温泉科学（J. Hot Spring Sci.），61，88-96（2011）

原　　著

Geochemical Study on Hot Spring Waters in the Northern Satsuma Area, Kagoshima Prefecture

Hiroo ISAGAI[1)]

(Received Dec. 9, 2010, Accepted Aug. 10, 2011)

鹿児島県北薩地域における温泉水の地球化学的研究

飯　盛　啓　生[1)]

要　　旨

桜島や霧島地域を含む鹿児島県の大部分はいわゆるシラスに覆われているが，鹿児島県北部（北薩地域）は広い範囲にわたって四万十層が分布している．そこでは，四万十層が露出している地域とシラスに覆われている地域が存在する．また，一部では安山岩や花崗岩が貫入している場所もある．

本研究では，北薩地域に湧出する温泉の化学成分について，地質との関連性から検討を行った．その結果，地質によって温泉水の化学成分に違いがみられた．特に，四万十層群から湧出する温泉水の化学成分組成は，ほぼ同じであるのに対し，他の温泉群とは異なっていた．このことから，四万十層群の露出地域から湧出している温泉は他の温泉とは湧出起源が異なることが示唆された．四万十層群以外の温泉はシラスや安山岩などの貫入の影響が推定される．

キーワード：温泉，化学成分，北薩地域，四万十層群

Abstract

The Shimanto Group is distributed across the southern Kyushu, Japan. Most of the Shimanto Group is covered with a pyroclastic flow deposit locally known as Shirasu except for the northern portion of Kagoshima Prefecture (northern Satsuma area). In addition, andesite and granite have intruded in this area.

This study examines the relationship between the characteristics of hot spring water and the geology of the northern Satsuma area. The chemical composition of the hot spring waters in the layers of the Shimanto Group was found to be quite similar each other, but differ from that of the hot springs in other parts of the northern Satsuma area. This suggests that the hot spring waters in the layers of the Shimanto Group have a different gush origin. It is estimated that the chemical components of the most hot spring waters except for those in the Shimanto Group area are influenced by Shirasu and the intrusion of

[1)] Kagoshima University Education Center, 1-21-35, Korimoto, Kagoshima 890-0065, Japan. [1)] 鹿児島大学教育センター　〒890-0065　鹿児島市郡元 1-21-35.

rocks such as andesite.

Key words : Hot spring, Chemical component, Northern Satsuma, Shimanto Group

1. Introduction

Many hot springs are distributed throughout Kagoshima Prefecture in Japan. Hot springs are generally classified as volcanic or non-volcanic. Volcanic hot springs are discharged around an active volcanic area. Many volcanic springs exist in Kagoshima Prefecture because of the presence of active volcanoes (Mt. Kirishima and Mt. Sakurajima). However, some non-volcanic hot springs are also present in this area (Tsuyuki, 1962). Tsuyuki (1992) classified the hot springs near Mt. Kirishima and Mt. Sakurajima as either volcanic or non-volcanic. In the northern Satsuma area, the non-volcanic hot springs are generally older than the volcanic ones. The host rock of non-volcanic hot springs consists of sedimentary rock, granite, and igneous rock of the Shimanto Group (Fig.1). Most of Kagoshima Prefecture is covered by a pyroclastic flow deposit so-called Shirasu, which covers the layers of the Shimanto Group ; however, the surface of the Shimanto Group is exposed in air in the northern portion of Kagoshima Prefecture (the northern Satsuma area). In addition, andesite and granite intrude the northern Satsuma area (Editorial Board of Nihon no Chishitsu, 1992). Some hot springs in this area are discharged from

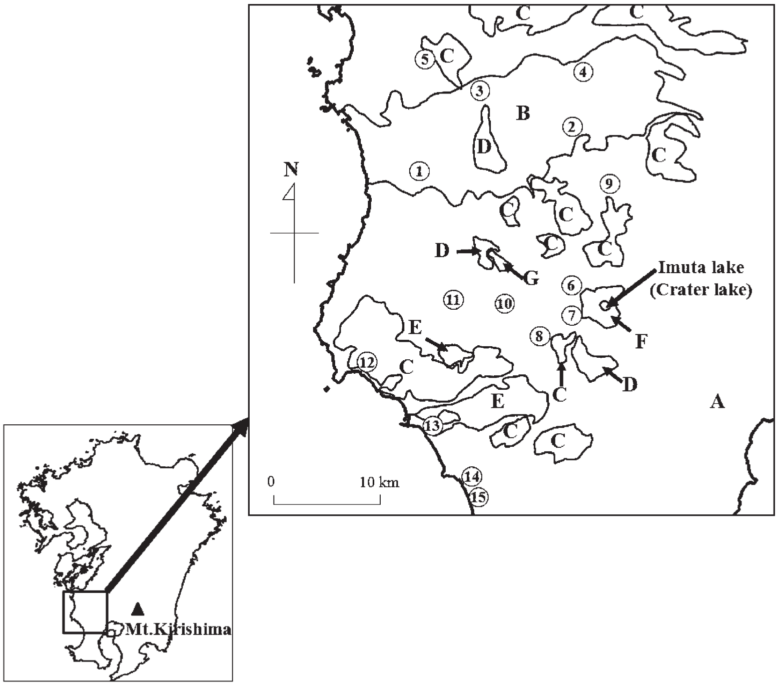

Fig. 1　Sampling points and geology of the northern Satsuma area (A : Shirasu. B : Shimanto Group. C : Pyroxene andesite. D : Granite. E : Rhyolite. F : Hornblende andesite. G : Basalt). ① : Sendai-taki. ② : Shibi. ③ : Yu-kawauchi. ④ : Shiraki-kawauchi. ⑤ : Takaono. ⑥ : Shibagaki. ⑦ : Suwa. ⑧ : Ichihino. ⑨ : Miyanojyou. ⑩ : Tougou. ⑪ : Sendai. ⑫ : Kushikino. ⑬ : Ichiki. ⑭ : Yunomoto-A. ⑮ : Yunomoto-B

the Shimanto Group, whereas others are discharged from layers other than those in the Shimanto Group covered by Shirasu.

In this study, hot springs in the northern Satsuma area were divided into three groups : the Shimanto Group area ; the Imuta area, which might be influenced by magma ; and the coastal area. In addition, the relationship between the chemical components of the hot spring waters and the geology of the northern Satsuma area, Japan, was examined to determine the characteristics of the hot springs.

2. Geology of the northern Satsuma area

In the Japanese islands, the area north of the Butsuzo Tectonic Line is called the Shimanto Belt. It consists of sedimentary rock, granite, and igneous rock (Miyaguchi, 1993). The sedimentary rock from Neogene and Cretaceous in the Shimanto Belt is called the Shimanto Group, and it consists of alternate layers of tuff, sandstone, and shale (Hashimoto, 1962). Shirasu extends over southern Kyushu, and thus most of the Shimanto Group is covered with a thick layer of Shirasu. Hence, the exposed layers of the Shimanto Group are typically not observed. However, the layers of Shimanto Group are exposed in a large portion of the northern Satsuma area. Pyroxene andesite and basalt intrusions appear in the exposed Shimanto Group. The geology of the northern Satsuma area is complicated, and the hot springs are surrounded by various geological features (Fig. 1). These sampling points include most of the hot springs in the northern Satsuma area (Kurokawa, 1997).

3. Experiment

Hot spring water samples were taken in the northern Satsuma area on March 26, 2009 and May 31, 2009 (Fig. 1). Water temperature was measured by an alcohol stem thermometer at the sampling sites. Electric conductivity (EC, calibrated at 25℃) was determined by EC meter (TOA CM-40S ; Tokyo, Japan). The pH was determined by pH meter (TOA-DKK HM-20P ; Tokyo, Japan). The concentrations of Na^+ and K^+ were analyzed using an atomic absorption spectrometer (Shimadzu AA-6200 ; Kyoto, Japan ; C_2H_2/air flame). The concentrations of Ca^{2+} and Mg^{2+} were analyzed by chelate titration using 0.01 M ethylenediaminetetraacetic acid (EDTA) solution. The concentration of SO_4^{2-} was analyzed by turbidimetry, while that of Cl^- was analyzed by colorimetry using a spectrophotometer (HACH DR/4000 ; Loveland, USA). The alkalinity (pH 4.8) was determined by titrating bromocresol green–methyl red (BCG-MR) indicator with 0.02 M H_2SO_4 (Japan Society for Analytical Chemistry, Hokkaido Branch, 1994). The concentrations of HCO_3^- was calculated from data of alkalinity (Pharmaceutical Society of Japan, 1990)

4. Results and discussion

The chemical components of the hot spring waters are listed in Table 1. The water temperature of No. 3 was the lowest (32.5℃), whereas that of No. 10 was the highest (59.9℃).

Table 1　Physicochemical properties and chemical components of hot spring waters in the northern Satsuma area (Group I : Nos. 1–5. Group II : Nos. 6–11. Group III : Nos. 12–15)

Group	Sample	Name of hot spring	Sampling Date	Water temperature (℃)	pH	Electric Conductivity (μS cm^{-1})	Ca^{2+} (mg dm^{-3})	Mg^{2+} (mg dm^{-3})	Na^{+} (mg dm^{-3})	K^{+} (mg dm^{-3})	HCO_3^{-} (mg dm^{-3})	Cl^{-} (mg dm^{-3})	SO_4^{2-} (mg dm^{-3})
I	1	Sendai-taki	May 30, 2009	42.0	8.87	305	1.60	0.05	94.3	17.5	138	5.94	40.2
	2	Shibi	March 27, 2009	46.0	9.34	372	0.80	0.24	106	1.62	183	39.4	13.6
	3	Yu-kawauchi	May 30, 2009	32.5	9.32	156	1.68	0.44	53.6	0.65	61.0	5.18	24.1
	4	Shiraki-kawauchi	March 26, 2009	41.9	9.14	422	0.64	0.10	94.3	1.80	201	10.7	36.8
	5	Takaono	May 30, 2009	52.0	8.21	761	3.05	1.31	202	3.33	373	80.2	3.60
II	6	Shibagaki	March 27, 2009	43.2	6.18	3440	116	8.50	667	62.2	464	768	294
	7	Suwa	March 26, 2009	45.7	6.24	5710	237	34.0	975	95.2	878	1146	584
	8	Ichihino	March 26, 2009	52.0	9.38	236	2.01	0.24	73.6	1.08	85.4	18.4	17.8
	9	Miyanojyou	May 30, 2009	38.5	7.55	1132	11.2	2.92	276	14.1	500	132	2.40
	10	Tougou	March 26, 2009	59.9	7.56	2060	13.0	6.08	552	23.1	1488	11.7	4.00
	11	Sendai	May 31, 2009	44.5	8.14	356	1.20	0.24	136	11.2	115	62.6	4.00
III	12	Kushikino	May 31, 2009	50.0	7.68	3320	40.7	6.90	644	52.5	256	938	44.9
	13	Ichiki	May 31, 2009	51.0	7.85	3770	36.6	4.28	805	35.0	207	850	562
	14	Yunomoto-A	May 31, 2009	45.0	7.46	225	4.25	1.07	110	8.18	108	12.3	88.5
	15	Yunomoto-B	May 31, 2009	43.0	7.64	463	3.61	0.34	131	8.11	105	41.4	77.8

These hot springs were divided into three groups ; Group I, II and III, according to their geology, and each group was examined.

The chemical components of the hot springs in the northern Satsuma area were plotted in trilinear diagrams (Fig. 2). In the diagram, the presence of cations in all the hot springs was plotted in the $Na^{+}+K^{+}$ region. The anions in the hot springs were plotted in various regions of the trilinear diagram. The anions in the hot springs in Group I (Shimanto Group) were plotted in the region rich in HCO_3^{-}.

In the diagram, no difference was observed in the distribution of the cation plots for the three groups, but the anion plots for Group I were more concentrated than those of the other groups (Fig. 2). The chemical components of the hot springs were plotted in regions C and D and the chemical components of the Shimanto Group were plotted in region C. These diagrams show that the chemical components of the hot springs in Group I differed from those in Groups II and III.

Gram equivalents of $Na^{+}+K^{+}$, Ca^{2+}, Mg^{2+}, Cl^{-}, and SO_4^{2-} and HCO_3^{-} were plotted on a hexa diagram (Fig. 3). The figure shows that the shapes of the plots for the hot springs in the exposed Shimanto Group (Nos. 1, 2, 3, 4, and 5) are almost similar, suggesting that the chemical components of the hot springs discharged from this area are similar, except for No. 5. In Groups II and III, some hot springs are similar to those of Group I, but others are not. It was suggested that the hot springs of Groups II and III originate in the Shimanto Group, but those that are not

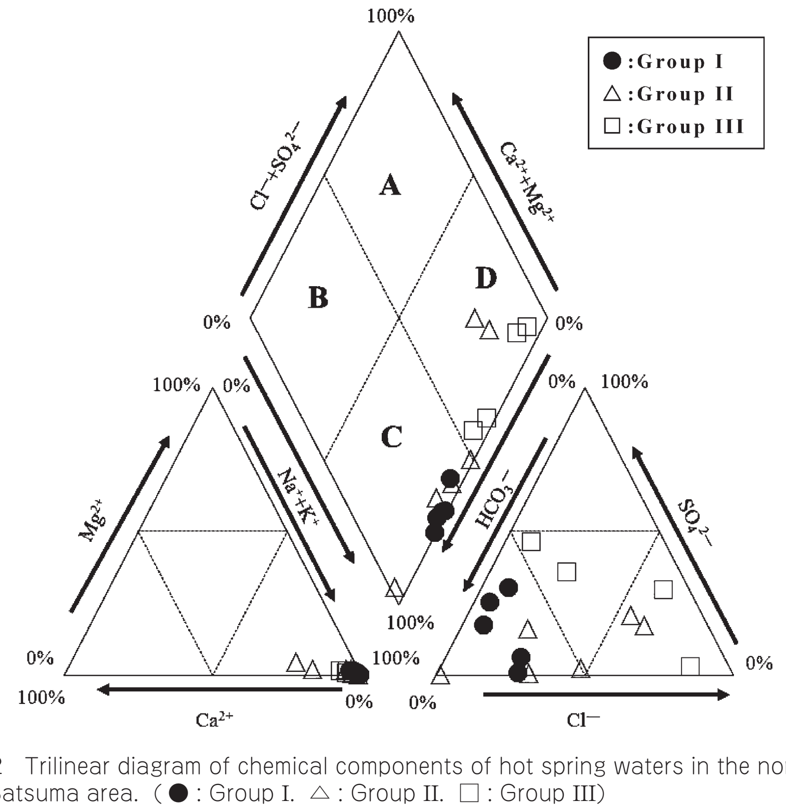

Fig. 2 Trilinear diagram of chemical components of hot spring waters in the northern Satsuma area. (●: Group I. △: Group II. □: Group III)

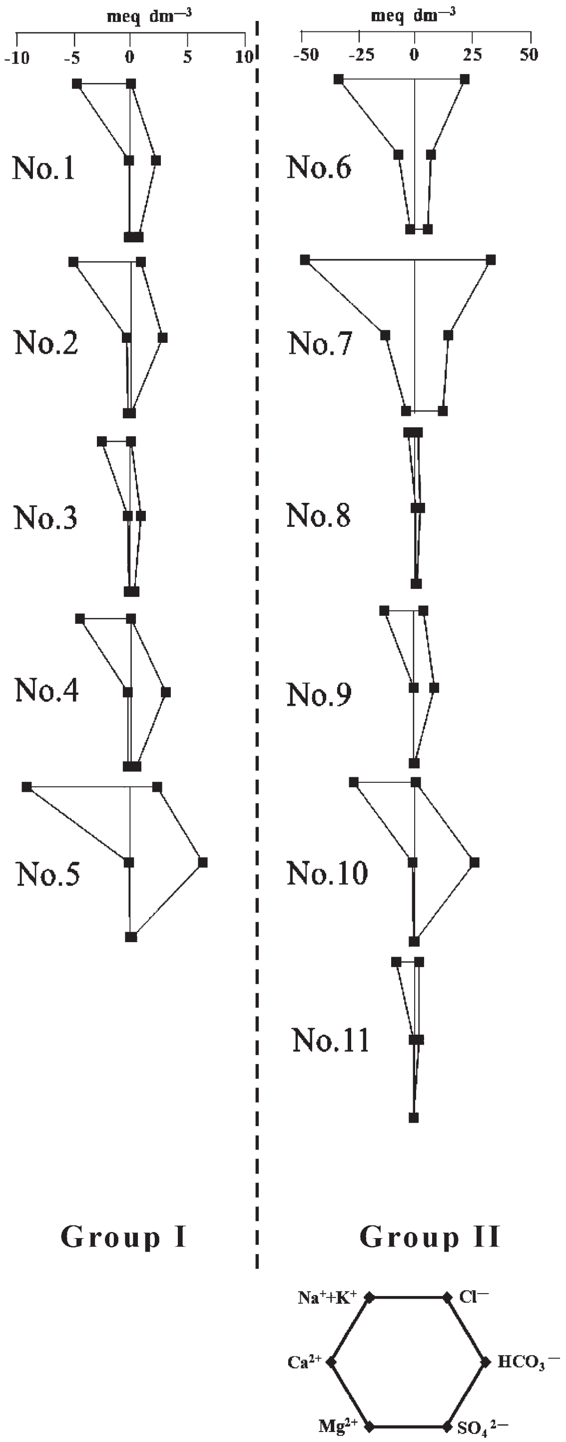

Fig. 3　Hexa diagram of chemical components of hot spring waters of Nos. 1 to 15 in the northern Satsuma area. Group I : Nos. 1–5.　Group II : Nos. 6–11.　Group III : Nos. 12–15.

similar to Group I were influenced by the Shirasu and magma covering the Shimanto Group. The water temperature of most samples was 40–50℃ (Table 1). Because the water from hot spring Nos. 5, 11, 12, and 13 was collected by pumping into a tank, the actual water temperatures were probably higher than those shown in Table 1.

4. 1 Hot springs in exposed Shimanto Group

The hot springs in the exposed Shimanto Group (Group I) comprised Nos. 1–5. The water temperatures of Group I were 32.5–52.0℃ (Table 1). The water temperature of No. 3 was the lowest ; this hot spring was discharged from the bedrock of the Shimanto Group. The thermal origin of hot springs in Group I has been reported to be the subsurface granitic magma of Mt. Shibi (Tuyuki, 1992). The hot springs of Group I are discharged from the host rock in the Shimanto Group. The origin of the waters is considered to be groundwater, which consists of rain water that percolates through the Shimanto Group, and the water is discharged through processes of dissolution, precipitation, and ion exchange. The water temperature of Group I was generally low. This might indicate that the source of these hot springs is shallow and that the geothermal gradient is low. The pH of Group I was somewhat high (8.21–9.34, Table 1). The concentration of HCO_3^- of Group I was lower than that in Group II. The concentration of Mg^{2+} of Group I was less than 1.31 mg/L, which is lower than that of Ca^{2+} in this group (Table 1). The concentrations of HCO_3^-, Ca^{2+}, and Mg^{2+} in No. 5 were the highest in Group I. This suggests that the upper layer around No. 5 was a Holocene sediment layer.

4. 2 Hot springs around Imuta volcano

The hot springs around Imuta volcano (Group II) include Nos. 6–11. Imuta volcano has long been inactive. Andesite from the volcano is found in its vicinity (Kagoshima Prefecture, 1990). It is thought that andesite magma has intruded this area and has not yet cooled. Thus, andesite is thought to be the source of heat for the hot springs of Group II.

EC data suggest that the concentrations of the chemical components of Nos. 6, 7, 9 and 10 were high (Table 1). These observations were similar to those of hot springs in Mt. Kirishima region (Kurokawa *et al.,* 1993).

The concentration of SO_4^{2-} in Nos. 6 and 7 was high (Table 1), suggesting that the weak acidity at these points was influenced by the presence of sulfur oxides. The concentrations of Na^+, HCO_3^-, Cl^- and SO_4^{2-} in Nos. 6 and 7 were high. The fact suggests that these hot spring waters were similar to NaCl and $Na/HCO_3/SO_4$ type of hot springs. The concentration of HCO_3^- was also high in these four hot springs. It has been suggested that this is a result of CO_2 supplied by magma (Iwasaki, 1970). Our results suggest that the water of these hot springs permeates and moves through a geothermal area. The concentrations of chemical components of Nos. 8 and 11 were low. Thus, these hot springs may not be strongly influenced by the volcano.

4. 3 Hot springs around the west coast of Satsuma Peninsula

The hot springs around the west coast of Satsuma Peninsula (Group III) include Nos. 12–15. They are discharged around the coastal area, the geology of which is similar to that of the Shimanto Group. Water from these hot springs was pumped up from holes with a depth of about 1,500 m. The water temperatures of Nos. 12 and 13 hot springs were higher than those in the other hot springs (Table 1). Their heat sources are believed to be the geothermal fluid. EC data indicate that the concentrations of the chemical components of Nos. 12 and 13 were high. These hot springs had higher concentrations of Na^+ and Cl^- than the other hot springs of Group III. The concentration of Ca^{2+} was higher than that of Mg^{2+} (this result was the same as that obtained for Groups I and II). This suggests that Group III was influenced by volcanoes rather than by seawater. The water temperatures and EC of Nos. 14 and 15 were lower than those of the other hot springs of Group III. Hence, they are considered to be influenced by the upper layer of the Shimanto Group rather than by volcanoes.

5. Conclusion

The water temperatures and pH values of the hot springs in the Shimanto Group (Group I, except for No. 5) in the northern Satsuma area were lower and higher, respectively, than those of other hot springs in this area. The Cl^- concentration in these spring waters was low ; therefore, these hot springs were considered to be similar to the $NaHCO_3$ type and not the NaCl type of hot springs. The concentrations of the chemical components of most hot springs in Group I were low. The pH of most of the hot spring waters in Groups II and III was greater than 7, and the concentrations of Na^+, HCO_3^-, and Cl^- were high. Hence, our results suggest that these hot springs are influenced by the reservoir.

Acknowledgments

The author is thankful to reviewers and Dr. G. Inoue for their helpful discussions and suggestions.

References

Editorial Board of Nihon no Chishitsu (1992) : Nihon no Chishitsu (No. 9) “Kyushu Area”, pp. 68–70, Kyoritsu Shuppan, Tokyo (in Japanese).

Hashimoto, Y. (1962) : Geological succession and structure of the undated strata in the Hokusatsu District, Kagoshima Prefecture. Reports on Earth Science, Department of General Education, Kyushu University, **8**, 47–62 (in Japanese).

Iwasaki, I. (1970) : Kazan Kagaku, pp. 20–25, Koudansha, Tokyo (in Japanese).

Japan Society for Analytical Chemistry, Hokkaido Branch (1994) : Mizu no Bunseki, pp. 153–158, Kagakudojin, Tokyo (in Japanese).

Kagoshima Prefecture. (1990) : Kagoshima-ken Chishitsuzu. Tokudaya Shoten, Kagoshima (in Japanese).

Koga, A. (1985) : New geochemical prospecting methods for geothermal sources in water vapour-dominated and non-manifestation fields. The reports of the Research Institute of Industrial Science, Kyushu University, **79**, 69–86 (in Japanese).

Kurokawa, T., Sakamoto, H. and Kobayashi, T. (1993) : Kagoshima-ken no Onsen—Kirishimakazanchiiki no Onsen—. pp. 53–56, Kagoshima Prefecture (in Japanese).

Kurokawa, T. (1997) : Ideyu no Kuni Kagoshima. pp. 89, Shunendo Shuppan, Kagoshima (in Japanese).

Miyaguchi, H. (1993) : Kyushu Shimantotai no Chitaikouzo to Onsen oyobi Chikasuikaihatsu ni tsuite. Chikasui Gijutsu., **35**, 9-16 (in Japanese).

Pharmaceutical Society of Japan. (1990) : Standard Methods of Analysis for Hygienic Chemists—With Commentary—. pp. 1172-1173, Kanehara Shuppan, Tokyo (in Japanese).

Tsuyuki, T. (1962) : Geological studies on the hot springs in the Kyushu District Part IV. Science Reports of Kagoshima University, **11**, 59-72 (in Japanese).

Tsuyuki, T. (1992) : Kyushu ni okeru onsen to chishitsu, pp. 65-66, Tokudaya Shoten, Kagoshima (in Japanese).

(A part of this study was presented at the 62^{nd} Annual Meeting of the Hot Spring Society of Japan on September 8, 2009)