SEISMIC ACTIVITY AND THERMAL PROCESS BENEATH THE KUJU-IWOYAMA FUMAROLIC AREA,CENTRAL KYUSU,JAPAN

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INTRODUCTION

There are four active volcanoes, that is, Tsurumi, Kuju, Aso and Unzen in central Kyushu Japan(Fig.1). The latter two volcanoes have erupted in historic ages. But only phreatic explosions occurred in the former two volcanoes. The Kuju volcano group is composed of many lava domes and a strato volcano. The main rock type is hornblende andesite(VSG and IAVCEI,1971). Kuju-iwoyama is an explosive crater of Mt.Hosshoyama of the group and shows the most intense geothermal (mainly fumarolic) activity in central Kyushu. The Otake and Hatchobaru geothermal power stations are 5 km west of the fumarolic area. Based on the measurement of heat and mass discharges, we proposed a simple thermal model for the area (Ehara et al.,1981). Recently we conducted a microearthquake observation in order to clarify the seismic activity and the undeground structure beneath the fumarolic area. As a result, an active seismic zone and an anomalous structure were observed just beneath the fumarolic area. In this paper, we tried to propose a thermal model to satisfy the observed thermal and seismological data.

GEOTHERMAL ACTIVITIES OF THE FUMAROLIC AREA

The fumarolic area(c.a.0.2 km^2) is at the northeastern flank of Mt. Hosshoyama and about 1500 m height a.s.l. The natural heat discharge is about 100 MW and most of it(more than 95%) are from fumaroles and steaming grounds. The total water discharge is about 65 kg/s. Part of it(about 19.5 kg/s) are by hot springs. However, the origin of most hot springs (about 15.3kg/s) is considered to be near surface meteoric water by the geochemical study (Ehara et al.,1981). These hot springs are acid ones(pH=1.5-2.0). The temperatures of fumaroles in a natural state usually exceed 200°C (Ehara et al.,1981) and the maximum temperature is 480°C (Iwasaki et al.,1964). An isotopic study of fumaroles,hot springs and ground water showed little if any contribution of the present meteoric water to high temperature fumaroles (Matsubaya et al.,1975). On the other hand, the mixing of the present meteoric water is deduced for hot springs and low temperature fumaroles as shown in Fig.2.

SEISMIC ACTIVITY BENEATH THE KUJU-IWOYAMA FUMAROLIC AREA

Previous seismological studies show that the seismic activity of Kuju volcano is extremely low (Wada et al.,1972, Mitsunami et al.,1981). However, recent our observation clarified an active seismic zone just beneath the fumarolic area. Such a result was obtained by installing seismometers just around the fumarolic area. The hypocenter distribution is shown in Fig.3. Most of the microearthquakes are located just beneath the fumarolic area. The depths of hypocenters are limited in a shallow depth than 2 km. The daily numbers of observed microearthquakes are 10 to 20 on the average. However, the mode of occurrence is rather swarm type. For example, about ten earthquakes occur very often in a few minutes. The b value is 0.91 and similar to that of the ordinary tectonic earthquakes. The seismic activity showed a very peculiar sequence during our observation. A felt earthquake (m=4.4) occurred at 10 km southwest of the fumarolic area. The seismic activity in the fumarolic area decreased suddenly for two weeks before the occurrence of the felt earthquake. Then the seismic activity increased suddenly one day before the occurrence of the felt earthquake. After that, the seismic activity beneath the fumarolic area decreased and five days after returned to the ordinary level (10 to 20 per day) as shown in Fig.3. The seismic activity just beneath the fumarolic area seems to be affected by the surrounding tectonic stress field.

Lower P wave velocity and lower Poisson's ratio are obtained just beneath the fumarolic area. The low P wave velocity may show the existence of many fractures beneath the fumarolic area. The low Poisson's ratio may show the existence of large two-phase (hot water and steam) zone beneath the fumarolic area. The study of the focal mechanisms was also conducted but a dominant focal plane solution was not obtained. It means that each earthquake is not triggered by the common stress field, for example, the regional tectonic stress field, even though many earthquakes were affected by the occurrence of the felt earthquake as mentioned before.

THERMAL PROCESS BENEATH THE FUMAROLIC AREA

As mentioned above, in the region from the surface to 2 km depth just beneath the fumarolic

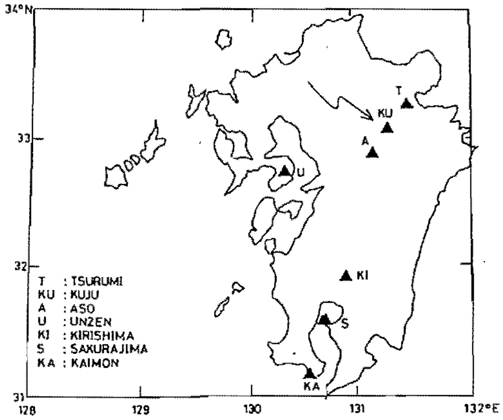


Fig.1 Location map of active volcanoes in Kyushu.

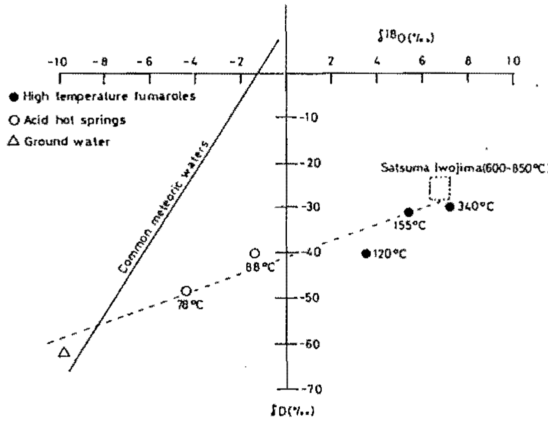
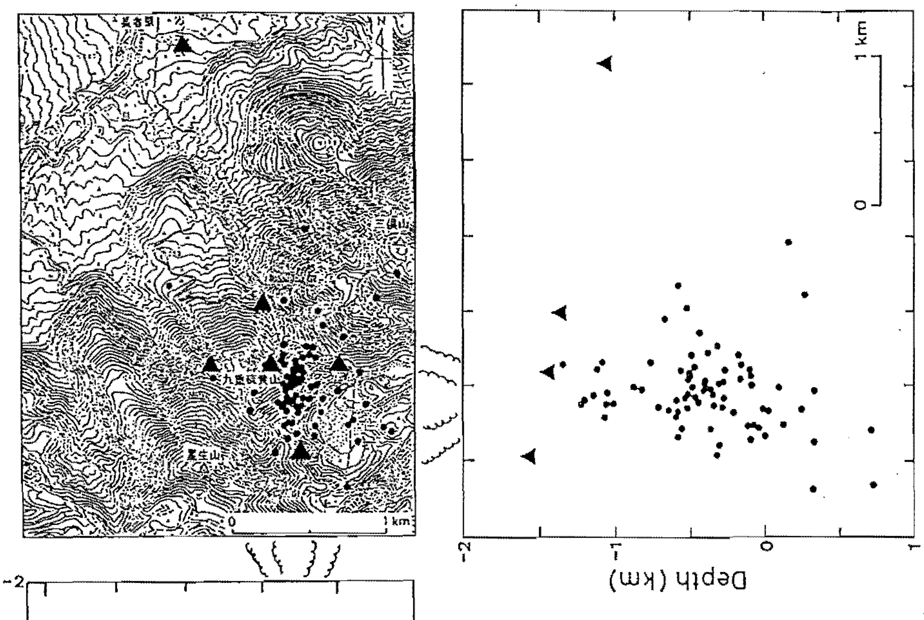


Fig.2 Isotopic variation in fumarolic gas, hot springs and groundwater in the Kuju-iwoyama region.



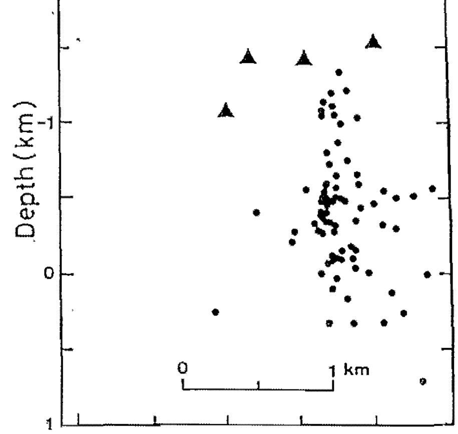


Fig.3 Hypocenter distribution at the Kuju-iwoyama region. Solid triangles; seismometers, Solid circles; hypocenters.

area, the seismic activity is high and the P wave velocity is low. Then the region is deduced to be fractured and accordingly permeable. That is , the active seismic zone is a hot geothermal reservoir. The magmatic steam supplied from below along the vent or the fault mixes with the meteoric water at the permeable zone. Finally, the rising steam and water are discharged from the fumarolic area into the air. Based on such a magmatic steam-meteoric water mixing model, we try to interprete the thermal data and the seismic activity quantitatively by computer modelling (modified SHAFT79 program, Pruess and Schroeder,1981, O'Sullivan,1985), assuming a cylindrical symmetric body (Fig.4). The central part (500 m in diameter) corresponds to the fumarolic area. The high permeable zone (permeability=5×10^{-14} m^2, zone A in Fig.4) extends from the surface to 2 km depth. The diameter of the area concerned is 5 km, considering the recharge area (Kawamura,1984). The permeability of zones B and C is 1×10^{-15} m^2. Magmatic steam is supplied from the bottom surface of the central part. At the top surface, the water and steam are discharged and recharged freely. Conductive heat is supplied from the bottom surface excluding the central part and the boundary conditions at the side are adiabatic and impermeable. A good fit model is shown in Fig.5 . In this model, the magmatic steam of 30 kg/s (enthalpy=3500 kJ/kg) is supplied from below, mixes with the meteoric water of about 10 kg/s and finally the steam (35.8 kg/s) and the hot water (4.4 kg/s) are discharged at the surface. The natural heat discharge is 104.4 MW. The temperature, pressure and vapor saturation are shown in Fig.6. The temperature of the first layer(0-250 m depth) at the central part is about 210°C, which agrees well with the observed fumarolic temperatures. The temperature in the bottom layer(1750-2000 m depth) exceeds 340°C. The central high permeable zone is in a state of two phase at any depth. The temperature outside the central part are nearly linear with depth, which means that the heat transfer is mainly by conduction. The pressure distribution outside the central part is nearly hydrostatic. In the central part, the pressure in the lower part is a little lower than the hydrostatic one but in the shallower part,is a little (to 1 MPa) higher than the hydrostatic one. The high pressure in the central part (high permeable zone) may become an origin of the high seismic activity in this part,since the high pore pressure lowers the strength of rocks. The temperature of the superheated steam with the enthalpy of 3500 kJ/kg and the pressure of about 15 MPa is about 580°C, which is reasonable, because the observed maximum temperature (480°C)is lower than this value. A production process was simulated by extracting the fluid of the second layer(250-500 m depth) in the central part. The production rate is 30 kg/s of the hot fluid, which is comparable to 10 MW power generation. In Figure 7, the temporal variations of several physical properties during exploitation are shown. As a result, it is concluded that the heat extraction for more than 10 years is possible, without having big effect on natural geothermal activities ,even when the supply rate of the magmatic steam does not increase. The development of the two-phase reservoir beneath the active fumarolic area is a possible method to utilize volcano energy in the near future.

CONCLUSION

A model for the underground thermal process of an active fumarolic area was presented based on the thermal and seismological data. The model shows the following features; High temperature magmatic steam (about 580°C and 30 kg/s) is supplied from below to a depth of 2 km. The magmatic steam mixes with the meteoric water (10 kg/s) in the high permeable zone (0 to 2 km depth) just beneath the fumarolic area. The permeable zone is in a state of two-phase. The pressure in the permeable zone is a little higher than the hydrostatic one. The higher pressure is considered to be an origin of the high seismic activity beneath the active fumarolic area. The development of the two phase reservoir just beneath the fumarolic area is a possible method to utilize volcano energy in the near future.

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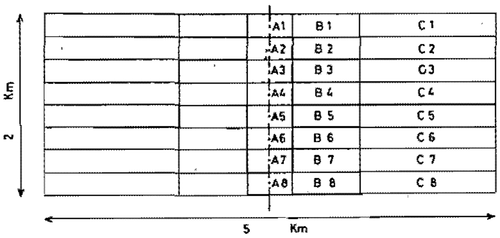

Fig.4 Block layout for the radially symmetric model.

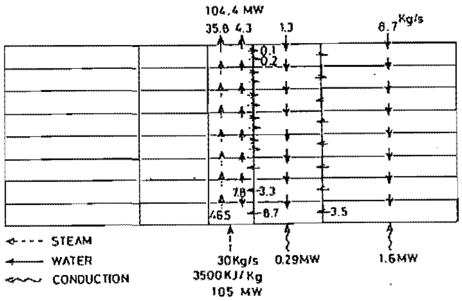

Fig.5 Some parameters of the best fit model.

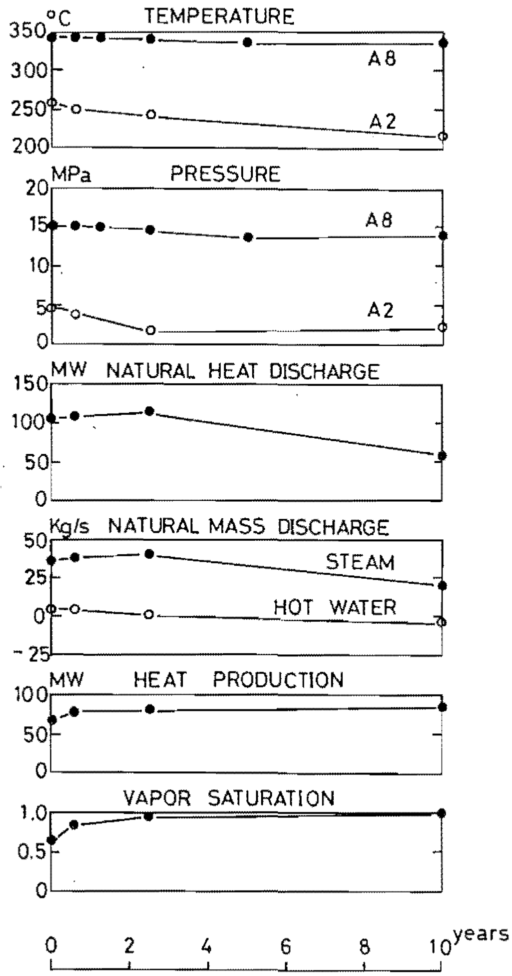

Fig.7 Temporal variations of several physical properties during exploitation.

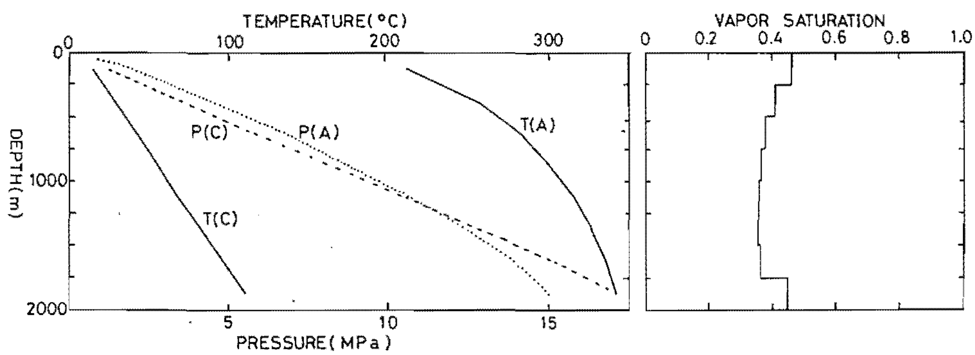

Fig.6 Temperature,pressure and vapor saturation profiles of zone A (discharge area) and zone C(recharge area).