Proc. 8th NZ Geothermal Workshop 1986

HEAT UISCIIAKCE AND SEISMIC ACTIVITY IN THE ACTIVE SOLFATARIC FIELD,CENTRAL KYUSHU,JAPAN

S. EHARA

Depart■ent of Mining,Faculty of Engineering,
Kyushu University,Fukuoka,Japan

ABSTRACT

The Kuju-iwoyama area shows the most intense solfataric activity in central Kyushu,Japan. In the area,we measured heat and water discharges by fumaroles , steaming grounds , hot springs and ther■al conduction. The total heat and water discharges amount to 9Y.2 MW and 235 T/H, respectively. Such a large discharge 'rate and high fu■arolic temperatures amounting to 500℃ suggest the upward transfer of magmatic **steam** flow. Anomalously high seismic noise level was observed at the solfataric area. The amplitudes. of the seismic noise have a close correlation with the surface lieat discharge rates. Such a fact suggests that the origin of the seismic noise is the motion of the steam and/or phase change of,water under the near—surface. A temporary seis■ographic network ras installed around active solfataric area.Aa a result; very active seismic activity has been clarified in and around tlie solfataric area. Based on the detailed hypocenter distribution. we can discuss the heat transfer process **below** such an active solfataric area.

INTKODUCTION

There are many active and dormant volcanoes in central Kyushu, Japan. Hany fumaroles and hot springs also exist in connection with the volcanoes. The Kuju volcano group which is one of them, is to the northeast of Aso volcano. The distance between the■ is about 25 K■. Kuju-iwoya■a is ari explosive crater of Mt.Hosshoya■a of the group and shows the most intense solfalaric activity. Phreatic explosions occurred in historic ages. In the Iwoyama area , we have measured heat and water discharges by fumaroles. steaming grounds, hot springs and thermal coaduction through soil in order to clarify the thermal state beneath the area. Also we have observed geother■al seismic noise and microearthquakes in and around the Iwoya■a area. By combining the thermal and seismic data. we tried to clarify the thermal process beneath this area.

THERMAL DATA AND AN MODEL OF THE IIYDRDTHERMAI. SYSTEM

In the Iwoyama area, heat and water discharges were measured in 1977(Ehara et al.,1979) , 1979(Ehara et al., 1981) and 1985. The heat discharges by fumaroles , steaming grounds, hot springs and ther■al conduction are 1.26×10^7 cal/sec, 1.04×10^7 cal/sec, 8.1×10^5 cal/sec aid 7.2×10^4 cal/sec, respectively. The total heat discharge amount to 2.38×10^7 cal/sec (99.2 MW). The bulk of it is transferred by steam. The water discharges by hot springs and' by steam are 19.5 Kg/sec and 45.7 Kg/sec ,respectively. The total water discharge amounts to 65.2 Kg/sec (235 T/H). The bulk of it is also transferred by steam.

Total volcanic gas emissions were also estiwted. based on chemical analyses and the water discharge, to be CO_2 166 t/day, H_2S 33 t/day, SO_2 26 t/day, S 3.2 t/day, HCl 3.2 t/day and HF 0.07 t/day.

A quantitative hydrothermal system was proposed, based on the total heat and water discharges. We assumed that the hydrothermal system is composed of the surface zone, the shallow thermal water reservoir and the heat source (the magma reservoir). From the ■ag■a,the heat and steam are transferred upward by magmatic gas and ther■al conduction. Cooling of the ■ag■atic steam on the way from the magma reservoir to the ther■al water reservoir **is** calculated by using the method developed by Yuhara(1968). We also assume that the depth of the thermal water reservoir is 2 Km deep. At the depth, the ■ag■atic steam mixes with the meteoric water and forms there a thermal water reservoir. The water discharged from the reservoir rises up to the surface and makes thermal ■anifestations. When the ther■al discharge is measured and the depth and the temperature **of** the heat source are assumed , re can estimate the ■ag■atic stea■ *flow* rate and the temperature of the steam at 2 Km deep. Using the observed heat and water discharge data, they are estimated to be about 20.3 Kg/sec to 24.0 Kg/sec and 990 ℃ to 790 ℃ depending on the assumed temperature of the ■ag■atic reservoir at 5 K■ deep to be 1000℃ to 800℃. In the above calculation , the upper limit **of** the heat supply'from below by ther■al conduction is assumed to be 2.5×10^6 cal/sec,

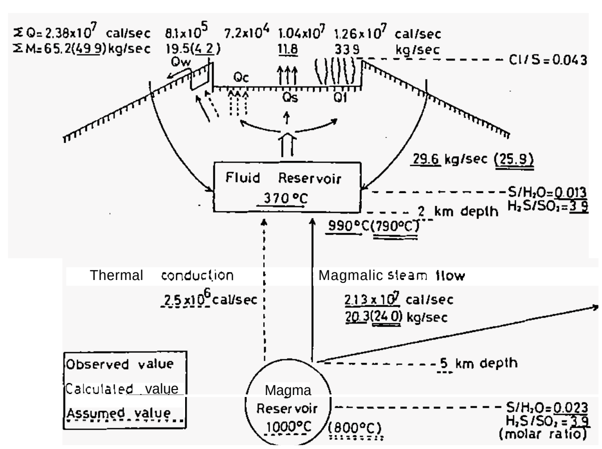

Fig.1 Hydrothermal system **of** the Kuju-iwoyama **area** estimated quantitatively from observed water and lieat discharges.

based on the theoretical study by Fukutomi(1965). The temperature of the thermal uater reservoir is estimated to be 370 ℃. Therefore the thermal state of the water in the reservoir is supposed to be near the critical point of uater on the average. The percentage of the magmatic steam to the total uater discharged is about 41% to 48%. A model of hydrothermal system is shown in Fig.1. One of the main features of this model is the existence of magmatic steam supply. The high fumarolic temperatures amounting to 500℃ support this idea. Furthermore, isotopic study of volcanic gases shows that the volcanic gases from high temperature fumaroles have retained their original chemical and isotopic compositions that had been acquired in the undergrouiid high temperature rock or in the source magma (Matsubaya, personal communication). Therefore high enthalpy magmatic gas supply must exist in the Iwoyama area.

SEISMOLOGICAL DATA

Geothermal seismic noise

A seismic noise study has been carried out on the Iwoyama area in 1977(Ehara et al.,1979) and 1985. As a result, anomalously high seismic noise level of several tens of Hz was observed in and near the active solfataric area as shown in Fig.2(a).Fig.2(b) shows the geothermal temperatures at 1m depth versus altitudes of measurement sites. Anomalies of geothermal temperatures and seismic noise level are confined to a narrow region. Predominant frequencies and amplitudes of seismic noise have a close correlation with the surface heal flow. Therefore the origin of the seismic noise observed in the Iuoyama area is considered geothermal.The depths of the seismic noise sources uere estimated by using a theoretical expression for seismic noise attenuation versus distance. As a result. the depths of the origins uere estimated to be less than 30 m ,that is , very shallow. Such a result shows that the origin of the high seismic noise is the motion of the steam and/or phase change of water under the near-surface.

Microearthquake observation

A temporary seismographic netuork was installed around the active solfataric area in order to clarify the underground thermal process as shown in Fig. 3. Accordindg to the recent seismological study in this region (Mitsunami et al.,1981), almost any micro-earthquake activity is not observed near the Iuoyama area. However,in their observational network,there is no observation point near the solfataric area. From the thermal study mentioned earlier, we anticipated lliat microearthquakes may occur beneath the active solfalaric area. After the preliminary observation in August,1985, we conducted an array observation (six seismograph stations) in and around the active solfataric area from May 27 to June 10, 1986. Other two stations uere installed to monitor the seismic activity in the arca from May 12 to July 11.

The 1985 preliminary observation (One seismometer was

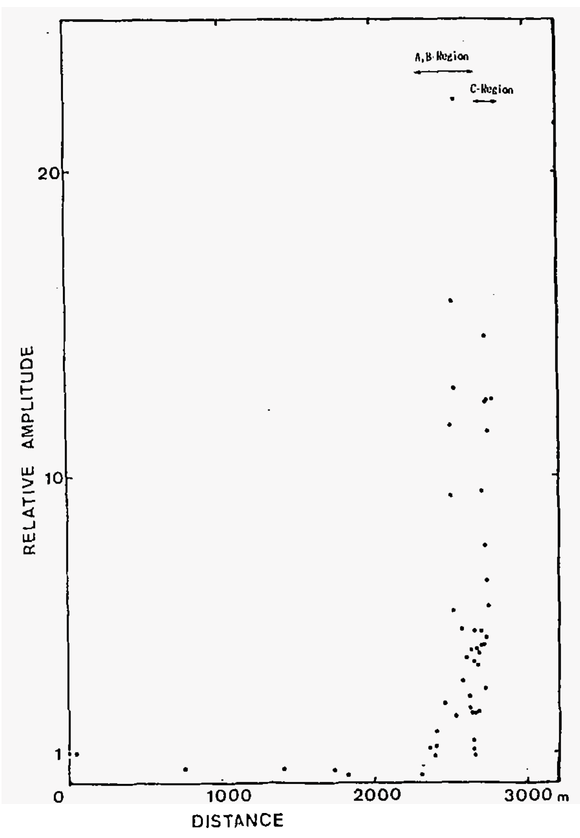

Fig.2 (a) Profile of seismic noise level from the foot of Kuju volcano to the Iwoyama area.

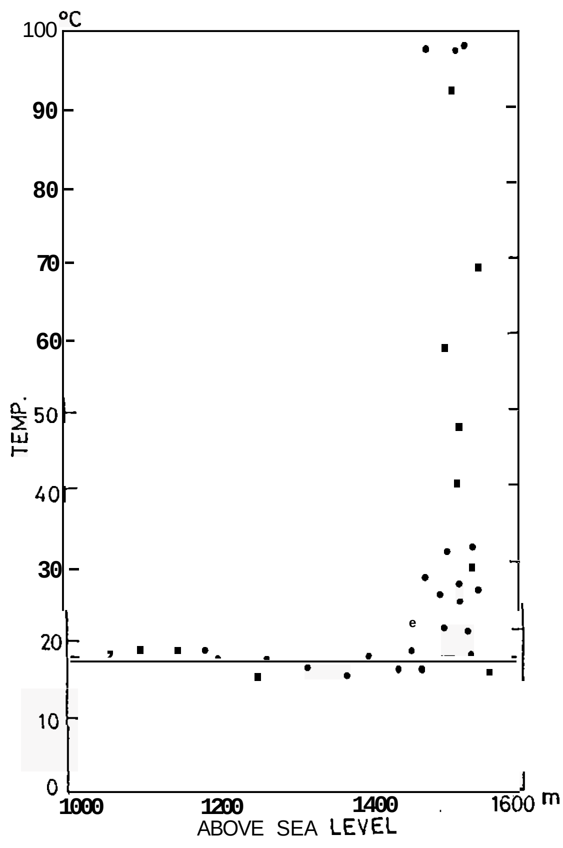

Fig.2 (b) Geothermal temperatures at 1 m depth versus altitudes of measurement sites from the foot of Kuju volcano to the Iwoyama area.

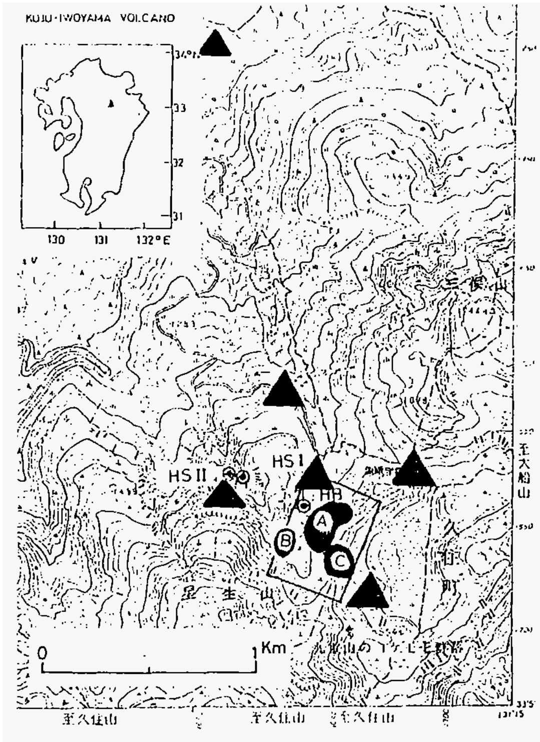

Fig.3 Hap of geothermal manifestations and seismic observation points in the Iwoyrma area. A.B and C regions show solfataric activities. HB, HS1 and HS2 are hot springs. Solid triangles show seismic observation points. Inset shows the location of Kuju volcano, Kyushu, Japan.

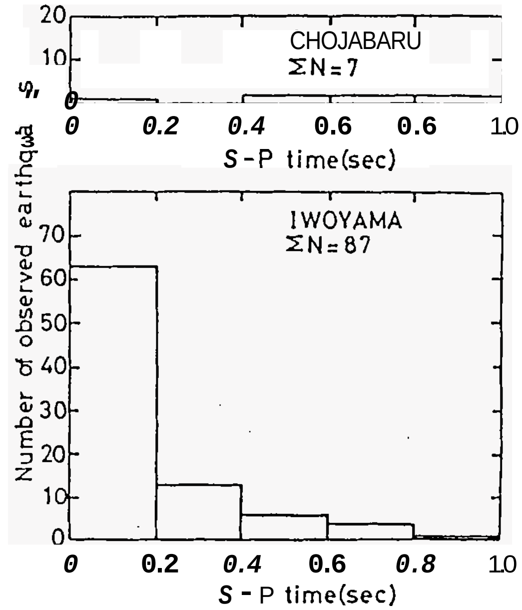

Fig.4 Frequency distribution of S-P time interval.
Upper: Chojabaru station (on the foot of the volcano).
Lower: Iwoyama station (near the solfataric area).

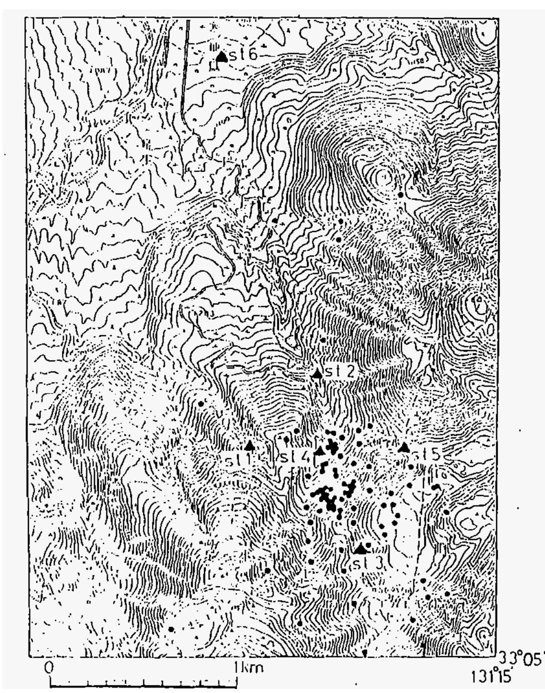

Fig.5 Epicenter distribution in and near the luoyama area.

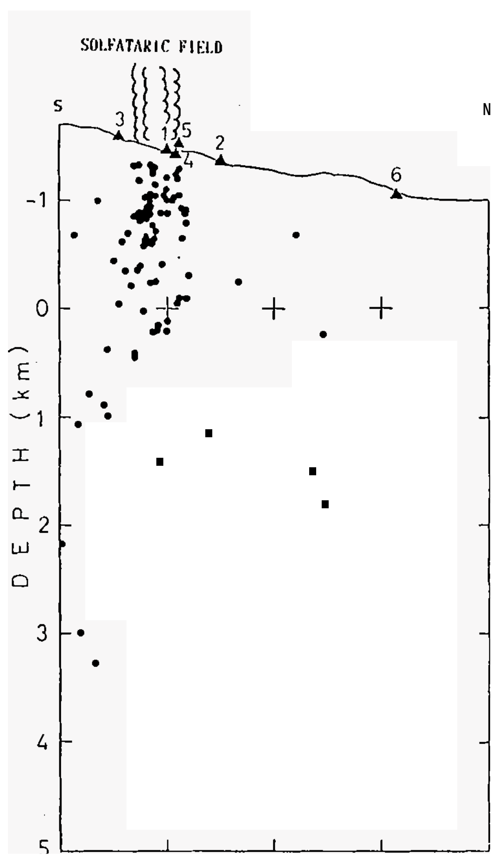

Fig.6 Hypocenter distribution along the north - south direction in and near the Iwoyama area.

installed near the solfataric area and another on the foot of the volcano which is about 2.5 Km distant from the solfataric area.) was conducted only for 5 days. At the station near the solfataric area, many micro-earthquakes were observed. The total number of earth-quakes with shorter S-P time interval than 1.0 sec is 87. Furthermore most of them have shorter S-P time interval than 0.2 sec as shown in Fig.4.Hypocenters are assumed to be shallower than several hundred meters.Most of the earthquakes observed at the station near the solfataric area were not detected at the station on the foot of the volcano.One of the reasons is a very shallow origin and another is strong seismic wave attenuation in the surface layer of the volcano.

The 1986 array observation clarified the characteristic pattern of the hypocenter distribution as shown in Fig.5 and Fig.6. Host of the earthquakes occurred beneath the solfataric area. The hypocenters are shallower than 5 Km below the. surface. Especially, many earthquahes occurred at the shallower depth than 1 Km below the solfataric field.

The observed earthquakes beneath the solfataric arca are divided intn two groups, according lo their depths of hypocenters. One is a shallow origin (several hundred meters to 3 Km deep). Another is an deep origin (deeper than 3 Km deep). They do not always occur together. Especially, most of the shallow microearthquakes seem to have occurred, stimulated by the felt earthquake (M=4.7) which occurred near the solfataric area. The distance between the solfataric area and the epicenter of the felt earthquake is about 7 Km. But, deep earthquakes were not stimulated by the felt earthquake. The above result is only preliminary. The detailed results will be given in another paper.

AVDROTHERHAL SVSTEH AND SEISMIC ACTIVITY

Thermal and chemical data shou the existence of magmatic steam supply from below. Part of the magmatic steam will contact with the groundwater at depth which infiltrates through the volcanic body. In other words, the high temperature steam mixes with the low temperature ground water. As a result, the temperature of the steam cools somewhat and part of the steam condensate. On the otherhand part of the groundwater may vaporize. The cooled magmatic steam including the vaporized groundwater will again mix with another groundwater at a shallower depth. Therefore the temperature of the steam decreases gradually. However, the vapor pressure decreases with upward movement of the gas. Therefore condensed steam may vaporize again. Thus, vaporization and condensation of the volcanic steam will be repeated.

The shallow seismic activity may reflect such a vaporization and condensation process. On the otherhand deep earthquakes may have a connection with the upward magmatic steam flow. In this case, ue may get saturated steam at shallower depth than a few kilometers and superheated steam at deeper depth than a few kilometers below the surface.

The above interpretation is tentatively. However,by locating the hypocenters beneath active solfataric fields , we shall be able to deduce the thermal process beneath them more concretely.

CONCLUSION

Various thermal measurements were made at the active solfataric field(Iwoyama area),central Kyushu,Japan. A model of hydrothermal system was presented based on the thermal and geochemical data. The model demands the upward transfer of the high temperature magmatic steam from below.

Hicroearthquakes occurred just below the solfataric field are divided into two groups ; deep (deeper than 3 Km below the surface) and shallower (shallower than 3 Km below the surface).

The underground thermal process was discussed by combining the model of hydrothermal system with occurrence of earthquahes. As a result, it is deduced that occurrence of earthquakes beneath the active solfataric field(Iwoyama area) has a contact connection with condensation and vaporization of upward volcanic steam flow.

Anomalously high seismic noise level was observed at the solfataric field.The depths of the origins are very shallow (shallower than 30 m). The origin of the geothermal seismic noise is the motion of the steam and /or phase change of water under the near-surface.

REFERENCES

Ehara,S., Yuhara,K. and Yoneda,K.(1979): A relation between heat flow and seismic noise at Kuju-iwoyama , Kyushu, Japan. Bull. Volcanol.Soci.Japan, Vol.24, 41-53 (in Japanese with English abstract).

Ehara,S., Vuhara,K. and Noda,T.(1979): 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.Soci.Japan, Vol.26,35-56(in Japanese with English abstract).

Fukutomi,T.(1965): Temperature of hot springs of meteoric water origin. Geophy.Bull.Hokkaido Univ, Vol.9, 53-70 (in Japanese with English abstract).

Hitsunami ,T, Kubotera, A.Omote, S.and Kinoshita,Y.(1981): Seismicity of the Hohi geotherwal area, Kyushu, Japan. Jour.Geotherm. Res.Soci .Japan. Vol.3,43-53(in Japanese with English abstract).

Vuhara, K.(1968): Quantitative estimation of hydro-thermal system of the Owakudani and Sounzan geothermal areas, Hakone volcano. Bull.Volcanol. Soci. Japan. Vol.13, 74-84 (in Japanese with English abstract).