NOTICE CONCERNING COPYRIGHT RESTRICTIONS

Geothermal Activity of the Yakedake Volcano, Gifu-Nagano, Japan

Jun Iriyama

Department of Natural Sciences, Chubu University, 1200 Matsumoto, Kasugai, Aichi 487-8501 Japan

ABSTRACT

The temperature of the most active solfatara in the summit crater of the Yakedake volcano (altitude 2,455 m) was 92.0 and 116.7°C in October 1997 and in September 1996, respectively. The temperature of the solfatara in the northern summit dome at an altitude of 2,240 to 2,270 m ranged from 51.3 to 92.7°C in October 1997. The water sample from a crater pond, Shoga-ike (altitude 2,350 m), located on the summit, showed a pH and electrical conductivity of 4.32 and 32.5 μS/cm in October 1997, respectively. In the water from the Shoga-ike pond, the amount of SO_4^{--}, CO_3^{--}, Cl^- and F^- in October 1997 was 7.75, 3.98, 0.21 and 0.027 mg/l, respectively, using Ion Chromatograph. The amount of Ca^{++}, Na^+, K^+, NH_4^+ and MG^{++} was 1.38, 0.61, 0.39, 0.16 and 0.091 mg/l, respectively.

Introduction

There are eighty-three active volcanoes in Japan (J.M.A., 1996), which correspond to approximately 10% of the total number in the world. The present study will consider thirty-seven major active volcanoes from among them (see Table 1 and Figure 1). As shown in Figure 1, the active volcanoes of Japan can be classified into two volcanic belts (Sugimura, 1960): one is eastern Japan volcanic belt from Hokkaido through 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 activities at the summit or the crater and hydrothermal activities at the foot (i.e. geothermal area). Some of them are related to the geothermal power stations at the foot or in the surrounding area for generation of electricity for industrial utilization of geothermal energy. The eruptive, fumarolic and hydrothermal activities and related or adjacent to geothermal power stations of these volcanoes are summarized in Table 1, in which new data from Takigami geothermal station are added. The accumulated information in this table indicated that the volcanoes which are related to geothermal power stations have common characteristics: 1) fumarolic activity at the summit or the crater except for Kaimondake, 2) geothermal area and many hot springs at the foot or on the slope, 3) eruptive activity in the ninth to the twentieth century except for the Hachiman-tai and 4) altitude higher than about five hundred meters above sea level (Iriyama, 1994). This shows that the Yakadake volcano meets the necessary conditions from geological aspects in order to operate geothermal power station.

The study area is in a rugged section of the southern part of the Japan's Northern Alps Mountains. The locations of explosion craters, valleys (sawa) and general topography in the study area are shown in Figure 2. Yakedake is a volcano with a lava dome, belonging to the Norikura volcanic zone (e.g. Haruyama, 1990). The volcano has been in a dormant state since the eruption of July 1962 to March 1963, whose explosions took place at an altitude of about 2,200 m on the northern side of the dome and formed an arc fissure of about five hundred meters in length and about thirty or less meters in width (Isshiki, 1962 ; Yamada, 1962). However, the fumaroles in the summit dome areas of Yakedake and the parasitic volcano, Iwodake (altitude 2,140 m), are still active. The eruption in 1915 created new craters in the areas of the Shimohori and Nakahori valleys at an altitude of about 1,900 m above sea level, and formed Taisho-ike pond by damming up the Azusa River with mud flows from the mountainside (Murayama, 1979). The basement comprises Paleozoic to Mesozoic sedimentary rocks, and Mesozoic volcanic rocks and intrusive granite (Kato, 1912).

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 their branching streams, 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).

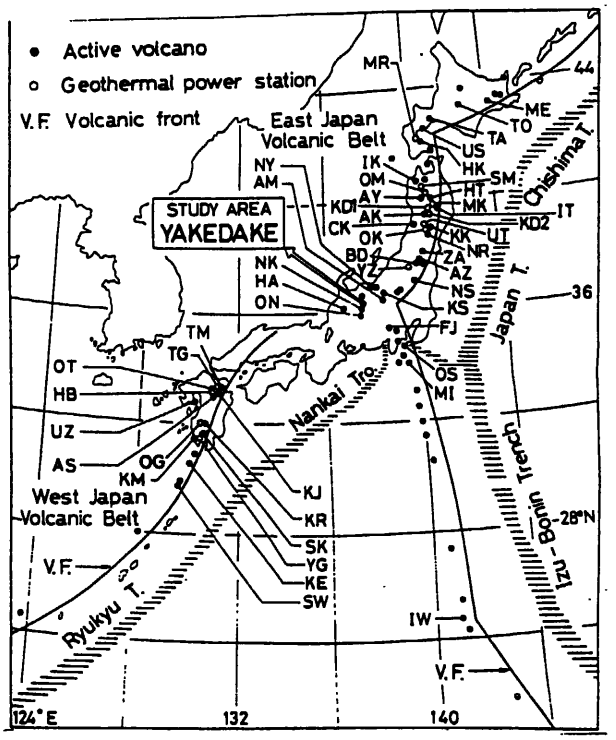

Figure 1. Distribution of active volcanoes, geothermal power stations, volcanic belts, volcanic fronts, trenches and trough in and around Japanese Islands. Abbrev.: T, Trench; Tro, Trough; ME, Meakan; TO, Tokachi; TA, Tarumae; US, Usu; MR, Mori; HK, Komagatake; IK, Iwaki; SM, Sumikawa; UM, Ohnuma; AY, Akita-Yakeyama; HT, Hachimantai, MK, Matsukawa; KD, Kakkonda; IT,Iwate; AK, Akita-Komagatake; CK, Chokai; UT, Uenotai; KK, Kurikoma; OK, Onikobe; NR, Naruko; ZA, Zao; AZ, Azuma; BD, Bandai; YZ, Yanaizu-Nishiyama; NS, Nasu; KS, Kusarsu-Shirane; AM, Asama; NY, Niigata-Yakeyama; NK, Norikura; ON, Ontake; HA, Hakusan; FJ, Fuji; OS, Oshima; MI, Miyakezima; IW, Iozima; TM, Tsurum; KJ, Kuju; OT, Otake; HB, Hatchobaru; UZ, Unzen; OG, Ogiri; KR, Kirishima; SK, Sakurajima; KM, Kaimondake; YG, Yamagawa; KE, Kuchinoerabujima; SW, Suwanosejima; TG, Takigami.

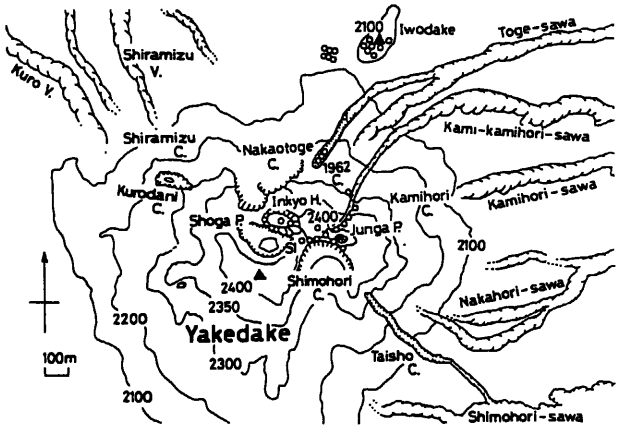

Figure 2. Location map of explosion craters, fumaroles, solfatara, valleys and general topography in the study area.

Yakedake and Iwodake Summit Dome Areas

Yakedake

The Yakedake dome consists of Quarternary biot bearing hornblende andesite (Iriyama et al., 1981). As shc in Figure 2, Yakedake has several explosion craters. Tl are two craters on the summit area. The eruption in 1 formed a crater called Inkyo-ko on the northern margin of old crater. The size of the Inkyo-ko crater is about 14(long and 80 m wide. The author threw stones at the bot on the 16 September 1996 and determined the depth of cr from the sound response, which was about 120 m deep. other is the old crater, which is about 240 m long and 18(wide surrounded by crater rim. A crater pond called Sho ike is formed on its bottom.

The temperature of the most active solfatra (S1 in Fig 2; altitude 2,445 m) in the summit crater was 92.0°C 116.7°C in October 1997 and September 1996, respectiv The boiling point of water at an altitude of 2,445 m is ab 92.1°C. Other sofatara are found along the 1962 explos crater within a dry valley from the crater-rim in the north summit dome at an altitude of 2,240 to 2,270 m. locations of sofatara and fumaroles in the study area shown in Figure 2. Sublimation of sulfur around th solfatara is observed there. The temperatures of f solfatara ranged from 51.3 to 92.7°C in October 1997. boiling point of water at an altitude of 2,250 m is ab 92.4°C. Variations of measured temperatures of the solfat over time since September 1986 are shown in Figure 3. temperature of the active solfatara Y_3 and Y_4 keeps a const temperature (~92.6°C) overtime since October 1989.

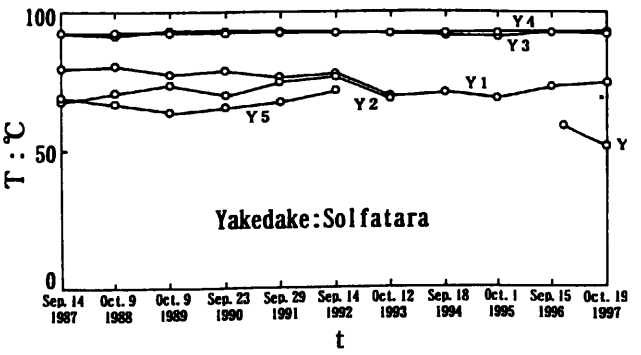

Figure 3. Measured temperatures (°C) of the Yakedake's solfatara as a function of time.

The water sample from a crater pond, Shoga-ike, on summit showed a pH and electrical conductivity (EC) of 4 and 32.5 μS/cm in October 1997, respectively. In the wa from the Shoga-ike pond, the amount of SO_4^{--}, CO_3^{--}, Cl^- F^- in October 1997 were 7.75, 3.98, 0.21 and 0.027 m respectively, using Ion Chromatograph TOA: ICA-3000. amount of Ca^{++}, Na^+, K^+, NH_4^+ and Mg^{++} was 1.38, 0. 0.39, 0.16 and 0.091 mg/l, respectively.

Iwodake

The summit lava dome of Iwodake, parasitic volcano of Yakedake, is made up of Quarternary 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. Some fumaroles appear in small cylindrical holes in the ground. Steam is mainly discharged from these holes and apertures. Variations of measured temperatures of the fumaroles over time since September 1986 are shown in Figure 2. The temperatures of eleven fumaroles ranged from, 43.7 to 64.1°C in October 1997. Variations of measured temperatures of the fumaroles over time since September 1986 are shown in Figure 4.

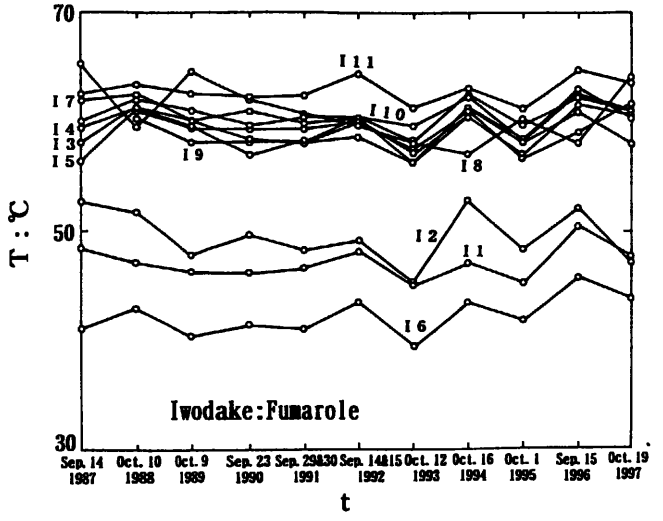

Figure 4. Measured temperatures (°C) of the Iwodake's fumaroles as a function of time.

Discussion

Geothermal Activity

The Yakedake volcano almost preserves the original volcanic topography. It can be inferred from the topography of the volcano that the eruptions have taken place continuously for about the last 100,00 years (Iriyama, 1981), i.e. the latest Late Pleistocene to the Recent. Variations of temperatures of the solfatara S1 in the summit over time since 1907 and eruption records of the volcano are shown in Figure 5. The temperature of the most active solfatara S1 has decreased quickly with time since 1933 in spite of the eruption in 1962. As is presented in Table 2, the temperature has ranged from 92.0 to 129.4°C for last five years. However, the fumarolic activity is still vigorous and just like the mountain tops are covered in a cloud, looking southwest from kamikochi, six kilometers from the summit of Yakedake.

Prediction of Eruption

In 1962 a steam explosion occurred on the northern side (altitude, 2,200 m) of the dome. The water sample from the crater pond Shoga-ike showed the pH and electrical conductivity of 3.7 and 80.8 μS/cm, respectively (Ossaka, 1961) in 1961. Variations of physico-chemical data over time since 1991 of the crater pond Shoga-ike's water and of the solfatara S1 in the summit are listed in Table 2. As is presented in Table 2, the values of the pH and electrical conductivity were 4.38 and 42.2 μS/cm in October 1991, 4.35 and 42.4 μS/cm in September 1992, and 4.11 and 76.6 μS/cm in October 1994, respectively. The values of the pH and electrical conductivity of water from the crater pond Shoga-ike in 1994 differ widely from those in 1991 and 1992, which approached the 1961 pre-eruption values of the volcano. It would seem that this indicates a possibility of the eruption and/or the high geothermal activity of the volcano. Because, the eruption in the summit dome area did not occur in 1995, however, a large steam explosion occurred in the Nakanoyu hot springs of the southeastern mountainside at an altitude of 1,310 m on 23 February 1995.

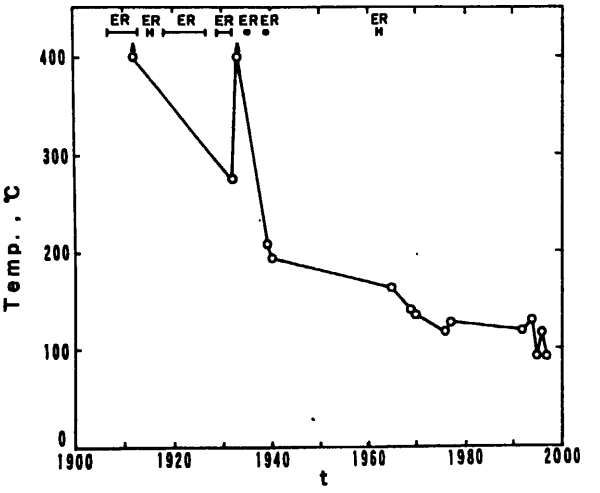

Figure 5. Variations of temperatures of the solfatara SI in the summit over time since 1910 and eruption records of the volcano. Abbrev.: ER, Eruption. Width of lime dénotes the period during eruption of Yakedake. Ref.: Kato (1912), Kodaira (1932), Oana (1939, 1942), Sugiura and Mizutani (1978), J.M.A. (1996), Iriyama (1992, 1995a,b, 1996, 1997, present study).

Geothermal Structure

From the results of the thermal investigations of natural hot springs, fumaroles, solfatara, drill holes and three-dimensional calculation of temperature field within the volcano (Yuhara and Iriyama, 1986; Iriyama, 1981, 1983, 1988, 1989, 1990, 1991, 1992, 1994, 1995a,b,c, 1996, 1997, present study), the geothermal structure model of the Yakedake volcanos presented in Figure 6. As shown in Figure 6, the subsurface temperature is very high in the volcanic central part with the vent. The isotherms encircle the volcanic center of Yakedake. The subsurface temperature is also high in the Shiramizu valley at an altitude of 1,600 m, Nakanoyu (altitude 1,300 m) and Karukaya (altitude 900 m) along the Gamada River. It is located at least one travertine terrace by the hot water flow (~33.3°C) in the Shiramizu

valley. The Nakanoyu and Karukaya are geothermal areas with self-flowing hot springs.

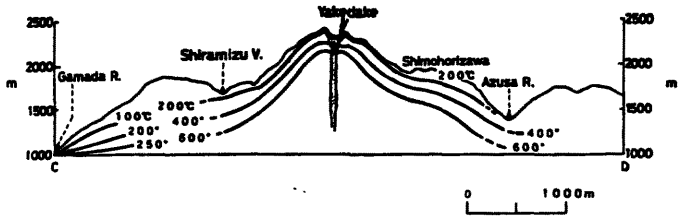

Figure 6. Geothermal structure of the Yakedake volcano, central Japan.

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.

Harayama, S., 1990. Geology of the Kamikochi district. Geol. Surv. Japan., Tsukuba, Japan.

Hayakawa, M., 1988. Geothermy. Tokai Univ. Press, Tokyo, Japan.

Hirabayashi, J., 1988. An instruction from the eruption of Kustasu-Shirane and Kiso-Ontake volcanoes. Bull. Volcanol. Soc. Jpn., 33: 102-104 .

Hirabayashi J., Ossaka, 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 Ossaka, 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. J. 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 Publ.), No. 10: 196-202.

Iriyama, J., 1988. Geothermal energy of the Yakedake volcano, Japan. Proc. Kagoshima Int. Conf. on Volcanoes. Kagoshima Pref., Japan, pp. 871-874.

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: 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., 1994. Geothermal energy and heat flow in the Yakedake volcano, Gifu-Nagano, Japan. Geotherm. Resources Council Trans., 18: 199-206.

Iriyama, J., 1995a. Case study of an active volcano in Japan: Geotherma process and energy of the Yakedake volcano, Japan. In "Terrestrial Heat Flow and Geothermal Energy in Asia", pp. 493-516, eds. M. L. Guputa and M. Yamano, A. A. Balkema Pub. Co., Rotterdom, the Netherlands. Iriyama, J., 1995b. Geothermal activity and process of the Yakedake volcano, Gifu-Nagano, Japan. GRC Bulletin, 24: 305-312.

Iriyama, J., 1995c. Geothermal activity of the Yakedake volcano, Gifu-Nagano, Japan Proc, 1995 Internat, Workshop on Volcanoes Commemorating 50th Anniv. Of Mt. Showa-shinzan, Sobetsu Town Office, Hakkaido, Japan, pp. 57-61.

Iriyama, J., 1996. Geothermal activity and energy of the Yakedake volcano, Gifu-Nagano, Japan. Geotherm. Resources Council Trans., 20: 316-322.

Iriyama, J., 1997. Geothermal activity and hot springs of the Yakedake volcano, Gifu-Nagano, Japan. Proc. 33rd Conf. of SITH in Hakone, Japan. The SITH Japan, pp. 185-188.

Iriyama, J., Susuki, 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

Isshiki, N., 1962. Explosion of the Yakedake volcano, Geol. News, No. 97: 20-22.

Japan Meteorological Agency, 1996. National catalogue of the active volcanoes in Japan.

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.

Kagiyama, T., Uhira, K., Watanbe, T., Masutani, F. and Yamaguchi, M., 1979. Geothermal survey of the volcanoes Kirishima. Bull. Earthq. Res. Inst., 54: 187-210.

Kagiyama, T. and Hagiwata, M., 1980. Geothermal survey in and around O-ana crater and jododaira 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 Skurajima 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: 1-75.

Kitsunezaki, C. and Kikuchi, S., 1988. Observation of ground temperaturre at Akita-Komagatake volcano in 1979-1987 and some considerations on the geothermal activity after the 1970 eruption. Rep. Resources Sci. Inst., Mining Faculty, Univ. Akita, No. 53, 57-68.

Kodaira, T., 1932. Recent activities of the Yakdake volcano. Bull. Volcanol. Soc. Jpn. (1st Ser.), 1: 52-64.

Muryama, I., 1979. Volcanoes of Japan (II). Taimeido, Tokyo, Japan.

National Astronomical Observatory, 1997. Chronological Scientific Tables, Maruzen Co. Ltd., Tokyo.

Noguchi, K., Goto, T., Ueno, S. and Ichikunui, M., 1961. Chemical composition of fumaroles gases obtained from volcano Iwate. Bull. Volcanol. Soc. Jpn., 5: 162-168.

Oana, S., 1939. Geochemische Untersuchungen der Vulkane in Japan. XVIII. Diehtemessungen des durch Kondensation von

Fumarolelendampf. Erhaltenen wassers. Bull. Chem. Soc. Jpn., 14: 279-283.

Oana, S., 1942. Geochemische Untersuchungen der Vulkane in Japan. XXV. Dichetemessungen des Wassers aud Gumarolen vomn dem Vulkan Yakedake. II. Bull. Chem. Soc. Jpn., 17: 302-304.

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.

Sugimura, A., 1960. Zonal arrangement of some geophysical and petrological features in Japan and its environs. J. Fac. Sci., Univ. Tokyo, Sec. 2, 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.

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.

Yamada, T., 1962. Report of the 1962 activity of Yakedake volcano, Central Japan. J. Fac. Lib. Arts and Sci., Shinshu Univ., No. 12: 47-68.

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. J. Jpn. Geotherm. Enrgy. Assoc., 11: 31-39.

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

Table 1. Eruption, fumarole, geothermal area, hot spring and adjoining geothermal station on the active volcanoes, Japan.

Name (alt.,m)	Recent [1,2] Eruption		Fumarole	Geothermal [3,13] Area	Hot [3,13] Spring	Geothermal [13] 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	
			Showa-shinzan, do: 830°C[6]			
HK-Komagatake (1,131m)	1942	○		Shikabe	Many	Mori
Iwaki (1,625m)	1863	○			Dake, 71°C	
Akita-Yakeyama (1,366m)	1957	○		Tamagawa	Many	Sumikawa
Hachimantai (1,613m)		○		Fukenoyu, Toshichi	Many	Onuma
Iwate (2,038m)	1719	○	Myokogatake, sl: > 360°C[7]	Matsukawa	Many	Matsukawa
Akita-Komagatake (1,637m)	1971	○	Medake, cr:490°C[8],86°C[9]	Kuroyu	Many	Kakkonda
Chokai (2,236m)	1974	○	Cr:52°C[10]		Yunodai, 29°C	
Kurikoma (1,628m)	1944	○		Sugawa, Komanoyu	Many	Uenotai
Naruko (461m)	837?	○		Naruko	Many	Onikobe
Zao (1,841m)	1923	○			Kamoshika, 75°C	
Azuma (2,035m)	1977	○	Jododaira, sl:62°C[11]		Shintakayu, 56°C	
Bandai (1,819m)	1888	○		Nakanoyu	Many	Yanaizu-Nishiyama
Nasu (1,915m)	1963	○		Sandogoya	Many	
Kusatsu-Shirane (2,171m)	1983	○	Mizugama, cr:91°C[12]	Sesshogawara	Kusatsu	
Asama (2,568m)	1990	○			Sengataki, 38°C	
Niigata-Yakeyama (2,400m)	1989	○			Sasakura, 60°C	
Yakedake (2,455m)	1963	○	Su:92°C, do:93°C[13]	Nakanoyu, Shinhotaka	Many	
Norikura (3,026m)					Shirahone, 49°C	
Ontake (3,067m)	1991	○	Kengamine, cr:145°C[14]		Nigorigo, 47°C[15]	
Hakusan (2,702m)	1579	○	Jigokudani	Oshirakawa		
Fuji (3,776m)	1707	○				
Izu-Oshima (764m)	1990	○	Miharayama, cr:145°C[16]			
Miyakejima (813m)	1983	○	Oyama, cc:910°C[17]			
Iwojima (161m)	1982	○		Chidorigahara		
Tsurumi (1,375m)	867	○		Myoban, Kannawa	Many	Suginoi H.
Kuju (1,791m)	1742	○	Iwoyama, cr:269°C[18]	Otake, Sujiyu	Many	Hatchobaru, Otake, Takigami
				Jigoku, Yunotani	Many	
Aso (1, 592m)	Present	○			Obama	
Unzen (1,359m)	1995	○	Fugendake, cr:772°C[19]	Tearai, Yunono	Many	Ogiri, Kirishima K.H.
Kirishima (1,700m)	1991	○	Iwoyama, sl:174°C[20]		Furusato, 52°C	
Sakurajima (1,117m)	Present	○	Minamidake, cr: > 760°C[21]	Narikawa	Many	Yamagawa
Kaimondake (922m)	885	○			Nishiura, 67°C	
Kuchinoerabujima (657m)	1980	○				
Suwanosejima (799m)	Present	○			Fukuseisi	

Abbrev. sl: slope, do: dome, su: summit, cr: crater, cc: cinder cone, HK Hokkaido. Ref.: 1) Nat. Astron. Obs., 1997 2) J.M.A., 1996 3) Yuhara, 1974 4) Hirabayashi et al., 1990 5) Sugoshi and Maekawa, 1981 6) Hayakawa, 1988 7) Noguchi et al., 1961 8) Suwa et al., 1971 9) Kitsunezaki and Kikuchi 1988 10) Ui and Shirabayashi, 1975 11) Kagiyama and Hagiwara, 1980 12) Hirabayashi, 1988 13) Present Study, 1996 14) Ossaka et al., 1983 15) Yamada, 1982 16) Ehara et al., 1975 17) Hirabayashi et al., 1984 18) Ehara et al., 1981 19) Joint Univ. Res. Gr., 1992 20) Kagiyama et al., 1979 21) Kamo et al., 1977

Table 2. Variations of physico-chemical data over time since 1991 of the crater pond Shoga-ike's water and of the solfatara Sl in the summit of Yakedake.

		20 Oct. 1997	16 Sept. 1995	30 Sept. 1994	30 Oct. 1994	15 Sept. 1992	21 Oct. 1991	1960
PH		4.32	4.34	4.30	4.11	4.35	4.38	3.7
Elec. Cond. (μS/cm)		32.5	37.1	45.1	76.6	42.4	42.2	80.8
Solfatara Sl Temp. (°C)		92.0	116.7	92.2	129.4	119.4		
	SO_4^{--}	7.748	8.373	11.561	22.92		11.25	29.6
	CO_3^{--}	3.978						
	Cl^-	0.212	0.032	0.150	0.25		0.32	
	NO_3^-	-	-	0.274	-		0.09	Ossaka
Chem.	Ca^{++}	1.380	1.423	1.668	2.65		1.71	(1961)
Comp.	Na^+	0.610	0.403	0.513	0.87		0.65	
(mg/l)	K^+	0.392	0.146	0.239	0.41		0.31	
	Mg^{++}	0.091	0.105	0.136	0.37		0.23	
	NH_4^+	0.156	0.118	0.090	0.068		0.02	
	Li^+	-	-	-	-		0.0003	
Water Temp. (°C) (Time)		2.7 (10:00)	14.5 (10:00)	9.9 (14:55)	6.7 (12:40)	14.5 (11:50)		