Special Contributions, Geophysical Institute, Kyoto University, No. 7, 1967, 125-132

HYDROTHERMAL SYSTEM IN YUFUIN GEOTHERMAL FIELD, ŌITA PREFECTURE

By

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(Received October 9, 1967)

Abstract

In Yufuin geothermal field, there are about 300 spa sources having a total daily discharge of 13,000 m^3. Karube [1950] shew that the origin of hot springs seems to have the same in all under the ground by mean of the relations among Cl, HCO_3 and SO_4 ions in the waters. Recently, the developments of spa resources have been carried out in the geothermal field and the spa sources have been increased in every place. New, the writer carried out the geochemical research again, and it is found that the thermal waters in this region are fed from two different origins of the hydrothermal waters.

1. Outline of spa sources in Yufuin

Yufuin spa is located at the western foot of Mt. Yufu-dake (1584.5 m above sea level) and the distance of 20 km to the direction of the west from Beppu spa. There is a basin to be shut in by mountains in all directions. The spa sources run about 3 km from north-east to south-west in the center of the basin. The hydrothermal activity is so strength as to be ranked the next to Beppu spa in Ōita Pref..

The observations of existing states of the spa sources were made two times in the past, (Yamashita [1950], Sato *et al.* [1967]) and Table 1 shows the summarized results.

Table 1. The statistical results of spa sources in Yufuin

Observation year & month		Total number of spa sources	Mean temp.	Mean discharge	Total discharge
1950	8	201	54.92°C	45.93 lit/min	13,200 m^3/day
1967	1-3	300	58.76°C	29.86 lit/min	13,000 m^3/day

In 1950, there were 201 spa sources, however, by the developments of hot spring recource, the spa sources were increased year by year, and in 1967 the number of wells becomes 300 wells. With the increase of the number of wells, however, a number of the natural hot springs ceased flowing, but some of them still remain nowadays. In 1967, the mean temperature is higher than that in

1950 due to the developments of the hot spring resource at high temperature. Whereas, the total discharge has scarcely changed since 1950 in spite of the developments of the deeper aquifers. This fact shows that the supply is equal to the flowing out of the thermal water in these aquifers.

2. Distributions of the chemical constituents in the thermal waters

Karube [1950] carried out analysis of the main anion as Cl, HCO_3 and SO_4 ions in the thermal waters and obtained the distributions of those ions. With the relations among those ions, he has inferred that the thermal waters in all the places are fed from a same origin under the ground.

I have carried out the analysis of main ions in the waters of 110 wells picked up in this region and have reconsidered on the hydrothermal system with the distributions of those ions and the correlations among them.

The main components in the thermal waters are Na, K, Cl, HCO_3 and SO_4 ions, and they belong almost to the simple thermal springs.

The distribution of Cl ion content is shown in Fig. 1. The area of the high concentration of Cl ion is in Yunotsubo area as being higher than 200 mg l, and the same area as in Yunotsubo is in Ishimatsu area where there are some boiling springs having the highest temperature of all the thermal waters in this region and a large quantity of the discharge. In this area, there is the boiling spring of which Cl ion concentration is the highest of all the thermal waters as 458 mg/l. This newly Cl ion map almost coincides with that obtained by Karube. On viewing the whole tendency, the higher the water temperature is, the more Cl ion is contained in the waters. Accordingly, the concentration of Cl ion in the boiling spring waters which were bored recently in Ishimatsu area is higher

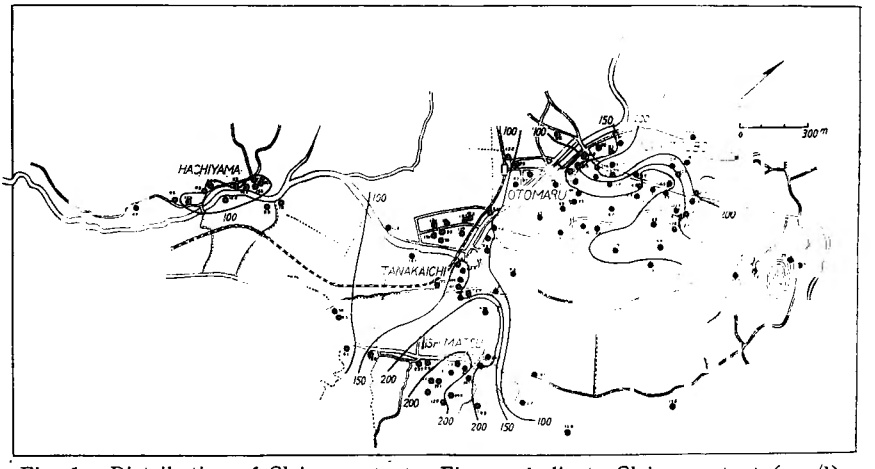


Fig. 1. Distribution of Cl ion content. Figures indicate Cl ion content (mg/l).

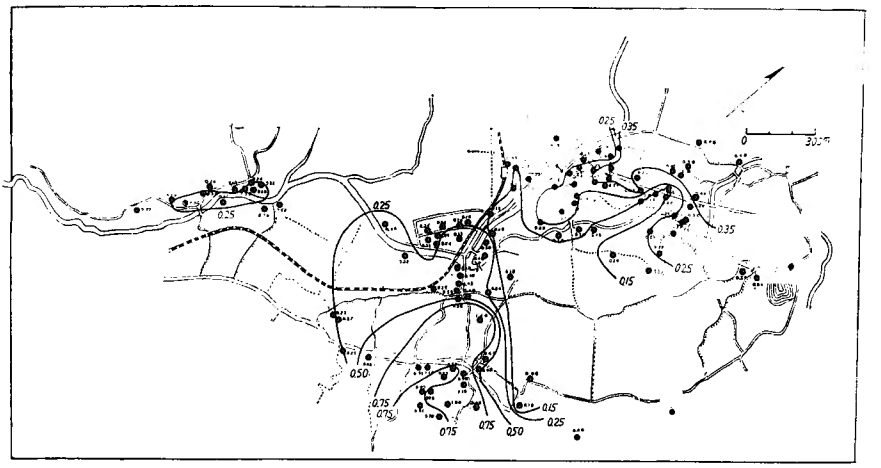


Fig. 2. Distribution of Li ion content. Figures indicate Li ion content (mg/l).

than that of the other thermal waters.

The higher Cl ion content is, the more Li ion is contained in the thermal waters of all places. Accordingly, the distributions of both ions have the same tendency to each other as will be seen in Fig. 2. Li ion is contained in the boiling spring waters in Ishimatsu area with the considerably high concentration as the highest value reaches to 1.40 mg/l. These facts will be understood by the relationship between Cl and Li ions contents as mentioned later.

The distribution of Na ion content also coincides with that of Cl ion content as shown in Fig. 3. By the relationship between Cl and Na ions contents as shown in Fig. 6, it can be also understood that the distributions of both ions have the same tendency to each other.

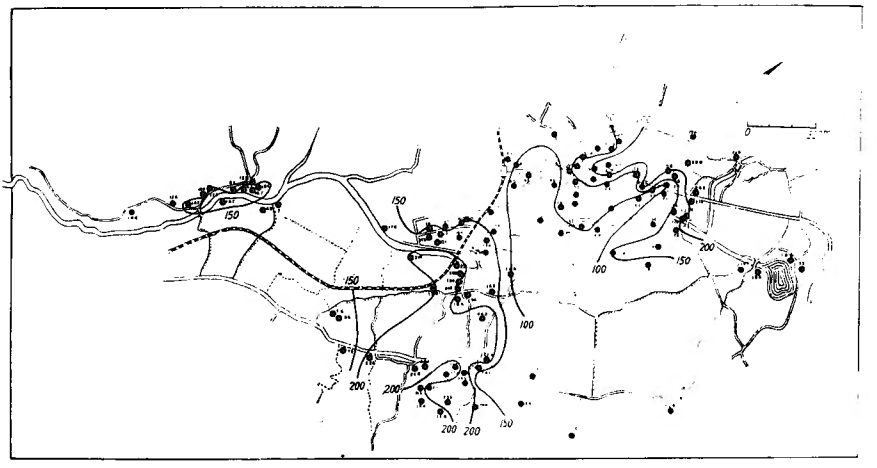


Fig. 3. Distribution of Na ion content. Figures indicate Na ion content (mg/l).

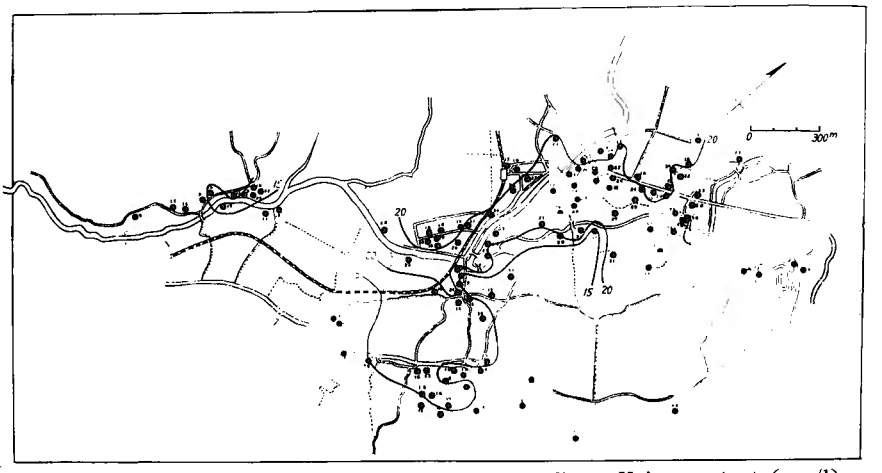


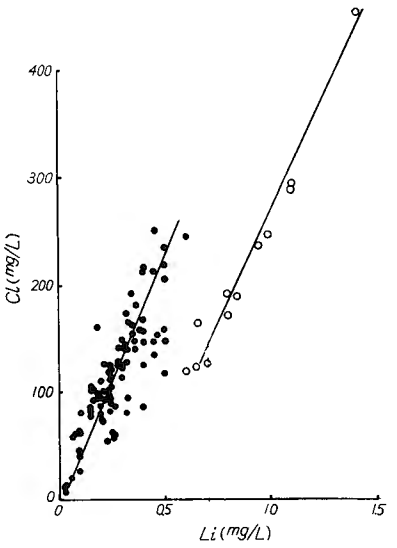
Fig. 4. Distribution of K ion content. Figures indicate K ion content (mg/l).

By a glance at the distribution of K ion content as shown in Fig. 4, the high concentration area is in the center of the region. Accordingly, this map shows the different tendency with that of Cl ion content, on the contrary the distributions of Cl, Li and Na ions contents have the same tendency. But the relationship could be found between Cl and K ions contents of the boiling spring waters and of the thermal waters in Ishimatsu area.

3. Chemical characters of the thermal waters

Cl and Li ions seem to be the most conservative ions in the thermal waters due to the distributions of the Cl and Li ions contents have the same tendency. Thereupon, the relation between both ions is shown in Fig. 5. The linear relation could be found between them on the thermal waters in the most areas of this region (black points). The straight line which expresses this relationship passes through near the original point. On the other hand, the group of the thermal waters (white circles) are the points apart from this relation. These thermal waters are in Ishimatsu area, being southern part in this region, and these wells are the boiling springs or the flowing wells of which the water temperature is very high as near to 100°C and the discharge is so much as more than 100 lit/min and the flowing condition would be seen as like as that of the boiling spring. These thermal waters are rich in Li ion compared with the other thermal waters, and the linear relation could be also found between Cl and Li ions contents in these waters.

The relation between Cl and Na ions contents is shown in Fig. 6. The linear relation could be also found between both ions contents on the thermal waters of both black points and white circles respectively. As well be seen in



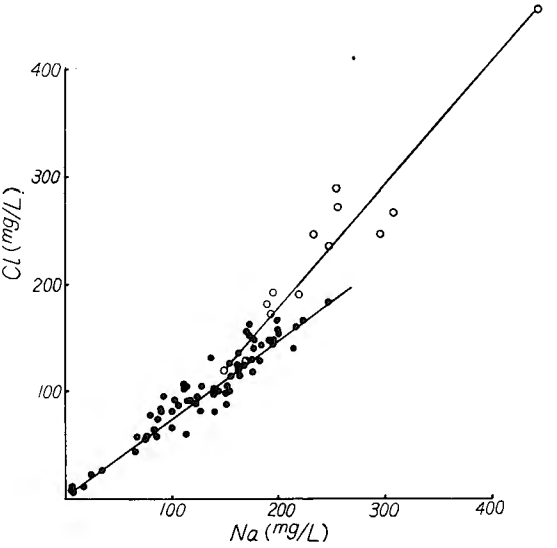


Fig. 5. Relation between Cl and Li ions. Fig. 6. Relation between Cl and Na ions.
○ Thermal waters in Ishimatsu area.
● Thermal waters in all the areas without Ishimatsu area

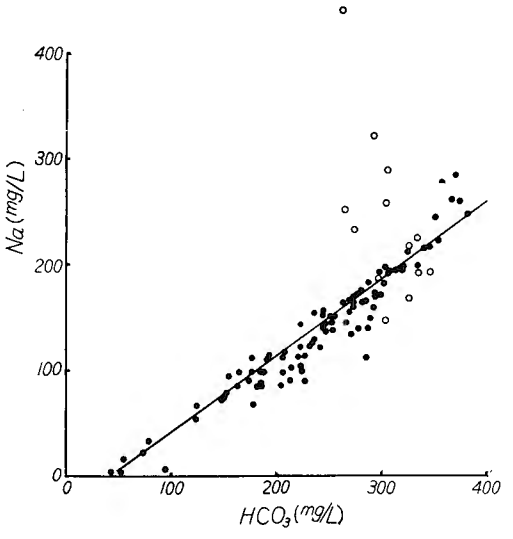


Fig. 7. Relation between Na and HCO_3 ions.

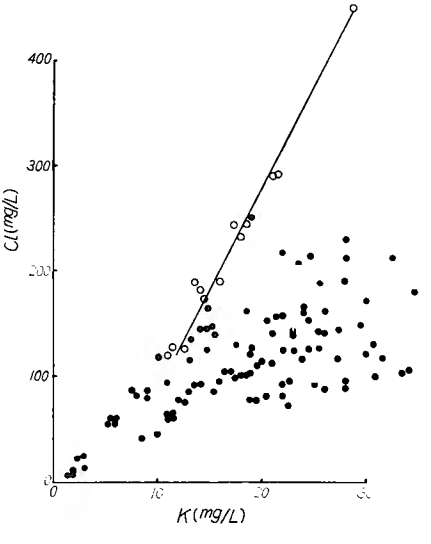


Fig. 8. Relation between Cl and K ions.

Fig. 6, the straight lines which are expressed the linear relations between both ions contents in the thermal waters in Ishimatsu area and the other areas have exactly their respective inclinations.

The relation between Na and HCO_3 ions contents is shown in Fig. 7. On the thermal waters of black points, there exists acculatly the linear relation between both ions contents. It may be seen that there exsists the linear relation between both ions contents on the thermal waters in Ishimatsu area. But it seems to be uncertain and the relationship is inverse.

Fig. 8 shows the relation between Cl and K ions contents. On the weters in Ishimatsu area, the relation between them is linear, but on the other areas, the relationship can not be found. This fact can be also understood in comparison the distribution of Cl ion content with that of K ion content (see Figs. 1 and 4).

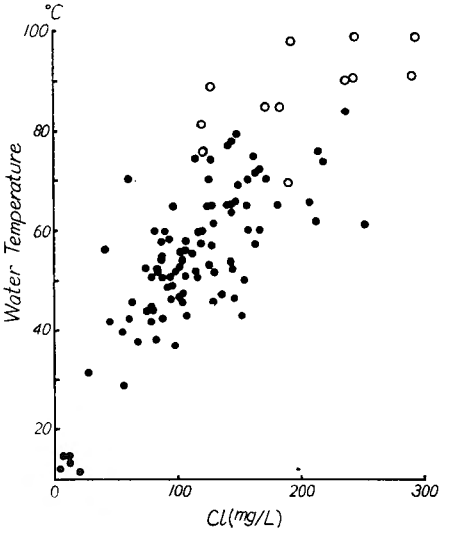


Fig. 9. Relation between water temperature and Cl ion.

The concentration of Ca and Mg ions are low in the waters of all areas. Especially, Mg ion content is considerable low as being smaller than 2 mg/l, and the correlations between these ions and others in the waters could not be found. The relation between the water temperature and Cl ion content is shown in Fig. 9. On viewing the whole tendency, the higher the water temperature is, the more Cl ion is contained in the waters, but the relation between them is not so clear owing to the difference in cooling of the water temperature on the way passing through the underground.

4. Hydrothermal system in Yufuin

From the distributions of above mentioned ions and the correlations among them, it is inferred that the thermal water flowing out from the wells in this region are supplied from two original hydrothermal waters diluting with surface ground waters. One is suppling to the thermal waters in Ishimatsu area where there are the boiling springs at high temperature and the flowing wells having high temperature and large quantity of discharge. This original hydrothermal water are rich in Li, Na and Cl ions and the water temperature under the ground is higher than 100°C. The wells in Ishimatsu area are the highest

ground in all wells of this region. Accordingly, the pressure head of the thermal waters in this area are remarkable hight compared with those of the other thermal waters. Suzuki [1937] found the geotectonic line near-by the nouthern side of this area of which the stricke is N. 68° E.. It is probable that this fault has an impotant role for isolating the communication between both hydrothermal waters and the pass of the hydrothermal water flowing out through the underground in Ishimatsu area.

The chemical chracters of the boiling springs in Yufuin and in Beppu (Yamashita [1965]) are shown in Table 2.

Table 2. Chemical compositions of the boiling spring waters in Yufuin and in Beppu (weight ratio)

Localty	Cl(mg/l)	Na/Cl	Li/Cl	K/Cl	Ca/Cl	SO_4/Cl	Mg/Ca
Yufuin	272	1.00	4.0×10^{-3}	0.08	0.047	0.29	0.037
Beppu	1540	0.65	4.5×10^{-3}	0.078	0.024	0.117	0.11

In comparison the chemical characters of the boiling springs in Yufuin with those in Beppu, the concentration of the chemical constituents of the waters in Beppu is remarkably higher than that in Yufuin, but the cemical compositions of the waters in both regions have the same characters. Especially, Li/Cl ratio is remarkably greater than those of river water in Yufuin (2.1×10^{-3}), surface ground water (1.5×10^{-3}) and the thermal water in the other areas (2.2×10^{-3}).

From the correlations among above mentioned ions as will be seen in Figs. 5, 6, 7 and 8, the ground waters mixing with the original hydrothermal water are remarkable different with the surface ground water, and it is inferred that the mixed waters have the same nature as the thermal waters flowing out at the other areas.

With regard to the thermal water in all areas without Ishimatsu area, a thermal water at low temperature contains the chemical elements with low concentration, accordingly, the lower the water temperature is, the more the constituent of the thermal water approaches to that of surface ground water. Therefore, these thermal waters are supplied from the original hydrothermal water with high concentrations of Na, Cl and HCO_3 ions diluting with surface ground waters. The value of Li/Cl ratio of the original hydrothermal water is estimated at 2.2×10^{-3}, and this value is approximately equal to that of river water and considerable small compared with the original hydrothermal water in Ishimatsu area (see Table 2). From these facts, it may be suggested that both original hydrothermal waters have different physical and chemical conditions into the generative process of the waters under the ground respectively.

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