Distribution of the Subterranean Temperature and the Hot Spring Veins in the Old City of Beppu

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Introduction

The earliest measurement of the temperature of the under-ground covering a wide area made for the purpose of studies of hot springs was made by W. Yoda[1], at Yubuin, in 1922. His measurement, however, is limited to the surface temperature within 1 metre under the ground, not extending to the depths. But covering 1265 points, it is almost perfect as an investigation of the distribution of the surface temperature. The late Suzuki ordered his co-workers to measure the temperature in the depths of the old city of Beppu by making use of 35 borings[2] from 1924 to 1926. Being a geologist, however, his attention was chiefly directed to the nature of the ground, and the temperature was measured at several points only when the boring was near completion, and there were only a few whose temperature was measured on the midway. Thus, his result is useful to know the distribution of the temperature at the bottoms of hot springs, but inadequate for the subterranean temperature. Therefore, in 1931 we newly intended to measure the subterranean temperature throughout the city. First we tried to use many dis-used pipes through which hot spring had ceased to come out to the surface. When we began observation actually, we knew unexpectedly that most of them were clogged several metres under the ground so that the thermometer could not be inserted down in the pipes. Inevitably, using new borings, we tried to research three-dimensional distribution of the subterranean temperature through the old city. Since a boring costs a large sum of money, it is impossible for the laboratory to make excavation for itself. Therefore, whenever a new or re-excavation was made in the city, we endeavoured to measure the temperature at various depths of the hole. Accordingly many years were needed to collect abundant data. Now we have one thousand and several hundred observed values

1. Tikyû-Buturi (Geophysics), 1 (1937), 285.
2. Table of Soil-nature in the Beppu City by Boring, Tikyû-Buturi 1 (1937), 305.

obtained from the measurements at some or scores of depth in over a hundred borings. This paper is the report of the results obtained. During our observation S. Yosimura[1] investigated the surface temperature at 59 points of Kamisuwa hot springs, and also the inspection of the distribution of the subterranean temperature there made by K. Misawa[2] with 22 borings has been made public. Referring to these studies with our result, the reader will be able to understand a general distribution of the subterranean temperature at a hot spring zone.

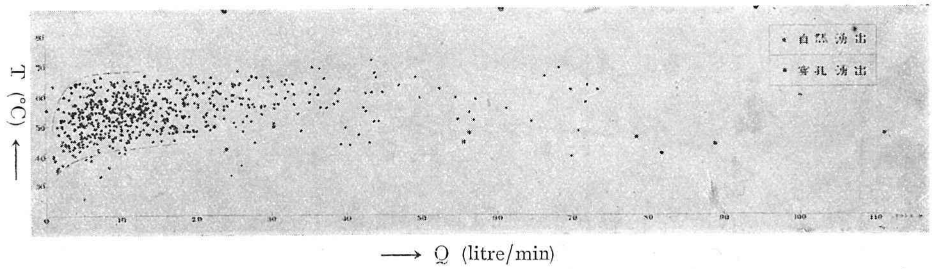
1. Preliminary investigation—the distribution of the welling temperature of the hot water

Before having obtained the sufficient data just mentioned we tried to find out preliminarily the distribution of subterranean temperature from the surface welling temperature of hot springs. We wanted to know the distribution of the subterranean temperature of the stratum from which we collected hot water by regarding the temperature at the bottom of the welling pipes inferred from the welling temperature as the subterranean one in the neighbourhood of the pipes. On account of their uneasiness for the measurement the owners of welling pipes in use did not allow us to measure the bottom temperature by putting the thermometer into the pipes. The welling temperature on the surface is commonly different from that at the bottom. The difference between the two is not the same in each mouth: $15^\circ \sim 20^\circ$ in some mouths, and less than 1° in another. And so we cannot mention with conviction the distribution of the bottom temperature from the welling temperature itself. Especially in a place where there are several layers containing hot water, such as Beppu, the welling temperature remarkably varies according to the depth of excavation even if the borings are side by side. Therefore, if the distribution is thoughtlessly shown in a figure, it would never be reliable on account of complexity with high or low temperatures. We adopted the following method of deducing the bottom temperature of the mouths from the discharge Q and the welling temperature T, taking the depth of excavation into account.

First, for trial, we plotted in Fig. 1 the $Q-T$ graph of all the welling mouths in the city, using the data in the register book[3] of Beppu hot springs. Though the distribution is not simple,

1, 2. Geographycal Journal, Tokyo, **7** (1931) 406.
3. Tikyû-Butsuri, **1** (1937), 28.

Fig. 1. Q-T diagram of all the springs in Beppu city.



on the average T is low when Q is small, and T rises according to the increase in Q, to a certain maximum. Q and T of a welling mouth should, of course, make a continuous curve; and we have just seen that even Q's and T's of nearly a thousand welling mouths in the present case generally lie in an asymptotic curve. Hence if we divide the city into adequate small areas, taking the depth of excavation, spring veins, etc. into account, and draw the $Q-T$ graph for each group of some welling mouths which seem to be in connection with each other and whose observation data can be arranged on a smooth continuous curve, it will be not improper that we assume their asymptotic maxima as the true bottom temperatures of the groups. For example, Fig. 2 shows the $Q-T$ curves of group 474 (consisting of springs No. 474, 474-1, 451, 476, 539, and 481), group 560 (No. 552, 560, 563, 564, 571, and 589), and group 1280 (No. 1280, 1283, 1284, 1289, 450-1, 451-4, and 451-1), their maximum values being assumed as 63°.5, 55°.5, and 51°.0C respectively. Marking 80 bottom temperatures thus obtained in the centre of each group

Fig. 2. Three examples of Q-T curves according to Groups

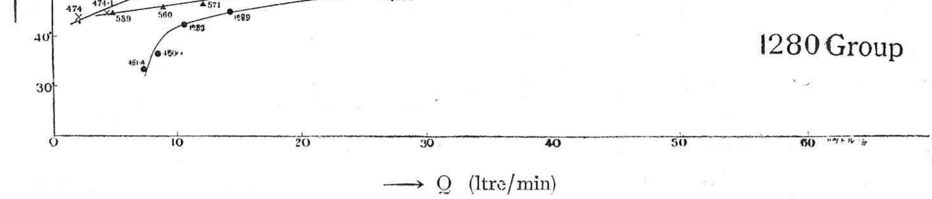
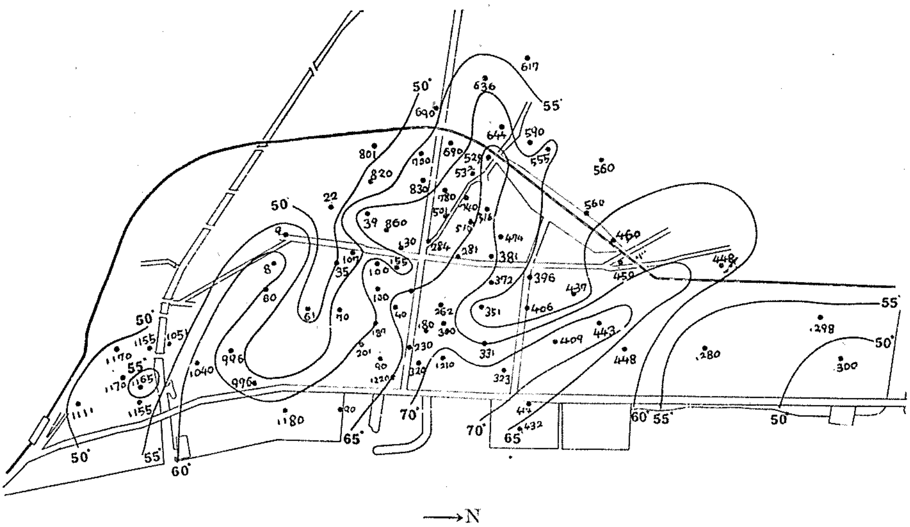


Fig. 3. Distribution of the bottom-temperature of Beppu springs.



to draw isotherms, we obtained the distribution graph of the bottom temperature as Fig. 3. These results were already reported at the annual meeting of the Physico-Mathematical Society of Japan held in 1936. In Fig. 3 three regions of high temperature are seen, and it is found that in the neighbourhood of the Nagarekawa street (in NWW from the habour) the temperature is highest.

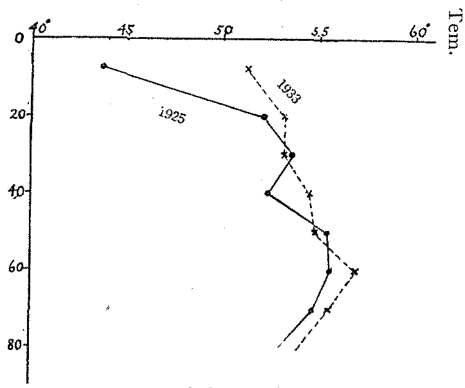
As the second preliminary research we examined statistically the relation between the depth of the spring bottom and their welling temperature from the register book of Beppu hot springs. The results obtained are Table 1 and Fig. 4. From these we find out the facts that (i) from 36 to 50 metres the welling temperature rises with the increase of depth, (ii) from 55 to 73 metres there are some ranges where the temperature rather falls, (iii) from 73 to 109 metres it rises again with increasing depth, and (iv) near 109 metres it reaches a maximum and over that depth it rather becomes lower.

The above mentioned two preliminary inspections made by the statistics of the depth of excavation and the welling temperature measured on the ground are nothing but suppositions. They may show a general tendency, but never indicate a precise state of the local subterranean temperature; nay, you will be often prevented from realizing the truth unless you are careful. For example, if you presume from Fig. 4 that the subterranean temperature of Beppu is a maximum at the depth of 109 metres and rather lower below that point, you are quite wrong. It corresponds to the fact that hot water of high temperature does not well out in a region far from a hot spring vein, where hot spring hardly wells, even if the depth is remarkably increased.

Table 1. Comparison of the temperature and the boring depth of the Beppu springs.
(Upper lines in 1933, Lower lines in 1925. * less weight, because the number of springs was small.)

Depth (*Ken*)	Number of springs	Mean depth	Temperature at welling mouth
0—15	31 82	9.2 8.9	51.28°* 48.78
<25	93 265	21.8 21.0	53.80 52.15
<35	145 209	30.5 29.8	53.26 53.62
<45	87 56	40.5 39.6	54.56 52.37
<55	55 19	50.1 50.8	54.88 55.53*
<65	50 17	60.6 60.9	56.93 55.61*
<75	15 14	69.8 70.1	55.57* 54.73*
76	28 20	104.6 98.8	51.52* 49.44*

Fig. 4. Q-T diagram of all the springs in Beppu city.



Depth (in *ken*=1.818 m.)

Now, regarding the preliminary investigations mentioned above as mere reference, we researched the real distribution of the subterranean temperature only from the temperatures practically measured at several depths of borings. In a few regions where the borings were lacking in number, however, the results of the preliminary investigations were used for reference.

2. Methods of measuring the subterranean temperature, and others

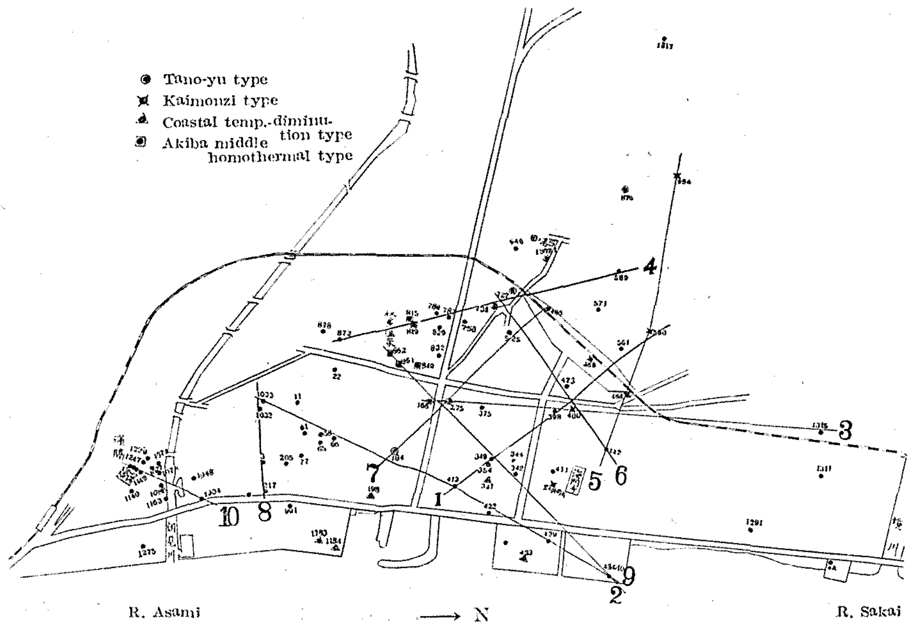
Whenever a new excavation or dredging was carried on, the temperature was always measured at each bottom, at the lunch time of the workers. The thermometer put in a closed metal cylinder with some heat-capacity was let down to the bottom of the hole with a piece of string and pulled up after about 30 minutes. The reading thus made was regarded as the subterranean temperature at that depth. Various matters causing observation error, such as badness of the thermometer or its rough treatment, were, of course, kept off and, besides, it had been ascertained by the preparatory tests in the laboratory that the influence caused by the lack of time during which the thermometer should be left alone, or by the strata of high temperature lying on the midway to the bottom were never produced on the occasion of our measurements because the container of the thermometer had adequate heat-inertia. In the case of "Kazusa" boring, cold water runs somewhat into the hole as clay water is poured into the hole from the mouth. So long as the quantity of the water flowing in was very small, the temperature read can be regarded as the temperature there. But rarely a large amount of cold water happens to flow in. In such a case, the temperature suddenly falls as compared with those obtained before and after it. This abnormally low temperature cannot be considered as the temperature there, but it has a special physical meaning, which will be explained later. Since the thermometer was used, the subterranean temperature lower than the atmospheric one could not be measured. Concerning such temperature at a shallow stratum the observation is to be made in future by some other suitable method.

The depth of the measurement was decided every time from the length of the string with which the meter was hung down, the length being kept right by comparing it with the length of 'Hego' (elastic bamboo-ribbon) used at the Kazusa boring.

The situation of the boring mouths measured was marked on a 1–3,000 ths map of the old city of Beppu by eye-measuring. Fig. 5 is its copy.

The area measured was limited within the old city so far as the present paper is concerned. From September in 1934 to the beginning of 1938 the measurement was made concerning about 100 borings. It is regretful to say that their distribution is not satisfactorily uniform, but it is rather natural since we have looked for only new excavations or dredgings. On the other hand, such unsatisfactory distribution is never caused by a mere chance, but indicates a certain feature of the flow of underground hot water. For example, the frequency of re-excavation means that of clogging of welling mouths. The welling mouths are generally clogged by deposits, or collapsed by grasping power based on the difference of the pressure between outside and inside of the wall which has become thin on account of erosion. Thus, in connection with this nature, the number of re-excavations presents a useful material to be considered.

Fig. 5. Distribution of borings at which the earth-temperature was observed. (Small numerals are No. of springs, Larger the No. of the sections considered afterwards,)



3. Vertical distribution of the subterranean temperature

All the data thus obtained are tabulated in our journal 'Tikyû-buturi' as "Table of the subterranean temperature in the old city of Beppu".[1] At first sight the table shows so much complexity that we cannot find out any simple law as a whole. It is rather natural because the world of subterranean flow must have various locality in such a wide hot spring zone as Beppu. The data seemed to have no unity for a few years since the beginning of the investigation during which we had only about two scores of borings. But now, inspecting carefully about a hundred data obtained for the whole city, we can recognize some groups which have very similar vertical distribution. Considering their mutual situation, and comparing the situation and vertical distribution of those which have intermediate nature, we could find a consistent general law, which contributed to show the state of the underground flows such as hot and cold water system.

Fig. 6 is the vertical distribution graphs of the subterranean tempera-

1. Tikyû-Buturi (Geophysics), **2** (1938), 291.

ture classified according to the nature and region. The following six types are the most characteristic.

(a) The Tanoyu type (Fig. 6–1), (b) The Kaimonzi type (Fig. 6–3), (c) The north dispersive type (Fig. 6–5), (d) The coastal temperature-falling type (Fig. 6–6), (e) The Akiba middle homothermal type (Fig. 6–7), (f) The Hamawaki type (Fig. 6–10 and 11).

These will be mentioned in order from the figures with their intermediate types (cf. Fig. 6).

(1) *The Tanoyu type*:—This type is seen along the Tanoyu hot spring vein including Tanoyu (No. 1207), hot springs of the Hirosima Hotel and Kusunokiyu, etc. which are natural springs. No. 727 and No. 184 among the hot springs shown in the figure reveal the same characteristics in spite of being situated considerably far from each other. They give concrete evidence to the conception of the hot spring vein. The characteristics of those springs which are generally called the Tanoyu type are as follows:

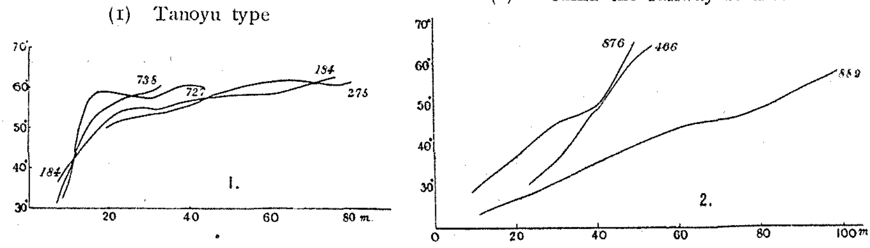
i) The temperature rises remarkably at a very shallow stratum and then becomes comparatively homothermal. The final temperature of the hot water collected is a little over 60°.

ii) The nearer to the bluff it is, the more distinctly the sudden rise of the temperature is seen. The hot water is obtained at a shallow part. Every welling mouth has a shallower depth than all the other mouths which are situated far from this hot spring vein.

Fig. 6. Vertical distribution of earth temperature.
(Numerals near curves are the spring no.)

(1) Tanoyu type

(2) Behind the railway station



(2) *On the bluff behind the railway station*:—The springs belong to the medium type between the Tanoyu and Kaimonzi types. Their characteristics are as below:

i) The temperature shows an almost a linear rising without a sudden rise. The nearer to the bluff and to the Tanoyu vein it is, the sharper the temperature slope is.

ii) The depth of collecting hot water becomes shallower, with the tendency similar to (i).

Hereafter, concerning the vertical distribution of temperature the springs which have no discontinuous layer and where the temperature slope is gentle will be called 'dispersive', and, when the slope is gentler, called 'more dispersive'. On the sectional figures these words will be used to express the expansion of the intervals of isotherms.

(3) *The Kaimonzi type* :—This type is found along the line which begins from somewhat north of Miyazidake Shrine (No. 970), runs through Noguti, a little north of the exit of Beppu Station, Kaimonzi Park, the back of the Beppu Post-office, and goes into the sea near the Nizyô Hotel (No. 427). The characteristics are:

i) There is a remarkable deep discontinuous layer (from about 60 metres on the upper part). The upper homothermal stratum of low temperature (up to 60 metres) is well developed.

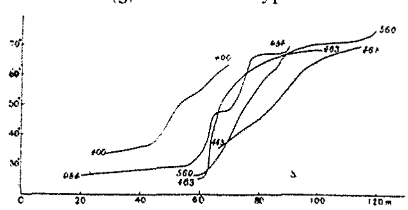
ii) The final temperature of the hot water collected is high, often exceeding 70°C. (i) is of the nature not seen near the sea, but (ii) is characteristic throughout the whole.

Chemical ingredients, rate of discharge, etc. along this line are distinctly different from those of other lines. It is an evidence of this line forming a hot spring vein.

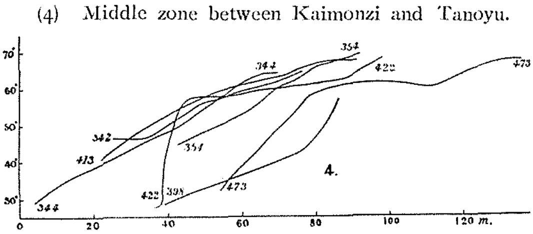
(4) *The middle area between the Kaimonzi and Tanoyu veins* :— The temperature of the hot water there becomes low and dispersive according as leaving from the Kaimonzi vein.

(5) *The northern*

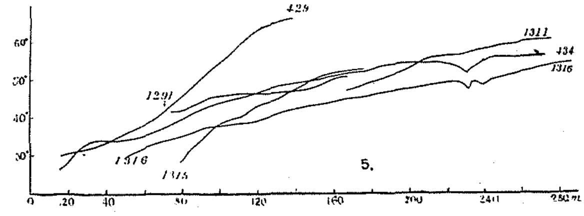
(3) Kaimonzi type



(4) Middle zone between Kaimonzi and Tanoyu.



(5) Northern dispersive type



dispersive type:—Northwards across the line of the Kaimonzi type, the dispersive state is suddenly seen. And we see that

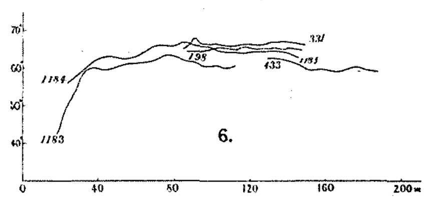
i) the dispersion is wider than at any other part of the old city. Though the figure is shortened in breadth, yet the slope drawn is gentler than others.

ii) The hot water was very deeply collected there. The deepest spring at the present time lies in this vein. Besides,

iii) according as approaching the Kaimonzi vein and leaving the sea, the temperature becomes high and its slope sharp.

(6) *The coastal temperature falling type*:—This type has such a tendency as the temperature falls rather in the deep stratum. Though the fall is very faint, the distribution, the maximum temperature, the depth, etc. are fairly systematic.

(6) Coastal temperature-diminution type



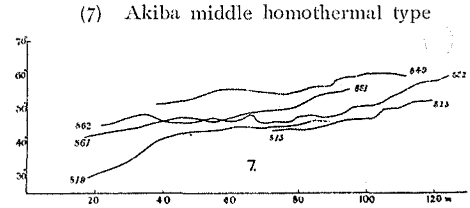
i) The fall of the temperature is about 3°C. The depth having the maximum temperature is 80～100 metres. It seems to deepen according as the situation moves northwards.

ii) The type is seen only in the district from the north end of the middle reclaimed ground (the Takasago Hotel) to the neighbourhood of the middle part of the north reclaimed ground (Seihûsô Hotel) or near the sea.

iii) The temperature is homothermal in quite a wide range of the upper and lower stratum of the maximum temperature.

(7) *The Akiba middle homothermal stratum*:—The type is seen between Akiba street and Nagaregawa street, that is, westward from the old highway (Nakamati-street).

(7) Akiba middle homothermal type



i) The temperature is homothermal in the depth from 40 to 90 metres, and it is recognized that it rises in deeper places.

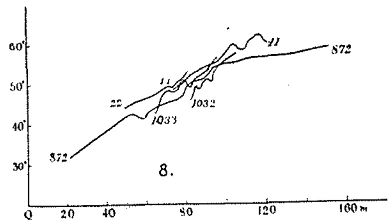
ii) The temperature of the homothermal stratum becomes higher according on approaching the sea and the Tanoyu vein.

iii) The hot water is not collected from the homothermal stratum. This shows that the amount of hot water is small there.

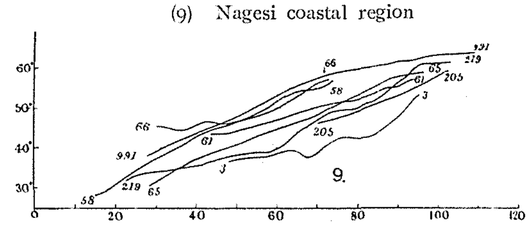
Southwards across Nagarekawa street, the final depth becomes suddenly over 100 metres. (Except in the neighbourhood of this place, the change of the final depth is smooth near the sea.)

(8) *Neighbourhood of the welling limit at the south-west* :—In the region from Nagesi hot spring to the west end of Matubara Park the dispersion is prominent. The final temperature of the warm water collected is not high.

(8) South-west limiting district



(9) Nagesi coastal region



(9) *Neighbourhood of Nagesi coast* :—This place is near the district of (8) by the sea shore. The nearer to the coast it is, the more deeply the hot water is collected. Its temperature also is fairly high and generally is dispersive as well as (8). Dredging is most frequently performed there. The distribution of the temperature is complicated. It is because this region is near the Tanoyu vein and would be much combined with other water systems such as Hamawaki.

(10) *The banks of the River Asami* :—This is called the Hamawaki type with the following (11). It has the following characteristics.

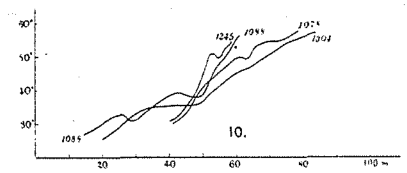
i) The layer of the warm water collected is generally shallow.

ii) The final temperature of the warm water collected is low.

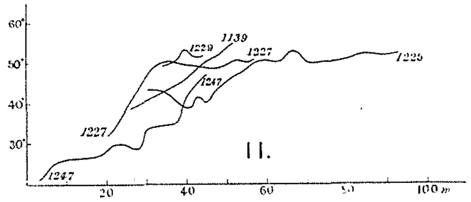
Across the scope of (9) to the south, Hamawaki, the final depth of boring decreases gradually and the discharge increases. It is evident that the district belongs to a distinctly different system. Natural welling was really observed in early times. It is clear that it forms a spring vein. It would be caused by the influence of underground flows from the River Asami that the temperatures of No. 1245 and No. 1078 shown in the figure fall sharply within 50 metres under the ground and that of the uppermost stratum is markedly lower than others.

(11) *The Hamawaki type* :—This has the above mentioned characteristics, too. It includes the area which is nearer to the spring vein

(10) Near the Asami river.



(11) Hamawaki type



than (10). From the sectional figures and others, the Hamawaki hot spring vein generally seems to run from the eastern corner of the City Hot Spring towards a little north of the Sand Hot Bath. The distribution of the subterranean temperature at Hamawaki has the other characteristic that the state is remarkably varied according to the situation (on the ground surface), having various types as samples of the distribution of the subterranean temperature. This proves that Hamawaki hot spring vein is on a small scale.

4. Correspondence of strata; existence of several hot water-bearing strata

Though mostly omitted in the figures to avoid confusion, the readings of the thermometer sometimes showed abnormally low subterranean temperature. This is not because the undisturbed temperature at that point is actually low, but because clay-water applied to the bore-hole by the 'Kazusa' boring flows into the hole heavily. As such flowing-in of clay-water was generally very small in quantity and water in a pipe was under the quasi-stratified state without any convection, we regarded the temperature of water on the bottom as the undistrubed temperature there. In the above mentioned case, however, flowing-in of the applied clay-water was clearly recognized.

Such phenomenon is not caused unless the bottom lies in a pervious stratum and accordingly it is often found at the same depth of some neighbouring mouths in common (for example, about 230 metres for No. 1316 and No. 434 given in Fig. 6–5). Not only abnormal falling of the readings of the subterranean temperature but also various matters are caused corresponding to almost the same depth of some borings. These corresponding matters are as follows: (1°) abnormal falling of the readings of the subterranean temperature, (2°) existence of structures of pervious nature (sand, gravel, etc.), (3°) collapse at the bottom of bore-hole, (4°) confirmation of "Toori" (flowing out), so called by boring-workers, (5°) existence of similar depths of collecting hot water in the neighbourhood, etc. These matters can be regarded as connected each other and serve us to know the horizontal connection of the pervious stratum. Comparing the "Table of the subterranean temperature obtained from the borings in the city of Beppu" with the "Table of the soil-nature by the boring" in our Journal "Tikyu-buturi", you would find that there are numerous correspondences to be mentioned. Some of them are tabulated in Table 2.

Table 2. Various correspondences of hot water strata.

Sp. No.	Corres. depth.	Correspond-ing facts
A Str: Inland side of Tano-yu Zone		
(A_1) Stratum		
1207,1	24—32 m	Sand Str.
523,1	28 m	To-ori
738	30	Taking hot water out
832	31	Abnormal fall of temp.
(A_2) Stratum		
1207,1	44 m	Taking hot water out
523,1	43	To-ori
727	42	Taking hot water out
758	45	,,
184	46	Abnormal fall of temp.
B Str: Both sides of Tanoyu Zone, and || to it.		
1281	49—55 m	Pervious
19	52 m	Hot water in early time.
864,1	55 ca.	Pervious
571	56	Taking hot water out
466	54	,,
525	58	,,
166	53	,,
832	55	,,
787	57	,,
646	54	,,
787	53	Abnormal fall of temp.

Sp. No.	Corres. depth.	Correspond-ing facts
184	59	Hot water in early time.
872	58	Abnormal fall of temp.
61	54	,,
C Str: || and outsides of (B) Str.		
1283	74 m	Collapse of boring wall.
19	73	Spring out of hot water.
864,1	72	Taking hot water out
344	70	,,
342	76	,,
275	79	,,
184	76	,,
66	71	,,
58	70	Abnormal fall of temp.
	73	Taking hot water out
22	71	Abnormal fall of temp.
1033	76	,,
560	76	Top of temp.-rising str.
375	74	Taking hot water out
D Str: Sea-side part of Tano-yu Zone and outsides of (C) Str.		
(D_0) Str: || and out-side of Southern (C)		
819	85 m	Taking hot water out
815	84	Abnormal fall of temp.
3	84	,,

Sp. No.	Corres. depth.	Correspond-ing facts
(D_1) Str: Ditto		
19	86—94 m	Pervious
11	93 m	Taking hot water out
829	95	,,
861	95	,,
3	93	,,
1033	95	,,
61	91	,,
849	89	Abnormal fall of temp.
11	94	,,
991	93	,,
(D_2) Str: Sea-side part of Tanoyu Zone, and || and outside of northern (C)		
1281	81—99 m	Pervious
1285	96 ca.	,,
Kita-hama 17	85—104	,,
434,13	93 m	Taking hot water out
434,9	99—102	,,
434,3	77—98	Pervious
1291	95	Collaspse of boring wall.
1283	86—98	Pervious
413	91	Taking hot water out
422	98	,,
331	92	Max. temp.
E Stratum		
(E_1) Str: South-side of and || to (D_0) & (D_1) Strata.		

Sp. No.	Corres. depth.	Correspond-ing facts
11	m 120	Taking hot water out
862	124	,,
815	116	,,
786	124	,,
(E_2) Str: Middle reclaimed land.		
203	m 103	Taking hot water out
217	101	,,
991	107	,,
1048	100	,,
1184	98	Top of temp.-falling stratum.
11	106	Abnormal fall of temp.
(SE) Stratum		
(SE_1) Str: *South side of* and || to (D_0) & (D_1) Strata.		
11	m 120	Taking hot water out
862	124	,,
849	111	,,
815	116	,,
786	124	,,
(SE_2) Str: Nighbourhood of middle reclaimed land.		
205	m 103	Taking hot water out
217	101	,,
991	107	,,
80	100	,,
1184	98	Top of temp-falling stratum
11	106	Abnormal fall of temp.
(SE_3) Str: Vicinity of the Kaimonzi Zone		
560	m 120	Taking hot water out
468	112	,,
442	116	,,
349	112	,,
Kita-hama 17	108—117	Pervious
434,14	120	Taking hot water out
434,7	103—110	Pervious
434,11	108—115	,,

Sp. No.	Corres. depth.	Correspond-ing facts
434,3	m 112	Taking hot water out
1256	112—131	Pervious
1315	111	Abnormal fall of temp.
1316	111	Pervious
SF Stratum		
(SF_1) Str: Vicinity of Nagesi Street.		
872	m 150	Taking hot water out
878	142	,,
(SF_2) Str: Central coast		
473	m 137	Taking hot water out
429	137	,,
331	148	,,
198	144	,,
1184	142	,,
434,9	131—141	Pervious
434,7	112	,,
	138	To-ori
	145	Taking hot water out
1291	139	Collapse of boring wall.
1283	136	To-ori
1278	133	Taking hot water out
1256	136	Pervious
(SF′) Str: Do.		
1291	m m 155—168	Pervious
1283	m 169	Taking hot water out
1289	160—173	Pervious
1256	172	Taking hot water out
434	166	Abnormal fall of temp.
SG, SH Strata: North side of Kaimonzi Zone and Kakusuiyen reclaimed land.		
(SG) Stratum		
433	m 182	Taking hot water out
434,9	195—200	Pervious str, Taking hot water out

Sp. No.	Corres. depth.	Correspond-ing facts
1289	176—180	Pervious To-ori
1315	178	Taking hot water out
434,8	190	,,
(SG′) Stratum.		
434,12	m 201	Collapse of boring wall.
434,10	212	To-ori
,,	206	Collapse of boring wall.
(SH′) Stratum		
434,12	m m 240—257	Pervious
434,11	237	Collapse of boring wall.
1316	231	Abnormal fall of temp.
,,	239	,,
434	232	,,
(SH) Stratum.		
434,11	m 274	To-ori
434,12	258	Taking hot water out
1310	287	,,
434	269	,,
Hamawaki Side.		
Hamawaki (A) Stratum		
1247	m 47	Taking hot water out
1229	43	,,
1149	43	,,
1227	47	Abnormal fall of temp.
1225	44	,,
Hamawaki (B) Stratum		
1245	m 54	Abnormal fall of temp.
1088	49	,,
1139	51	Taking hot water out
1227	55	,,
Hamawaki (C) Stratum		
1245	m 59	Taking hot water out
1078	64	Abnormal fall of temp.
1088	61	Taking hot water out

In short, first the strata (A_1 and A_2) which are 30 metres and 44 metres below the ground exist along the Tanoyu vein. Along the east part of them (i. e., the coastal part), both southward and northwards there are hot water-bearing strata which lie about 55 metres (B), 73 metres (C), 95 metres (D), 120 metres (the southern part, E), and 110 metres (SE_3) below the ground respectively. Among these strata the stratum which lies about 73 metres under the ground is not used as the spring-source in the neighbourhood of the Akiba middle homothermal area. In the northern part, various pervious strata deeper than 73 metres are used in sequence for the 'dispersive' area and the depth of boring suddenly increases north of the Kaimonzi vein, while in the southern part the utilized stratum becomes shallow after the maximum depth of 150 metres and runs to the stratum at the depth of 50 metres at Hamawaki. As to the geological characteristics of these strata, see another paper.[1]

5. Distribution of the subterranean temperature on the vertical section

Let us make many sections to consider the distribution of isothermal lines. Some of them only are given here as space is limited (Fig. 7).

I. The section between Noguti and Beppu Harbour. Spring sources are presumed to be near No. 561 and the left-hand of No. 413. Isothermal lines of below 45° begin to fall near No. 463, but lines of more than 50° not. Such a phenomenon as the former is supposed to be caused by the action of ground water of low temperature, from various facts: the presence of a shallow underground flow of cold water (there are artesian wells of cold water) along the Noguti old highway near No. 561, the existence of a prominent flow of low temperature water (head is about 1.50 metres under the ground, that of hot water being 3.25 metres under the ground), collapse of the boring-bottom near the railway crossing, several shallow borings giving water of low temperature in the neighbourhood, etc. The influence of the high temperature near No. 561 seems no longer to be produced far from No. 473. Therefore, No. 561 is regarded as belonging to an independent spring vein. It is for this reason that we consider the 'Kaimonzi vein' along the Kaimonzi type already stated.

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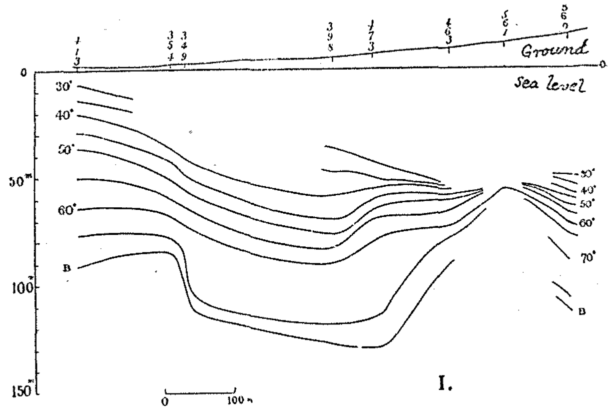
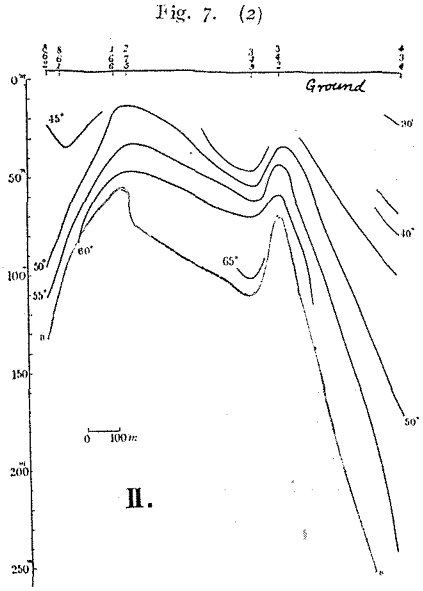
1. Tikyû-buturi (Geophysics), **1** (1937), 282.

Fig. 7. Temperature distribution in vertical sections: (1)
BB=Depth of taking hot water out.



II. The section drawn from the north end of the north reclaimed ground nearly at right angles to the section I. The surface of depths collecting hot water is parallel with the isothermal lines. This section cuts the Kaimonzi vein near No. 342 and the Tanoyu vein near No. 275. Near No. 862 which belongs to the middle homothermal stratum of Akiba street, the line of 45° tends upwards, but lines of more than 50° still downwards. The ground water of about 45° is supposed to lie in the upper stratum of No. 862. A large pressure (about 3 metres) of clay-water was used for the boring of No. 434. It indicates that there is a powerful upper flow of low temperature.

Fig. 7. (2)

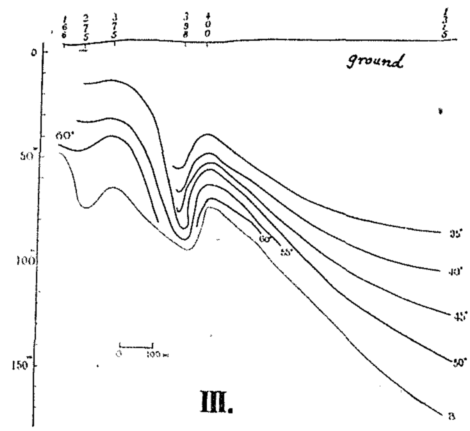


III. The section being nearly parallel with the coast line near the north part of the railway. This section cuts the Kaimonzi vein near No. 400 and the Tanoyu vein near No. 375. The isothermal lines are dispersive from No. 400 towards No. 1315, but not so remarkably as II.

IV. The section drawn from the north-north-west to the south-

south-east, being farthest from the coast of the area observed in the present investigation. This section cuts only the Tanoyu vein near No. 738. The isothermal lines of 40° to 50° expand with wide intervals between No. 787–819 and again gather towards No. 872, tending upwards on the whole. Accordingly, along this section there is no flow to move from No. 819 to No. 872. But it is evident from another section that there is no spring vein near No. 872.

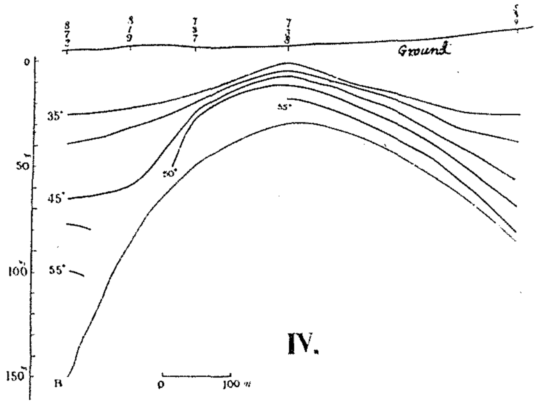
Fig. 7. (3)



V. The section along the hot spring vein which seems to be the Kaimonzi vein, except No. 442. The characteristics of this case are as follows:

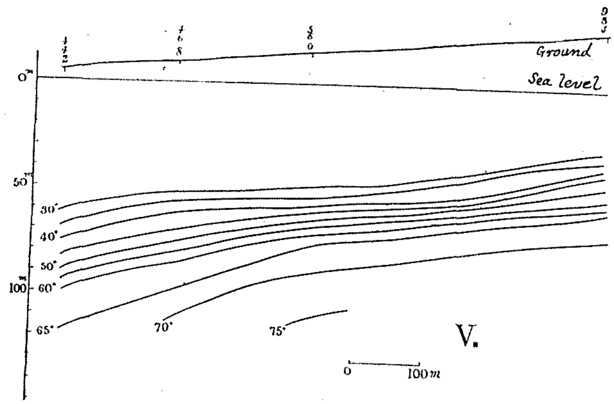
(a) The isothermal lines are all parallel with the ground surface and so it is naturally supposed that there is a flow along them. However, if the whole of hot spring water comes from the upper stream and keeps its temperature till it reaches the lower stream, the flow must be fairly rapid in velocity. It will be, therefore, rather proper to consider that there is a system of water flowing horizontally, along which heated water or vapour is constantly supplied from beneath.

Fig. 7. (4)



(b) It must be noted that the isothermal lines, massing about 50–100 metres in depth, represent a remarkable discontinuous stratum. The fact that such a discontinuous stratum is always kept steady makes us suppose a water flow of low temperature which is situated over the stratum and constantly takes away heat. If there were nothing but the conduction by sand, the isothermal lines would finally disperse and fill the space between the ground surface and the surface of hot water at equal intervals.

Fig. 7. (5)



VI. The section near Beppu Station, being fairly parallel with the railway. Here the Tanoyu vein (near No. 738) and the Kaimonzi vein (near No. 400) are most distinctly revealed.

VII. The section drawn from the southern part of Beppu Station towards Kusunokiyu, a part of which runs along the Tanoyu vein. The isotherms are almost horizontal between No. 275–183 and parallel with the ground surface having the same signification as V.

Fig. 7. (6)

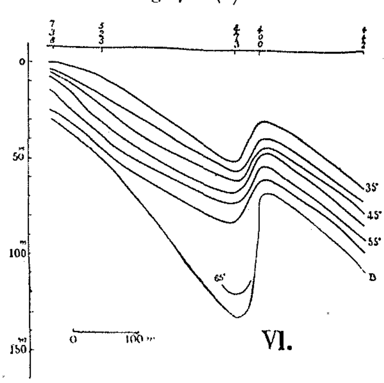
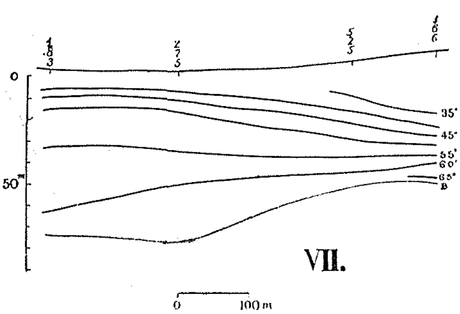


Fig. 7. (7)



VIII. The section drawn from east to west near the southern limit of hot water from the Tanoyu vein. The temperature is low between No. 3 and No. 1033, namely in the middle. Such a phenomenon is likewise seen along a paralleling section near Nagesi street, a little north. It would signify the existence of a flow of low temperature running northwards through the centre on the upper stratum, or that both ends belong to the hot water from the Tanoyu vein. Probably these two may exist in truth because the symptoms are sometimes found in chemical ingredients or distribution of density.

Fig. 7. (8)

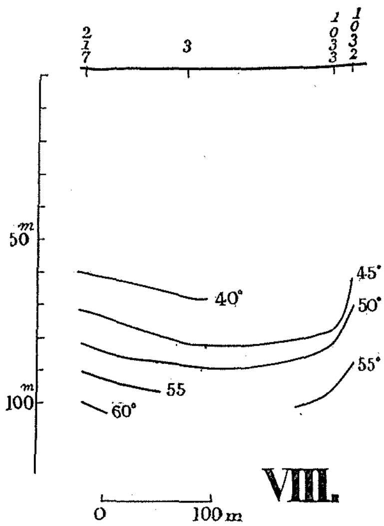
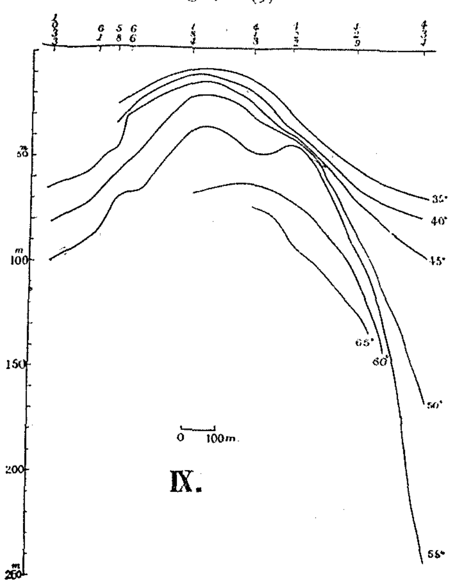


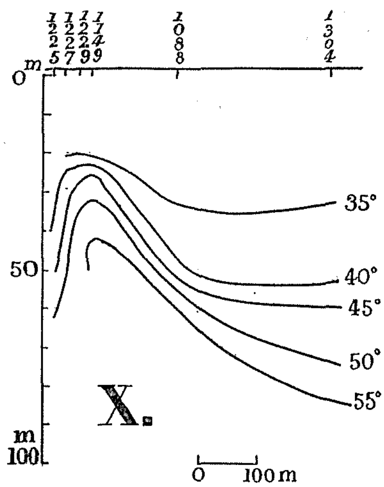
Fig. 7. (9)



IX. The section drawn from the north reclaimed ground south-south-westwards. The isothermal lines of less than 50° are the shallowest near No. 184, but the lines of more than 50° near No. 413-422. It proves that there are two hot spring veins. The vein corresponding to the Kaimonzi vein lies a little to the south. This fact will be made clear some day. The lines of more than 60° do not extend to No. 434. Thus there is perhaps a transition pivot between No. 429–434.

X. The cross section of the Hamawaki hot spring vein across the River Asami. The lines are typically dispersive from the centre of the vein near No. 1149 towards No. 1088–1304 across the River Asami. The fact that the lines fall sharply towards No. 1229–1227–1225 shows that there is hardly any flow of hot water. In fact No. 1225 is situated on the limit of active welling mouths.

Fig. 7. (10)



From other sections or matters, the Hamawaki vein seems to run from a corner (the east corner) of the Municipal Hamawaki Hot Spring towards a little north of the Hamawaki Sand-bath. From its scope, temperature, head, etc., the vein is fairly weak as compared with the other two spring veins.

Though there are welling mouths of comparatively high temperature north of the River Asami and up to somewhat east of Matubara Park, it has not yet been made out because of no data concerning the subterranean temperature that these form an isolated spring vein or belong to either the Hamawaki or the Tanoyu vein.

6. Distribution of the subterranean temperature on the horizontal sections

Many horizontal sections at various depths under the sea surface were drawn and distributions of the temperature on them were studied. The three cases of 20, 55, and 90 metres in depth are given in Fig. 8.

(I). *20 metres under the sea surface* (Fig. 8–1):—The lines of 50°–55° run along the Tanoyu vein, towards both whose sides the temperature falls sharply. The Kaimonzi vein also appears somewhat on the coast.

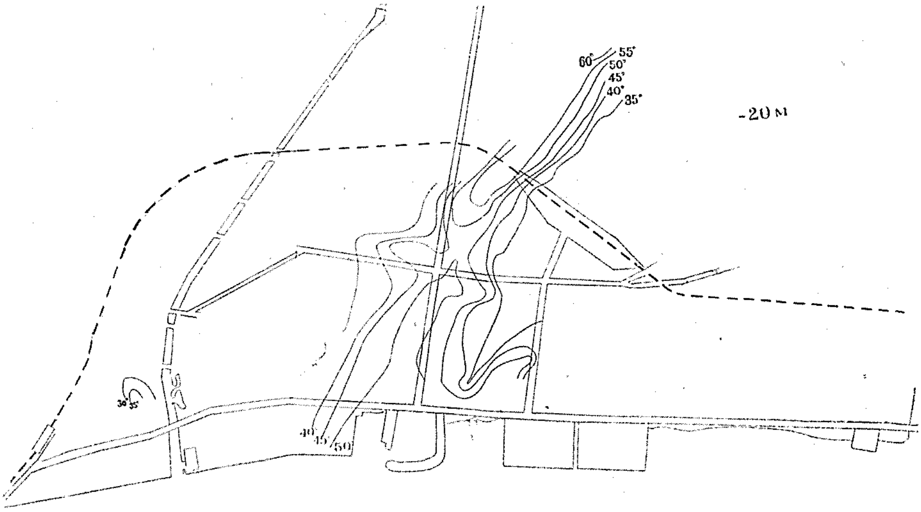
With increasing depth each pair of isothermal lines parts right and left having the Tanoyu vein as the centre. The Kaimonzi vein begins to present itself, and not only cuts into the inland with the increase of depth, but also the area as a belt surrounded by the isothermal lines extends its width. The same phenomenon is seen in the case of the Hamawaki vein.

(II). *55 metres under the sea surface* (Fig. 8–2):—Here we see that

1) The isothermal lines, dispersing to the left-hand from the Tanoyu vein, suggest the flow-off from the vein.

2) There is an area of low temperature obliquely under the front of the station, which presents such a phenomenon as water of low

Fig. 8. (I) Distribution of temperature in a horizontal section 20 m below the sea level.

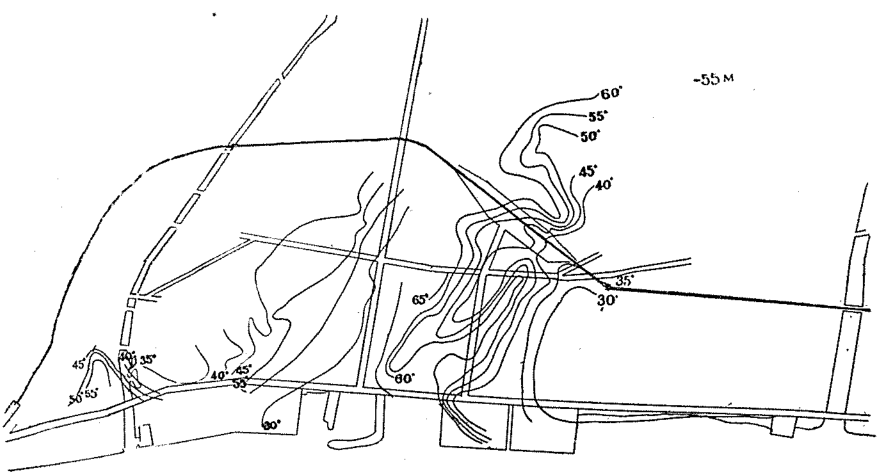


temperature flows in there. It is recognized from other matters too, and so it is presumed that there is truly a new water system there.

3) The isotherm of 55° running on its north side points out the 'Kaimonzi vein'.

4) The area more northern is occupied by water of low temperature. It seems to be caused by influence from the direction of the River Sakai.

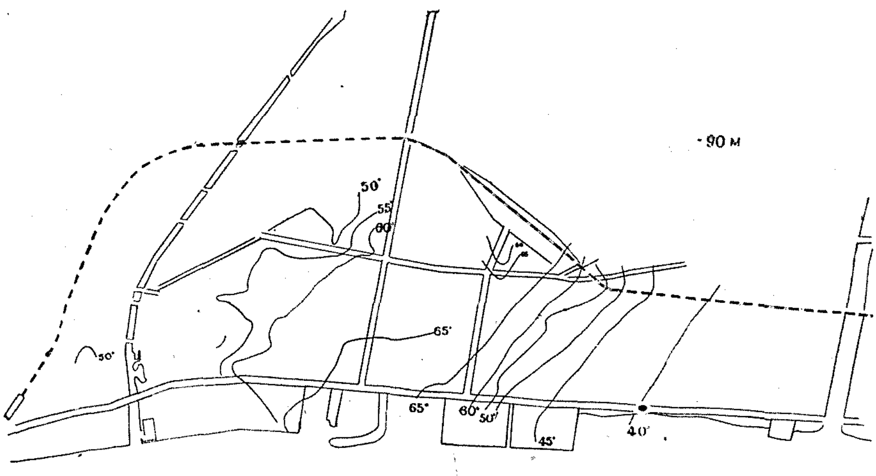
Fig. 8. (II) Horizontal section 55 m below the sea level.



5) The Hamawaki vein is seen on the south end of the city.

(III). *In a deeper place* the isothermal lines disperse much more, having the vein as a centre and the area of low temperature mentioned in (2) is narrowed. The lines of more than 30° run on the north side of the Kaimonzi vein and tend to the north with increasing depth. The isothermal lines from Tanoyu go south as far as Matubara Park. Near the coast, however, it becomes suddenly cold on the south of Nagesi street (70 m depth). When it becomes deeper the isothermal lines separate, and at 90 metre depth (Fig. 8–3) the area of low temperature in front of the station disappears (from the coast towards the inland). The area of high temperature expands between the Tanoyu and Kaimonzi veins.

Fig. 8. (III) Horizontal section 90 m below the sea level.



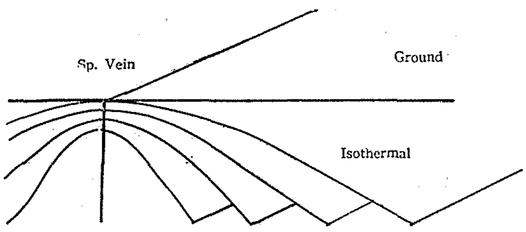
7. Spring veins and their construction, General distribution of the temperature

Thus we obtain the schematic representation of the distribution of temperature on both sides of a spring vein as Fig. 9. And we consider:

(1) A spring vein is a zone area having a fracture in the bed rock, from which heated water or vapour rises and runs off to both sides of each upper pervious stratum and the remainder of hot water ascends to come out to the earth surface as a natural welling. Therefore, some veins may have no natural welling, such as the Kaimonzi vein.

(2) In the place where ground water of low temperature flows, the hot spring water is heaped up just like a slit source. Generally

Fig. 6. Schematie distribution of temperature in both sides of a hot spring vein.



speaking, according as leaving from a spring vein and from the contact point with a ground water stratum of low temperature, the temperature distribution becomes as if it were commanded only by heat conduction. This indicates that a discontinuous distribution occurs near either a spring vein or a contact point of water of low temperature. As heat at a certain point is inferred to be caused by equilibrium between horizontal flow and vertical conduction, a middle homothermal stratum suggests a fairly rapid flow. Concerning Beppu the flow of high temperature from the three spring veins—the Hamawaki, Tanoyu, and Kaimonzi veins—is combined there with the underground flows of low temperature from the bluff and the Rivers Asami and Sakai. (There are several systems in the flow of low temperature from the bluff. They are clear from chemical ingredients or distribution of density, as will be mentioned in another paper.) The most powerful Tanoyu vein dominates the area from a little south of the Kaimonzi vein to the neighbourhood of Matubara street, the southern part of which is under the influence of the Hamawaki vein. The Kaimonzi vein makes water of high temperature flow, but is weak in power. Both ends of the area between the Tanoyu and Kaimonzi veins are supported by the two veins, forming the most abundant welling area. On the north side of the Kaimonzi vein hot water conceals itself suddenly into the depths, temperature being not so high. But it seems to communicate as far as north of the River Sakai though at low temperature. The northern limit which is regarded today as belonging to this vein lies on Motigahama coast, which is not so far from the south bank of the River Haruki (the southern limit of Kamegawasyôhaen vein).

The directions of the three spring veins are nearly parallel with each other, corresponding to the directions of the tectonic line from Horita to Hamawaki. Finally there remains a great problem how these veins are supplied with hot water from underneath. However, it should be discussed from the results of a more comprehensive investigation throughout the whole Beppu hot spring zone. The investigation of the subterranean temperature of the new city has made some progress, giving various interesting problems. Now we promise you we shall deal with the distribution of the subterranean temperature in the future in this journal with ampler data.

Conclusion

As above described, the distribution of the subterranean temperature in Beppu with the hot spring veins and the cold water zones has been made clear from the data obtained from the measurements at various depths of more than one hundred borings in the old city of Beppu during the past five years. The important points are summarized :

1) There are three hot spring veins in the old city. Though the Tanoyu and Hamawaki veins have been known as the open spring veins that have natural welling, it has been first ascertained from our present investigation that the Kaimonzi vein, as we named it, is a hidden spring vein that has no natural welling.

2) The hot springs in the city are almost all what de Launay calls the artesian *nappe*. Many pervious and impervious strata are layered under the city. That hot spring water is included in several strata of the former is recognized not only from the depth of the hot water collected or the nature of the soil gathered but also from various phenomena under the borings, such as collapse of the bottom of bore-holes, existence of 'Toori' (water-flow in the boring), abnormal fall of the reading of the temperature, etc.

3) There are six types of the rise of the subterranean temperature under the borings ; they are the Tanoyu, Kaimonzi, North dispersive, Akiba middle homothermal, coast temperature falling, and Hamawaki types. In the Tanoyu and Hamawaki types of the open spring vein, the temperature rises at a jump in the shallow strata ; they hardly have an upper homothermal stratum of low temperature above them, and the final depth of boring is shallow. The final temperature is high in the powerful Tanoyu type, but low in the weak Hamawaki type. In the Kaimonzi type of the hidden spring vein, both the final depth and the discontinuous strata are far deeper than those of the former two, above which an homothermal stratum of definite low temperature is well developed. Generally speaking, the fact that the strata of almost uniform temperature lie above and below a discontinuous transition suggests that there are ground flows in both strata. Even at the north dis-

persive type there is an homothermal stratum of definite low temperature till 60 metres in depth, and it indicates likewise a ground flow of low temperature. Below 60 metres the temperature rises gently. In the Akiba middle homothermal type, the definite stratum of medium temperature lies at medium depth. It proves that there are flows of medium temperature though weak, although warm water was not utilized from the strata at the medium depth. In certain areas on the coast, the hot water is collected from a stratum considerably deeper than the stratum of the highest temperature and its temperature is a little lower. It will be because there is a more powerful ground flow of somewhat lower temperature below the stratum of the highest temperature.

4) The distribution graphs of the subterranean temperature on various vertical sections show realistically the characteristics of the spring veins. The sectional graph III is a model of vertical section crossing spring veins, generally tending to the north and south. The isothermal lines on it are swollen as two crests, indicating the Tanoyu and Kaimonzi veins. The graph V is a model of sections along veins. The isothermal lines are nearly parallel to the earth surface, making no crest and trough. The graph X shows the Hamawaki spring vein.

5) The distribution graphs of the subterranean temperature on horizontal sections make clear not only the position and the influencing scope of the three hot spring veins in Beppu, but also the position and nature of cold water systems. For example, it is evident that there are the Noguti water zone from the bluff between the Tanoyu and Kaimonzi veins, the Akiba middle flow of low temperature on the south-west of the Tanoyu vein, and the cold underground flow in the basins of the Rivers Sakai and Asahi.

6) Let us presume the underground construction of Beppu hot springs from the above stated facts. Parallel to the tectonic line in Beppu region, the three rents of Kaimonzi, Tanoyu, and Hamawaki lie on the several layers of pervious strata where there is abundant ground water supplied by underground flows from the bluff, the River Asami or Sakai. Hot water or vapour ascends from the lower part of those rents, flowing right and left on each pervious stratum. Its surplus wells to the earth surface as natural spring, as at the Tanoyu vein, forming an open spring vein, while at the Kaimonzi vein the hot water or vapour flowing into the pervious stratum is not so powerful and forms a hidden spring vein having no natural welling. The Hamawaki

vein was an open one till about 1870, but has withered to a hidden one today.

The observations were made with the assistance of Mr. K. Seno, Ko. Yamasita, and S. Morinaga, to whom our thanks are due.