GEOTHERMAL ENERGY AND ACTIVITY OF THE YAKEDAKE VOLCANO, GIFU-NAGANO, JAPAN

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ABSTRACT

The geothermal energy within the summit dome at the altitule of 1,800 to 2,455 m of the Yakedake volcano (alt., 2,455 m), Gifu-Nagano, Japan is calculated to be about 2.4 x 10^{18} J, which represents a thermal power output of 2,500 MW_{th} averaged over 30 yrs. The temperatures of solfatara in the northern summit dome at the altitude of 2,240 to 2,270 m ranged from 67.1 to 92.4° C in Oct., 1991. The water sample from a crater pond, Terugaike, on the summit showed pH and electrical conductivity of 4.38 and 42.2 μs/cm in Oct., 1991. The geothermal energy within the parasitic volcano, Iwodake summit dome at the altitudes of 2,100 to 2,140 m is calculated to be 1.9 x10^{15} J, which represents a power out of 2.0 MW_{th} over 30 yrs.

1. INTRODUCTION

The study area is in a rugged section of the southern part of the Japan Northern Alps Mountains (Fig. 1). 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 whose explosions took place on the northern side of the dome and formed a fissure of several hundreds of 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 on the areas of Shimohorisawa and Nakahorisawa valleys of at the altitute 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). 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 by the hot water flow along the Gamada, Takahara and Azusa Rivers and the tributaries, i.e., the Ashiarai, Shiramizu, Abo and Shiratani valleys. The author has classified the geothermal zones according to the rivers, i.e., Gamada, Takahara and Azusa River geothermal zones (Iriyama, 1983).

The geothermal energy of the Yakedake volcano is considered quantitatively. The volcanic eruption, heat flow and geyser of the study area are discussed in this paper. A preliminary study of those problems has been performed by present author (Iriyama,1981, 1988a&b, 1989, 1990). Yakedake has a crater pond, Terugaike (alt., 2,400 m) on the summit, which is shown in Fig. 2.

2. YAKEDAKE AND IWODAKE SUMMIT DOME AREAS

Yakedake

The solfatara are found within a dry valley from the crater rim in the northern summit dome at the altitude of 2,240 to 2,270 m. Their localities and general topography in the study area are shown in Fig. 3. The water sample from a crater pond, Terugaike, on the summit showed pH and electrical conductivity (EC) of 4.38 and 42.2 μS/cm in Oct., 1991, respectively. When Ossaka measured these values in 1960, pH and EC were 3.7 and 80.8 μS/cm, respectively (Ossaka, 1961). In the water from the Terugaike pond, the amount of SO_4^{2-}, Cl^- and NO_3^- was 11.25, 0.32 and 0.09mg/l, respectively. F^-, No_2^- and Br^- were not detected from the water. For the cation the amount of Ca^{2+}, Na^+, Mg^{2+}, NH_4^+ and Li^+ was 1.71, 0.65, 0.31, 0.23, 0.02 and 0.0003 mg/l, respectively at present study by TOA: ICA-3000. In 1960 Ossaka (1961) obtained 29.6 mg/l of SO_4 for the same pond.

Variations of measured temperatures of the solfatara with time since Sep., 1986 are listed in Table 1. The temperatures of six solfatara ranged from 67.1 to 92.7° C in Sep., 1991. The boiling point of water at the altitude of 2,250 m is about 92.4° C. Taking into account the results of present temperature measurements and also those by Ossaka (1961) and Sugiura & Mizutani (1978), and also the high geothermal gradient of the volcano (Yuhara and Iriyama, 1986 ; Iriyama, 1988a&b, 1989, 1990; present study), the geothermal gradient is assumed to be about 2.5° C/m at depths between 0 and 300 m. Thus one can assume the temperature difference of δT = 600 deg between the inside and the outside of the dome at the altitude of 1,800 to 2,455 m. The altitude of 1,800 m indicates the lower limit of crater lacation 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 = 1.4 x 10^9 m^3, which is calculated from topographic map "Yakedake", 1:25,000 in scale; the geothermal energy G_{th} within the summit lava dome is calculated to be 2.4 x 10^{18} J, which represents a thermal power output of 2.5 x 10^3 MW_{th} averaged over 30 yrs.

The author has measured the solfatara temperatures in the Yakedake and the Iwodake summit domes using a thermistor thermometer with a precision of 0.1° C. The solfatara are found within a dry valley from the crater rim in the northern summit dome at the altitude of 2,240 to 2,270 m. There is a sublimation of sulfur around the solfatara.

Iwodake

The Iwodake summit lava dome is made up of Quaternary hornblende andesite (Iriyama et al., 1981). The locality map of fumaroles and general topography in the study area are shown in Fig. 3. Many fumaroles are found in the bottoms of the large stones on the southern dome at the altitude of 2,110 to 2,140 m. Some fumaroles appear in the small cylindrical holes on the ground. Mainly steam is discharged from these holes, apertures and so on. Variations of measured temperatures of the fumaroles with time since Sep., 1986 are listed in Table 2. The temperatures of eleven fumaroles range from 41.0 to 62.4° C in Sep., 1991.

By assuming δT = 300 deg and V = 2.5 x 10^6 m^3, the geothermal energy G_t within the Iwodake summit dome at the altitude of 2,100 to 2,140 m becomes 2.2 x 10^{15} J, which represents a thermal power output of 2.3 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 the branch streams, i.e., the Shiramizu and the Ashiarai valleys on the northwestern foot of Mt. Yakedake. Their localities and general topography in the study area are shown in Fig. 4. The data indicate that the subsurface temperatures are high. Especially the temperatures of the shallow part are very high in the Karukaya area. From the lithology data of core samples in the boreholes CU (Chubu Univ.)-W1 and W2, the subsurface rock structure is made up of Quaternary andesite, very hard Mesozoic rhyolitic tuff and Paleozoic chert.

There was, formerly, an active boiling spring in the vicinity of Karukaya Hotel. The boiling spring was caused to disappear by thick sedimentation of mud and rock flows from the Yakedake volcano. However a geyser suddenly appeared when Yamano Hotel drilled a hole to obtain hot water, down to the depth of 101 m under the Karukaya area in Apr., 1987 whose locality is shown in Fig. 4. Iriyama and Iriyama (1987) named it Karukaya geyser. The temperature at the depth of 100 m in the Karukaya geyser (alt., 920 m) changed about 120° to 140° C at the various times . The temperature at the well-head during the full eruption was about 96° to 97° C, which is nearly equal to the boiling point of water of 96.8° C at the altitude of 920 m. The pressure change with time at the well-head is shown in Fig. 5. The gauge pressure amounts to 1.2 kg/cm^2 at the well-head during the eruption.

The Gamada River geothermal zone extends about 4,000 m from nearby the Nakasaki hydropower station through the Karukaya hot spring to the Gamada hot spring along the river. The accessible depth (d) will be 500 m on average in the mountain region. The width (a) and the length (l) of this zone are assumed to be 200 m and 4,000 m, respectively. Measured density of rhyolitic tuff is 2.8 x 10^3 kg/m^3 for boring-core sample from 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. Taking this temperature difference and these parameters, the geothermal energy (G_{th}) within the Gamada River geothermal zone is calculated to be 3.7 x 10^{17}J, which represents a thermal power output of 3.9 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 the tributaries, i.e., the Abo and Shiratani valleys at the southwestern foot of Yakedake volcano. Their localities and general topography in the study area are shown in Fig. 6.

The Takahara River geothermal zone extends about 4,500 m from nearby the Hirayu bus terminal , through the Fukuji hot spring, to the Uwajigane hot spring along the river. By assuming the temperature difference δT = 150 deg and the length l = 4,500 m of this zone, the geothermal energy within the Takahara River geothermal zone is calculated to be 4.2 x 10^{17} J, which represents a power output of 4.4 x 10^2 MW_{th}.

Azusa River

The Azusa River geothermal zone extends about

2,000 m from nearby the Kama tunnel, through the Nakanoyu hot spring, to the Sakamaki hot spring along the river. The present study area is located at the southeastern foot of Yakedake volcano. The hydrothermal activity is intense in the Azusa River and on the mountainsides along the National Road Route 158. The localities of the self-flowing hot waters, surface temperatures and general topography in the study area are shown in Fig. 7. The numerical value shown nearby the marks of black circle and double circle in this figure indicates the measured temperature of the water and the surface of rock. Contours in this figure indicate the altitude above sea level in meters. The highest temperature was observed at the mountainside (alt., 1,300 m) in the vicinity of the Nakanoyu-spa. The hot water gushes mainly at the mountainside of Yakedake volcano on the right bank of the Azusa River.

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 1.9×10^{17} J, which represents a power output of 2.0×10^{2} MW_{th} averaged over 30 yrs.

4. DISCUSSION

Eruption

To calculate the heat power output in Section 2, a characteristic time interval of 30 yrs between cousecutive eruptions within the summit lava dome was chosen. The latest records of the main eruptions that formed a new crater are as follows; 1962, 1935, and 1915, which supports this value. A big eruption will eject all materials from within the crater having a high heat energy (including the magma body). After the eruption the inside of crater will cool down, but very soon its temperature will be raised again by ascending and newcoming magma.

As listed in Tables 1 and 2, the fumarolic temperatures of the Yakedake summit dome and of the Iwodake dome have not increased greatly during the several years. The field evidence shows that the movement of magma and the formation of vent and of fissure have not occurred within the Yakedake volcano. However as the fumarolic temperatures at altitudes between 2,240 and 2,270 m in the Yakedake lava dome are exceeded or are equal to the boiling point of water at the altitude at any time; land slides or collapses of dome by earthquake and by long and heavy rains will easilyresult from a steam explosion on the Yakedake volcano.

Heat Flow

The heat flow escaping by vertical conduction from the mountain foot will be discussed.

Firstly, for the Gamada River geothermal zone , the mean thermal gradient is 0.487 ° C/m at depths between 30 and 105 m within the CU-1 well in the Karukaya area. The measurements were performed at the newly reached bottom depths of the borehole at least 18 hours after drilling was completed. There is a notable water movement at depths between 105 and 140 m of the bottom depth. The mean thermal conductivity is 3.38 W/m·° C in the stratum. 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 Japanese islands. However, for the heat flow in the Okinawa Trough, Yamano et al. (1988) have measured 1.60 W/m^2, which is comparable with the present measurement. Thermal conductivity of rocks from the volcano and the mountain foot is measured by a non-steady method and is listed in Table 5.

Secondly, heat flow measurement station of the Esakake area is in a mountain section about 800 m east of the Takahara River geothermal zone. The mean thermal gradient is 0.212 ° C/m at depths between 50 and 180 m within the S2-hole (alt., 1,112 m) in the Esakake area. The thermal conductivity measured by Kiyohashi et al (1983) was 0.246 for core samples in the stratum. The corresponding surface heat flow by vertical conduction is 0.246 W/m^2 in the S2-hole.

Geyser

A mechanism of eruption of the geyser will be discussed (see Sec. 3). The field observation shows that at the first stage the eruption of a small amount of hot water is recognized (see Fig. 8) and the eruptions in advance happen several times (Fig. 9). At the main stage a big eruption occurs (Fig. 10). And at the final stage some amounts of erupted water go back from ground-surface around the well-head to the conduit. If the water temperature reaches the boiling point of water at a depth, the boiling and bubbling are commenceing there. Therefore the hot water in the conduit rises toward the ground-surface and a small amount of hot water gushes out from the well-head, followed by decreasing water pressure in the conduit. Second boiling phenomena occur easily in the conduit. If the process is repeated some times, the hot water in the conduit will transform to the steam successively. Then explosive eruption will occur. The time during the eruption and the rest of the Karukaya geyser was 26 minutes and 180 minutes, respectively, in Apr. 19 and 20, 1987. The maximum height of this eruption was about 20 m.

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REFERENCES

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: 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 Geothermal 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 publ.), 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. and Iriyama, M., 1987. Observations of the Karukaya geyser, Yakedake volcano (I). Geotherm. Res. Soc. Jpn. 1987 Ann. Meeting, Abstr., p.30.

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.

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. Jour. Geotherm. Res Soc. Jpn., 5: 305-320.

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

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.

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.

Uyeda, S., 1967. Terrestrial heat flow. Bull. Volcanol. Soc. Jpn., 12: 41-59.

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.

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

Solfa.	Sep.29,1991	Sep.23,1990	Oct.9,1989	Oct.9,1988	Sep.14,1987	Sep.7,1986
Y 1	76.0	78.8	77.2	80.2	79.3	77.5
Y 2	74.9	69.9	73.5	70.5	67.9	47.6
Y 3	92.7	92.5	92.8	92.6	92.7	92.6
Y 4	92.6	92.4	92.7	92.7	92.7	92.7
Y 5	68.0	60.0	66.9	70.8	60.5	
Y 6	67.1	65.4	63.6	66.9	68.8	

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

Fumar.	Sep.29 & 30,1991	Sep.23,1990	Oct.9,1989	Oct.10,1988	Sep.14,1987
I 1	46.9	46.4	46.4	47.1	48.6
I 2	48.1	49.8	47.9	51.8	52.8
I 3	58.3	58.7	60.1	61.8	58.0
I 4	59.2	59.6	59.4	61.2	59.2
I 5	58.1	57.0	59.8	61.0	56.3
I 6	41.0	41.7	40.3	42.8	40.1
I 7	59.8	61.1	60.3	62.5	61.9
I 8	61.4	62.3	64.7	59.0	65.4
I 9	58.1	58.2	58.2	60.5	52.1
I10	60.7	59.4	61.2	62.1	60.0
I11	62.4	62.2	62.6	63.5	62.5

Table 3. Measured thermal conductivity of rocks from the Yakedake volcano and the geothermal zones

Locality and Number of samples	Type of rock	Depth [m]	K [W/m° C]
Yakedake dome			
YF4-2(= YAK-1)	Andesite	~ 0	0.973
YA81-2	Andesite	~ 0	1.60
YF4-1	Andesite	~ 0	1.23
Gamada River (Karukaya)			
CU1-21	Andesite	21.5	3.36
CU1-40	Chert	40.6	3.54
CU1-85	Rhyolitic tuff	85.0	3.21
CU1-105	Rhyolitic tuff	105.0	3.70
Takahara River (Obakobara)			
HIR-OB	Slate	~ 0	3.19

Figure captions

Fig. 1. Location map of water recharge area and hot water discharge area, and general topography in the study area. Contours indicate the alititude above sea level in meter.

Fig. 2. View of the crater pond Terugaike of Yakedake from the eastern crater-rim, in October, 1991.

Fig. 3. Locality map of solfatara (Y) and fumaroles (I) studied in the summit dome areas of Yakedake and Iwodake volcanoes. Contours indicate the altitude above sea level in meter.

Fig. 4. Locality map of self-flowing springs, geyser and hot spring wells studied in the Gamada River geothermal zone. Contours indicate the altitude above sea level.

Fig. 5 Pressure change (gauge pressure) with time at well-head, Karukaya geyser.

Fig. 6 Locality map of hot springs studied in Hirayu and the surrouding areas, Takahara River geothermal zone. Contours indicate the altitude above sea level.

Fig. 7 Locality map of self-flowing hot springs, and the surface temperatures in the Nakanoyu area, Azusa River geothermal zone. Contours indicate the altitude above sea level.

Fig. 8 Eruption of small amount of hot water at the first stage, Karukaya geyser, Gamada River geothermal zone.

Fig. 9 Eruption in advance happening several times, Karukaya geyser.

Fig. 10 Full eruption at the main stage, Karukaya geyser.

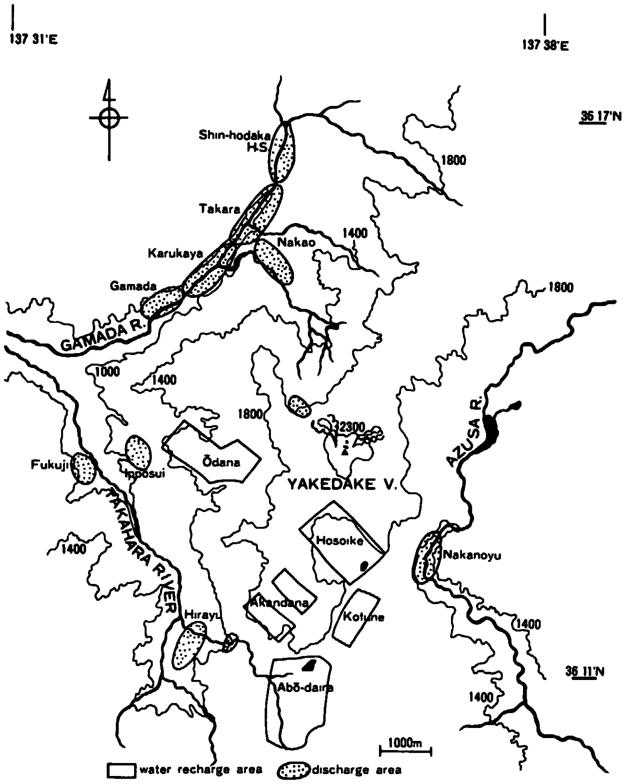


Fig. 1

Fig. 2

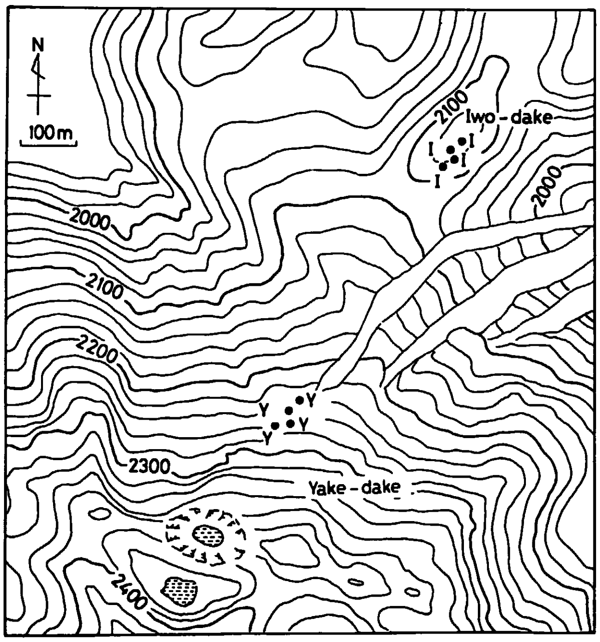
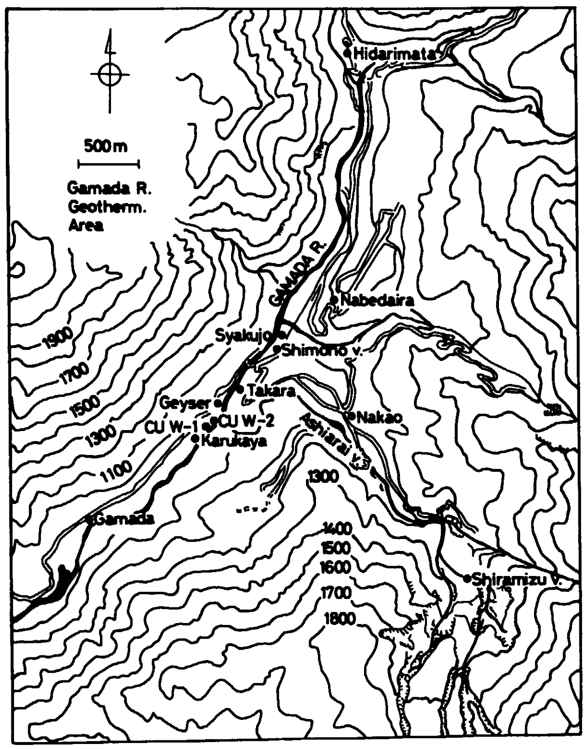


Fig. 3



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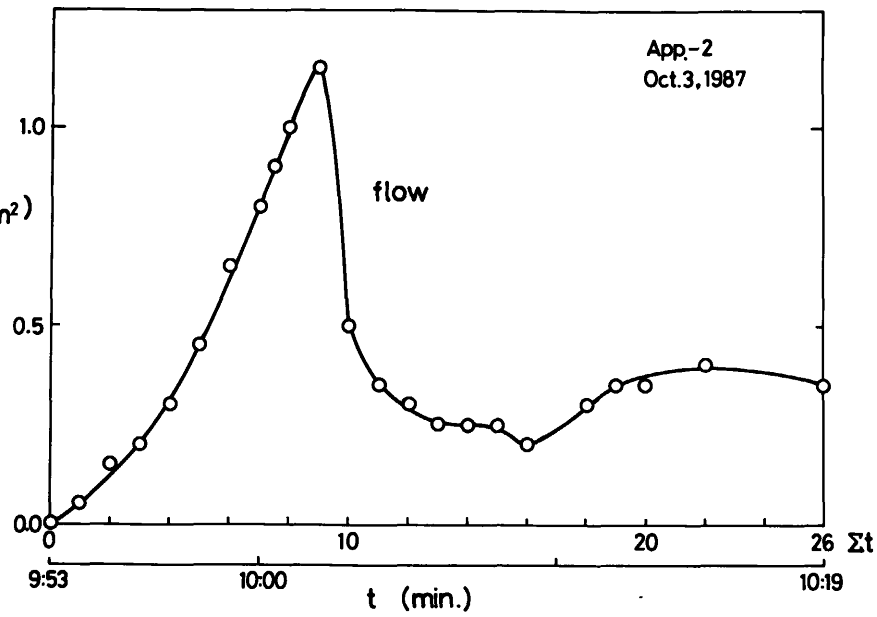
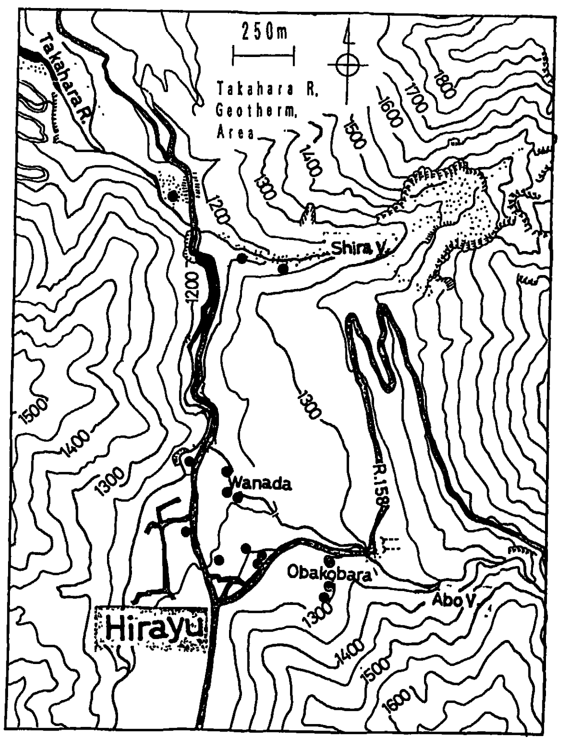


Fig. 5



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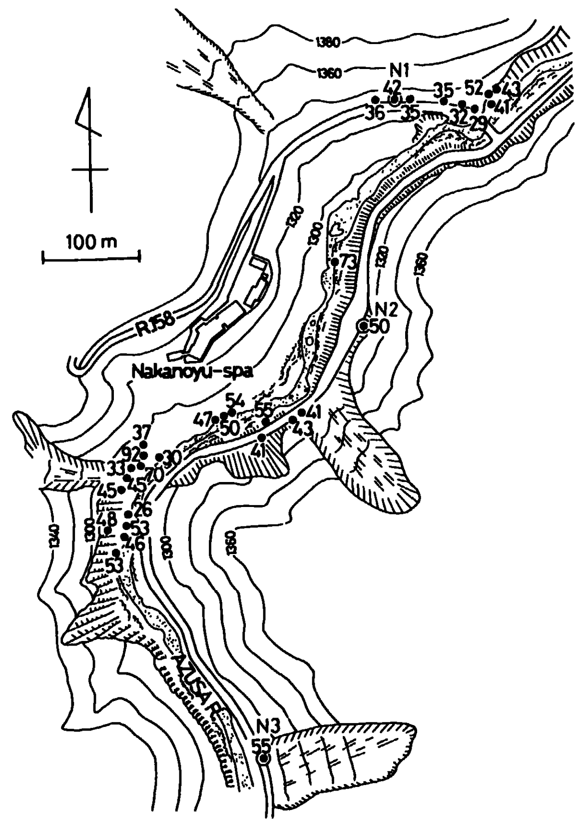

Fig. 7

Fig. 8

Fig. 9

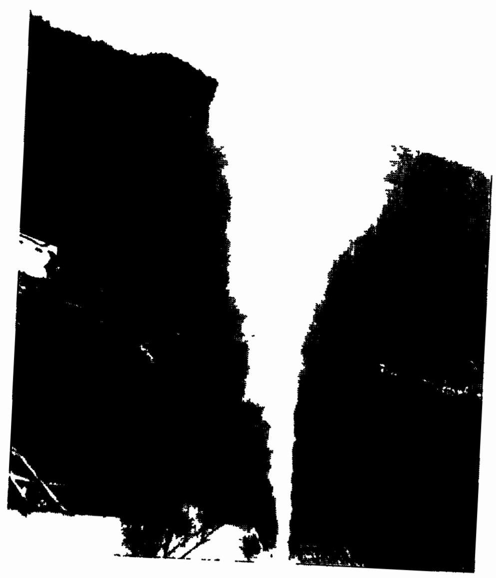

Fig. 10