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Rates of Discharge of Heat Energy from the Principal Hot Spring Localities in Hokkaido, Japan

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Abstract

The total discharge rate of heat energy Q from a hot spring locality is the sum of the discharge rate of heat Q_1 flowing out as hot water from orifices in that locality and the heat Q_2 emitted from the ground surface of the locality by heat conduction. Some discussion is presented on the method of estimation of Q_2.

The heat energy Q generated from the principal and some of the small Hokkaido hot spring localities in Japan was estimated at $0.3\times10^7\sim120\times10^7$ cal/min from the data which were collected chiefly by the writer and his collaborators as shown in Table I. Presumption of the amount of heat energy in uninvestigated localities was also made using a newly introduced quantity, that is, "heat energy index." Then, the order of magnitude to the total sum of heat energy per unit time from all of the hot spring localities in Hokkaido was estimated at 5.5×10^9 cal/min. This heat energy is equivalent to the combustion heat of six hundred thousand tons of coal per year.

Heat energy generated from some famous hot spring localities in other parts of Japan and in the world were also discussed. It is concluded from the result that heat energy generated from a hot spring locality is in the range from less than $10^{6.5}$ to 10^{10} cal/min and accordingly the heat energy index of a hot spring varies from O to VII.

§ I. Introduction.

The writer and his collaborators have investigated temperature, volume output, chief chemical constituents and geographical distribution of hot springs in many of the principal and in several small hot spring localities in Hokkaido, Japan in these several years, and also have investigated the geographical distribution of underground temperature at a depth of 1 m with temperature gradients in 15 of these hot spring localities. They have measured also the heat conductivities of surface soil in several hot spring localities.

In this paper, the writer estimates the discharge rate of anomalous heat energy derived from underground heat sources as hot spring veins in these hot spring localities using the above mentioned data. The writer tried, further, to estimate the order of magnitude of the total sum in discharge rate of heat energy due to all the hot springs in Hokkaido.

§ II. Estimation of total discharge rate of heat energy from a hot spring locality.

The total discharge rate of heat energy Q from a hot spring locality is the sum of the discharge rate of heat Q_1 flowing out as hot water (or rarely as steam) from orifices in that locality and the heat Q_2 emitted from the ground surface of the locality to the air by heat conduction.

If V_i and T_i are respectively the volume output and the orifice temperature of hot spring of i-th orifice, n the total number of hot springs in the locality, ρ and c respectively the density and the specific heat of hot water and T_0 the temperature of normal underground water in the out-skirts of that hot spring locality, the former heat Q_1 per unit time is written as :

$$Q_1 = \rho c \sum_{i=1}^{n} V_i (T_i - T_0) \tag{1}$$

Further, if $(d\theta/dr)_i$ and $(d\theta/dr)_0$ are respectively the vertical component of ground-temperature gradient at certain depth near the ground surface in the hot spring locality and the normal value of that gradient in the out-skirts of the locality, S_i the horizontal area where $(d\theta/dr)_i$ indicates the value in a same class, κ the heat conductivity of soil at that depth and m the total number of classes in the value of temperature gradient, the latter heat Q_2 per unit time is indicated by

$$Q_2 = \kappa \sum_{i=1}^{m} S_i \left\{ \left(\frac{d\theta}{dz} \right)_i - \left(\frac{d\theta}{dz} \right)_0 \right\} \tag{2}$$

The observed value of $\{(d\theta/dz)_i - (d\theta/dz)_0\}$ at a depth of 0.75 m in a hot spring locality is found to be proportional to the corresponding observed value of underground temperature $(\theta_i - \theta_0)$ at a depth of 1 m, where θ_i and θ_0 are respectively the underground temperature measured during successive 2 or 3 days in the hot spring locality and in the out-skirts of the locality. This relation holds in almost all of the hot spring localities, though the value of the proprotional constant λ is more or less different due to heat conductivity of soil and heat emission to the atmosphere. Two examples are shown in Fig. 1. It has already been proved theoretically by the writer[1)] that this experimental relation is reasonable.

Then, equation (2) may be written as

$$Q_2 = \kappa \lambda \sum_{i=1}^{m} S_i (\theta_i - \theta_0) \tag{3}$$

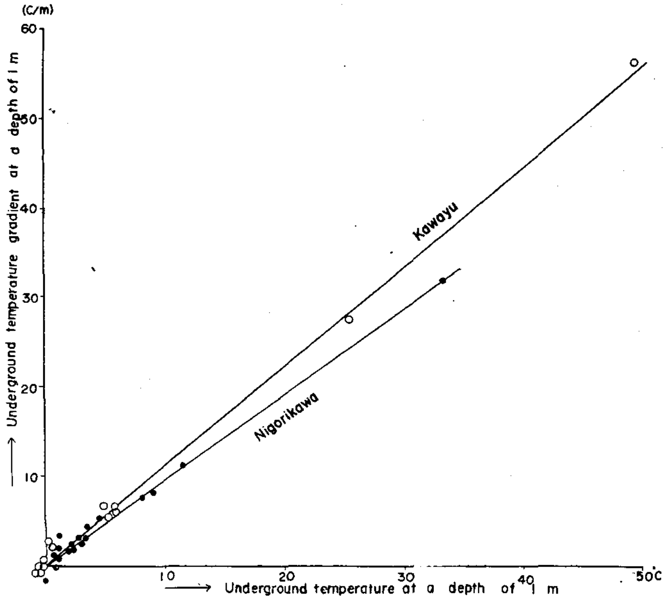

Fig. 1. Relation between $\{(d\theta/dz)_i - (d\theta/dz)_0\}$ and the corresponding $(\theta_i - \theta_0)$ in Kawayu and Nigorikawa hot spring localities.

where S_i is the horizontal area where $(\theta_i - \theta_0)$ indicates a value of the same class in this case and m the total number of the classes of underground temperature.

Then, the total discharge rate of heat energy Q from a hot spring locality is expressed by

$$Q = Q_1 + Q_2 \tag{4}$$

For an example of estimation of the value of Q_1 and Q_2 from a hot spring locality, the writer will describe the case of Kawayu hot spring in the following.

In Kawayu hot spring locality,[2] situated in the western part of the Kuccharo calderon of the Kuril volcanic chain, about 50 orifices of water temperature $T_i = 43 \sim 65$°C are distributed in a narrow area of 0.2×0.9 km^2 as shown in Fig. 2. Hot water discharged from these orifices is flowing as a hot river into Kuccharo lake. The total discharge rate of hot water and that of heat Q_1 are estimated respectively as 8360 l/min and 37×10^7 cal/min, adopting the value of T_0 as 10°C, i.e., the temperature of the underlying normal water of the hot spring stratum.

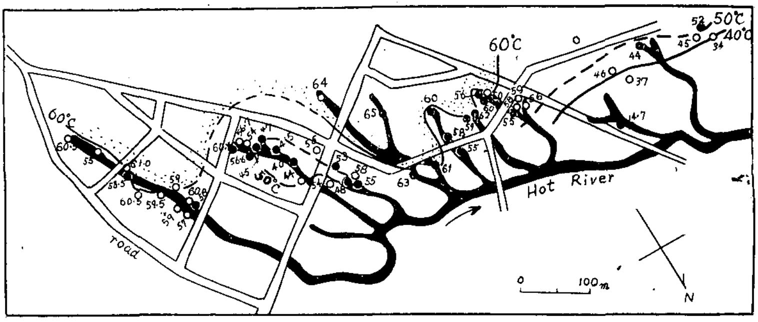

Fig. 2. Distribution of hot spring orifices in Kawayu. Black circles and white circles are respectively sites of natural hot springs and self-discharging wells due to shallow boring. Numerals attached to the circles are the value of temperature observed at the orifice. Full and dotted lines are the isotherms.

Geographical distribution of underground temperature $(\theta_i-\theta_0)$ at a depth of 1 m in the locality shows, as illustrated in Fig. 3, that a high temperature zone runs about 2.5 km from the group of hot spring orifices which is indicated by the rectangle in the right-hand side of the figure to the south as far as the northern foot of the hill line of Iwosan fumaroles. Adopting $\lambda=1.12\times10^{-2}$ cm^{-1} from Fig. 1 and assuming $\kappa=1.7\times10^{-3}$ cal.cm^{-1}. deg^{-1}. sec^{-1} for volcanic

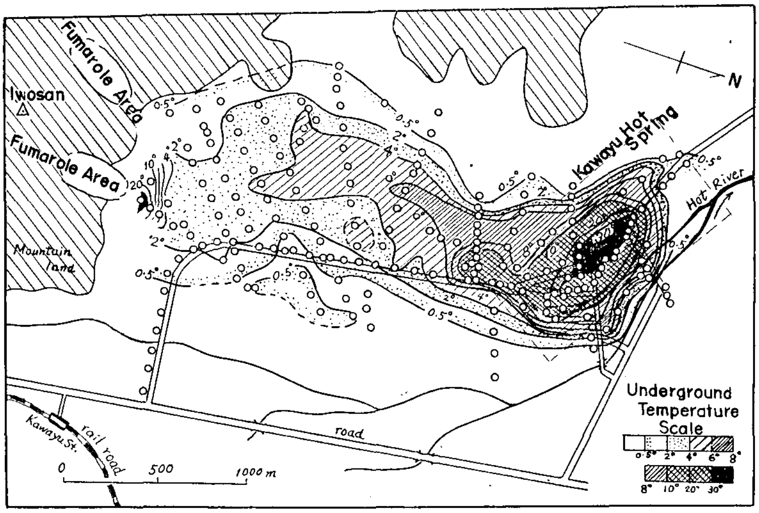

Fig. 3. Horizontal distribution of underground temperature $(\theta_i-\theta_0)$ at a depth of 1 m in Kawayu hot spring locality. White circles are points of measurement of underground temperature, and thick curves are isotherms of respectively 0.5°, 2°, 4°, 6°, 8°, 10°, 20° and 30°C.

tuff of the locality, the value of Q_2 is estimated as 17×10^7 cal/min from Fig. 3.

Then, the total discharge rate of heat energy Q from Kawayu hot spring locality is estimated as 53×10^7cal/min.

The writer measured, in his recent estimations of Q_2, the value of heat conductivity κ of the surface soil in hot spring localities, using the prove method which was developed by Buettner[3], Lachenbruch,[4] Blackwell[5] and Saito[6], but he assumed $\kappa=1.7\times 10^{-3}$ cal. cm^{-1}. deg^{-1}. sec^{-1} in his former estimations.

§ III. Discharge rate of heat energy from many of the principal hot spring localities and from several hot spring localities of smaller scale in Hokkaido.

Applying the same method as that described above in § II to the result of investigations of the principal hot spring localities and of several hot spring localities of smaller scale in Hokkaido carried out by the writer and other observers, the writer estimated the discharge rate of heat energy flowing out as hot water Q_1, that conducted through rock and soil Q_2, and the total heat energy per unit time Q in these localities as indicated in Table I. In the table, total number of hot spring orifices, the maximum temperature of hot spring in the underground and total sum of volume output in respective hot spring locality are tabulated for reference data. 10^7 cal/min is adopted, in this paper, for unit of the discharge rate of heat energy in conformity to Japanese custom of using litre/min in volume output of hot spring.

There are many cases where Q_1 is known but Q_2 is unknown. To estimate the approximate value of Q in these cases, $Q_2/(Q_1+Q_2)$ is calculated, as shown in the table, for the cases in which both values of Q_1 and Q_2 were observed. Then, the rough value of Q in the unknown case of Q_2 was estimated, using the mean value $Q_2/(Q_1+Q_2)=0.28$ and the observed value of Q_1. These values are expressed by the numerals in brackets in the column of Q in the table.

It is concluded from the table that the discharge rate of heat energy Q from hot spring localities in Hokkaido ranges from 0.3×10^7 cal/min to 120×10^7 cal/min in accordance with its hot spring activity.

The value of Q_2 is smaller than that of Q_1 in 11 cases of 15 hot spring localities, that is $0.5 > Q_2/(Q_1+Q_2)$, except Nigorikawa, Akan-kohan, Nukabira and Onneyu. It is noted that almost all of the hot springs in these four localities are natural springs or self-discharging wells of shallow boring and on the contrary, hot springs in Jôzankei, Yunokawa, Doyakohan and Yumoto localities where $Q_2/(Q_1+Q_2)$ has a value of less than 0.1 are self-

Table I. Heat energy discharged from the principal hot spring localities in Hokkaido and from some of small dimensions.

Explanation of the notations adopted in the table :

Q_1 : Heat energy discharged as hot water from all orifices in a hot spring locality, in unit 10^7cal/min,

Q_2 : Heat energy emitted from ground surface due to heat conduction in the locality, in unit 10^7cal/min.

Q ; Total heat energy discharged from the locality, in unit 10^7 cal/min,

T_m : The maximum underground (or orifice) temperature of hot spring in the locality,

V_m : Sum of volume output of hot springs in the locality of which temperatures are more than 30°C,

No.	Name of hot spring locality	Q_1	Q_2	Q	Q_2/Q
1	Hot lake area, Noboribetsu	84	—	(116)	—
2	Jigokudani, Noboribetsu	49	18	67	0.27
	〃 〃	31	9	40	0.23
3	Jozankei	58	2	60	0.03
4	Kawayu	37	17	53	0.32
5	Yumoto hot lake, Niseko	27	1	28	0.04
6	Yunokawa	22	2	24	0.09
7	Nigorikawa	4.7	14	18	0.74
8	Yukomanbetsu	12	—	(17)	—
9	Doyakohan	12	1.1	13	0.08
10	Sôunkyo	8.6	2.8	11	0.25
11	Tokachigawa	5.8	—	(8.1)	—
12	Teshikaga	4.0	—	(5.6)	—
13	Nukabira	2.8	4.0	6.8	0.53
14	Niseko	3.4	—	(4.8)	—
15	Akankohan	1.4	3.4	4.8	0.71
16	Onneyu	1.4	1.7	3.1	0.55
17	Yachigashira	2.2	0.4	2.6	0.15
18	Konbu	1.8	0.3	2.1	0.14
19	Tenninkyo	1.7	—	(2.4)	—
20	Niimi	1.3	—	(1.8)	—
21	Karurusu	0.84	0.15	$1.0+\alpha$	0.15
22	Bankel	1.1	—	(1.6)	—
23	Nibushi	1.0	—	(1.4)	—
24	Benkei	0.90	—	(1.3)	—
25	Oakan	>0.82	—	(1.1)	—
26	Tôbetsu	1.2	—	(1.7)	—
27	Konbugawa	0.83	—	(1.0)	—
28	Shiobetsu	0.78	—	(1.0)	—
29	Narita	0.61	—	(0.8)	—
30	Shikerebetsu	0.55	—	(0.8)	—
31	Yamada	0.44	—	(0.6)	—
32	Koganeyu	0.06	—	(0.1)	—

Mean Value $Q_2/Q = 0.28$

discharging or pumping-up wells of moderately deep boring and natural hot lake.

n : Number of hot springs in the locality of which the temperatures exceed 30°C,
N : Natural hot spring,
NY : Natural hot lake,
NP : Natural hot spring, but the discharge is artifically increased by the aid of pumping,
NNB : Some of the springs are artesian wells of shallow boring,
NBB : Some of the springs are natural and the others are self-discharging wells or pumping up wells of moderately deep boring,
NB : About one-half of the total hot springs are self-discharging wells of shallow boring,
B : Self-discharging well of moderately deep boring,
BP : Pumping-up wells of moderately deep boring.

n	T_m(°C)	V_m (l/min)	Heat energy index	Notes
—	>120	6040	VI	NY 7)
Numerous	>150	4350	V	N 8) Feb., 1952
〃	〃	3740	V	N 7) Nov., 1952
50	89	9300	V	NP 9)
50	>120	8360	V	NB 2)
—	>120	330	IV	NY 10)
37	66	3980	IV	B 11)
37	97	620	IV	NNB 12)
18	53	2510	IV	N 13)
20	55	3140	IV	B 14)
32	94	1300	IV	NNB 15)
8	50	1880	III	B 16)
30	98	770	III	NBB 17)
28	65	600	III	NNB 18)
6	87	500	III	N 19)
26	100	250	III	NNB 20)
15	55	350	III	N 21)
5	69	490	II	B 11)
8	56	380	II	NB 19)
8	51	430	II	N 13)
2	66	250	II	N 19)
6	56	170	II	NNB 22)
5	76	250	II	NNB 23)
8	46	290	II	NNB 24)
3	66	160	II	N 23)
9	76	> 200	II	N 25)
6	70	220	II	NNB 16)
2	43	250	I	B 19)
3	42	250	I	B 21)
3	43	210	I	N 19)
6	41	200	I	N 21)
1	44	130	I	N 19)
1	31	30	0	N 26)

§ IV. Hot spring Heat Energy Index.

There are about 90 hot spring localities in Hokkaido ; two-thirds of them have not yet been scientifically investigated. It may require a few decades of years to investigate all of the discharge rate of heat energy Q from these hot spring localities. But, it is not so difficult to estimate the order of magnitude of their discharge rate of heat energy, if the following described heat energy scale of a hot spring is adopted.

The writer's method is to express the discharge rate of heat energy in a hot spring locality Q by a notation of class in which the value of Q lies, dividing the possible extent of the heat energy of hot spring localities into 8 classes of O, I, II,---VII by 8 successive critical values of $10^{6.5}$, 10^{7}, $10^{7.5}$,---10^{10} cal/min, as indicated in Table II. The expression of the discharge rate of heat energy, that is, O, I, II,---VII will be called "Heat energy index of a hot spring."

Table II. Heat energy scale of hot springs

Heat energy in unit cal/min	Heat energy index
less than 0.32×10^{7} ($10^{6.5}$)	0
$0.32\times10^{7}\sim 1.0\times10^{7}$ (10^{7})	I
$1.0\times10^{7}\sim 3.2\times10^{7}$ ($10^{7.5}$)	II
$3.2\times10^{7}\sim 10\times10^{7}$ (10^{8})	III
$10\times10^{7}\sim 31.6\times10^{7}$ ($10^{8.5}$)	IV
$31.6\times10^{7}\sim 100\times10^{7}$ (10^{9})	V
$100\times10^{7}\sim 316\times10^{7}$ ($10^{9.5}$)	VI
$316\times10^{7}\sim 1000\times10^{7}$ (10^{10})	VII

Applying this method to data in Table I, the heat energy index of the respective Hokkaido hot springs was estimated as shown in the same table in numerical order.

§ V. Order of magnitude of total sum of the discharge rate of heat energy of hot spring localities in Hokkaido.

Two-thirds of the total number of hot springs in Hokkaido are uninvestigated as mentioned above. It would be, roughly, possible to presume the heat energy indices of these hot spring localities in comparison to the hot spring activities in the localities of known heat energy indices shown in Table I, if the estimator had ever been there. Even in the uninvestigated localities, there are many cases in which the total number of hot spring orifices and the maximum temperature of the hot springs in the locality are clearly known. In these cases, the value of heat energy index is more or less accurately presumable.

The relation between the heat energy index and the corresponding number of hot spring orifices n in a hot spring locality is shown in Fig. 4, taking the latter as the abscissa and the former as ordinates from the data in Table I. Full lines in the figure indicate nearly the probable number of hot spring orifices for the corresponding value of heat energy index. There is, as seen from the figure, a tendency for the value of heat energy index to rise with the increase of number of hot spring orifices.

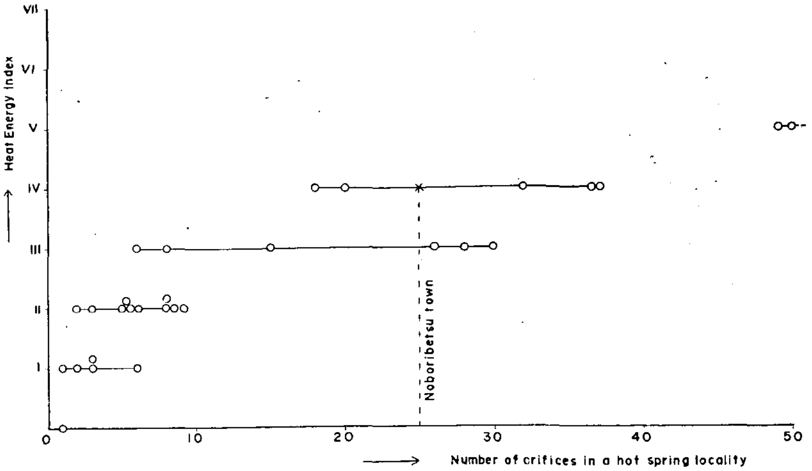

Fig. 4. Relation between the heat energy index and the corresponding number of orifices in a hot spring locality.

Taking the maximum underground (or orifice) temperature T_m in a hot spring locality as absicssa and the corresponding heat energy index as ordinates from the data in Table I, the relation between these two quantities is indicated in Fig. 5. Full lines in the figure show the approximate ranges of the maximum temperature for the respective value of heat energy index. Here also there is a rough tendency for the value of heat energy index to rise with the increase of the maximum temperature.

Taking the number of hot spring orifices in a locality as abscissa and the maximum temperature as ordinates, the writer plotted points indicating the relation in Fig. 6 and wrote respectively the values of heat energy indices attached to the points. The lines in the figure show the rough boundaries

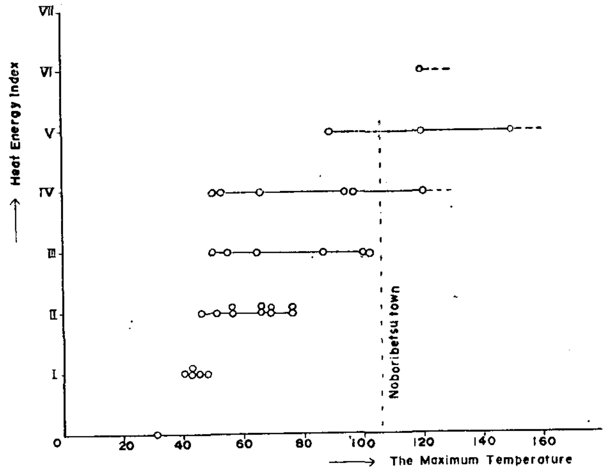

Fig. 5. Relation between the heat energy index and the corresponding maximum underground (or orifice) temperature of hot springs in a locality.

between the successive heat energy indices. From this figure, it may be easy to understand the relation among the number of hot spring orifices, the maximum underground (or orifice) temperature and the heat energy index of a hot spring locality in comparison with Fig. 4 and Fig. 5.

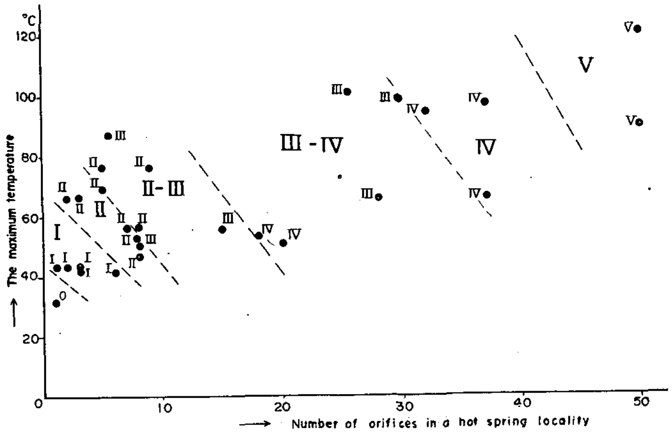

Fig. 6. Relation among number of orifices in a hot spring locality, the maximum underground (or orifice) temperature of the locality and the corresponding heat energy index.

The writer will explain, for example, the estimation of heat energy index in the hot spring locality of Noboribetsu town, where the number of orifices n is

25 and the maximum underground temperature T_m is more than 100°C. The heat energy index corresponding to $n=25$ is given as III or IV from Fig. 4 and the index corresponding to $T_m>100°C$ is given as IV or more than IV from Fig. 5. Therefore, the heat energy index in Noboribetsu town area is estimated at IV.

The writer presumed by the above method the heat energy indices of all of the uninvestigated hot spring localities in Hokkaido, as shown by thin letters in Tabel III. The heat energy indices of the investigated hot spring localities of Q (Table I) are also tabulated in Gothic letters in the table.

Fig. 7 represents the geographical distribution of hot spring localities

Table III. The heat energy indices in all of the hot spring localities of Hokkaido, and sum of heat energy in respective heat energy index.

Heat energy index	Name of hot spring locality	Number of hot spring localities (That in %)	Sum of heat energy in cal/min
VI	**Three hot-lakes area** in Noboribetsu	1(1.2)	116×10^7
V	**Jigokudani** (Noboribetsu), **Jozankei, Kawayu**	3(3.5)	173 〃
IV	**Yumoto hot lake, Sounkyo, Doyakohan, Yunokawa, Nigorikawa, Yukomanbetsu,** Kitayuzawa, Noboribetsu-town	8(9.4)	153 〃
III	**Nukabira, Tokachigawa, Teshikaga, Akan-kohan, Niseko, Onneyu,** Shikabe, Esan	8(9.4)	47 〃
II	**Karurusu, Yachigashira Bankei, Konbu, Niimi, Tenninkyo, Nibushi, Benkei, Oakan, Tôbetsu,** Marukoma, Pirikanepu, Isoya, Rausu, Toyotomi, Aizankei	16(18.8)	29 〃
I	**Shikerebetsu, Shiobestu, Konbukawa, Narita, Yamada,** Futamata, To menoyu, Oonuma, Ponyu, Shikaribetsu, Fukiage, Yamada, Asari, Nonaka, Sunayu, Ikenoyu, Wakoto, Kawakumi, Oofune, Ginkonyu, Slope in Meakandake, Pirika, Raiden, Oshamanbe, Chinai, Himenoyu, Meto, Osousu, Ofuna-shimonoyu, Kumane, Namarikawa, Kennichi, Horonai, Ooki, Tokiwa, Chihashiri, Geinai, Nagasawa, Hongo, Yoroushi, Kawakita, Seseki	42(49.4)	27 〃
0	**Koganeyu,** Toyoha, Sesekimoyu, Akanmangan, Ponto, Usubetsu, Kawakami	7(8.2)	1 〃
	Total sum :	85(100)	5.5×10^9 cal/min.

in Hokkaido. Black rectangle, double circle, large black circle, black circle of medium size, white circle of medium size, small white circle and small triangle indicate sites of the hot spring localities having respective heat energy indices of VI, V, IV, III, II, I and O.

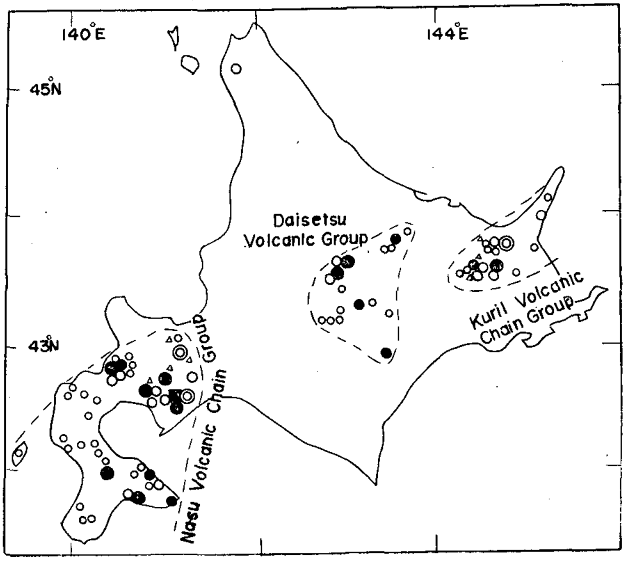

Fig. 7. Geographical distribution of the heat energy indices of hot spring localities in Hokkaido. Black rectangle : VI, Double circle : V, Large black circle : IV, Black circle of medium sixe : III, White circle of medium size : II, Small white circle : I, Small triangle : 0.

Numerals in the third column of Table III are the number of hot spring localities which indicate the same heat energy index. It is noted that one-half of the total number of hot spring localities have heat energy index I, that is, small heat energy of 10^7 cal/min$>Q>10^{6.5}$ cal/min. The principal hot spring localities in Hokkaido have heat energy indices of more than III and especially, the Hot-lake Area in Noboribetsu, Jigokudani in the same region, Jôzankei and Kawayu have indices of VI or V, that is, large heat energy of $40\times10^7\sim120\times10^7$ cal/min, as seen in Table I.

The total sum of heat energy from all of hot spring localities in Hokkaido (area of Hokkaido$=7.70\times10^4$ km^2) is estimated at 5.5×10^9 cal/min as indicated in Table III, adopting the respective value of Q in Table I for an investigated hot spring locality and taking the respective median value of the corresponding two critical values of the heat energy instead of heat energy index for an uninvestigated locality. The heat energy amounts to 2.9×10^{15} cal/year and it is converted into 1.2×10^{23} ergs/year in terms of mechanical energy neglecting effect of mechanical efficiency. It is, also, equivalent to the combustion heat of six hundred thousand tons of coal per year, if combustion heat of coal is assumed as 5×10^{3} cal/gr.

The average heat energy per unit time and per unit area of Hokkaido due to heat generation of hot springs is evaluated as 0.71×10^{-5} cal cm^{-2} min.$^{-1}$

Next, the writer will discuss briefly the error of estimating the total sum of heat energy in hot spring localities in Hokkaido. The sum of heat energy of the principal hot spring localities which indicate respectively heat energy index III∼VI and IV∼VI are 5.0×10^{9} cal/min and 4.6×10^{9} cal/min. These values correspond respectively to 89% and 82% of the total sum of heat energy. And in these principal hot spring localitites, only small number of the hot springs are left quite uninvestigated. It should be noted that the error due to presumption of heat energy indices in many uninvestigated localities occurs in the cases of small heat energy indices of less than II, but the effect is not so large as to change the order of magnitude of the total sum of heat energy.

§ VI. Heat energy discharged from some famous hot spring localities in Japan and in the world, and their heat energy indices.

In the former chapter, the writer estimated heat energy Q discharged from the principal hot spring localities in Hokkaido. For the sake of contrast, there will be noted in the present chapter, the energy given off from some famous hot spring localities in other parts of Japan and in the world.

Q_1 in Table IV is the discharge rate of heat energy flowing out as hot water or steam from orifices in a hot spring locality as measured by many observers. Applying the same method and the same constant mentioned in § III, total heat energy in a hot spring locality Q is estimated as shown in Table IV.

The Wairakai Area in New Zealand and the Upper Geyser Basin in Yellowstone, U.S.A. are hot spring localities of the largest class of activity.

It may be concluded from Tables IV and I, that heat energy discharged from a hot spring locality is in the range from less than $10^{6.5}$ to 10^{10} cal/min, and accordingly heat energy index of a hot spring is indicated by categories designated O∼VII.

Table IV. Rates of discharge of heat energy Q in unit 10^7 cal/min from some famous hot spring localities in other parts of Japan and in the world, and their heat energy indices.

Hot spring locality	Q_1	Q	Max. underground temperature	Heat energy index
Wairakai Area (New Zealand)[27]	660	(910)	270°C	VII
Upper Basin[17] Yellowstone (U.S.A)	540	(750)	180	VII
Mammoth & Hot River Area (〃)[27]	200	(280)	75	VI
Frying Pan Lake (N.Z.)[26]	140	(190)	55	VI
Atami (Japan)[28]	130	(150)	130	VI
St. Vincent (West Indies)[29]	110	(150)	200	VI
Solfatara Dominica (W.I.)[29]	103	(140)	200	VI
Qualibau Solfatara, St. Lucia[29] (W.I.)	52	(72)	——	V
Norris Basin, Yellowstone[27]	48	(67)	205	V
Steamboat, Nevada (U.S.A.)[27]	42	(58)	——	V
Ito (Japan)[28]	26	(36)	56	V

§ VII. Concluding remarks.

It is estimated in this paper that the discharge rate of heat energy from a hot spring locality lies in the values from less than $10^{6.5}$ to 10^{10} cal/min and accordingly its heat energy index is indicated by categories from O to VII. The order of magnitude of heat energy per minute discharged from all of the hot spring localities in Hokkaido is also estimated at 5.5×10^9 cal/min.

There are several active volcanoes in Hokkaido such as Komagatake, Showa-dome in Usu, Tarumae, Tokachidake and Meakan, and they have respectively some fumarole areas of high temperature in the vicinity of their craters. Measurements were carried out by Seino[30] on temperature and discharge rate of steam from some of these fumaroles. The order of magnitude of the heat energy calculated by the writer using Seino's data comes to 5×10^8 cal/min. (Max. temp.=318°C) for some fumaroles in Showa-dome of Usu volcano and 2×10^8 cal/min (Max. temp.=285°C) for two fumaroles on Tarumae volcano. The heat energy discharged from a fumarole area in an active volcano may be comparable in order of magnitude with that from a principal hot spring locality.

The hot spring localities considered in this paper do not include such fumarole areas in the neighborhood of the craters of active volcanoes.

Since the origin of hot springs[31] is considered to have intimate connection with the volcanic magma chamber, it is desirable, in future, to investigate further the heat energy discharged from all of fumarole areas in the vicinity of the active volcanoes in Hokkaido in order to estimate the total heat energy discharged from the total area of Hokkaido.

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