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Thermal Waters and Hydrothermal Activities in Arima Hotspring Area, Hyogo Prefecture

by

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Abstract

In addition to the remarkably high concentration of Cl^-, the occurrence of hotspring gases containing H_2 and sulphide minerals such as galena and zincblende from core samples are unexampled in the other hotsprings in Japan. The present thermal waters may be the residue of magmatic water derived from the volcanic activity of Tertiary liparite, and seem to reveal the genetic conditions of some kinds of epithermal ore deposits and the properties of ore depositing hydrothermal solution.

Introduction

The hotspring "Arima" in Kobe city, Hyogo prefecture situated on the southern foot of Rokko-zan is one of the famous bathing hotsprings in Japan.

Hotsprings of Arima are characterized by remarkably high content of alkali halides (Ikeda, 1949), by strong radioactivity (Nakai, 1938) and by high temperature of thermal waters. The hotspring area consists of Tertiary liparite (Ueji, 1954), and is located on the outside of Quaternary volcanic zones. Referring to the genesis of the hotsprings of Arima, the anomalies of haloid content and water temperature suggest that the hotsprings were formed under some confined condition. Rock alteration and distribution of thermal waters are, also, considered to present characteristic features connected with the hydrothermal activities.

In this paper, the writers describe the geology of the hotspring area and chemical properties of thermal waters and gases. On the basis of characteristic hydrothermal activities in this area, the genesis of hotspring in Arima is discussed and it is pointed out that the thermal waters of Arima are Tertiary igneous origin, and have a possibility to be analogous to a highly concentrated magmatic solution by which some epithermal ore deposits would be made.

Geology of the hotspring area

The area of thermal water issue consists of Tertiary liparite bounded on the north of Arima with Mesozoic granite by a reverse fault named Rokko thrust which runs about 20 km along the northeastern foot of Rokko-zan, and is overlain by the Tertiary formation consisting of sandstone and conglomerate, and younger fan deposits.

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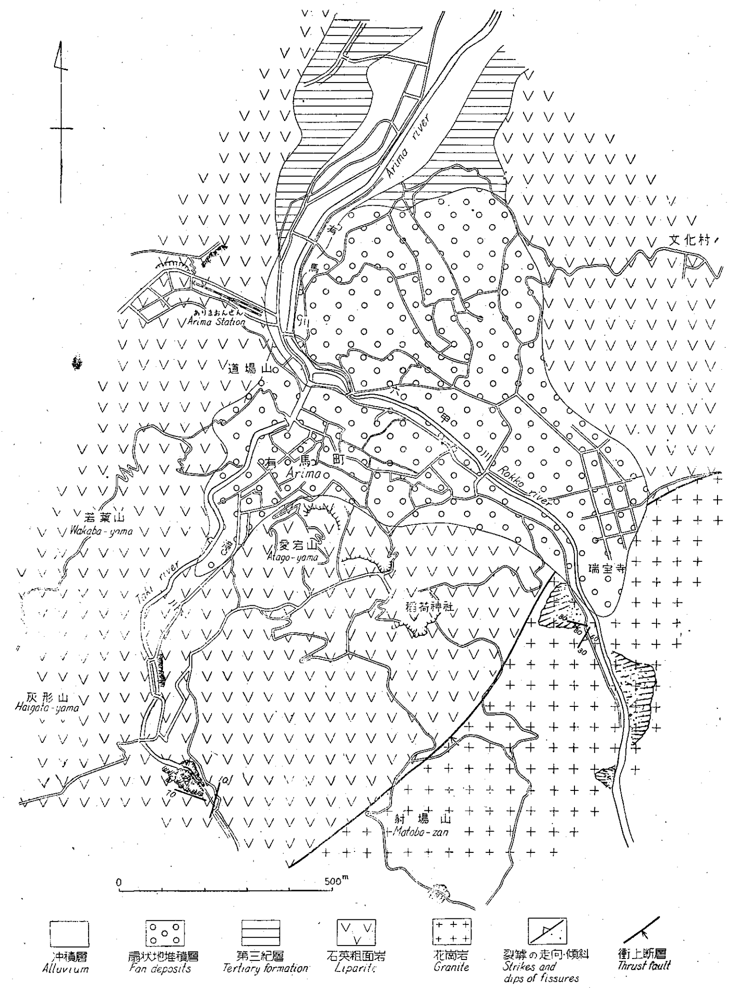

Fig. 1 Geological map of Arima hotspring area

Table 1 Analysis of Altered Liparite Collected from Coldspring Area, in Volume Percent

SiO_2 (%)	TiO_2 (%)	Al_2O_3 (%)	Fe_2O_3 (%)	MnO (%)	MgO (%)	CaO (%)	Na_2O (%)	K_2O (%)	SO_3 (%)	$+H_2O$ (%)	Total (%)
44.98	0.27	20.13	0.55	0.00	0.12	0.13	0.37	5.22	19.96	7.81	99.54

(Fig. 1). Fissures and cracks of rocks seen along the Taki river and Rokko river are predominated in the directions N 10°E and N 70°W.

The trend of altered rock areas by hydrothermal action elongates toward N10°E. The chemical composition of the altered rocks collected near Ari-Jigoku (mofette) are shown in Table 1. According to this table, the altered products are com posed of quartz and alunite formed under acidic condition as in the oxidized zone of fumarolic areas. The fact that not only liparite but fan deposits are also altered suggests that the thermal activity on the surfacebegan after fan deposition. Therefore, it seems possible that crustal movements, which occurred repeatedly since the beginning of Rokko thrust, made fissures and cracks in the liparite through which emanations ascended to the surface, after fan deposition. From these matters, as to the heat source of hotsprings of Arima, two different origins can be considered; one is the volcanism relating to the Tertiary Setouchi volcanic zone, the other is the vol canic activity of the Tertiary liparite widely distributed in this area. Referring to this problem, the facts that chemical properties of the thermal waters of Arima are resemble to some mineral waters issued from the liparite or granite areas near Arima, besides to igneous saline waters which occur from Tertiary volcanic or plutonic area in another regions, while there are not any outcrops of Setouchi volcanic rocks and any geothermal evidences, derived from its volcanism, suggest that the origin of the hotsprings of Arima is related to the volcanic activity of the liparite.

Distribution of mineral springs

There are two types of mineral springs in Arima; one is thermal springs con-

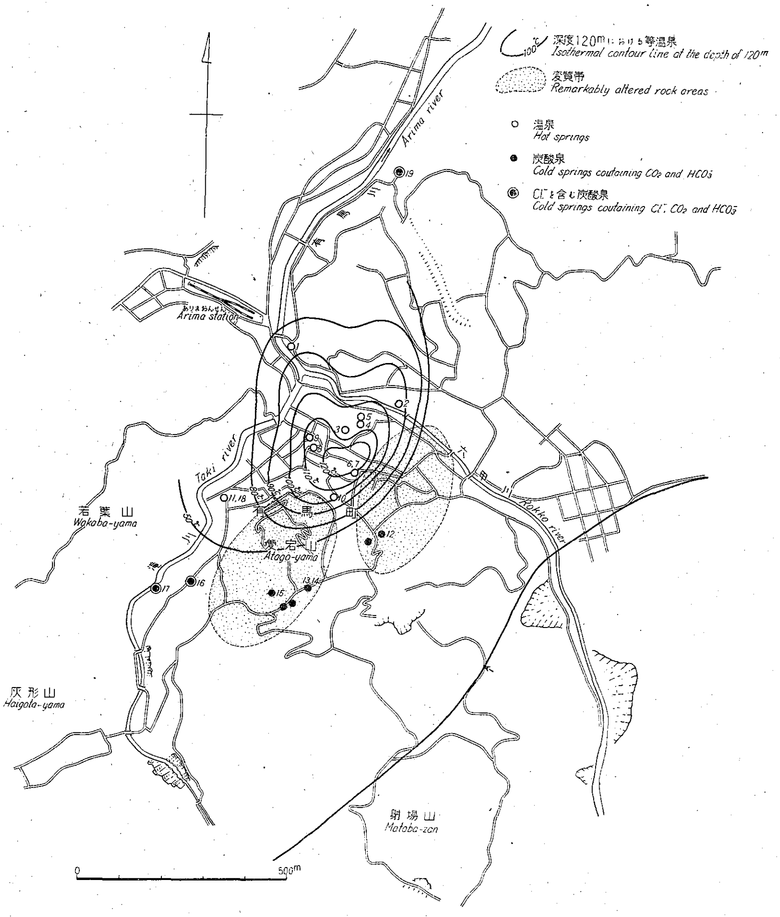

Fig. 2 Distribution map of isothermal contour lines at the depth of 120 m and altered-rock areas (after Ueji and Nakamura)

Table 2 Analysis of Mineral Springs in Arima,

	Temp.	pH	Free CO_2	HCO_3^-	Cl^-	SO_4^{2-}	H_2S
1. Tamoto-ishi	58	6.6	150	338.6	22,987	2.5	0.0
2. Ikejiri	62	6.6	174	474.3	11,015	tr.	0.0
3. Tenjin	77.5	6.2	133	212.0	23,766	7.0	tr.
4. Ariake No. 1	87.5	6.5	90	244.0	28,300	2.1	tr.
5. Ariake No. 2	83.5	6.3	109	228.8	34,959	tr.	tr.
6. Uwanari	90.5	6.4	119	146.4	33,259	1.0	tr.
7. Uwanari	78	6.2	48	146.4	25,396	1.2	tr.
8. Gosyo	96	6.5	36	195.2	32,515	tr.	tr.
9. Hon-onsen	54	6.1	190	355.4	4,002	18.9	0.0
10. Gokuraku	94	6.5	149	94.6	39,953	tr.	tr.
11. Gekko-en	48	6.5	101	536.8	12,644	4.5	0.0
12. Tansan Hotel	17	4.7	928	73.2	8.0	6.6	—
13. Sakae	20	5.1	1,520	173.9	52.3	<0.1	—
14. 〃	16	5.1	227	48.8	18.6	1.6	—
15. Sugi	16	4.4	1,063	30.5	11.5	22.2	—
16. Morishita-Jintan-ryō	16.5	5.3	639	176.9	2,609	4.1	—
17. Daihatsu-ryō	13	5.3	866	237.9	3,095	2.5	—
18. Gekko-en	16	6.7	—	176.9	716.3	4.1	—
19. Kokutetsu-ryō	16	5.9	61	76.3	924.1	4.1	—
20. Kōsenkaku	16.5	5.1	92	30.5	20.4	4.9	—
21. Thermal spring located on upper stream of Rokko river	27	6.8	15	186.1	367.0	0.8	—
22. 〃	25	7.0	10	149.5	296.1	0.8	—
23. 〃	19	6.8	5	67.1	65.6	1.6	—
24. Gosha	33	6.4	139	561.2	1,730	1.6	—
25. Takarazuka	19.5	6.6	701	2,842	15,457	0.8	—
26. 〃	19	6.4	835	3,794	15,613	0.8	—

taining high content of alkali halide, the other is cold mineral springs accompanied with carbonic acid gases. The former issues from the center of thermal area situ ated on the low ground, while the latter places on the slope occupying the southern outside thermal area. The trend of the thermal areas takes the direction of N 10°E parallel to that of fissures developed in liparite. The distribution of the mineral springs is shown in Fig. 2.

in mg per liter

Br^-	I^-	Al^{3+}	Total Fe	Mn^{2+}	Mg^{2+}	Ca^{2+}	Na^+	K^+	H_2SiO_3	HBO_2	T. S. M.
42.36	<0.01	3.2	96.1	20.8	35.8	2,292	11,160	1,880	70.2	259.8	40,172
20.51	<0.01	5.3	152.6	11.1	15.3	899	5,880	1,080	78.0	151.6	19,630
43.42	<0.01	5.3	50.1	36.1	17.9	2,475	11,070	2,440	72.0	303.3	41,180
51.42	<0.01	4.2	166.7	44.5	23.2	2,953	13,700	2,620	94.0	363.5	48,780
64.02	<0.01	4.2	206.2	55.6	28.0	3,716	16,840	3,300	118.0	454.9	60,794
60.82	<0.01	12.7	186.5	61.1	24.0	3,533	16,200	3,160	90.0	428.2	57,376
46.62	<0.01	7.4	132.8	45.8	17.9	2,638	12,640	2,260	78.0	330.0	44,018
59.41	<0.01	4.2	166.7	45.8	24.5	3,345	15,800	3,160	88.0	403.6	56,796
7.19	<0.01	4.2	28.3	8.3	3.1	279	2,380	445	60.0	91.4	7,404
72.99	<0.01	4.2	197.8	66.7	27.5	4,214	20,000	3,800	120.0	518.5	70,420
23.58	<0.01	3.2	tr.	11.1	31.9	1,621	6,500	920	74.0	120.4	22,224
0.16	0.00	1.6	5.5	0.3	0.9	13.9	11.4	1.7	46.8	—	163
0.56	0.00	2.7	5.5	0.5	2.0	34.8	47.2	5.2	70.2	15.6	333
0.90	0.00	<0.1	<0.1	0.0	0.8	8.9	15.4	1.1	19.5		123
—	—	0.6	4.2	0.1	0.7	5.9	13	2.7	23.4	2.2	160
5.06	0.00	3.8	16.6	6.5	6.1	301.9	1,387	242.5	119.6	31.2	5,098
6.05	0.00	7.1	24.9	10.8	10.3	464.7	1,562	238.7	126.1	44.6	6,227
1.63	0.00	3.4	24.9	0.3	6.8	121.6	390	37.5	29.9	7.8	1,685
1.94	0.00	<0.1	<0.1	<0.1	6.1	88.4	560	60.0	29.9	17.8	1,873
—	—	<0.1	<0.1	0.0	1.7	9.9	17.5	2.6	20.8	4.9	141
0.82	0.00	<0.1	<0.1	0.0	3.3	57.6	250	61.0	48.1	15.6	836
0.77	0.00	<0.1	<0.1	<0.1	2.6	47.7	230	42.3	48.1	13.4	674
0.37	0.00	<0.1	<0.1	0.0	1.5	18.9	46.2	1.8	14.9	5.6	190
4.42	0.00	<0.1	<0.1	—	19.2	280.5	1,142	132.5	58.5	31.2	3,978
38.57	0.01	12.9	20.8	0.5	83.9	802.3	9,200	970.0	49.4	374.6	29,728
35.70	0.01	46.2	6.9	3.2	50.5	1,660	9,640	1,012.0	75.4	169.5	30,078

Chemical composition of waters and gases

(I) Chemical composition of waters

The chemical compositions of thermal waters and cold mineral waters are shown in Table 2. According to the table, the thermal waters are characterized by high contents of Cl^-, Na^+, K^+, Fe^{2+}, Mn^{2+} and HBO_2. Among the thermal waters, those issuing from the center of the thermal area have a high water temperature above 90°C. The relation of Cl^- to water temperature as seen in Fig. 3, seems to take an equal proportion. It is one of the remarkable facts that the contents of

H_2S and SO_4 are very poor in spite of high concentration of other elements.

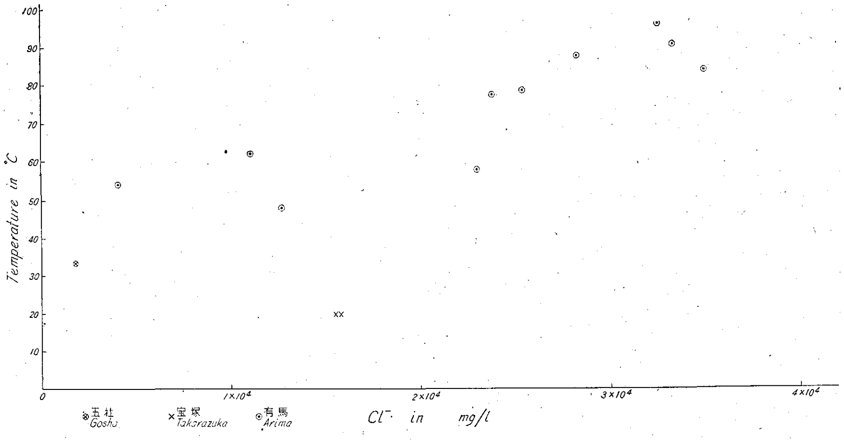

Fig. 3 Relation of Cl^- to temperature

The chemical composition of cold mineral waters, except CO_2 and HCO_3^-, is analogous to that of ground water. Cold springs situated in the outside thermal area have only CO_2, but someone located in the area between the thermal area and outside area are characterized by Cl^-, besides CO_2 and HCO_3^-. This group is regarded as the mixed type of thermal waters and cold mineral waters.

(II) Chemical composition of gases

As to the chemical composition of gases in Arima, any data have not been reported. The writers had a chance to collect hotspring gases emitted from the bore hole of Uwanariyu situated near the center of thermal areas. In addition to the hotspring gases, gases from the cold springs had been collected.

The chemical composition of gases is shown in Table 3. It is notable facts that hotspring gases in Arima contain H_2 above 50%, which are not familiar with usual hotsprings, although they occur from some typical volcanic hotsprings (White, 1957). The existence of H_2 gas suggests that the thermal waters in Arima hold the original property of magmatic water.

Table 3 Analysis of Gases from Arima Hotspring Area, in Volume Percent

	CO_2 (%)	O_2 (%)	H_2 (%)	A, N_2 (%)
Uwanari (hotspring)	46.70	0.40	51.40	1.50
Tansansen (coldspring)	98.61	0.28	0.00	1.11

Data obtained from drilling

(I) Bottom temperature of bore holes

The water temperature of hotsprings in Arima before drilling was a little higher than 40°C. By drilling since 1942, thermal waters with boiling point in temperature have been issued. According to the data of Dr. Ueji, the maximum bottom temperature of holes measured during drilling reached to 133°C in the depth of 168 m at Uwanari-yu (Ueji, 1957). Fig. 2 is the distribution map of isothermal contour line at the depth of 120 m and altered rock areas. The figure shows the relation between the hydrothermal activity and rock alteration.

(II) Minerals discovered from the core samples

The writers discovered some pieces of core samples kept in Arima Civil Engineering Office. The samples are those from Ariake-yu, Gosho-yu, Gokuraku-yu and Uwanari-yu. They consist of altered liparite, and have sulphide and carbonate minerals. It is attractive to notice that the minerals are composed of galena, zincblende and siderite, besides pyrite and calcite. Galena and zincblende occur from deeper parts, while siderite grows in the druses near the surface. According to Table 4 which shows the chemical composition of core samples from Ariake-yu, it is

Table 4 Analysis of Core Sample Collected from Bore-hole of Ariake-yu, in Volume Percent

Ag (%)	Cu (%)	Pb (%)	Zn (%)	Fe (%)	S (%)	U_3O_8 (%)	CO_2 (%)	Cl^- (%)
0.104	0.01	2.85	2.08	4.58	4.57	0.001	0.51	0.01

recognized that the samples occurred from the main thermal area have not only Pb, Zn, Fe but Ag and U. It is one of the most important problems relating to the genesis of hotsprings in Arima whether the mineralization in this area has a direct relation with the present thermal waters or not. The known ore deposit near Arima hotspring area is only an old adit of copper mine located in the neighbourhood of Arimaguchi station at a distance of 2.5 km from Arima. Judging from the relation that the thermal area fairly coincides with the mineralized area, the minerals discovered from the core samples seem to be related to the thermal waters of Arima.

Relation of thermal waters and cold mineral waters

The chemical property of thermal waters as seen in Table 2 is characterized by high content of Cl^-. On the other hand, cold mineral waters contain CO_2 and HCO_3^-.

According to the continual analyses of the thermal waters made by Dr. Miyake and others (Miyake, 1949), it becomes clear that Cl^- content in the thermal waters takes a reverse proportion to that of HCO_3^-.

This implies the fact that the thermal waters are diluted by cold ground water containing CO_2 gas. The source of CO_2 must be derived from confined thermal waters accompanied with CO_2 and H_2. In general, the thermal waters in Arima have a tendency to decrease the content of Cl^- for a few years after drilling. Temperatures of the thermal waters are lowered, too. This is due to the agency of the ground waters containing CO_2 which act to the iron casing pipes of the bore holes, corrode the pipes to make leaking and mixing with the thermal waters in the pipes through the leakes. Judging from the relation between Cl^- and HCO_3^-, it seems that the thermal waters have no direct connection with shallow ground water under the confined condition.

Some considerations on the genesis of hotsprings in Arima

The hotspring "Arima" is situated on the Tertiary liparite area occupying the outside of Quaternary volcanic zones. However, the content of Cl^- is abnormally high as compared with the other hotsprings. For example, the highest content of Cl^- in the Quaternary volcanic hotsprings is 3. 4 g/l in Manza, Gumma prefecture or 3. 1 g/l in Tamagawa, Akita prefecture, while the thermal waters of Arima have

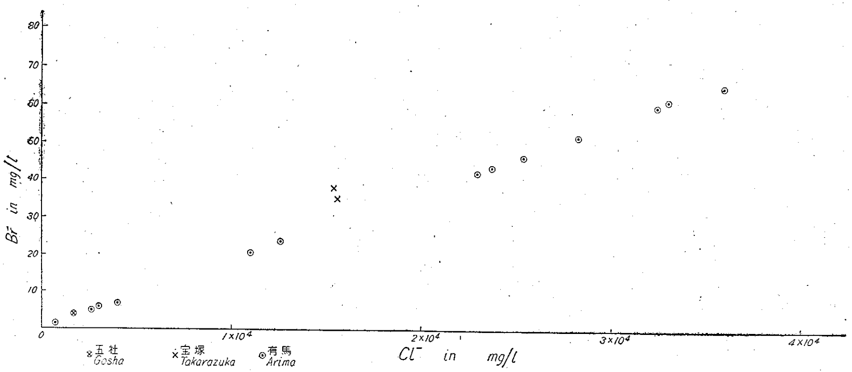

Fig. 4 Relation of Cl^- to Br^-

40 g/l which is more than twice content of sea water (Nakamura, 1959).

The reason that Cl^- of Arima is regarded as igneous origin is due to the fact that the ratio of Br^- to Cl^- takes a small value such as 0. 18, as shown in Fig. 4. The range from 0. 1 to 0. 23 is common to the thermal waters of volcanic origin in Japan.

In addition to the remarkably high concentration of Cl^-, the occurrence of hotspring gases, containing H_2 and sulphide minerals such as galena and zincblende from core samples, are unexampled in the other hotsprings in Japan. These specialities on hotsprings of Arima seem to connect with condensation and concentration of magmatic volatiles separated from liparite.

Then, it is suggestive that a high salinity of the thermal waters resulted from the condensation of magmatic volatiles confined in the cracks of country rocks and perhaps this magmatic volatiles did not contact with the ground water which percolated to greater depth as in the case of the Quaternary volcanic hotspring areas. The rock alteration may be due to the hydrothermal activity of the condensed magmatic volatiles, especially when the volatiles had been released from a condition of high pressure to a lower one along fractures formed by the crustal movement.

Although the mechanism forming minerals is not clear, sulphide and carbonate minerals may have precipitated from the concentrated magmatic solution. The present thermal waters of Arima may be the residue of this magmatic solution. The characteristics of the hydrothermal activities and the thermal waters in Arima hotspring area seem to reveal the genetic conditions of some kinds of epithermal ore deposits and the properties of ore depositing hydrothermal solution.

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兵庫県有馬温泉の温泉水とその熱水活動

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要　旨

兵庫県有馬温泉は，第三紀石英粗面岩から湧出する温泉で，きわめて高い塩分含量で特徴づけられる。これらの食塩泉の外側には炭酸泉が存在するが，これらの炭酸泉がいずれも変質帯上に位置することは，熱水活動と温泉・炭酸泉との関係を暗示するものとして注目を引く。

食塩泉から発散する温泉ガスの中に，50%以上の水素ガスが検出され，また，温泉存在地域内のボーリングのコーアの中に，方鉛鉱・閃亜鉛鉱等の金属硫化物がみいだされる。これらの金属硫化物の生成は，現在の温泉と成因的な関係があると考えられる。このように，食塩泉の Cl^- が海水の2倍以上という高い値をとり，しかも Cl^- の根源が火成源と考えられること，温泉ガス中に水素ガスを含むこと，硫化物の沈殿を伴なうこと等から判断して，有馬の食塩泉は，岩漿水に近い性質を保持し，同時にある種の浅熱水性鉱床の生成に関連ある鉱液の性質を示しているように思われる。