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THE CHEMICAL CHARACTER OF THE BOILING SPRINGS IN THE BEPPU HYDROTHERMAL FIELD

By

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Abstract

The boiling spring waters of which the temperature is highest in the thermal waters in the Beppu hydrothermal field seem to be the original hydrothermal water in this region. Alkali chloride and sulhpates are contained in this solution with high concentration, while the concentration of alkali earth metal calcium and magnesium ions are low, and the value of Li/Na is remarkably great. These chemical characters of the boiling spring water have been also found in another geothermal fields and seem to be not depend on a kind of the country rocks.

1. Introduction

In Beppu, well known as the city of hot-springs, there are about 2,000 thermal wells having a total daily discharge of 5,000 m^3. These wells distribute in so wide area as 24 sq. km. that the various kinds of hydrothermal phenomenon can be found among them of this region, that is natural fumarole, bored fumarole, boiling spring, natural thermal spring, thermal flowing-well, etc., and the various kinds of the chemical constituent in the thermal waters have been also found among them. Especially, the boiling springs are an excellent geothermal area and the concentration of dissolved substances in the waters is higher than the others. Alkali chlorides and sulphates are contained in this solution with high concentration, while the concentration of alkali earth ions as calcium and magnesium are low. Futhermore, these waters are also characterized by many chemical constituents. According to the results of analyses by Koga (1960) and Kawakami (1964), the concentrations of silica, boric acid and of the rare elements as germanium, arsenic, zinc, titanium, vanasium, fluorine, bromine and iodine in the boiling spring waters were the highest of all the thermal waters in Beppu.

This chemical character of the boiling spring waters in Beppu have been also found on the boiling spring waters in another hydrothermal fields.

2. Outline of Boiling Springs in Beppu

Fig. 1 shows the distribution of the boiling springs in Beppu. All of them are the bored boiling springs. The bored depth is 80~300 m in the southern part of the city (A group), 100~350 m in Kannawa area (B group), and 200 m in Kamegawa area (c group). The water temperature at the bottom of holes is about 150~180°C. The country rock of the hot waters is propylite or pyroxene-andesite altered by hot water. The hot waters flow out from the fissures in these rocks.

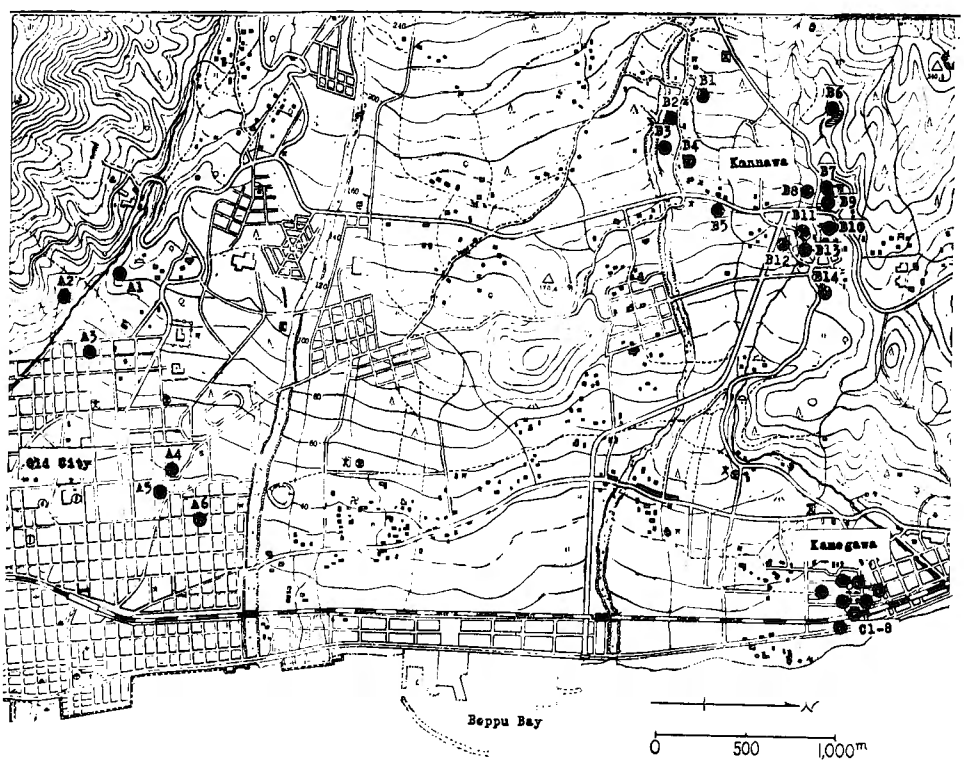

Fig. 1. Distribution of the boiling springs in Beppu.

Towared the western hill area from A group, there are almost fumaroles, but on the other hand, towards the eastern area from them, there are common hot springs. In Kannawa area, towards the western area from B group, there are fumaroles and towards the eastern from them, there are common hot springs as like as A group. Whereas, in Kamegawa area (C group), there are only common hot springs around the boiling springs. Consquently, it seems that the hot waters of this group are fed from the source standing alone in this area.

3. Experiment Procedure

As the discharge of the boiling springs is fed from an underground weter phase at high temperature, the hot waters mixed with steam are gushing out from the orifice owing to the water comes to the boil by the pressure depression on the way passing through the casing pipe and some quantity of the waters turns into the steam. The samples of hot waters were obtained at the orifice of the hot water flowing out from the separater where the discharge are divided into water and steam at atmospheric pressure. Hence, the chemical constituents in the sampled water were concentrated more than those of the underground water owing to evaporated some quantity of the underground water. But the difference of the concentration between sampled water and underground water does not affected upon the discussion of chemical characters of the boiling spring waters.

The analyses of the waters was carried out by following methods.

Lithium, sodium and potassium ions by flame spectrophotometry.

Calcium and magnesium ions by titration with a standard solution of ethylene diamine tetra-acetate.

Chlore ion by Mohr's method.

Sulphate ion by the gravimetric analyses.

The results of chemical analyses are shown in Table 1.

4. Chemical Character of the Waters

Na, K, Cl and SO_4 ions are contained in the waters as the major components and Ca and Mg ions as the minor. Moreover, Li ion could be also found with the considerable high concentration.

These waters are almost alkaline as their pH values being 7.2~8.9. But some of them are acid as their pH values being 2.3~3.4. Whereas, the composition of the waters is almost the same value in spite of these nature. (see Table 1)

Cl ion content in the waters varied from 655 to 2,810 mg/l, while Na ion content varied from 472 to 2,070 mg/l. Moreover, the linear relation could be found between them as will be seen in Fig. 2.

The linear relation could be found between Li and Na ions contents and the same relationship could be also found bedween Na and K ions contents. (see Fig. 3 and 4)

SO_4 ion content in the waters varied from 90 to 740 mg/l and the relationship could be found between Cl and SO_4 ions contents as shown in Fig. 5, but it seems to be uncertain compared with that between above mention ions.

Table 1. Chemical constituents of the boiling spring waters in Beppu (mg 1/.

Well No.	pH	Li^+	Na^+	K^+	Ca^{2+}	Mg^{2+}	Cl^-	SO_4^{2-}
A. 1	8.9	6.8	744	86	23	4.3	1160	240
A. 3	8.4	4.5	480	50	6.4	1.8	655	90
A. 4	8.5	4.2	467	43	43	4.7	737	125
A. 5	8.1	6.2	688	53	37	0.8	1340	220
A. 6	8.0	5.6	660	44	54	1.9	1090	90
B. 1	8.4	7.6	1040	116	45	0.9	1760	223
B. 2	7.8	9.6	1490	163	35	12	2120	305
B. 3	8.5	9.0	1300	142	45	6.0	2010	140
B. 4	8.3	7.0	960	97	33	2.2	1460	190
B. 5	8.0	6.8	920	86	47	3.7	1420	320
B. 6	2.3	4.8	750	158	76	11	1240	740
B. 7	3.4	10.0	1460	209	32	5.4	2420	380
B. 8	3.3	12.3	2070	253	27	8.7	2810	391
B. 9	7.2	7.8	1300	157	61	11	1940	354
B.10	8.3	3.9	614	78	47	1.0	909	—
B.11	8.2	8.8	1270	183	33	6.6	2020	333
B.12	7.2	9.0	1600	190	38	4.9	2070	401
B.13	8.3	7.6	1190	157	35	2.3	1750	325
B.14	8.4	6.0	800	96	16	2.2	1240	268
C. 1	8.1	7.7	1540	138	45	13	2190	276
C. 2	8.3	5.7	770	96	40	1.2	1270	251
C. 3	8.5	5.4	777	111	26	1.1	1190	208
C. 4	8.2	5.5	732	74	24	0.9	1210	218
C. 5	8.3	6.4	816	127	1.1	0.4	1590	352
C. 6	7.3	6.6	860	135	37	1.5	1490	338
C. 7	7.3	6.8	1000	144	31	2.0	1580	262
C. 8	8.5	4.8	650	68	45	1.3	1020	208
C. 9	8.5	6.0	1040	91	45	1.2	1420	207

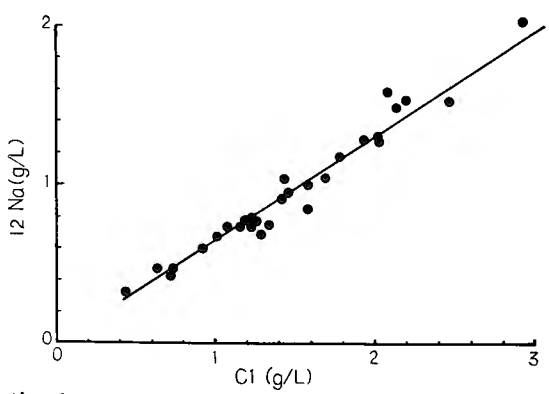

Fig. 2. Relation between Cl^- and Na^+ contents of the boiling spring waters.

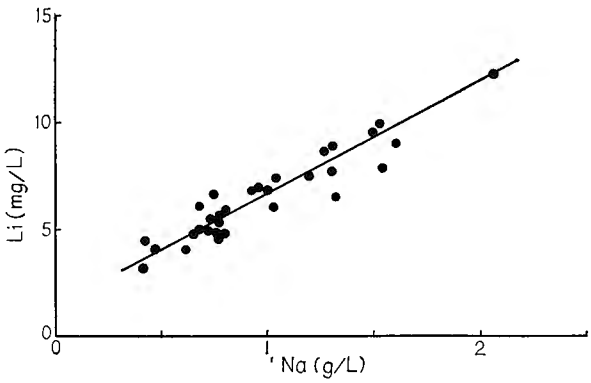

Fig. 3. Relatation betwee Na^+ and Li^+ contents of the boiling spring waters.

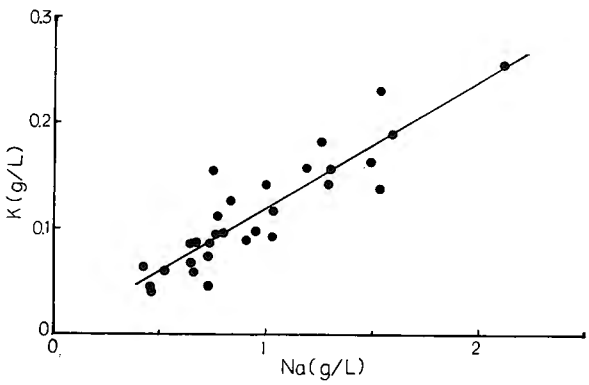

Fig. 4. Relation between Na^+ and K^+ contents of the boiling spring waters.

In Kannawa area, the hydrothermal activity is so strength that the concentration of these solutions is higher than the others.

In discussing chemical analyses of thermal waters, it is convenient to use the atomic or weight ratios between constituents to avoid the effects of evaporation or dilution with surface ground waters. Table 2 shows the mean values of the weight ratios between constituents analysed the thermal waters and others in Beppu.

The mean value of Na/Cl ratio of the boiling spring waters is 0.65, and this value is greater than that of sea water as 0.55. The mean values of Li/Na and K/Na ratios of the boiling spring waters are considerable great as 6.9×10^{-3} and 0.12 compared with these of sea water as 1.6×10^{-5} and 0.04. (see Table 2) The concentration of calcium and magnesium ions in the boiling spring waters are such a low that the mean values of Ca/Cl, Mg/Cl and Mg/Ca

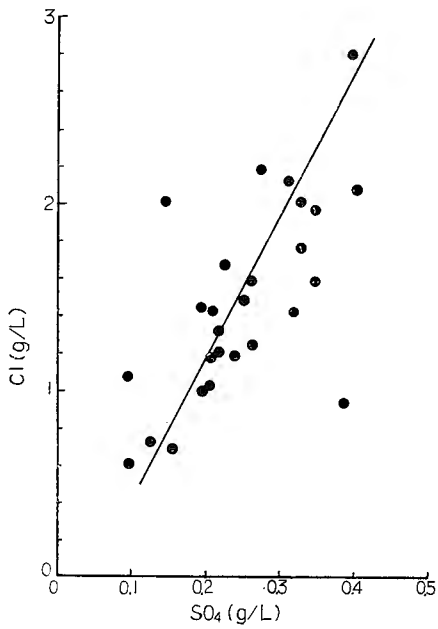

Fig. 5. Relation between Cl^- and SO_4^{2-} contents of the boiling spring waters.

Table 2. The mean weight ratios between constituents in the thermal waters and others in Beppu.

Locality	Na/Cl	SO_4/Cl	Ca/Cl	Mg/Cl	Li/Na	K/Na	Mg/Ca
Boiling springs	0.65	0.177	0.024	0.0026	6.9×10^{-3}	0.12	0.11
Old city area	1.05	0.41	0.40	0.18	5.7 〃	0.12	0.47
Kamegawa area	0.78	0.48	0.090	0.016	4.8 〃	0.15	0.18
Kannawa area	0.84	0.87	0.16	0.025	5.0 〃	0.15	0.16
Hot springs in natural fumarole areas	4.36	79.5	2.3	2.1	1.0 〃	0.17	0.91
River waters in Beppu	1.47	—	2.16	0.57	1.0 〃	0.14	0.27
Ground water	0.86	—	1.50	0.47	2.2 〃	0.20	0.31
Sea water (Beppu bay)	0.55	0.14	0.02	0.07	0.016 〃	0.04	3.5

are smaller than the others. Especially, Mg ion content is considerable low and this nature is characteristic of the underground hot water at high temperature. Accordingly, the chloride in the waters seems to be almost juvenile chloride.

From the research of the hydrothermal system in the old city of Beppu, (Yamashita, 1965) the relationship was found between Li, Na, K and Cl ions

contents as like as these of the boiling spring waters and the concentration of the A group boiling spring waters was the highest of all in this region. It was also found that the chloride in the waters may be not evidently derived from sea water. Accoringly, it is inferred that the thermal waters are supplied from the hydrothermal waters as the boiling spring waters diluting with cold ground waters on the way passing through the underground stratums and the quantity of the original hydrothermal waters is about 20 % of the total discharge in this region. The difference of the compositions between the boiling spring waters and the thermal waters in the old city area may be coused by the dissolution or ion exchange on the way passing through the underground stratums. In Kamegawa and Kannawa areas, the difference of the compositions between the boiling spring waters and the thermal waters may be coused by the reason as like as the old city area. (see Table 2)

As will be seen in Table 2, the considerable difference can be found between the compositions of the boiling spring waters and of the hot spring waters in natural fumarole areas in spite of both thermal waters flow out from an excellent geothermal areas. The hot waters of the natural fumarole areas may be characterized by the high concentration of sulphate in this solution, while the others are low. Moreover, the chloride content and Li/Na ratio are approximatly equal to these of the surface waters. Accordingly, it is probable that the hot waters are mainly surface waters infiltrated into the natural fumarole area where they were heated by a fumarole and charged with chemicals.

5. Chemical Character of Boiling Springs in Other Hydrothermal Fields

Table 3

Locality	Cl^-(mg/l)	Weight Ratios					
		Na/Cl	Li/Na	K/Na	Ca/Cl	Mg/Ca	SO_4/Cl
Beppu	1540	0.65	6.9×10^{-3}	0.12	0.024	0.11	0.177
Otake, Kuju Volcano Area, Oita Pref.	1680	0.60	5.5 〃	0.12	0.007	0.55	0.07
Kurokawa Hotsprings, Kumamoto Pref.	506	0.68	5.7 〃	0.23	0.10	0.20	0.53
Tsuetate Hotsprings, Kumamoto Pref.	830	0.62	2.7 〃	0.06	0.051	0.046	0.12
Atagawa Hotsprings, Shizuoka Pref.	1170	0.67	—	0.16	0.095	0.032	0.17
Wairakei No. 4 Hole New Zealand	1927	0.59	10.3 〃	0.13	0.014	0	0.018
Norris Basin, Yellowestone, U. S. A.	780	0.62	14.0 〃	0.16	0.008	0.08	0.11

There are many boiling springs in other hydrothermal fields having the chemical characters as like as those of Beppu. Some of them are shown in Table 3. (Allen et al., 1935 ; Ministry of Health & Welfare, 1956 ; Ellis et al., 1960)

The concentrations of these hydrothermal waters are different each other. Whereas, the chemical composition in the waters shows the similar character and this character seems to be not depend on a kind of the country rocks of these waters. From these facts, it may be suggested that there is a constant physical and chemical condition on the becoming process of the waters. The hot waters of boiling springs in Beppu seem to be the original hydrothermal waters in the Beppu geothermal field. Such being the case, the physical and geochemical research of this water will be most interest problem contributing to the research of the hydrothermal system in Beppu.

Acknowledgment

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