

Geothermal Energy Resources in the Yakedake Volcano, Gifu-Nagano and General Features of Volcanic Activities in Japan

Jun IRIYAMA*

(Received May 31, 1994)

The geothermal energy within the summit dome at an altitude of 2,050 to 2,455 m of the Yakedake volcano (alt., 2,455 m: Gifu-Nagano, Japan) is calculated to be about 5.2×10^{17} J, which represents a thermal power output of $5.5 \times 10^3 \text{ MW}_{\text{th}}$ averaged over 30 yrs. The temperature of solfatara in the northern summit dome at an altitude of 2,240 to 2,270 m ranged from 68.2 to 92.4°C in Oct., 1993. The water sample from a crater pond, Terugaiké, located on the summit, showed pH and electrical conductivity of 4.35 and $42.4 \mu \text{ S/cm}$ in Sept., 1992, respectively, and of 4.38 and $42.2 \mu \text{ S/cm}$ in Oct., 1991, respectively. The temperature of the most active solfatara in the summit dome (alt., 2,440 m) was 119.4° C in Sept., 1992. The general features of volcanic activities in Japan are also analyzed with relation to the utilization of geothermal energy.

I. INTRODUCTION

The study area is in a rugged section of the southern part of the Japan Northern Alps Mountains (Figs. 1 & 2). Yakedake is a volcano with a lava dome, belonging to the Mt. Norikura volcanic zone. The volcano has been in a dormant state since the eruption of June, 1962 to Mar., 1963, whose explosions took place on the northern side of the dome and formed a fissure of several hundred meters in length. However, the fumaroles in the summit dome areas of Yakedake and the parasitic volcano, Iwodake (alt., 2,140 m) are active. The eruption in 1915 created several new craters in the areas of the Shimohorisawa and Nakahorisawa valleys at an altitude of about 1,900 m above sea level, and formed Taishoike pond by damming up the Azusa River with mud flows from the mountainside (Murayama, 1979). The Yakedake dome is made up of Quaternary biotite-bearing hornblende andesite (Iriyama et al., 1981). Yakedake has a crater pond, Terugaiké (alt., 2,350 m) on the summit, which is shown in Fig. 3. The basement comprises Paleozoic sedimentary rocks, Mesozoic volcanic rocks and granite (Kato, 1912). It will be inferred from topography of the volcano that eruptions have taken place continuously for about the last 100,000 years. The hydrothermal activity is intense in the valleys at the western and southeastern feet of the volcano. There are many hot springs, a geyser and at least one travertine terrace formed by the hot water flow along the Gamada, Takahara and Azusa Rivers and

*Department of Natural Sciences - Earth Sciences

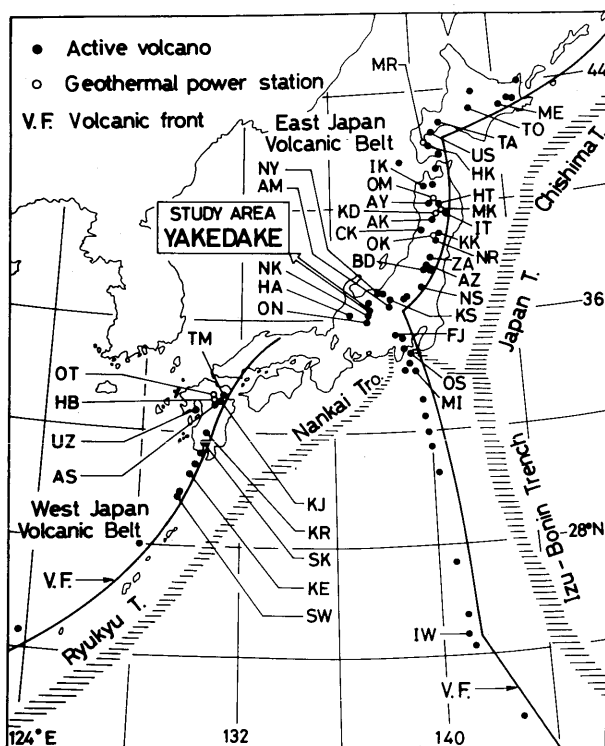


Fig. 1. Distribution of active volcanoes, geothermal power stations, volcanic belts, volcanic fronts, trenches and trough in and around Japanese Islands. Abbreviations : T, Trench; Tro, Trough; ME, Meakan; TO, Tokachi; TA, Tarumae; US, Usu; HK, Komagatake; IK, Iwaki; OM, Ohnuma; AY, Akita-Yakeyama; HT, Hachimantai; MK, Matsukawa; KD, Kakkonda; IT, Iwate; AK, Akita-Komagatake; CK, Chokai; KK, Kurikoma; OK, Onikobe; NR, Naruko; ZA, Zao; AZ, Azuma; BD, Bandai; NS, Nasu; KS, Kusatsu-Shirane; AM, Asama; NY, Niigata-Yakeyama; NK, Norikura; ON, Ontake; HA, Hakusan; FJ, Fuji; OS, Oshima; MI, Miyakejima; IW, Iwojima; TM, Tsurumi; KJ, Kuju; OT, Otake; HB, Hatchobaru; UZ, Unzen; KR, Kirishima; SK, Sakurajima; KE, Kuchinoerabujima; SW, Suwanosejima.

their tributaries, i.e., the Ashiarai, Shiramizu, Abo and Shiratani valleys. The author has classified the geothermal zones according to the rivers, i.e., the Gamada, Takahara and Azusa River geothermal zones (Iriyama, 1983).

The geothermal energy of the Yakedake volcano is calculated in the present paper. The general features of volcanic activities in Japan are also analyzed with relation to the utilization of geothermal energy. Studies of these problems have been performed by the present author (Iriyama, 1981, 1988a&b, 1989, 1990, 1991, 1992).

II. GENERAL FEATURES OF VOLCANIC ACTIVITIES IN JAPAN

There are sixty-seven active volcanoes in Japan (J.M.A., 1984), which correspond to approximately 10% of the total number in the world. Present study will consider thirty-five major active volcanoes from among them (see Table 1 and Fig. 1). As shown in Fig. 1, the active volcanoes of Japan can be classified into two volcanic belts (Sugimura, 1960) : one is the eastern Japan volcanic belt from Hokkaido through

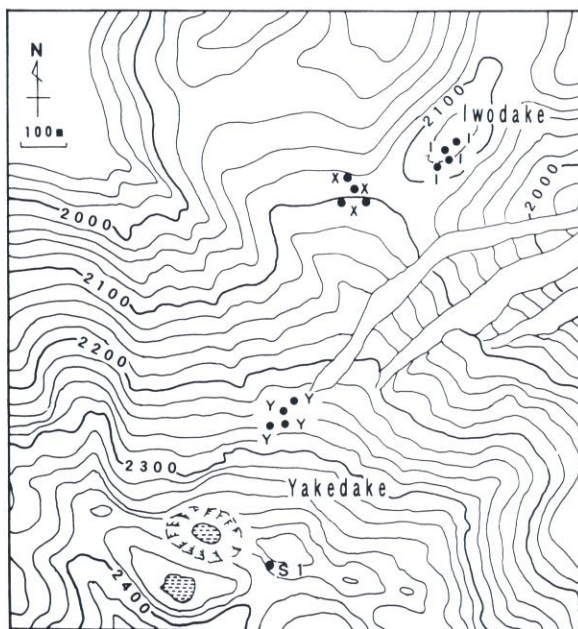


Fig. 2. Locality map of solfatara (S1 & Y) and fumaroles (X & I) studied in the summit dome areas of Yakedake and Iwodake volcanoes. Countours indicate an altitude above sea level in meter.

northeastern and central Japan to the Izu-Ogasawara Islands (i.e., the Chishima, Nasu, Chokai, Fuji and Norikura volcanic zones), the other is the western Japan volcanic belt from Honshu through Kyushu to the Ryukyu Islands (i.e., the Daisen and Kirishima volcanic zones). Many of the active volcanoes have fumarolic activity at the summit or the crater and hydrothermal activity at the foot (i.e., geothermal field). Some of them are related to the geothermal power stations at the foot or in the surrounding area for generation of electricity as an important industrial utilization of geothermal energy. The eruptive, fumarolic and hydrothermal activities and related



Fig. 3. View of the crater pond, Terugaike, of Yakedake from the eastern crater rim in October, 1991.

Table 1. A summary on eruptions, fumarolic activities, geothermal areas, hot springs and related geothermal stations of the main active volcanoes in Japan

Name (alt., m)	Recent ^{1,2} eruption	Fumarolic activity	Geothermal ³ field	Hot ³ springs	Geothermal station
Meakan (1,499m)	1988	○		Akankohan, 64 °C	
Tokachi (2,077m)	1989	○ cr: 356°C ⁴	Tomuraushi	many	
Tarumae (1,041m)	1979	○			
Usu (732m)	1980	○ cr: 737°C ⁵		Toyako, 51°C	
HK-Komagatake (1,131m)	1942	○	Shikabe	many	Mori
Iwaki (1,625m)	1863			Dake, 71°C	
Akita-Yakeyama (1,366m)	1957	○	Tamagawa	many	Ohnuma
Hachimantai (1,613m)		○	Fukenoyu, Toshichi	many	Ohnuma, Matsukawa
Iwate (2,038m)	1719	○ Myokogatake, sl: >360°C ⁶	Matsukawa	many	Matsukawa, Kakkonda
Akita-Komagatake (1,637m)	1971	○ Medake, cr: 490°C ⁷ , 86°C ⁸	Kuroyu	many	Kakkonda
Chokai (2,236m)	1974	○ cr: 52°C ⁹		Yunodai, 29°C	
Kurikoma (1,627m)	1944	○	Sugawa, Komanoyu	many	
Naruko (461m)	837?	○	Naruko	many	Onikobe
Zao (1,841m)	1923	○		Kamoshika, 75°C	
Azuma (2,035m)	1977	○ Jododaira, sl: 62°C ¹⁰		Shintakayu, 56°C	
Bandai (1,819m)	1888	○		Nakanoyu, 65°C	
Nasu (1,915m)	1963	○	Sandogoya	many	
Kusatsu-Shirane (2,171m)	1983	○ Mizugama, cr: 91°C ¹¹	Sesshogawara	Kusatsu	

Table 1 (continued)

Name (alt., m)	Recent ^{1,2} eruption	Fumarolic activity	Geothermal ³ field	Hot ³ springs	Geothermal station
Asama (2,568m)	1990	○		Sengataki, 38 °C	
Niigata-Yakeyama (2,400m)	1989	○		Sasakura, 60 °C	
Yakedake (2,455m)	1963	○ su: 119 °C, do: 93 °C ¹²	Nakanoyu, Shinhotaka	many	
Norikura (3,026m)				Shirahone, 49 °C	
Ontake (3,067m)	1991	○ Kengamine, cr: 145 °C ¹³		Nigorigo, 47 °C ¹⁴	
Hakusan (2,702m)	1579	○ Jigokudani	Oshirakawa		
Fuji (3,776m)	1707	○			
Izu-Oshima (764m)	1990	○ Miharayama, cr: 542 °C ¹⁵			
Miyakejima (813m)	1983	○ Oyama, cc: 910 °C ¹⁶			
Iwojima (161m)	1982	○	Chidorigahara		
Tsurumi (1,375m)	867	○	Myoban, Kannawa	many	Suginoi H.
Kuju (1,791m)	1742	○ Iwoyama, cr: 269 °C ¹⁷	Otake	many	Hatchobaru, Otake
Aso (1,592m)	present	○	Jigoku, Yunotani	many	
Unzen (1,359m)	present	○ Fugendake, cr: 772 °C ¹⁸		Obama	
Kirishima (1,700m)	1991	○ Iwoyama, sl: 174 °C ¹⁹	Tearai, Yunono	many	Kirishima Kokusai H.
Sakurajima (1,117m)	present	○ Minamidake, cr: >760 °C ²⁰		Furusato, 52 °C	
Kuchinoerabujima (657m)	1980	○		Nishiura, 67 °C	
Suwanosejima (799m)	present	○		Fukuseisi	

sl: slope, do: dome, su: summit, cr: crater, cc: cinder cone, HK: Hokkaido

References: 1) Nat. Astron. Obs., 1993 2) J.M.A., 1986 3) Yuhara, 1974 4) Hirabayashi et. al., 1990 5) Sugoshi and Maekawa, 1981 6) Noguchi et. al., 1961 7) Suwa et. al., 1971 8) Kitsunozaki and Kikuchi, 1988 9) Ui and Shirabayashi, 1975 10) Kagiya and Hagiwara, 1980 11) Hirabayashi, 1988 12) Present study 13) Osaka et. al., 1983 14) Yamada, 1982 15) Ehara, et. al., 1975 16) Hirabayashi et. al., 1984 17) Ehara et. al., 1981 18) Joint Univ. Res. Gr., 1992 19) Kagiya et. al., 1979 20) Kamo et. al., 1977.

geothermal power stations of these volcanoes are summarized in Table 1. Data on geothermal field and hot springs in this table are mainly taken from Yuhara (1974). The accumulated information in this table indicates that the volcanoes which are related to geothermal power stations have common characteristics as follows: 1) fumarolic activity at the summit or the crater, 2) geothermal field and many hot springs at the foot or on the slope, 3) eruptive activity from the ninth to the twentieth century and 4) altitude higher than about five hundred meters above sea level.

III. SUMMIT DOME AREAS

Yakedake

The temperature of the most active solfatara (Fig.4: S1 in Fig. 2; alt., 2,445m) in



Fig. 4. View of the most active solfatara in the Yakedake summit dome in October, 1991.

the summit crater was 119.4°C in Sep., 1992. When Sugiura and Mizutani (1978) measured the solfatara temperatures in 1976 and 1977, these were 117° and 127°C, respectively. The boiling point of water at an altitude of 2,445m is about 92.1°C. Other solfatara are found within a dry valley from the crater rim in the northern summit dome at an altitude of 2,240 to 2,270 m. Sublimation of sulfur around these solfatara is observed there. Their localities and general topography in the study area are shown in Fig. 2. Variations of measured temperature of the solfatara over time since Sept., 1987 are listed in table 2. The temperatures of five solfatara ranged from 71.3 to 92.6°C in Sept., 1992. The boiling point of water at an altitude of 2,250 m is about 92.4°

Table 2 . Measured temperatures (°C) of the Yakedake's solfatara as a function of time

Solfa.	Oct. 12, 1993	Sep. 14, 1992	Sep. 29, 1991	Sep. 23, 1990	Oct. 9, 1989	Oct. 9, 1988	Sep. 14, 1987
Y 1	68.8	77.0	76.0	78.8	77.2	80.2	79.3
Y 2	68.2	76.3	74.9	69.9	73.5	70.5	67.9
Y 3		92.6	92.7	92.5	92.8	92.6	92.7
Y 4	92.4	92.6	92.6	92.4	92.7	92.7	92.7
Y 5		71.3	67.1	65.4	63.6	66.9	68.8

C. The water sample from a crater pond, Terugaike, on the summit showed pH and electrical conductivity (E.C.) of 4.35 and $42.4 \mu\text{S}/\text{cm}$ in Sep., 1992, respectively, and of 4.38 and $42.2 \mu\text{S}/\text{cm}$ in Oct., 1991, respectively. When Ossaka (1961) measured these values in the water from the same pond in 1960, pH and EC were 3.7 and $80.8 \mu\text{S}/\text{cm}$, respectively. In the water from the Terugaike pond in Oct., 1991, the amount of SO_4^{2-} , Cl^- and NO_3^- was 11.25, 0.32 and 0.09 mg/l, respectively, at the present study using Ion Chromatograph TOA: ICA-3000. F^- , NO_2^- and Br^- were not detected from the water. For the cation the amount of Ca^{2+} , Na^+ , K^+ , Mg^{2+} , NH_4^+ and Li^+ was 1.71, 0.65, 0.31, 0.23, 0.02 and 0.0003 mg/l, respectively. Ossaka (1961) obtained 29.6 mg/l of SO_4 in the water from the same pond in 1960.

Taking into account the results of present temperature measurements and high geothermal gradient of the volcano (Yuhara and Iriyama, 1986; Iriyama, 1988a&b, 1989, 1990, 1991, 1992; present study), the geothermal gradient in the dome is assumed to be about $2.5^\circ\text{C}/\text{m}$ at a depth between 0 and 300 m. Thus one can assume the temperature difference of $\delta T = 600$ deg between the inside and outside of the dome at an altitude of 2,050 to 2,455 m. An altitude of 2,050 m indicates the lower limit of fumarolic activity on the dome. Given this temperature difference, for the specific heat and density of andesite, respectively, of $C_p = 1.1 \times 10^3 \text{J}/\text{kg} \cdot ^\circ\text{C}$ and $\rho = 2.6 \times 10^3 \text{kg}/\text{m}^3$ and the dome volume of $V = 3.0 \times 10^8 \text{m}^3$, the geothermal energy G_{th} within the summit lava dome is calculated to be $5.2 \times 10^{17} \text{J}$, which represents a thermal power output of $5.5 \times 10^2 \text{MW}_{\text{th}}$ averaged over 30 yrs.

Iwodake

The Iwodake summit lava dome consists of Quaternary hornblende andesite (Iriyama et. al., 1981). Many fumaroles are found at the bottom of the large stones on the southern dome at an altitude of 2,110 to 2,140 m as shown in Fig. 5. Some fumaroles appear in small cylindrical holes in the ground. Steam is discharged mainly from these holes, apertures and so on. Variations of measured temperatures of the fumaroles over time since Sept., 1987 are listed in Table 3. The temperatures of eleven

Table 3. Measured temperatures ($^\circ\text{C}$) of the Iwodake's fumaroles as a function of time

Fumar.	Sep. 14 & 15, 1992	Sep. 29 & 30, 1991	Sep. 23, 1990	Oct. 9, 1989	Oct. 10, 1988	Sep. 14, 1987
I 1	48.2	46.9	46.4	46.4	47.1	48.6
I 2	49.1	48.1	49.8	47.9	51.8	52.8
I 3	60.1	58.3	58.7	60.1	61.8	58.0
I 4	60.2	59.2	59.6	59.4	61.2	59.2
I 5	58.7	58.1	57.0	59.8	61.0	56.3
I 6	43.4	41.0	41.7	40.3	42.8	40.1
I 7	60.9	59.8	61.1	60.3	62.5	61.9
I 8	59.3	61.4	62.3	64.7	59.0	65.4
I 9	60.7	58.1	58.2	58.2	60.5	52.2
I 10	60.8	60.7	59.4	61.2	62.1	60.0
I 11	64.7	62.4	62.2	62.6	63.5	62.5

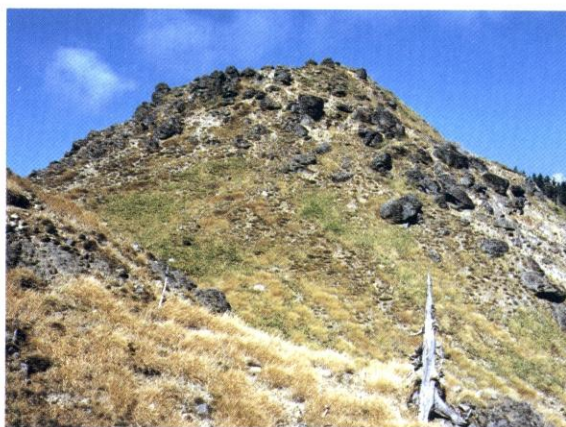


Fig. 5. View of the parasitic volcano, Iwodake, from the northern side of the Yakedake dome in October, 1991.

fumaroles ranged from 39.5 to 61.6°C in Oct., 1993.

By assuming $\delta T = 300$ deg and $V = 2.2 \times 10^5 \text{ m}^3$, the geothermal energy G_{th} within the Iwodake summit dome at an altitude of 2,100 to 2,140 m is calculated to be $1.9 \times 10^{14} \text{ J}$, which represents a thermal power output of 0.20 MW_{th} over 30 yrs.

REFERENCES

- Ehara, S., Yokoyama, I., Shimozuru, D. and Miyazaki, T., 1975. Ground surface temperature distributions of the Miharayama volcano, Izu-Oshima. Rep. Geophys. Geochem. Obs. Miharayama Volcano, Izu-Oshima -July 1974 -, pp. 8-16.
- Ehara, S., Yuhara, K. and Noda, T., 1981. Hydrothermal system and the origin of the volcanic gas of Kuju-Iwoyama volcano, Japan, deduced from heat discharge, water discharge and volcanic gas emission data. Bull. Volcanol. Soc. Jpn., 26: 35-56.
- Hirabayashi, J., 1988. An instruction from the eruption of Kusatsu-Shirane and Kiso-Ontake volcanoes. Bull. Volcanol. Soc. Jpn., 33: 102-104.
- Hirabayashi, J., Osaka, J., Ozawa, T. and Yoshida, M., 1984. Change in chemical composition of volcanic gases and sublimates collected after the 1993 eruption of Miyakejima. Bull. Volcanol. Soc. Jpn., 29; Sp. Issue : s308 -s318.
- Hirabayashi, J., Yoshida, M. and Osaka, J., 1990. Chemistry of volcanic gases from the 62-1 crater of Mt. Tokachi, Hokkaido, Japan. Bull. Volcanol. Soc. Jpn., 35 : 205-212.
- Iriyama, J., 1981. Thermal structure of the Yakedake volcano, Japan : Karukaya and Takara geothermal areas. Jour. Volcanol. Geotherm. Res., 10: 299-308.
- Iriyama, J., 1983. Exploration and development of geothermal energy: A case study of the Yakedake volcano, Gifu-Nagano. I. F. Report (Ishida Foundation Pub.), no. 10, pp. 196-202.
- Iriyama, J., 1988a. Geothermal energy of the Yakedake volcano, Japan. Proc. Kagoshima Int. Conf. on Volcanoes, Kagoshima, Japan, pp. 871-874.
- Iriyama, J., 1988b. Thermal process and geothermal energy in and around the Yakedake volcano, Gifu-Nagano, Japan. Proc. Int. Symp. on Geothermmal Energy, 1988, pp. 102-103.
- Iriyama, J., 1989. Exploration and development of geothermal energy in the Yakedake volcano, Japan: Thermal process and assessment of geothermal resources in the summit dome areas and Gamada River geothermal area. I. F. Report (Ishida Foundation Pub.), no. 16, pp. 482-487.
- Iriyama, J., 1990. Geothermal process and

- energy of the Yakedake volcano, Gifu-Nagano, Japan. Geotherm. Resources Council Trans., 14: 1483-1488.
- Iriyama, J., 1991. Hydrothermal system and thermal process of the Yakedake volcano, Gifu-Nagano, Japan. Geotherm. Resources Council Trans., 15: 19-26.
- Iriyama, J., 1992. Geothermal energy and activity of the Yakedake volcano, Gifu-Nagano, Japan. Geotherm. Resources Council Trans., 16: 233-240.
- Iriyama, J., Suzuki, K., Yamada, T., Kobayashi, Y. and Saito, T., 1981. Thermal structure of the Yakedake volcano, Gifu-Nagano. Geotherm. Res. Soc. Jpn. 1981 Ann. Meeting, Abstr., p. 20.
- Japan Meteorological Agency, 1986. National catalogue of the active volcanoes in Japan. Japan Meteor. Assoc., Tokyo.
- Joint Univ. Res. Gr. (Geochem. Party), 1992. A review on the geochemical observation associated with the volcanic activity of Unzen volcano. Bull. Volcanol. Soc. Jpn., 37: 103-108.
- Kagiya, T., Uhira, K., Watanabe, T., Masutani, F. and Yamaguchi, M., 1979. Geothermal survey of the volcanoes Kirishima. Bull. Earthq. Res. Inst., 54: 187-210.
- Kagiya, T. and Hagiwara, M. 1980., Geothermal survey in and around O-ana crater and Jodo-daira flat, the volcanoes Azuma. Bull. Earthq. Res. Inst., 55: 681-703.
- Kamo, K., Eto, T., Nishi, K. and Ishihara, K., 1977. Observation of high surface temperature anomaly areas by infrared images on Minamidake of the Sakurajima volcano, Japan. Rep. 2nd Joint Obs. Sakurajima Volcano, pp. 34-42.
- Kato, T. 1912. Investigation of eruption and geology of Mt. Iwodake (Yakedake). Rep. Earthq. Invest. Com., no. 75, pp. 1-75.
- Kitsunezaki, C. and Kikuchi, S., 1988. Observation of ground temperature at Akita-Komagatake volcano in 1979 - 1987 and some considerations on the geothermal activity after the 1970 - eruption. Rep. Resoueces Sci. Inst., Mining Fac., Univ. Akita, no. 53, pp. 57-68.
- Murayama, I., 1979. Volcanoes of Japan (II). Taimeido, Tokyo.
- National Astronomical Observatory, 1993. Chronological Scientific Tables. Maruzen Co., Ltd., Tokyo.
- Noguchi, K., Goto, T., Ueno, S. and Ichikuni, M., 1961. Chemical composition of fumaroles gases obtained from volcano Iwate. Bull. Volcanol. Soc. Jpn., 5 : 162-168.
- Ossaka, J. 1961. Some alteration phenomena in the volcanic rocks at the fumaroles, volcano Yakedake, prefectures Nagano-Gifu. Bull. Volcanol. Soc. Jpn., 5: 145-153.
- Ossaka, J., Ozawa, T., Sakai, H. and Hirabayashi, J., 1983. Geochemical study on the volcanic activity of Kiso-Ontake volcano, after the 1979 eruption. Bull. Volcanol. Soc. Jpn., 28: 59-74.
- Shimozuru, D. and Kagiya, T., 1976. Newly devised infra-red radiometer (ERI type IR ground scanner) and the surface temperature of the Mihara crater, Oshima. Bull. Volcanol. Soc. Jpn., 21: 95-105.
- Sugimura, A., 1960. Zonal arrangements of some geophysical and petrological features in Japan and its environs. Jour. Fac. Sci. Univ. Tokyo, Sec. II, 12: 133-153.
- Sugiura, T. and Mizutani, Y., 1978. Variations in isotopic and chemical compositions of fumarolic gases from Yakedake volcano, Honshu, Japan. Bull. Volcanol. Soc. Jpn., 23: 241-248.
- Sugoshi, T. and Maekawa, T., 1981. Geothermal and fumarolic parameters measured in situ during the 1978 - 1980 activities of Usu volcano. Bull. Volcanol. Soc. Jpn., 26 : 71-73.
- Suwa, A., Nagamune, T. and Watanabe, M., 1971. The outline of the 1970- 71 eruption of Akita-Komagatake. Bull. Volcanol. Soc. Jpn., 16: 112-121.
- Ui, T. and Shibahashi, K., 1975. 1974 activity of Chokai volcano, Northeastern Japan. Bull. Volcanol. Soc. Jpn., 20 : 51-64.
- Yamada, I., 1982. Observation of thermal spring at Nigorigo-onsen, Gifu Prefecture. Bull. Volcanol. Soc. Jpn., 27: 15-25.
- Yuhara, K. 1974. Morphological, hydrological

and thermal characteristics of active volcanoes having no geothermal areas; and artificial hydrothermal systems for utilizing their latent internal heat energy. Jour. Jpn. Geotherm. Energy Assoc., 11 : 31-39.

Yuhara, K. and Iriyama, J., 1986. 3-dimensional subsurface thermal structure in the underplan Abo tunnel area, Nagano. Bull. Volacanol. Soc. Jpn., 31: 241-252.