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9. *Studies of the Thermal State of the Earth. The 10th Paper: Terrestrial Heat Flow Measurements in Tohoku District, Japan.*

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Abstract

Terrestrial heat flow values at three localities were added to the previous heat flow determinations in Tohoku District. Of the newly-added three localities, two (Kamaishi and Nodatamagawa) are on the Pacific coast side of the District while the other (Osarizawa) is on the central part slightly nearer to the Japan Sea coast of the District. Thermal gradients observed in these localities are 0.66–1.16°$C/100\,m$ in Kamaishi, 1.38°$C/100\,m$ in Nodatamagawa, and 3.34°$C/100\,m$ in Osarizawa. Geothermal heat flux in each of these localities was determined from the thermal gradient combined with thermal conductivity of rocks collected at each place. The values of heat flux are $0.37\sim0.66\times10^{-6}\,cal/cm^2 sec$ in Kamaishi, $1.14\times10^{-6}\,cal/cm^2 sec$ in Nodatamagawa and $2.24\times10^{-6}\,cal/cm^2 sec$ in Osarizawa. The results, together with the previously determined heat flow values ($2.01\times10^{-6}\,cal/cm^2 sec$ in Yabase and $1.49\times10^{-6}\,cal/cm^2 sec$ in Innai), indicate that the heat flow is high on the Japan Sea coast of the District, while it is low on the Pacific coast of the District. This observation is in accord with the results of heat flow measurements in Kanto and Hokkaido Districts and in the sea off the Tohoku District.

1. Introduction

Terrestrial heat flow was determined at three localities in Tohoku District. The results of these measurements will be described in this paper which constitutes the 3rd of a series of papers[1),2)] on heat flow survey in Japan. The new localities are Osarizawa Au–Ag–Cu–Pb–Zn mine, Nodatamagawa Mn mine, and Kamaishi Cu–Fe mine. As reported

1) S. UYEDA and K. HÔRAI, *Bull. Earthq. Res. Inst.*, 41 (1963) 85.
2) S. UYEDA and K. HÔRAI, *Bull. Earthq. Res. Inst.*, 41 (1963) 109.

already[3),4),5)] heat flow had been measured in two places in the District i.e. 2.05×10^{-6} *cal/cm²sec* at Yabase and 1.49×10^{-6} *cal/cm²sec* at Innai respectively. The localities are shown in Fig. 1.

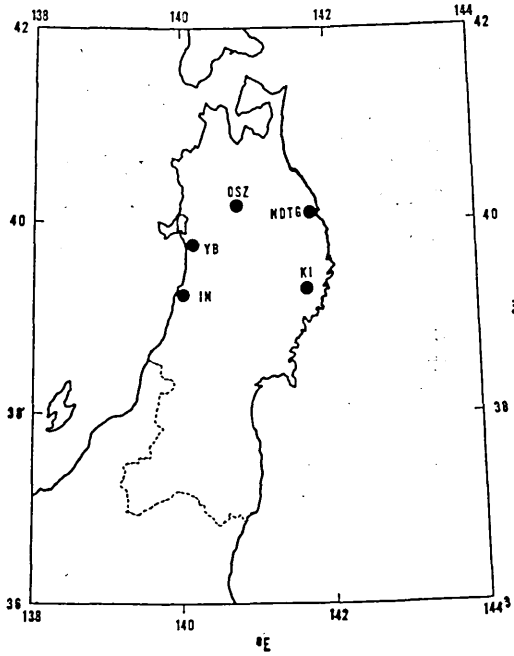

Fig. 1. Localities of heat flow stations in Tohoku District.
OSZ : Osarizawa
NDTG: Nodatamagawa
YB : Yabase
KI : Kamaishi
IN : Innai

2. Osarizawa

Underground temperature distribution was measured using boreholes in the drifts and a borehole from the surface in Osarizawa Mine (40°10′N, 140°45′E), Akita Prefecture (Fig. 1, Fig. 2).

Geology of the mine belongs to the Miocene formation composed of tuff, shale and andesite, and to the Quarternary one.[6)] The drifts used

3) S. UYEDA, T. YUKUTAKE and I. TANAOKA, *Bull. Earthq. Res. Inst.*, **36** (1958), 251.
4) K. HÔRAI, *Bull. Earthq. Res. Inst.*, **37** (1959), 571.
5) S. UYEDA and K. HÔRAI, *Bull. Earthq. Res. Inst.*, **38** (1960), 421.
6) K. SATO, private communication.

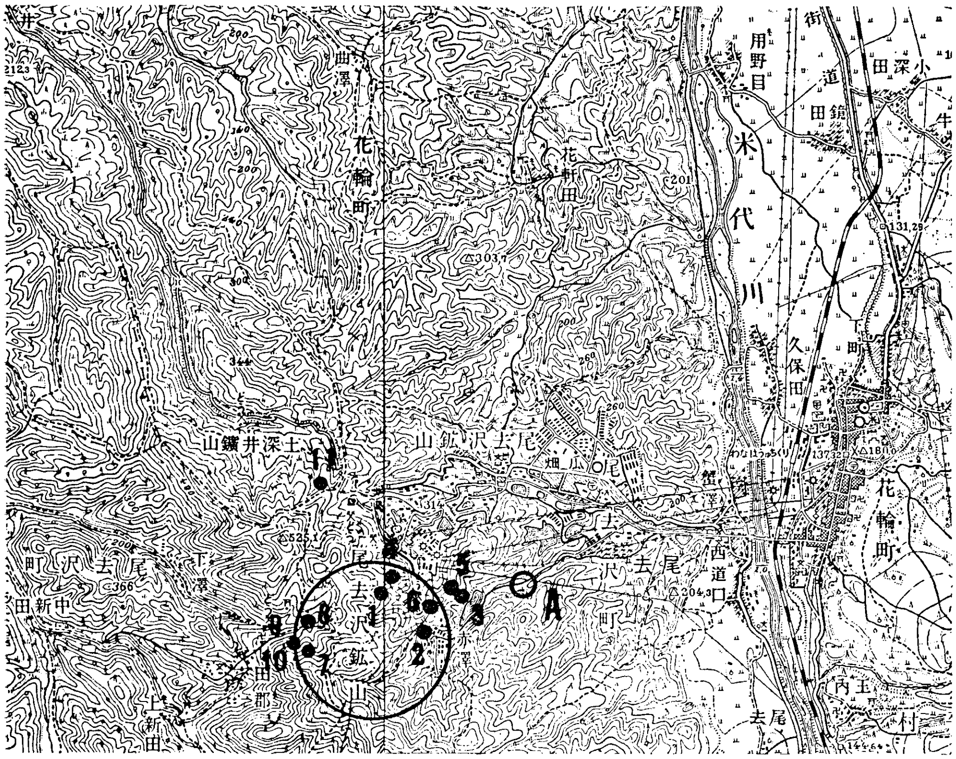

Fig. 2. Localities of the boreholes used in Osarizawa Mine. The map covers the area from 40°10′ N to 40°13′ N in latitude and from 140°43′10″4 E to 140°48′10″4 E in longitude

A: Akasawa boring
Numbers refer to Table 1.

Table 1. Temperature in horizontal boreholes from drifts of various levels in Osarizawa Mine.

(For vertical borehole from the surface, see Text and Fig. 3).

No.	Level	Altitude of site (m above sea level)	Length of insertion (m)	Rock temperature ($°C$)
1	L-0	309	10	10.6
2	L-1	279	10	11.8
3	L-3	219	10	13.3
4	L-4	189	7	13.0
5	L-5	159	5	14.1
6	L-2	249	10	10.0
7	L-6	129	3	16.2
8	L-6	129	10	14.9
9	L-5	159	10	15.1
10	L-5	159	8	15.2
11	L-4	189	10	14.5

for temperature measurement were cut through a hill and extend in various depths ranging about 200 *m* from 129 *m* to 309 *m* above sea level, as listed in Table 1. The borehole from the surface (Akazawa boring) was drilled vertically on the foot of the hill. Its mouth is at 209 *m* above sea level and its length is about 300 *m*.

The measured temperatures are plotted in Fig. 3 against the altitude of temperature stations. Coincidence of tempearture distribution

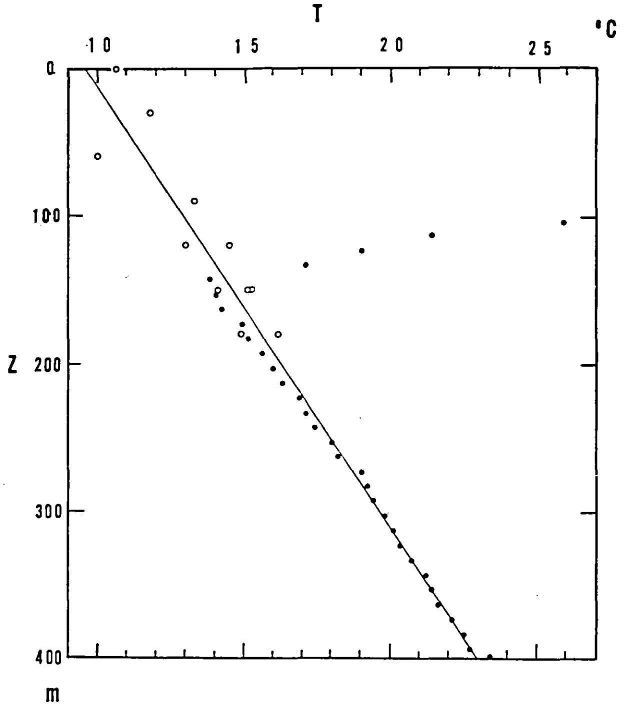

Fig. 3. Underground temperature in Osarizawa Mine.
Full circles : Akasawa boring
Hollow circles: Short horizontal borings at various depths in the drifts.
The ordinate is altitude measured from the local reference level (L-0), which is 309 m above sea level.

measured in the drifts and in the borehole taking the altitude as the ordinate indicates that the isotherms in this area seem to be nearly horizontal regardless of the surface topography. The "least squares" geothermal gradient amounts to $3.34 \pm 0.09°C/100\,m$.

Thermal conductivity was measured on the collected samples of tuff, shale and propylite. The result is listed in Table 2. Mean thermal conductivity is $6.70 \times 10^{-3} (\frac{R}{2} = 2.91 \times 10^{-3})\ cal/cm\ sec\ °C$ and, therefore, the heat flow amounts to $2.24 \times 10^{-6}\ cal/cm^2\ sec$.

Table 2.

Specimen	Rock Type	Thermal conductivity (10^{-3} *cal/cm sec °C*)	Temperature during measurement (°*C*)	Density (*gr/cm*^{3})
OSZ I	Tuff	7.55	27.9	2.46
II		5.17	27.8	2.30
III		4.55	27.9	2.12
IV		4.21	28.0	2.13
V		4.62	27.9	2.20
VI	Shale	10.38	28.1	2.63
VII		10.40	28.2	2.56
VIII		11.57	28.1	2.65
IX		10.69	28.2	2.63
X	Propylite	5.34	28.1	2.60
XI		5.49	28.1	2.63
XII		4.35	28.0	2.74
XIII		4.89	28.4	2.73
XIV		4.62	28.4	2.79

3. Nodatamagawa

Underground temperature was measured using boreholes in the drifts

Fig. 4. The area studied in Nodatamagawa Mine. The map covers from 40°03′ N to 40°06′ N in latitude and from 141°46′10″4 E to 141°51′10″4 E in longitude.

of the Nodatamagawa Mine (40°05′ N, 141°49′ E), Iwate Prefecture (Fig. 1, Fig. 4). The mine is situated on the northern end of the Kitakami mountain range and the geology[7] around it belongs to Mesozoics (old Cretaceous) formation composed of sandstone, chert and slate. The Mesozoics are intruded by granitic rocks and covered by younger Cretaceous and Pleistocene sedimentary rocks and are partly changed to hornfels.

Temperature was measured in the drifts at various depths ranging about 400 *m* (Table 3). The result is plotted in Fig. 5, giving the " least squares " thermal gradient: 1.38 ± 0.11 °C/160 *m*.

Table 3. Temperature stations in Nodatamagawa Mine.

Borehole	Altitude of boring site referring to the borehole No. 80 (*m*)	Altitude of temperature site (*m*)	Dip angle of bore	Rock temperature (°*C*)
No. 64	−240	−311	−55°	14.4
No. 65	−240	−328	−67°	15.0
No. 92	−330	−400	−58°	15.2
No. 80	0	0	0	10.0
No. 86	−240	−240	0	13.6
No. 91	−300	−300	0	14.6

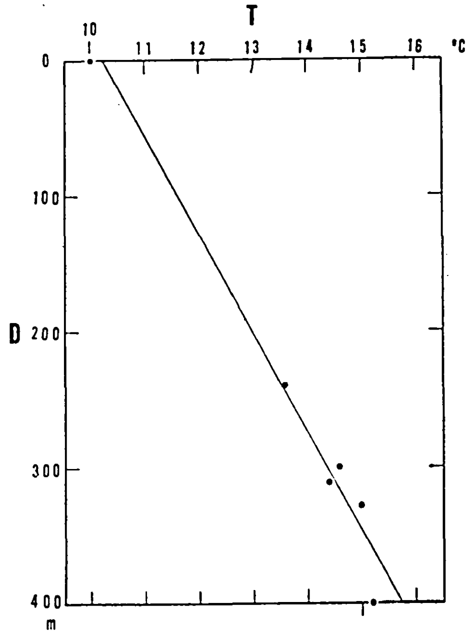

Fig. 5. Temperature-depth relation in Nodatamagawa Mine. Points from top to bottom refer to boreholes Nos. 80, 86, 91, 64, 65, and 92 (Table 3).

7) T. KAJITA, private communication.

Thermal conductivity was measured about the samples of sandstone, chert, and shale. The result is listed in Table 4. Mean thermal conductivity is 8.28×10^{-3} *cal/cm sec* °*C* ($\frac{R}{2}=4.81\times10^{-3}$ *cal/cm sec* °*C*).

Table 4.

Specimen	Rock type	Thermal conductivity (10^{-3} *cal/cm sec* °*C*)	Temperature during measurement (°*C*)	Density (*gr/cm*^{3})
NDTG Ia	Chert	14.56	28.5	2.68
Ib	Chert	14.50	28.5	2.67
IIa	Sandstone	4.39	28.6	3.43
IIb	Sandstone	5.42	28.6	3.35
IIIa	Shale	5.80	28.3	2.79
IIIb	Shale	5.01	28.4	2.78

The heat flow in this area amounts to 1.14×10^{-6} *cal/cm*^{2} *sec.*

4. Kamaishi

Terrestrial heat flow measurement was made in Kamaishi Mine (39°

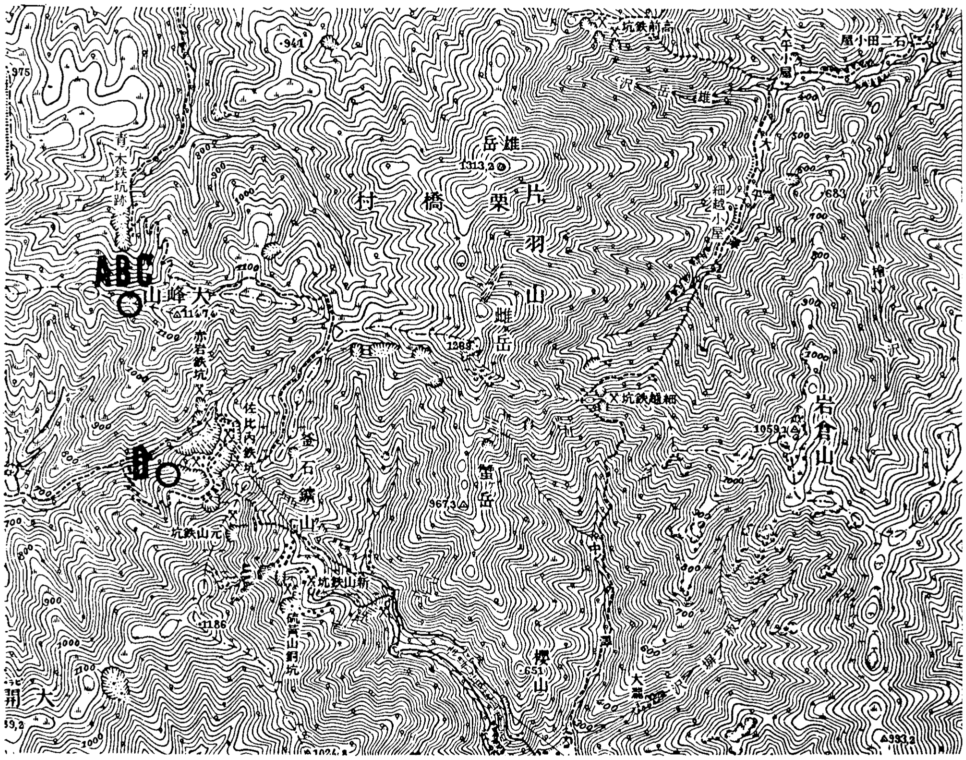

Fig. 6. Localities of boreholes used in Kamaishi Mine. For symbols see Table 5. The map covers the area from 39°17′ N to 39°20′ N in latitude and from 141°40′10″4 E to 141°45′10″4 E in longitude.

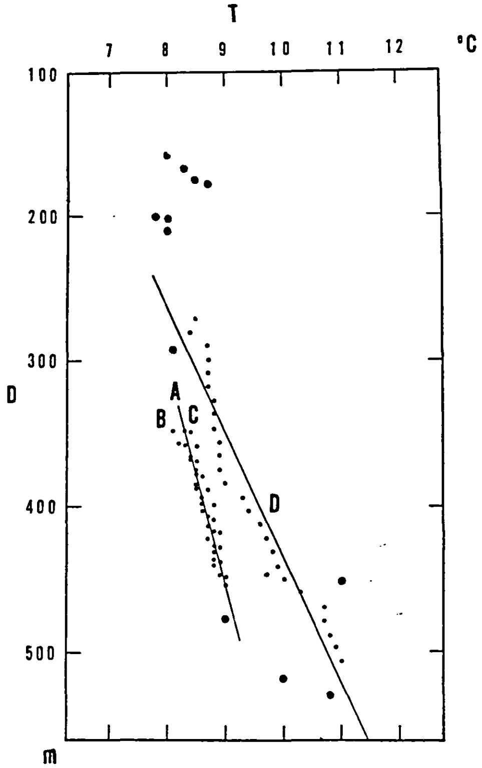

Fig. 7. Temperature-depth relation in Kamaishi Mine.

Small circles are the temperature along the boreholes.
A: Borehole A
B: Borehole B
C: Borehole C
D: Borehole D
Large circles are the temperature in short boreholes.

17–18′ N, 141°42′ E), Iwate Prefecture (Fig. 1, Fig. 6). Temperature was measured in the boreholes cut horizontally or vertically in the drifts. In Fig. 7 all the measured temperatures are plotted against the depth from the surface. The scattering of the points indicates that the temperature distribution under the area is considerably irregular, and the thermal gradients defined along the vertical holes vary from place to place. In the figure thermal gradients along the boreholes A, B, C drilled at nearly the same place and D are indicated by two lines. Other boreholes (See Table 5) are short and only the bottom temperatures are recorded. The indicated thermal gradients amount to 0.66 ± 0.05 and 1.16 ± 0.07 $°C/100\,m$ respectively. The representative thermal gradient in the area may be between these two.

Geology[8] in and around the mine belongs to the Permian formation composed of sandstone, limestone and slate partly altered by the intrusion of monzonite, porphyrite and granodiorite. Thermal conductivity was measured on the rock samples of limestone, skarn, chert, porphyrite, diorite and shale collected from the boring cores. The result is listed in Table 6. Mean thermal conductivity is $5.66 \times 10^{-3} (\frac{R}{2} = 2.22 \times 10^{-3})\, cal/cm\,sec\,°C$.

Using this value of thermal conductivity, the heat flux is 0.37 to $0.66 \times 10^{-6}\, cal/cm^2\,sec$ corresponding to the two values of thermal gradients mentioned above.

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

Table 5. Temperature stations in Kamaishi Mine.

Borehole	Altitude of boring site (*m* above sea level)	Depth of boring site (*m*)	Length of borehole (*m*)	Dip angle of bore	Depth of site where temperature was measured (*m*)	Rock temperature (°*C*)	Remarks
No. 2	449	451	16	0°	451	11.0	Short bore
No. 6	449	451	43	−38°	477	9.0	〃
No. 3	357	478	63	−40°	518	10.0	〃
No. 16	357	478	73	−45°	529	10.8	〃
	772	158	47	−65°	201	7.8	〃
	772	159	52	−90°	211	8.0	〃
	721	149	53	−90°	202	8.0	〃
	721	219	74	−90°	293	8.1	〃
	720	130	57	−60°	158∼179	8.0∼8.7	〃
A (Omine)	734	336	101	−80°			Long bore
B	734	336	119	−68°		see	〃
C	734	336	118	−88°		Fig. 7	〃
D (Sahinai)	563	222	303	−70°			〃

Table 6.

Specimen	Rock type	Thermal conductivity (10^{-3} *cal/cm sec* °*C*)	Temperature during measurement (°*C*)	Density (*gr/cm*^{3})
KI I	Limestone	5.79	28.6	2.69
II	Limestone	7.52	28.7	2.70
III	Limestone	6.92	28.5	2.74
VI	Epidote skarn	4.83	28.5	3.30
VII	Epidote skarn	4.85	28.6	3.26
IX	Garnet skarn	9.06	28.8	3.43
X	Porphyrite	4.89	28.8	2.77
XI	Porphyrite	5.12	28.8	2.82
XIV	Diorite	4.65	28.9	2.85
XV	Diorite	4.58	29.0	2.89
XVI	Slate	4.17	29.0	2.74
XVII	Slate	5.48	29.0	2.74

5. Summary

The results of the terrestrial heat flow measurements described above are summarized in Table 7, together with the results of heat flow

Table 7. Terrestrial Heat Flow in Tohoku District.

Locality	Abbreviation	Site	Latitude (N)	Longitude (E)	Geothermal gradient (°C/100 m)	Thermal conductivity (10^{-3} cal /cm sec °C)	Terrestrial heat flow ($\times 10^{-6}$ cal /cm^2 sec)	Remarks
Yabase	YB	Oil field	39°44′	140°06′	4.80	4.19	2.01	9),10)
Innai	IN	Oil field	39°16′	139°58′	4.80	3.11	1.49	9),11)
Osarizawa	OSZ	Au, Ag mine	40°11′	140°45′	3.34	6.70	2.24	
Noda-tamagawa	NDTG	Mn mine	40°04′	141°50′	1.38	8.28	1.14	
Kamaishi	KI	Fe mine	39°16′	141°42′	0.91	5.66	0.52	

measurements in the District reported in previous papers[9),10),11)]. The heat flow is more than 2×10^{-6} *cal/cm*^{2} *sec* in Osarizawa and Yabase, on the 1×10^{-6} *cal/cm*^{2} *sec* level in Nodatamagawa and Innai, and less than 1×10^{-6} *cal/cm*^{2} *sec* in Kamaishi. Considering the localities of these places as indicated in Fig. 1, the results seem to suggest a zonal distribution of terrestrial heat flow in the District, i.e., a zone of high heat flow on the north-western part of the District and a zone of low heat flow on the south-eastern part of the District with the intermediate zone between them. This fact, together with the heat flow measurement in adjacent Districts[12)] and in the sea off the Tohoku District[13)], will confirm the basic tendency of the heat flow distribution in Japan that the heat flow is high in the belt along the Japan Sea coast, where volcanic activity has been prominent since Tertiary ages, and low on the Pacific coast of north-eastern Honshu.

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9. 地球熱学 第10報 東北地方に於ける
地殼熱流量測定結果

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. 東北地方では従来八橋・院内の2地点で地殼熱流量の測定が行なわれていたが，今回更に3地点での測定を行なつた．以下にその要点を述べる．

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9) *loc. cit.*, 3).
10) *loc. cit.*, 4).
11) *loc. cia.*, 5).
12) *loc. cit.*, 1).
13) S. UYEDA, K. HÔRAI, M. YASUI and H. AKAMATSU, *J. Geophys. Res.* **67** (1962), 1186; *Oceanographical Mag.*, **13** (1962), 185.

2. 尾去沢： 秋田県鹿角郡尾去沢町の三菱金属鉱業尾去沢鉱業所において，地殻熱流量測定を行なつた．鉱山付近の地質は第三紀中新世に属する凝灰岩・頁岩・安山岩および洪積層・沖積層から成つている．鉱山の坑道内および地表からの探査用ボーリングによつて温度測定を行ない，地下等温面が山体その他地表面の起伏によらずほぼ水平をなしている事実および地下温度増加率が 3.34 °*C*/100 *m* であることを推定した．測定地の概略の位置は北緯 40°11′ 東経 140°45′，利用した坑道の高低差は約 200 *m*，使用したボーリングの深さは約 300 *m* である．また測定点付近の地層から採集した凝灰岩・頁岩・変朽安山岩等の試料について熱伝導率の測定を行ない，それらにもとづいて地層が全体として示す熱伝導率を 6.70×10^{-3} *cal*/*cm sec* °*C* とした．地下温度増加率と熱伝導率とから，この地点の地殻熱流量の値は 2.24×10^{-6} *cal*/*cm*^{2} *sec* となる．測定にあつて尾去沢鉱業所地質課の主任技師佐藤孝市氏，試錐係の西村博氏はじめ各位のお世話になつた．

3. 野田玉川： 岩手県九戸郡野田村字玉川に，新鉱業開発株式会社野田玉川鉱山がある．鉱山の概略の位置は北緯 40°04′ 東経 141°50′ で北上山地の北端に位置し，付近一帯の地質は砂岩・chert・粘板岩から成る中生層（古白堊系）とそれを貫入する花崗岩類，さらにこれらを覆う中世層（新白堊系）と第四紀層（洪積世）の堆積岩類から成るといわれ，中生層の一部は hornfels 化されている．この鉱山の坑道内の試錐孔数本を利用して温度測定を行ない，地下温度増加率 1.38 °*C*/100 *m* を得た．利用した坑道の高低差は約 400 *m* である．また採集した砂岩・chert・頁岩等の熱伝導率を測定し，平均熱伝導率 8.28×10^{-3} *cal*/*cm sec* °*C* をえた．これらによると，この地点の地殻熱流量は 1.14×10^{-6} *cal*/*cm*^{2} *sec* となる．測定にあたつて，野田玉川鉱業所の梶田民夫氏ほか各位の御助力をいただいた．

4. 釜石： 岩手県釜石市甲子町の日鉄鉱業株式会社釜石鉱業所で地殻熱流量の測定を行なつた．鉱山付近の地質は二畳紀古生層に属する砂岩・緑色岩・石灰岩・粘板岩等とそれらを貫入した Monzonite・玢岩・閃緑岩・花崗閃緑岩等から成つている．鉱山の坑道内の多数の点で温度測定を行なつてみると，この地域では地下温度の分布が相当に不規則で，垂直ボーリング数本を利用して測定した温度増加率も，測定位置によつて 0.66 °*C*/100 *m* から 1.16 °*C*/100 *m* にわたるいろいろの値を示している．ボーリングコアから石灰岩・skarn・玢岩・閃緑岩・粘板岩等の試料を採集して熱伝導率を測定し，平均値 5.66×10^{-3} *cal*/*cm sec* °*C* を得た．この値を用いて地殻熱流量を求めると，地下温度増加率の不定に応じて，その値は $0.37\sim0.66\times10^{-6}$ *cal*/*cm*^{2} *sec* となる．調査に際して釜石鉱業所採鉱課長和田成人氏・地質係長田中良雄氏・内山久男氏はじめ各位のお世話になつた．

5. さて今回の測定結果を，すでに得られている地殻熱流量の測定結果（八橋において 2.01×10^{-6} *cal*/*cm*^{2} *sec*，院内において 1.49×10^{-6} *cal*/*cm*^{2} *sec*）とあわせ考えると，東北地方北部の地殻熱流量は帯状の分布を示していて，北西部で地殻熱流量が大きく（八橋：$Q=2.01\times10^{-6}$ *cal*/*cm*^{2} *sec*，尾去沢：$Q=2.24\times10^{-6}$ *cal*/*cm*^{2} *sec*），中間の地帯（野田玉川：$Q=1.14\times10^{-6}$ *cal*/*cm*^{2} *sec*，院内：$Q=1.49\times10^{-6}$ *cal*/*cm*^{2} *sec*）を経て東南部では地殻熱流量が小さい（釜石：$Q=0.37\sim0.66\times10^{-6}$ *cal*/*cm*^{2} *sec*）という特徴がみとめられる．この特徴が，日本列島の地殻熱流量分布の主要な特徴の一つであることは，隣接諸地域におけるこの種の測定結果から確かめられるのである．

以上の研究調査を行なうにあたつて，必要なる便宜を提供するとともに，進んで研究に協力して下さつた各鉱山会社・鉱業所の方々に心から感謝の意を表する．