Geothermal Resources Council TRANSACTIONS, Vol. 18, October 1994

GEOTHERMAL ENERGY AND HEAT FLOW IN THE YAKEDAKE VOLCANO, GIFU-NAGANO, JAPAN

Jun Iriyama

Dept. of Natural Sciences, Chubu University, 1200 Matsumoto-cho,
Kasugai-shi, Aichi 487 Japan

ABSTRACT

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 x 10^{17} J, which represents a thermal power output of 5.5 x 10^2 MW_{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, Terugaike, located on the summit, showed pH and electrical conductivity of 4.35 and 42.4 μS/cm in Sept., 1992, respectively, and of 4.38 and 42.2 μS/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 geothermal energy within the summit dome of Iwodake, parasitic volcano of Yakedake, at an altitude of 2,100 to 2,140 m is calculated to be 2.2 x 10^{15} J, which represents a thermal power output of 2.3 MW_{th} over 30 yrs.

1. INTRODUCTION

There are sixty-seven active volcanoes in Japan (J.M.A., 1984), which correspond to approximately 10% of the total number in the world. The 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 in to two volcanic belts (Sugimura, 1960): one is the 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 surrouding 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. Data on geothermal area and hot spring 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: 1) fumarolic activity at the summit or the crater, 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 Hachimantai volcano and 4) altitude higher than about five hundred meters above sea level (Iriyama, 1994).

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 in June, 1962, 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 the Azusa River with mud flows from the mountainside (Murayama, 1979). The Yakedake dome consists of Quaternary biotite-bearing hornblende andesite (Iriyama et al., 1981). The basement comprises Paleozoic sedimentary rocks, Mesozoic volcanic rocks and granite (Kato, 1912).

The geothermal energy of the Yakedake volcano is calculated in the present paper. The thermal process in the volcano is also analyzed. Studies of these problems have been performed by the present author (Iriyama, 1981, 1983, 1988, 1990, 1991, 1992, 1994).

2. YAKEDAKE AND IWODAKE SUMMIT DOME AREAS

Yakedake

The temperature of the most active solfatra (alt., 2,445 m) in the summit dome was 119.4° C in Sept., 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 2,445 m 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. Variation of measured temperatures of the solfatara over time since Sept., 1987 are listed in table 2. The temperatures of three solfatara ranged from 68.2 to 92.4° C in Oct., 1993. The boiling point of water at an altitude of 2,250 m is about 92.4° C.

The water sample from a crater pond, Terugaike(alt., 2,350 m), on the summit showed pH and electrical conductivity (E.C.) of 4.35 and 42.4 μS/cm in Sept., 1992, respectively, and of 4.38 and 42.2 μS/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 μS/cm, respectively.

Taking into account the results of present temperature measurements and high geothermal gradient of the volcano (Yuhara and Iriyama, 1986; Iriyama, 1981, 1988, 1990, 1991, 1992, present study), the geothermal gradient within the dome is assumed to be about 2.5° C/m at a depth between 0 and 300 m. Thus one can assume a temperature difference of δT = 600 deg between the inside and the outside of the dome at an altitude of 2,050 to 2,455 m. The 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 x 10^3 J/kg·° C and ρ = 2.6 x 10^3 kg/m^3 and the dome volume of V = 3.0 x 10^8 m^3, calculated from the topographic map 'Yakedake' (1:25,000 in scale), the geothermal energy G_{th} within the summit lava dome is calculated to be 5.2 x 10^{17} J, which represents a thermal power output of 5.5 x 10^2 MW_{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. Some fumaroles appear in small cylindrical holes in the ground. Steam is discharged mainly from these holes, apertures and so on. The temperatures of eleven fumaroles ranged from 39.0 to 61.6° C in Oct., 1993.

By assuming δT = 300 deg and V = 2.5 x 10^6 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 x 10^{15} J, which represents a thermal power output of 2.0 MW_{th} over 30 yrs.

3. GEOTHERMAL AREA

Gamada River

There are many hot springs, a geyser and at least one travertine terrace by the hot-water flow along the Gamada River and its branch streams, i.e., the Shiramizu and Ashiarai valleys on the northwestern foot of Mt. Yakedake (Iriyama, 1990).

The Gamada River geothermal zone extends about 4,000 m from the nearby Nakasaki hydropower station through the Karukaya hot springs to the Gamada hot springs along the river. The accessible depth (d) is probably 500 m on average in the montane region. The width (a) and length (l) of this zone are assumed to be 200 m and 4,000 m, respectively. The measured density of rhyolitic tuff is 2.8 x 10^3 kg/m^3 in boring-core sample from CU-W1 well of the Karukaya area. The temperature difference (δT) and the specific heat (C_p) are assumed to be 150 deg on average and 1.1 x 10^3 J/kg·° C, respectively. Given this temperature difference and these parameters, the geothermal energy (G_{th}) within the Gamada River geothermal zone is calculated to be 1.8 x 10^{17}J, which represents a thermal power output of 1.9 x 10^2 MW_{th} averaged over 30 yrs.

Takahara River

There are many hot springs, i.e., the Hirayu, Fukuji, Ipposui and Uwajigane hot springs, along the Takahara River and its tributaries, i.e., the Abo and Shiratani valleys at the southwestern foot of the Yakedake volcano (Iriyama, 1991).

The Takahara River geothermal zone extends about 5,000 m from the nearby Hirayu bus terminal, through the Fukuji hot springs, to the Uwajigane hot springs along the river. Assuming the temperature difference δT = 130 deg and the length l = 5,000 m of this zone, the geothermal energy G_{th} within the Takahara River geothermal zone is calculated to be 2.0 x 10^{17} J, which represents a thermal power output of 2.1 x 10^2 MW_{th}.

Azusa River

The Azusa River geothermal zone extends about 2,000 m from the nearby Kama tunnel, through the Nakanoyu hot springs, to the Sakamaki hot springs along the river (Iriyama, 1992). Hot waters gush mainly at the mountainside of Yakedake volcano on the right bank of the Azusa River. It is noted that the coincidence between the landslides and places of hot water gushes is fairly good.

By assuming l = 2,000 m in length of the geothermal zone and the temperature difference δT = 150 deg, the geothermal energy G_{th} within the Azusa River geothermal zone is calculated to be 9.2×10^{16} J, which represents a thermal power output of 9.8 x 10 MW_{th} averaged over 30 yrs.

4. DISCUSSION

Heat Flow

The heat flow escaping by heat conduction from the mountain foot is discussed below.

(i) For the Gamada River geothermal zone, the mean thermal gradient is 0.487 ° C/m at a depth between 30 and 105 m within the CU-1 well in the Karukaya area. Vertical distribution of temperature in this well is shown in Fig. 3. Measurements were taken at the newly reached bottom depth of the borehole at least 18 hours after daily drilling was finished. There is a notable water movement at a depth between 105 and 140 m of the bottom depth. The mean thermal conductivity is 3.38 W/m·° C in the stratum. Thermal conductivity of rocks from the volcano and the mountain foot was measured by a non-steady method. The corresponding surface heat flow by vertical heat conduction is 1.65 W/m^2 in the CU-1 well, which is very much higher than those reported by Uyeda (1967) in the non-geothermal areas of the islands of Japan. However, for the heat flow in the axial part of the middle Okinawa Trough, Yamano et al. (1988, 1989) have measured from 1.3 to 1.6 W/m^2, which is comparable with the present study. They (1989) have attributed the high heat flow anomaly in the deep to the present or recent volcanism in the central rift zone. Kinoshita et al. (1991) have also observed very high heat flow from 1.7 to 2.0 W/m^2 around "biological communities" located off Hatsushima Island in thewestern Sagami Bay, Japan, where a high methane content anomaly had been found indicating fluid venting activity.

In the Nakasaki area of the Shin-hotaka hot springs, the mean thermal gradient is 0.143° C/m at a depth between 20 and 290 m within the HTK well. Vertical distribution of temperature in this well is shown in Fig. 4. The temperature measurement was taken by Chinetsu Co. The thermal conductivity in this stratum will be assumed the conductivity of rhyolitic tuff in the CU-1 well. The corresponding surface heat flow by vertical conduction is 0.459 W/m^2 in the HTK well. This well is located on the northern limit of the Gamada River geothermal zone.

(ii) The heat-flow measurement station of the Esakake area is in a montane section about 800 m east of the Takahara River geothermal zone. The mean thermal gradient is 0.212 ° C/m at a depth between 50 and 180 m within the S2-hole (alt., 1,112 m) in the Esakake area. Vertical distribution of temperature in the S2-hole is shown in Fig. 5. The thermal conductivity measured by Kiyohashi et al (1983) was 1.16 W/m° C for core samples in this stratum. The corresponding surface heat flow by vertical conduction is 0.246 W/m^2 in the S2-hole. For S1-hole of this area, the mean thermal gradient is 0.178° C/m at a depth between 50 and 180 m within this hole. The surface heat flow is 0.206 W/m^2 in the S1-hole.

Radioactivity

Contents of U, Th and K were obtained by a neutron activation method for rock samples from the Yakedake volcano and its foot. Their concentrations are listed in Table 3. The analysis was done by Japan Chemical Analysis Center. The results show a content of 2.1 [μg/g] uranium, 9.3 [μg/g] thorium and 2.0 x 10 [mg/g] potassium for andesite sample (Yak-1) from the Yakedake summit dome. Radioactive heating of the rock is attributed to the decay of the uranium isotopes U^{238} and U^{235}, the thorium isotope Th^{232} and the potassium isotope K^{40}. Natural uranium is composed of 99.27% by weight U^{238} and 0.72% U^{235}. Natural thorium is 100% Th^{232}. Natural potassium is composed of 0.0128% K^{40}. Therefore to obtain the concentrations of U^{238}, U^{235}, Th^{232} and K^{40}, one should multiply the empirical contents of U, Th and K by these natural abundances. Their concentrations calculated are listed in Table 4. Radioactive heat production by the Yakedake rocks is also listed in Table 4.

If one considers a one-dimensional column with no erosion or deposition and a constant heat flux, the equilibrium distribution of temperature T is determined by

$$K\,(d^2T/dZ^2) = -A(z) \qquad (1)$$

where K is the thermal conductivity, Z is the depth measured from the surface and A is the rate of heat production per unit volume. The solution to the differential equation is

$$T = -(1/2)(AZ^2/K) + BZ + C \qquad (2)$$

This can be solved given boundary conditions: (i) $T = T_s$ on $Z = 0$ and (ii) a surface heat flow $Q = -K(dT/dZ) = -Q_0$ on $Z = 0$.
The constant B is equal to

$$B = Q_0/K \qquad (3)$$

C is the temperature T_s at the surface. As the observed stations are in a montane region at an altitude between 1,000 and 1,400 m, T_s = 5° C is adopted in the present calculation.

Therefore, from the values of heat flow, thermal conductivity and heat production, the approximate temperatures at the relatively shallow depth in various areas of the volcano and its surroundings will be obtained as follows: For the

Karukaya area of the Gamada River geothermal zone, the temperature at a depth of 300 and 500 m within the CU-1 well is 160 and 250° C, respectively. In the Nakasaki area, the temperature within HTK well is 40 and 70° C, respectively. For the Esakake area of the Takahara River geothermal zone, the temperature at a depth of 300 and 500 m within the S2-hole is 70 and 110° C, respectively. The temperature within the S1-hole in this area is 70 and 120° C, respectively.

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. Sco. 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., 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, Japan, pp. 871-874.

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. Case study of an active volcano in Japan: Geothermal process and energy of the Yakedake vocano, Japan. In "Terrestrial Heat Flow and Geoheraal Energy in Asia", eds. M.L. Guputa et al., Oxford & IBH Pub. Co., New Delhi (in press).

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.

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

Kagiyama, 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: 1-75.

Kinoshita, M., Yamano, M. and Makita, S., 1991. High heat flow anomaly around Hatsushima biological community in the western Sagami Bay, Japan. J. Phys. Earth, 39: 553-571.

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. Resources Sci. Inst., Mining Faculty, Univ. Akita, No. 53, 57-68.

Kiyohashi, H., Kyo, M., Ishihama, W. and Tanaka, S., 1983. Temperature dependence of the thermal conductivity of core samples from the test wells at Yakedake geothermal area. J. Geotherm. Res. Soc. Jpn., 5: 305-320.

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.
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.
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.
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.
Uyeda, S., 1967. Terrestrial heat flow. Bull. Volcanol. Soc. Jpn., 12: 41-59.
Yamada, I., 1982. Observation of thermal spring at Nigorigo-onsen, Gifu prefecture. Bull. Volcanol. Soc. Jpn., 27: 15-25.
Yamano, M., Kinoshita, M. Uyeda, S. and Post, J., 1988. Heat flow and hydrothermal circulation in the Okinawa Trough. Proc. Int. Symp. on Geothermal Energy, 1988, pp. 313-317.
Yamano, M., Uyeda, S., Foucher, J.P. and Siduet, J.C., 1989. Heat flow anomaly in the middle Okinawa Trough. Tectonophys., 159: 307-318.
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. Energy 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] area	Hot[3] spring	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	Onuma
Hachimantai (1,613m)		○	Fukenoyu,Toshichi	many	Onuma, 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	Fumarole	Geothermal[3] area	Hot[3] spring	Geothermal station
Asama (2,568m)	1990	O		Sengataki,38℃	
Niigata-Yakeyama(2,400m)	1989	O		Sasakura,60℃	
Yakedake (2,455m)	1963	O su:119℃,do:93℃[12]	Nakanoyu,Shinhotaka	many	
Norikura (3,026m)				Shirahone,49℃	
Ontake (3,067m)	1991	O Kengamine,cr:145℃[13]		Nigorigo,47℃[14]	
Hakusan (2,702m)	1579	O Jigokudani	Oshirakawa		
Fuji (3,776m)	1707	O			
Izu-Oshima (764m)	1990	O Miharayama,cr:542℃[15]			
Miyakejima (813m)	1983	O Oyama,cc:910℃[16]			
Iwojima (161m)	1982	O	Chidorigahara		
Tsurumi (1.375m)	867	O	Myoban,Kannawa	many	Suginoi H.
Kuju (1,791m)	1742	O Iwoyama,cr:269℃[17]	Otake	many	Hatchobaru, Otake
Aso (1,592m)	present	O	Jigoku,Yunotani	many	
Unzen (1,359m)	present	O Fugendake,cr:772℃[19]		Obama	
Kirishima (1,700m)	1991	O Iwoyama,sl:174℃[18]	Tearai,Yunono	many	Kirishima Kokusai H.
Sakurajima (1,117m)	present	O Minamidake,cr:>760℃[20]		Furusato,52℃	
Kuchinoerabujima(657m)	1980	O		Nishiura,67℃	
Suwanosejima (799m)	present	O		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)Kitsunezaki and Kikuchi, 1988 9)Ui and Shirabayashi, 1975 10)Kagiyama and Hagiwara, 1980 11)Hirabayashi, 1988 12)Present study, 1993 13)Ossaka 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)Kagiyama et. al., 1979 20)Kamo et. al., 1977.

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

Talble 3. Uranium, thorium and potassium contents in rocks of the Yakedake volcano.

Type of rock	Sample number	K[mg/g]	Th[μg/g]	U[μg/g]
Andesite	YAK-1	2.0 X 10	9.3	2.1
Chert	CU1-40	2.3 X 10	1.71 X 10	4.7
Rhyolitic tuff	CU1-105	2.7 X 10	1.61 X 10	5.0
Slate	HIR-OB	2.4 X 10	1.31 X 10	3.0
Slate	S5-71	2.9 X 10	2.4	1.9

Analysis: Japan Chemical Analysis Center.

Table 4. Heat production by the Yakedake rocks

Type of rock	Sample name	K^{40} $(10^{-8}g/g)$	Th^{232} $(10^{-8}g/g)$	U^{235} $(10^{-8}g/g)$	U^{238} $(10^{-8}g/g)$	Heat produced by U, Th & K ($\mu W/m^3$)
Andesite	YAK-1	23.4	930	1.51	209	1.18
Chert	CU-40	26.9	1710	3.39	467	2.46
Rhyolitic tuff	CU-105	31.6	1610	3.60	496	2.56
Slate	HIR-OB	28.1	1310	2.16	298	1.73

FIGURE CAPTIONS

Fig. 1. Distribution of active volcanoes, geo thermal 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, Miyakezima; IW, Iwozima; TM, Tsurumi; KJ, Kuju; OT, Otake; HB, Hatchobaru; UZ, Unzen; KR, Kirishima; SK, Sakurajima; KE, Kuchinoerabujima; SW, Suwanosejima.

Fig. 2. Location map of water recharge area and hot water discharge area, and general topography in the study area (Iriyama, 1981). Contours indicate the alititude above sea level in meter.

Fig. 3. Vertical distribution of temperature and lithology data in the CU-1 well, Karukaya hot springs.

Fig. 4. Vertical distribution of temperature in the HTK well, Shin-hotaka hot springs. GWL indicates the ground water level in meter.

Fig. 5. Vertical distribution of temperature in the S2-hole, Ipposui hot springs. GWL indicates the ground water level in meter.

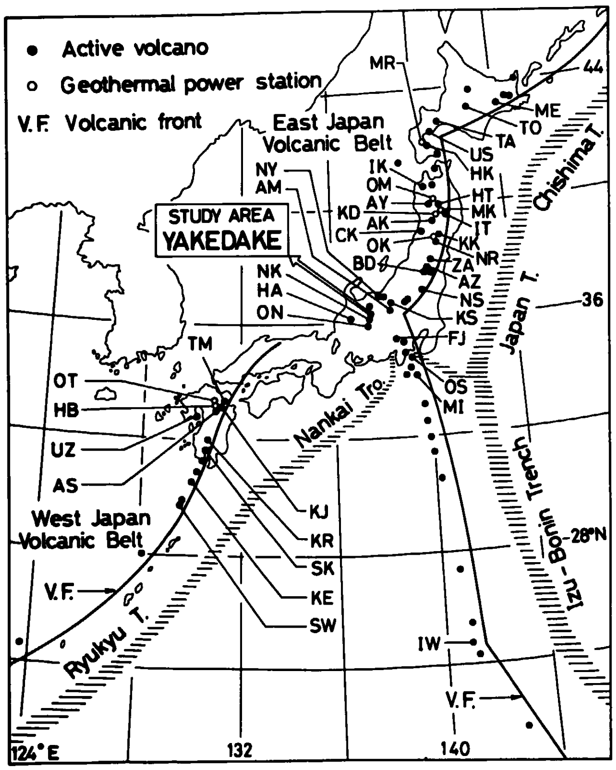

Fig. 1

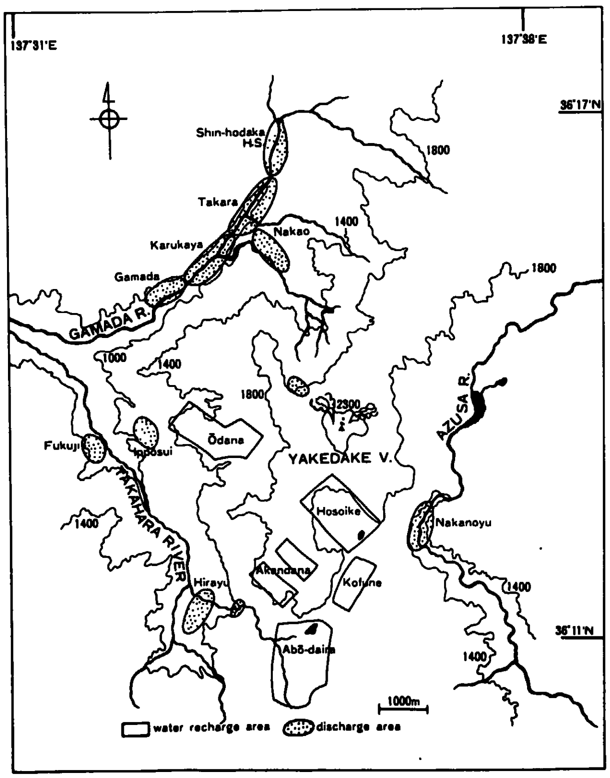

Fig. 2

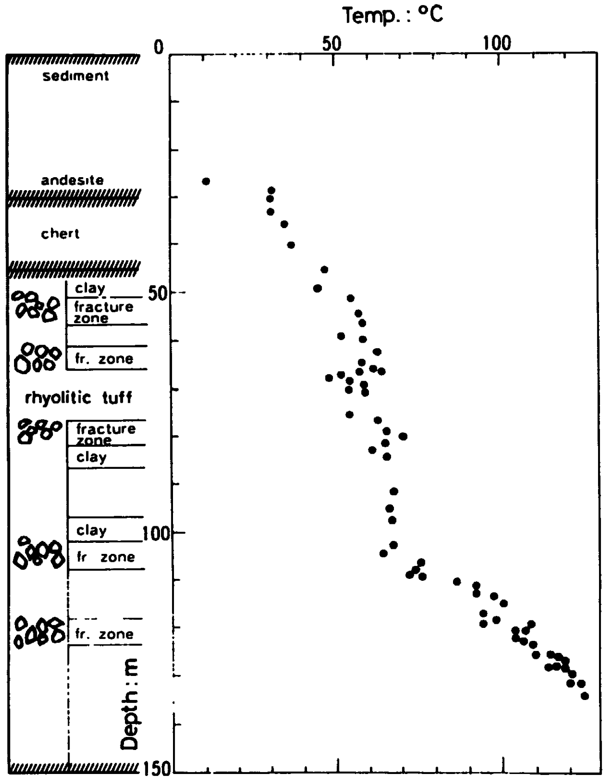

Fig. 3

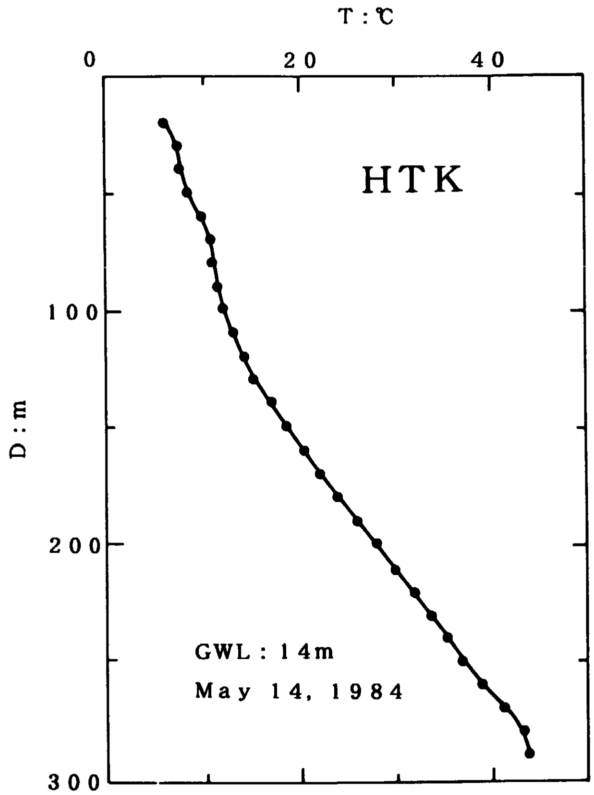

Fig. 4

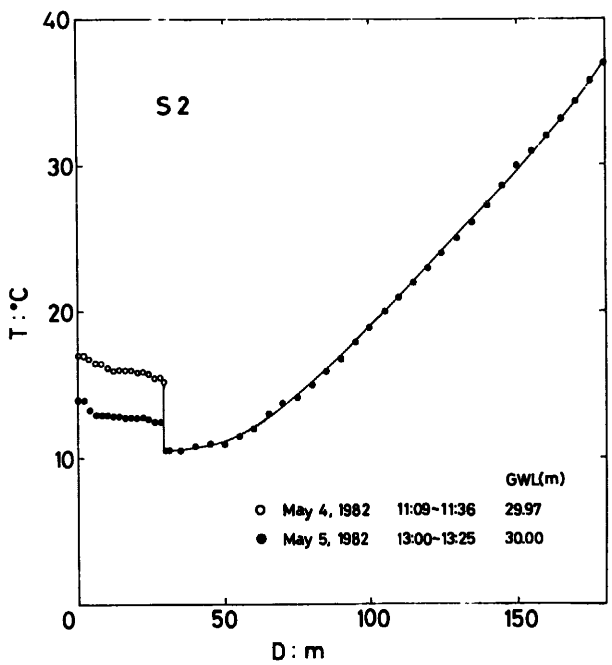

Fig. 5