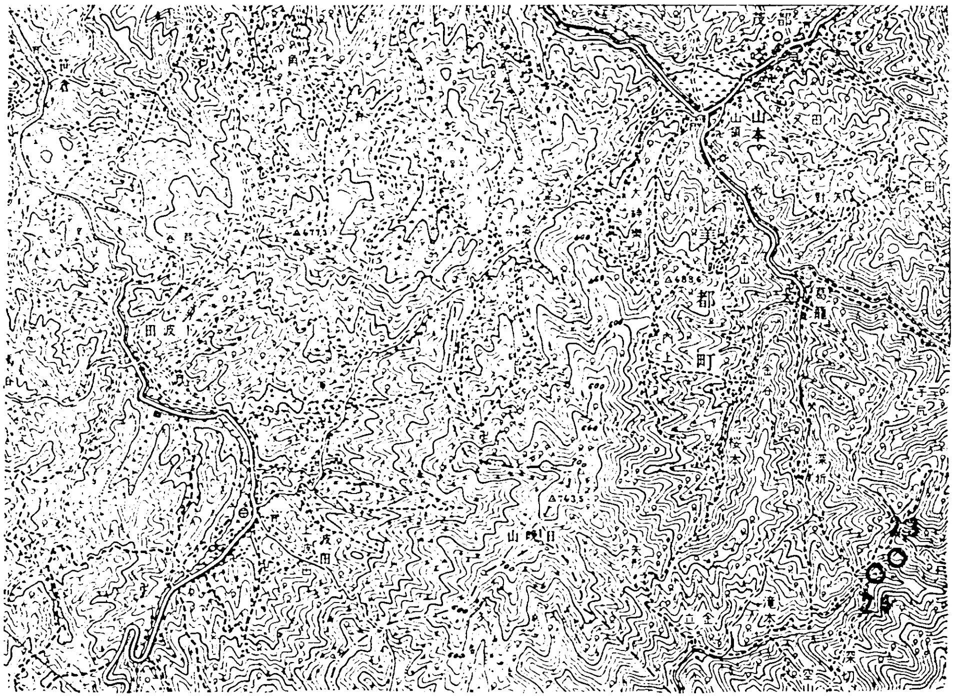

Fig. 10. Locality of the boreholes used in Tsumo Mine. The map covers the area from 34°37′ N to 34°40′ N in latitude and from 131°55′10″4 E to 132°00′10″4 E in longitude.

5) Y. IIDA, Private communication.

in this area is not as high as in other areas treated in the present study.

6. Tsumo

In Tsumo Mine, Shimane Prefecture (Fig. 1 and Fig. 10), two boreholes (34°37′N, 132°00′E) drilled from the main drift were utilized for the temperature measurements. The boreholes are: No. 24 from 0 *m* level (353 *m* above sea level) of Maruyama mine, dipping-60°, effective depth=200 *m*, and the depth of the boring site=115 *m*, No. 23 from 0 *m* level (353 *m* above sea level), of Maruyama mine dipping 45°, effective depth = 140 *m*, and the depth of the boring site=160 *m*.

The temperature-depth relation obtained in these boreholes is shown in Fig. 11. In the present case, whether the temperature should be plotted against the depth or the altitude is not clear, the difference being not substantial. The geothermal gradient obtained from Fig. 11 is 1.80±0.05 °*C*/100 *m*. In Tsumo, Cu and Zn ores were formed in skarn which were derived from limestone by igneous intrusions.[6)]

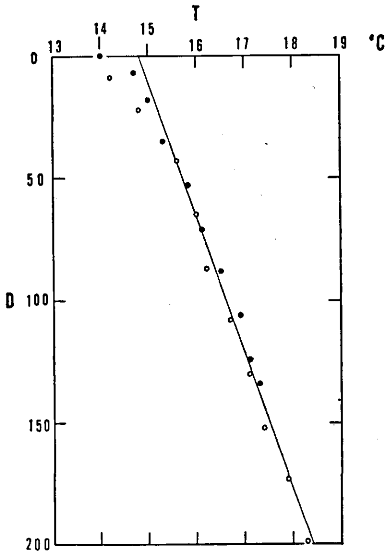

Fig. 11. Temperature-depth relation in Tsumo Mine.
Full circles: borehole No. 23,
Hollow circles: borehole No. 24.

The rocks concerned with the pre-

Table 7

Specimen	Rock type	Thermal conductivity (10^{-3} *cal/cm sec °C*)	Temperature during measurement (°*C*)	Density (*gr/cm*^{3})
TSM I	Limestone	5.78	33.6	2.70
II	Skarn	8.16	33.6	3.15
III	Skarn	6.49	33.5	3.41
IV	Skarn	5.23	33.5	3.18
V	Skarn	7.99	33.5	3.28
VI	Hornfels	6.55	33.5	2.86
VII	Hornfels	4.37	32.7	2.86

6) T. HONDA, Private communication.

sent temperature measurements are mainly hornfels, and less predominantly skarn and limestone. The mean thermal conductivity was obtained from the measured values (Table 7) on specimens of each rock by taking a proper weighted mean, considering the geological column, as $K=6.08\times10^{-3}$ ($\frac{R}{2}=0.76\times10^{-3}$) $cal/cm\ sec\ °C$.

Therefore, the value of heat flow is estimated as $Q=1.09\times10^{-6}$ $cal/cm^2\ sec$.

7. Kawayama

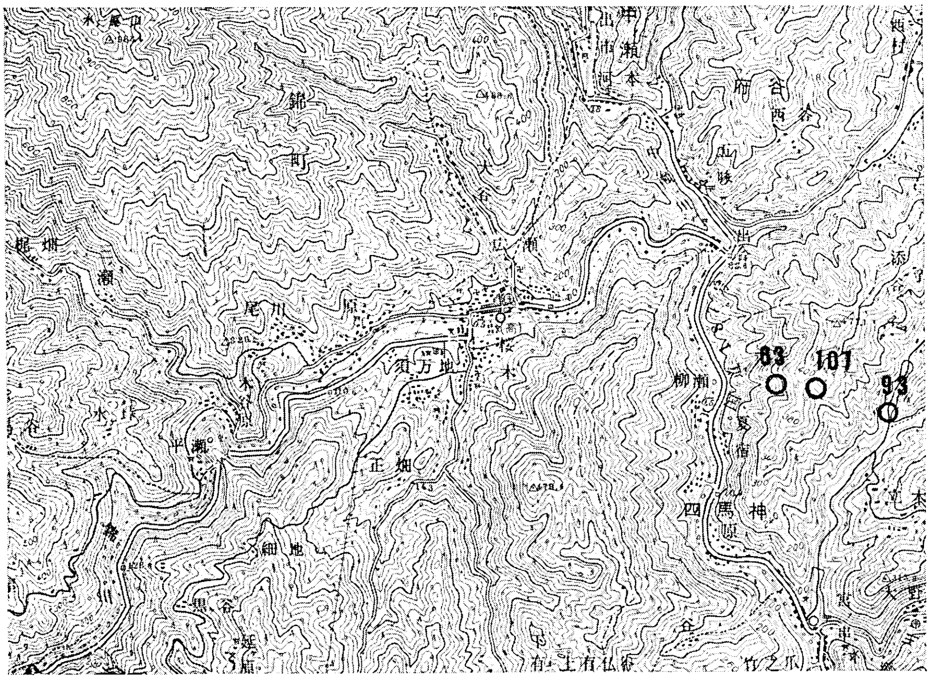

Fig. 12. Localities of boreholes used in Kawayama Mine. Numbers attached to circles refer to Table 8. The map covers the area from 34°14′ N to 34°17′ N in latitude and from 131°55′ E to 132°00′ E in longitude.

Table 8. Temperature stations in Kawayama Mine

Name	Depth of boring site (m.)	Altitude of boring site (m above sea level)	Length of borehole (m)	Thermal gradient (°C/100 m)
No. 63	0	230	450	1.98±0.03
No. 107	0	350	300	1.49±0.02
No. 93	163	27	300	1.56±0.03

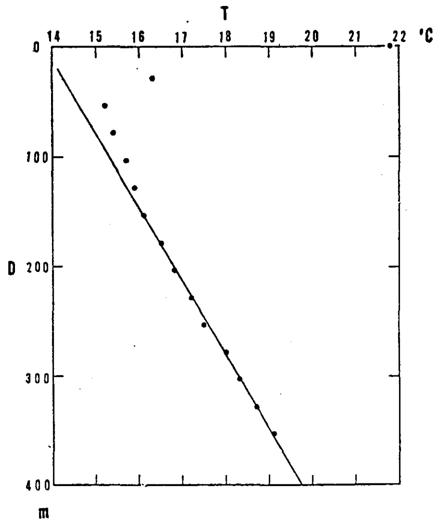

Fig. 13 b. Temperature-depth relation in borehole No. 107, Kawayama Mine.

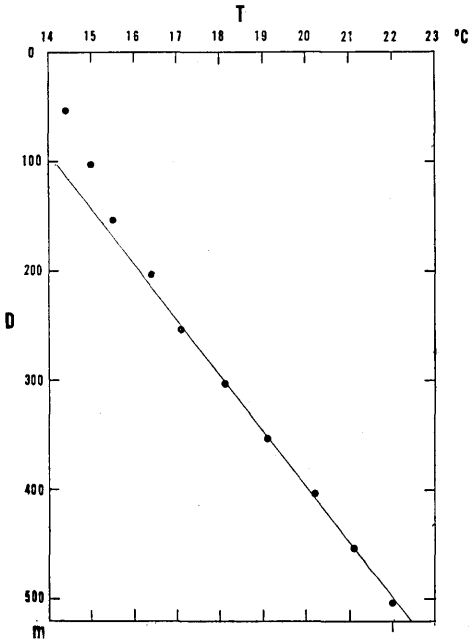

Fig. 13 a. Temperature-depth relation in borehole No. 63, Kawayama Mine.

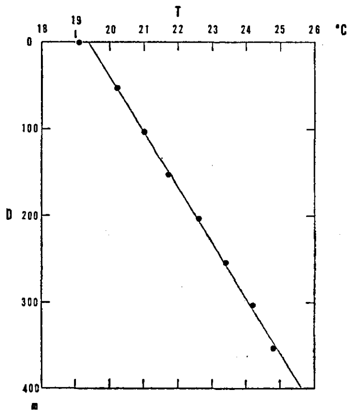

Fig. 13 c. Temperature-depth relation in borehole No. 93, Kawayama Mine.

Table 9

Specimen	Rock type	Thermal conductivity $\left(\frac{10^{-3}\ cal/cm\ sec}{°C}\right)$	Temperature during measurement (°C)	Density (gr/cm^3)
KY I	Sandstone	6.34	26.8	2.71
II	Slate	4.29	26.8	2.69
III	Meta-diabase	5.88	26.6	2.92
IV	Limestone	6.22	26.2	2.69
V	Black phyllite	5.68	26.2	2.71
VI	Black schist	6.05	26.1	2.74

Three borehols were used for underground temperature survey in Kawayama Mine (34°15′N, 132°59′E), Yamaguchi Prefecture (Fig. 1 and Fig 12). Descriptions and geothermal gradients of the boreholes are shown in Table 8.

The temperature-depth relations observed in each borehole are shown in Fig. 13 a, b, c.

Dominant geology of the area is the weakly metamorphozed paleozoics belonging to Sangun Zone. The iron-sulphide ore of the mine was formed by Cretaceous replacement mineralization of limestone.[7] Specimens of sandstone, slate, meta-diabase, limestone, black phillite and black shist were obtained from the cores of the boreholes, and their thermal conductivity was measured as listed in Table 9, $(\frac{R}{2}=1.03\times10^{-3}\,cal/cm\,sec\,°C)$.

Weighted mean of the conductivities, considering the geological column of each borehole, was computed. These estimated mean conductivities for each borehole were combined with respective geothermal gradients and the heat flow was computed as:

$$Q=1.14\times10^{-6}\,cal/cm^2\,sec \quad (\text{No. } 63) \quad (K=5.76\times10^{-3}\,cal/cm\,sec\,°C)$$

$$Q=0.86\times10^{-6}\,cal/cm^2\,sec \quad (\text{No. } 107) \quad (K=5.76\times10^{-3}\,cal/cm\,sec\,°C)$$

$$Q=0.93\times10^{-6}\,cal/cm^2\,sec. \quad (\text{No. } 93) \quad (K=5.94\times10^{-3}\,cal/cm\,sec\,°C)$$

8. Naka (Iimori Mine)

In Iimori Mine, Wakayama Prefecture (Fig. 1 and Fig. 14), borehole No. 2 (34°15′N, 135°25′E) of the 10th drift, 31 South Cross Cut, was utilized for the temperature survey. The site of this borehole has its altitude 197 *m* below sea level and the depth from the land surface 453 *m*. The depth of the borehole is 187 *m*. Results of the measurement are shown in Fig. 15 and the geothermal gradient is $3.04\pm0.06\,°C/100\,m$. The ores of Iimori Mines belong to so called Kieslager-type pyrite in Sambagawa schists.[8] The observed thermal conductivity of rock

Table 10

Specimen	Rock type	Thermal conductivity ($\times10^{-3}\,cal/cm\,sec\,°C$)	Temperature during measurement (°C)	Density (gr/cm^3)
NK I	Crystalline schist	5.46	33.6	3.04
II	Crystalline schist	6.33	33.8	2.95

7) T. SAKAMOTO, Private communication.
8) Y. OKUBO, Private communication.

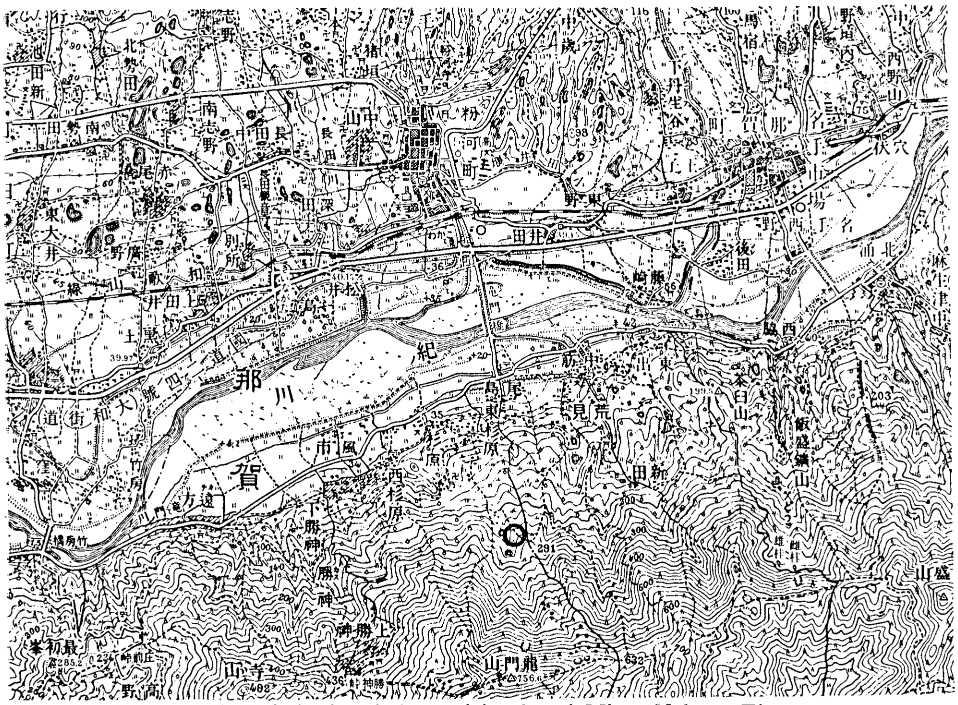

Fig. 14. Locality of the borehole used in Iimori Mine, Naka. The map covers the area from 34°14′ N to 34°17′ N in latitude and from 135°22′10″4 E to 135°27′ 10″4 E in longitude.

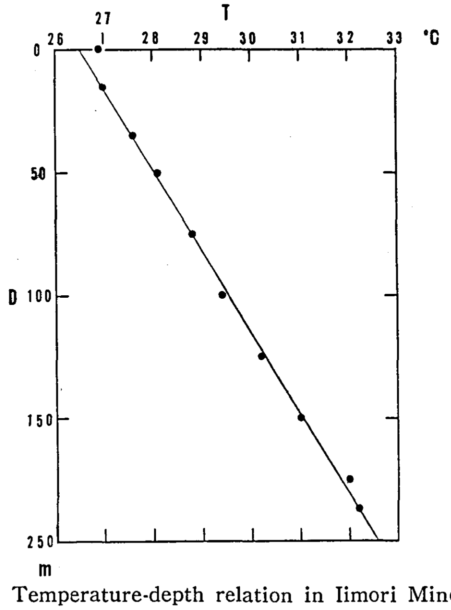

Fig. 15. Temperature-depth relation in Iimori Mine, Naka.

samples is shown in Table 10. The average value is $K=5.90\times10^{-3}$ ($\frac{R}{2}=0.44\times10^{-3}$) $cal/cm\ sec\ ^{\circ}C$. This gives the heat flow as $Q=1.79\times10^{-6}$ $cal/cm^2\ sec$.

9. Hidaka

In Hidaka (Fig. 1 and Fig. 16), Wakayama Prefecture, one borehole, originally drilled for exploration of hot spring, was available for the present work. The borehole (33°57′N, 135°05′E) is vertical and about 310 m deep. Apparently it did not reveal any hot spring. It penetrates

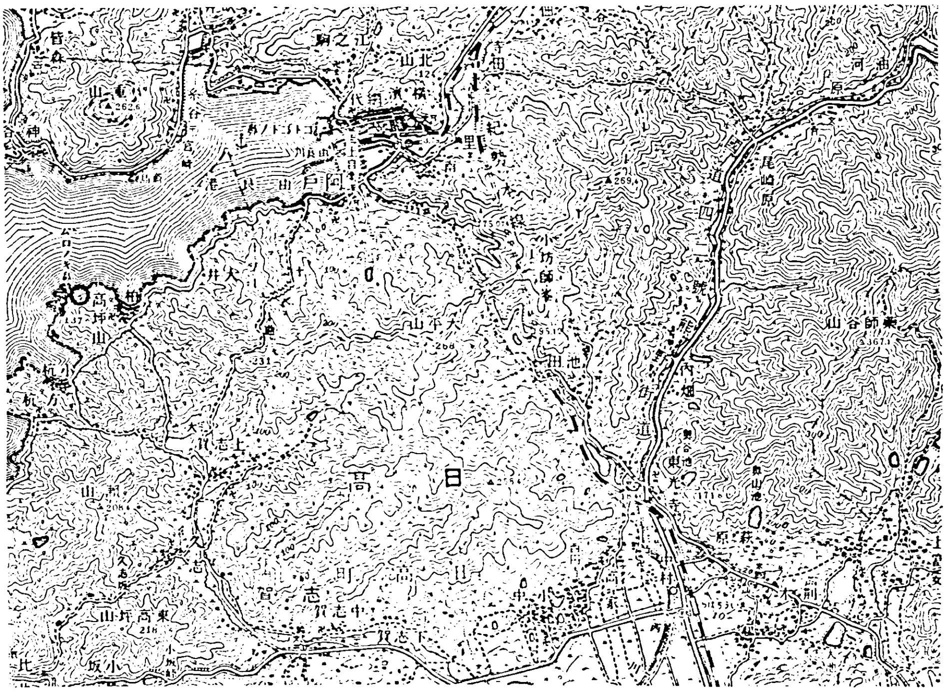

Fig. 16. Locality of the borehole used in Hidaka. The map covers the area from 33°55′ N to 33°58′ N in latitude and from 135°05′10″4 E to 135°10′10″4 E in longitude.

Table 11

Specimen	Rock type	Thermal conductivity (10^{-3} $cal/cm\ sec\ ^{\circ}C$)	Temperature during measurement ($^{\circ}C$)	Density (gr/cm^3)
HD I	Sandstone	8.29	34.2	2.63
II	Sandstone	8.16	34.3	2.62
III	Sandstone	6.67	34.2	2.63
IV	Sandstone	6.47	34.3	2.63

the exposed rocks on the shore. The results of our temperature measuremets are as shown in Fig. 17, from which the geothermal gradient can be found as 2.87 ± 0.02 °$C/100\,m$.

The core-specimens recovered from the borehole were all sandstones of Mesozoic age. The average thermal conductivity of these sandstones (Table 11) is $7.40 \times 10^{-3} (\frac{R}{2} = 0.91 \times 10^{-3})$ $cal/cm\ sec$ °C, so that the amount of heat flow is given as 2.12×10^{-6} $cal/cm^2\ sec$. This is the only case where heat flow exceeds 2×10^{-6} $cal/cm^2 sec$ in the area away from the Japan Sea coast area. That a hot spring was sought may mean that this area is a geothermal area. But, at the same time, this high value is in accord with that in a nearby station, i.e. Naka (Iimori Mine). It may then be possible that the general area around the western Kii Peninsula has relatively high heat flow. The area around these stations has been known for its anomalous concentration of fosi of very shallow earthquakes.[12] It is, at present, not known whether these two phenomena have any causal relationship, but seems to be worthy of closer investigation.

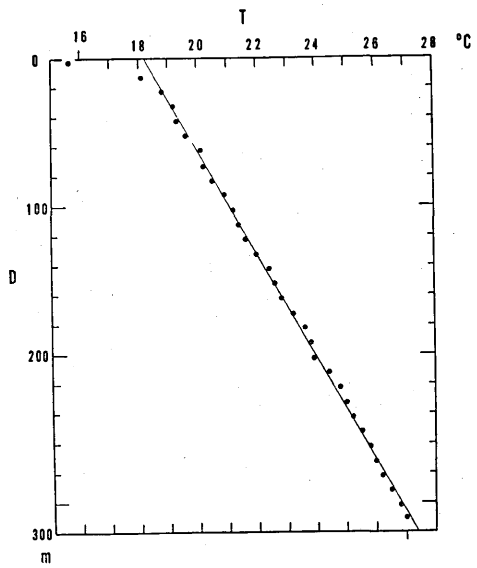

Fig. 17. Temperature-depth relation in Hidaka borehole.

10. Kiwa (Kishu Mine)

In Kishu Mine (Fig. 1 and Fig. 18), Kiwa, Mie Prefecture, three boreholes were used for the determination of geothermal gradient. Approximate position of the boreholes is 35°50′N, 153°53′E. The description of the boreholes is in Table 12.

Results of the temperature measurements are shown in Fig. 19, from which geothermal gradient of the area can be obtained as 1.85 ± 0.11 °$C/100\,m$. In Fig. 19, the temperatures are plotted against the altitude because they are better lined up than when plotted against the depth.

12) S. MIYAMURA, *Bull. Earthq. Res. Inst.*, **37** (1959), 347-358, 593-608, 609-635, **38**, (1960), 71-112.

S. MIYAMURA, Thesis, University of Tokyo, 1961.

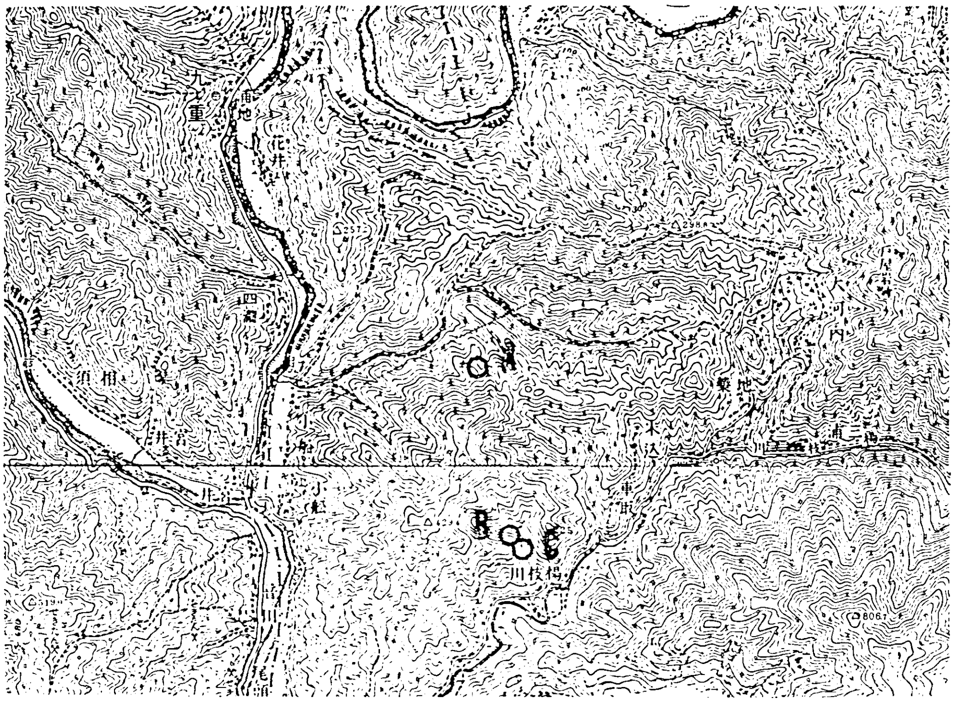

Fig. 18. Localities of boreholes used in Kishu Mine, Kiwa. The map covers the area from 33°49′ N to 33° 52′ N in latitude and from 135°50′10″4 E to 135°55′ 10″4 E in longitude. Letters A, B, and C refer to Table 12.

Table 12. Temperature stations in Kishu Mine

Name of borehole	Altitude of boring site (*m* above sea level)	Depth from surface (*m*)	Length of borehole (*m*)	Dip angle of borehole
A	82	123	290	90°
B	−120	305	100	41°
C	− 91	256	150	44°

Table 13

Specimen	Rock type	Thermal conductivity $\left(10^{-3}\,\frac{cal/cm\ sec}{°C}\right)$	Temperature during measurement (°*C*)	Density (*gr*/*cm*³)
KW I	Sandstone	6.42	29.4	2.45
II	Sandstone	5.84	29.1	2.49
III	Sandstone	8.61	29.1	2.47
IV	Sandstone	9.39	29.4	2.59
V	Silty sandstone	6.25	29.1	2.62
VI	Silty sandstone	5.82	29.3	2.63

The geology in the vicinity of Kishu Mine is composed of sandstone, shale, silty sandstone of Miocene age and liparite that intruded the sediments.[13] However, the geologic columns of the boreholes are exclusively sandstones, so that only specimens of sandstones are used for thermal con ductivity estimation (Table 13). The mean value of the conductivity is 7.06 $\times 10^{-3}$ ($\frac{R}{2}=1.79\times 10^{-3}$) *cal/cm sec °C*, and whence the amount of heat flow becomes 1.31×10^{-6} *cal/cm² sec.*

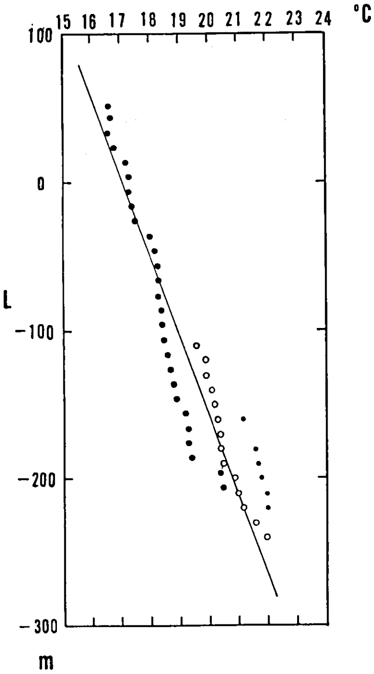

Fig. 19. Temperatures plotted against the altitude in Kishu Mine, Kiwa.

Large full circles: borehole A
Small full circles: borehole B
Hollow circles: borehole C

11. Besshi

In Besshi Mine, Ehime Prefecture, three boreholes (34°01′N, 133°09′E) (Fig. 1 and Fig. 20) from different drifts were utilized for the temperature measurement. The descriptions of the boreholes are listed in Table 14.

The temperatures obtained in these boreholes are well lined up when plotted against the altitude (Fig. 20). This may mean that in the mine, as in the case of Kishu Mine, the isotherms are more or less horizontal at these depths. The geothermal gradient is obtained as 2.49 ± 0.04 *°C/100 m.*

Besshi Mine belongs to so-called "Kieslager-type" cupriferous ores in pyrites and the dominant rocks are Sambagawa crystalline shists.[14]

Table 14. Temperature stations in Besshi Mine

Name of borehole	Altitude of boring site (*m* above sea level)	Approx. depth of boring site (*m*)	Length of borehole (*m*)	Dip angle of borehole
Adit, No. 4, 3600 *m*, borehole No. 1	164	800	705	32°～47°
Adit, No.4, 3600 *m*, borehole No. 2	164	800	530	31°～47°
22 L, E 6	−348	1300	149	90°

13) T. Watanabe, "*Progress in Economic Geology*". Fuzanbo, Tokyo, (1956).
14) T. Watanabe, "*Progress in Economic Geology*", Fuzanbo, Tokyo, (1956).

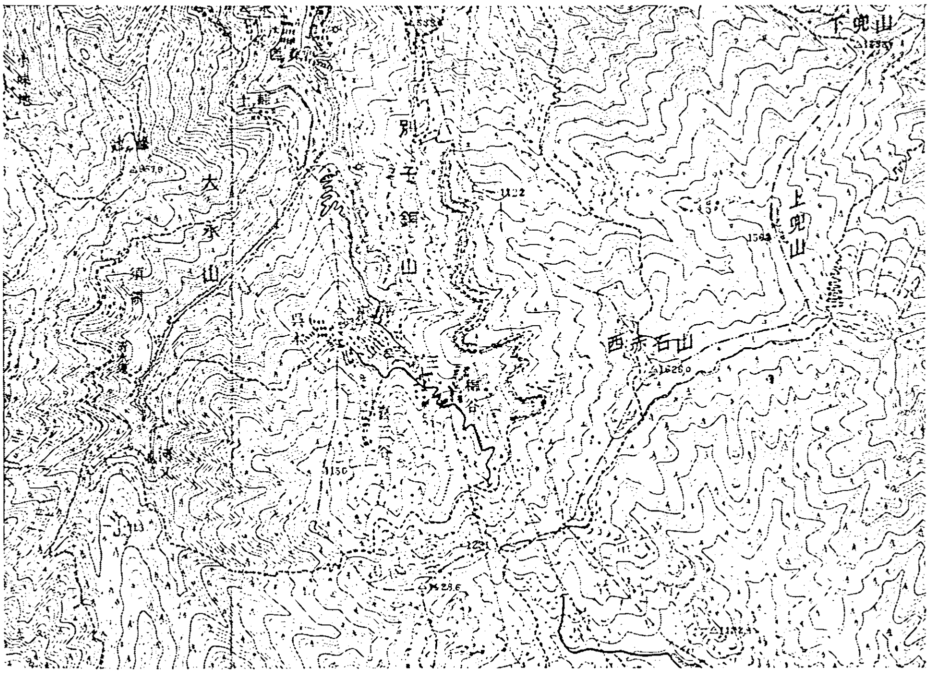

Fig. 20. The area studied in Besshi Mine. The map covers the area from 33°51′ N to 33°54′ N in latitude and from 133°17′ E to 133°22′ E in longitude.

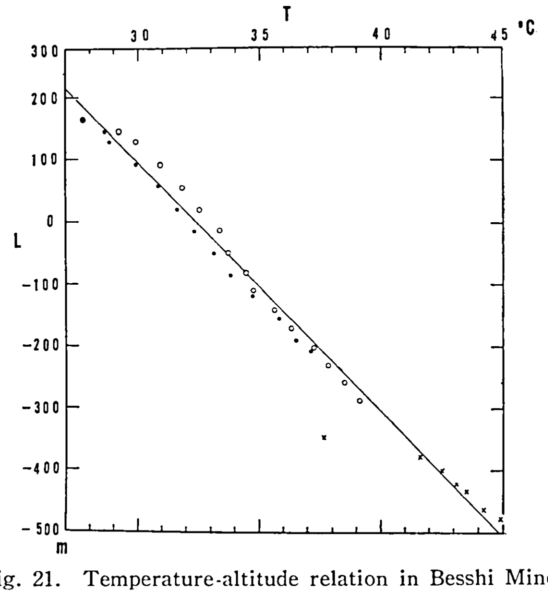

Fig. 21. Temperature-altitude relation in Besshi Mine.
Hollow circles: No. 1 borehole, Adit No. 4
Full circles: No. 2 borehole, Adit No. 4
Crosses: 22 L, E 6

Table 15

Specimen	Rock type	Thermal conductivity $\left(10^{-3}\ cal/cm\ sec\ {}^{\circ}C\right)$	Temperature during measurement (°C)	Density (gr/cm^3)
BS I	Garnet-muscovite-chlorite-albite schist	5.79	26.4	2.76
II	Epidote amphibolite	5.21	26.6	2.67
III	Actinolite-epidote-schist	4.56	26.4	2.91
IV	Muscovite-chlorite-albite-quartz phyllite	6.16	26.8	2.69
V	Epidote amphibolite	3.66	26.8	3.00
VI	Garnet-chlorite-muscovite-albite-quartz schist	4.76	27.0	2.69
VII	Garnet-chlorite-muscovite-albite-quartz schist	4.24	26.9	2.74
VIII	Epidote-actinolite schist	4.77	26.9	2.96

Table 15 summarizes the thermal conductivity data of the shists. Mean of the eight measurements is $K=4.89\times10^{-3}\ cal/cm\ sec\ {}^{\circ}C$ ($\frac{R}{2}=0.96\times10^{-3}\ cal/cm\ sec\ {}^{\circ}C$), and whence the heat flow value becomes $Q=1.22\times10^{-6}\ cal/cm^2\ sec$.

12. Conclusion

Data on terrestrial heat flow in Kinki, Chugoku and Shikoku Districts are summarized in Table 16. Comparison of these data with Fig. 1 will show the following: 1) Japan Sea coast side of the southwestern Japan has relatively high heat flow ($Q\gtrsim2.0\times10^{-6}\ cal/cm^2\ sec$). It seems possible that this high heat flow region is a continuation of the same in the northeastern Japan, which coincides with the Tertiary volcanic zone.[15] The number of stations supporting this observation is still quite small, one of which (Isotake) is a poor one in that the depth of the boreholes is only 160–170 *m*. It is necessary to make more observations in the area to establish the above statement. 2) In the southwestern Japan, there seems to be no region of low heat flow ($Q<1.0\times10^{-6}\ cal/cm^2\ sec$). This is in contrast to the observation in the northeastern Japan.[16] The zone of intense orogeny in the Mosozoic age, i.e. the zonal area around the Median Line shows no systematic high heat flow. 3) Two high heat flow stations in Wakayama Prefecture, i.e.

15) S. UYEDA and K. HÔRAI, *Bull. Earthq. Res. Inst.*, 41 (1963), 85.
16) K. HÔRAI, *Bull. Earthq. Res. Inst.*, 41 (1963), 137.

Table 16. Terrestrial heat flow in Kinki, Chugoku, and Shikoku Districts, Japan

Locality	Abbreviation	Site	Latitude (N)	Longitude (E)	Geothermal gradient ($°C/100\ m$)	Thermal conductivity ($10^{-3}\ cal/cm\ sec\ °C$)	Terrestrial heat flow ($10^{-6}\ cal/cm^2\ sec$)	Remarks
Ikuno	IKN	Au, Ag, Cu mine	35°10′	134°50′	1.88	7.33	1.38	
Nakaze	NS	Sb, Sn, Au, An mine	35°21′	134°57′	3.35-3.43	6.31-6.72	2.11-2.30	
Yanahara	YH	Cu, S, Fe, Gypsum mine	34°57′	134°04′	1.92-2.14	5.89	1.13-1.26	
Isotake (Iwami)	IST	Pb, Zn, mine	35°11′	132°26′	3.82-4.25	8.65	3.30-3.68	
Tsumo	TSM	Cu, Zn mine	34°37′	132°00′	1.80	6.08	1.09	
Kawayama	KY	Cu, S, Fe mine	34°15′	132°59′	1.49-1.98	5.76-5.94	0.86-1.14	
Naka (Iimori)	NK	Cu, S, Fe mine	34°15′	135°25′	3.04	5.90	1.79	
Hidaka	HD	Sea shore	33°57′	135°05′	2.87	7.40	2.12	*
Kiwa	KW	Cu mine	33°50′	135°53′	1.85	7.06	1.31	
Besshi	BS	Cu, Ni, Au, Ag, S mine	34°01′	133°09′	2.49	4.89	1.22	

* Borehole drilled for hot spring exploration.

Naka (Iimori) and Hidaka are located in the area where foci of very shallow local earthquakes are concentrated. It may be an interesting problem to see if these two have any causal relationship.

8. 地球熱学 第9報 近畿，中国，四国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. 本州西部および四国地方の10地点において地殻熱流量 Q ($\times 10^{-6}$ *cal/cm² sec*)，を測定した．すなわち，

兵庫県生野：	$Q=1.38$
兵庫県中瀬：	$Q=2.11\sim2.30$
岡山県柵原：	$Q=1.13\sim1.26$
島根県五十猛（石見鉱山）：	$Q=3.30\sim3.68$
島根県都茂：	$Q=1.09$
山口県河山：	$Q=0.86\sim1.14$
和歌山県那賀（飯盛鉱山）：	$Q=1.79$
和歌山県日高：	$Q=2.12$
三重県紀和（紀州鉱山）：	$Q=1.31$
愛媛県別子：	$Q=1.22$

である．

本文第1図の測点分布と，この熱流量の値とを総合すると，次のことが見出される．すなわち，$Q>2.0$ 以上の高熱流量地域が山陰地方に帯状にあり，所謂大山火山帯と軌を一にしている趣がある．都茂，河山で，$Q\simeq1.0$ の比較的小さい値を示す他には，東北日本にみられる太平洋側の低熱流量域の不在が顕著であり，このことは，日本列島のテクトニックスにとつて意味があると思われる．中生代に大変動をうけた，中央構造線をはさむ変成帯には，現在熱流量の異常はみられないようである．

各測点での記録は以下のごとくである．本研究にあたつて多大の御援助をいただいた各鉱山会社鉱業所の方々に対して深い感謝を表明したい．

2. 生野：兵庫県朝来郡生野町の三菱金属鉱業生野鉱業所の坑道内15点で，岩盤温度の測定を行なつた．概略位置は北緯35°10′,東経134°50′であつた．測温結果を測点の深さおよび標高に対して図示してみると（第3図 a, b），深さに対するものの方が明瞭な関係を示し，地下等温面が地表面の形にほぼ平行であることを示している．地下温度増加率は 1.88°*C*/100 *m* である．鉱山附近の主な地質は，古第三紀基盤（凝灰角礫岩を伴なつた砂岩，頁岩の互層）上に酸性凝灰岩，凝灰角礫岩が厚く堆積し，更にこれらは石英粗面岩，安山岩，石英斑岩等の熔岩流によつて被われている．石英粗面岩，凝灰岩，安山岩等の試料について熱伝導率を測定し平均を求めると，7.33×10^{-3} *cal/cm sec °C* となり，地殻熱流量は，1.38×10^{-6} *cal/cm² sec* となつた．調査に際し，生野鉱業所地質課技師坂井定倫氏のお世話になつた．

3. 中瀬：兵庫県養父郡関宮町，日本精鉱，中瀬鉱業所 (35°21′N, 134°57.5′E) では，探鉱課長，山本儀作氏他の御協力を得て，万寿坑南タテ入れ試錐 No. 85（地表下 265 *m* より 100 *m*），万寿下5坑水平試錐 No. 77,（地表下 420 *m*），および石間歩11坑試錐 No. 55（地表下 340 *m*），石

間歩 6 坑試錐 No. 16 (地表下 195 m), 石間歩 3 坑試錐 No. 68 (地表下 103 m), No. 87 (地表下 28 m) で測温を行なつた. 結果は, 第 5 図のごとくであり, 地表からの深さに対して温度をプロットすると, 石間歩坑, 万寿坑について, 別な線上にのり, 各地温勾配は, 3.43°C/100 m, 3.35°C/100 m となる. 鉱床は, 中新世における石英斑岩等の貫入に伴なう, 裂罅充填型であり, 地層は主として, 秩父古生層 (石間歩), および安山岩質凝灰岩 (万寿) である. 入手した岩石試料につき熱伝導率を測定した結果, $K=6.72\times10^{-3}$ $cal/cm\ sec$ °C (石間歩), $K=6.31\times10^{-6}$ $cal/cm\ sec$ °C (万寿) が得られ, 熱流量としては, $Q=2.30\times10^{-6}$ (石間歩), $Q=2.11\times10^{-6}$ $cal/cm^2\ sec$ (万寿) が得られた.

4. 柵原(やなはら): 岡山県久米郡柵原町の同和鉱業柵原鉱業所では, 地表からの探査用ボーリング3本を用いて地下温度の測定を行つた. 概略位置は北緯 34°57′, 東経 137°04′ である. 使用した 3 本の試錐のうち, 地温勾配の推定に役立つたのは 2 個で, No. 247 (深さ 950 m), No. 248 (深さ 200 m) であつた (第 7 図). 関係地層は主として古生層 (粘板岩) であるが試錐 No. 247 の下部 (深さ 840~930 m) には古期火山砕屑岩, 930 m 以深には基盤の黒雲母花崗岩がみられる. No. 247 中の深さ対温度曲線の 750 m 附近に屈曲のみられるのは, この故であるかもしれない. 粘板岩中での地温勾配は, No. 247 で 1.92°C/100 m, No. 248 では 2.14°C/100 m である. 粘板岩試料の熱伝導率の測定値の平均は, 5.89×10^{-3} $cal/cm\ sec$ °C であるから, 地殻熱流量は, それぞれ, 1.13×10^{-6} および 1.26×10^{-6} $cal/cm^2\ sec$ となる. 調査に当つて, 同鉱業所探査課の中野忠直氏の御世話になつた.

5. 五十猛(いそたけ)(石見鉱山): 島根県大田市五十猛町の石見鉱山株式会社石見鉱業所で探査用試錐 2 個を用いて, 地温測定を行なつた. 試錐孔の位置は (35°11′N,132°26′E) である. 利用した 2 本の試錐は, 互に数米はなれた位置にあり, 温度測定はそれぞれ, 160 m, 170 m の深さまで行なわれた. 測温結果 (第 9 図) によると, 深さ 100 m 辺までは擾乱がはげしく, 一様な温度上昇を示すのは 110 m 以深の 60~70 m の間にすぎない. その部分の地温勾配は, 3.82°C/100 m, 4.25°C/100 m である. 試錐柱状図によると, 深さ 110~170 m に相当する岩石は, 石膏, 粘土, 珪化岩であるが, 熱伝導率は, 珪化岩のそれが, 他に比べて特に大きく, 地層全体の有効熱伝導率を求めることが困難である. 柱状図に表われている存在比から平均を求めると, 8.65×10^{-3} $cal/cm\ sec$ °C となる. したがつて, 熱流量は, $3.30\sim3.68\times10^{-6}$ $cal/cm^2\ sec$ となるが, 上述の諸理由から, この値の信頼度は小さいといわねばならぬ. 測定にあたつて同鉱山調査班の千田良三氏, 飯田良邦氏のお世話になつた.

6. 都茂(つも): 島根県美濃郡, 中外鉱業都茂鉱業所 (34°37′N, 132°00′E) では, 同所本多谷雄氏等の御協力により, 坑道内での 2 ケの試錐中での測温が行なわれた. それらの試錐は, 丸山坑, 0 m レベル (標高海抜 353 m), No. 24 孔, (傾角=60°, 有効深さ=200 m), および No. 23 孔 (傾角=45°, 有効深さ=140 m) であつた. 結果は第 11 図のごとくであり, 地温勾配は, 1.80 °C/100 m である. 都茂鉱山は, 火成岩貫入に伴なう, ホルンフェルス, スカルンに関連して発達したもので, 関係地層の岩石は, ホルンフェルス(主として), スカルン, 石灰岩である. 実験的に求めた熱伝導率を, 柱状図からみて適当に平均すると, $K=6.08\times10^{-3}$ $cal/cm\ sec$ °C となる. したがつて, 地殻熱流量は 1.09×10^{-6} $cal/cm^2\ sec$ となる.

7. 河山: 山口県玖珂郡美川町の日本鉱業河山鉱業所 (34°15′N, 132°59′E) で, 地表および坑道内からの, 探査用試錐 3 本を用いて地温測定を行なつた. 地温勾配は, それぞれ 1.98°C/100 m (試錐 No. 63, 深さ 450 m), 1.49°C/100 m (試錐 No. 107, 深さ 300 m), 1.56°C/100 m (試錐 No. 93, 深さ 300 m), であつた. 附近の地質は, 三郡変成帯に属する弱変成岩で, 母岩は古生層に属する. コア試料から, 砂岩, 頁岩, 石灰岩, 変輝緑岩, 千枚岩, 片岩等をえらび, 熱伝導率を測定した. 各試錐孔柱状図を参照して求めた荷重平均熱伝導率は, No. 63 について 5.76×10^{-3} $cal/cm\ sec$ °C, No. 107 について 5.76×10^{-3} $cal/cm\ sec$ °C, No. 93 について, 5.94×10^{-3} $cal/cm\ sec$ °C となり, したがつて, 熱流量は, それぞれ 1.14×10^{-6} $cal/cm^2\ sec$, 0.86×10^{-6} $cal/cm^2\ sec$, 0.93×10^{-6} $cal/cm^2\ sec$ であった. 測定に当つて, 鉱業所地質課の坂本卓氏他各位のお世話になつた.

8. 那賀(飯盛): 和歌山県那賀郡那賀町, 古河鉱業, 飯盛鉱業所では, 同所, 大久保義和氏等の御協力を得て, 10 坑南タテ入れ, 試錐 No. 2 (34°15′N, 135°25′E) において測温を行なつた. この試錐は孔口標高海抜 −197 m, 地表よりの深さ 453 m, 孔深 187 m であつたが, 測温結果は第 15 図のごとくで, 地温勾配は 3.04°C/100 m であつた. 飯盛鉱山は三波川帯に属する結晶片岩中の含銅

硫化鉄鉱床である．入手した結晶片岩についての熱伝導率の測定値は $K=5.90\times10^{-3}$ *cal/cm cec* °*C* であつた．熱流量としては，1.79×10^{-6} *cal/cm² sec* を推定した．

9．日高：和歌山県日高郡日高町で温泉探査のために掘られた試錐孔1本を利用して温度測定を行なつた試錐孔の深さは約 310 *m* で，概略の位置は北緯 33°57′，東経 135°05′ である．海岸の岩盤に垂直に掘られたこの試錐孔中の地温勾配は，2.87°*C*/100 *m* であつた．コア試料はすべて砂岩で，時代未詳中生層日高川統に属する．熱伝導率は 7.40×10^{-3} *cal/cm sec* °*C* であつた．故に，地殻熱流量は，2.12×10^{-6} *cal/cm² sec* となる．温度測定および，岩石試料の採集を許可された試錐孔管理者の一人，中家昇氏に感謝する．

10．紀和（紀州鉱山）：三重県南牟婁郡紀和町，石原産業紀州鉱業所の坑道内試錐孔を利用して，地温測定を行なつた．測定点の位置は，北緯 33°50′，東経 153°53′ である．数本の試錐孔のうち，長さ 290 *m* で垂直のもの，長さ 100 m で傾斜 41° のもの，および，長さ 150 *m* で傾斜 44° のもの，についての測温結果から，地温勾配を求めると，1.85°*C*/100 *m* となる．鉱山附近の地質は，中新世に属する砂岩，頁岩，砂質頁岩等と，これに貫入した石英粗面岩類から成るといわれるが，測温の行なわれた試錐の柱状図には，砂岩のみが現われているので，それらのコア試料について熱伝導率を測定した．熱伝導率の平均値は，7.06×10^{-3} *cal/cm sec* °*C* であり，地殻熱流量は，1.31×10^{-6} *cal/cm² sec* となる．調査にあたつて，鉱業所採鉱課の佐川徳雄氏のお世話になつた．

12．別子：愛媛県新居浜市の住友金属鉱業別子鉱業所で，坑道内の試錐孔を利用して地温測定を行つた．測定地の概略の位置は北緯 34°01′ 東経133°09′ である．用いた試錐孔は，長さ 705 *m*，傾角 32°～47°，長さ 530*m*，傾角 31°～47°，長さ 150 *m*，傾角 90° の3本であつた．このうち，第一，第二の試錐孔は，地表からの深さ約 800 *m*，第三のものは，更に約 500 *m* 下位にある．温度は標高を縦軸にして図示するとよい一致を示し，山体の内部で地表から数 100 *m* 以深では，等温面はほぼ水平であることを示している．温度増加率は 2.49°*C*/100 *m* である．附近の地層は三波川変成帯に属する結晶片岩で，試料 8 個の熱伝導率の平均は 4.89×10^{-3} *cal/cm sec* °*C* であつた．したがつて，地殻熱流量は 1.22×10^{-6} *cal/cm² sec* となる．調査に当つて，鉱業所採鉱課の天野熈三氏，地質課の土井正氏はじめ各位の御世話になつた．