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MONITORING OF A VOLCANIC GEOTHERMAL RESERVOIR THROUGH MULTIPARAMETER MEASUREMENTS-A CASE STUDY OF THE CENTRAL PART OF KUJU VOLCANO, JAPAN-

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ABSTRACT

Kuju volcano is situated in central Kyushu, Japan, which has a two-phase volcanic geothermal reservoir beneath the active fumarolic field. In October 1995, a phreatic eruption occurred near the fumarolic field of Kuju volcano. After that, active steam discharge activity has been continuing from the new craters and the pre-existing fumarolic field. We have been continuing to monitor the volcanic geothermal reservoir through the multiparameter measurements (including thermal, hydrological, gravimetric, magnetic, seismic, geodetic etc.). The mass balance in the volcanic geothermal reservoir and the cooling of the heat source concerned were discussed based on the multiparameter measurements, which shows that the hydrological state of the volcanic geothermal reservoir is reaching a new equilibrium state gradually and the temperature of the heat source is decreasing after the eruption. Monitoring by thermal, magnetic and gravimetric measurements are very effective to understand changes in the physical state of a geothermal reservoir, especially for phreatic eruption which is very similar to production without reinjection of geothermal fluids.

INTRODUCTION

Kuju volcano began to erupt on 11 October, 1995 at the eastern flank of Mt. Hossho, which is in the central part of Kuju volcano. The eruption was phreatic and there was no magmatic activity at the surface even though the vesiculated glass shards were detected in the ash (Hatae et al., 1997). We conducted multiparameter measurements including thermal, magnetic and gravimetric measurements in order to monitor the volcanic geothermal reservoir.

Surface and subsurface thermal states were monitored by the repeat infrared and geomagnetic measurements, respectively. The water mass balance around the new craters and the pre-existing fumaroles was monitored by the repeat measurements of the discharged steam and the gravity, respectively.

The hydrological state around the new craters and the pre-existing fumaroles was discussed based on changes in the subsurface temperature and the water mass balance.

KUJU VOLCANO AND ITS VOLCANIC GEOTHERMAL RESERVOIR

Kuju volcano, composed of many lava domes, is situated in central Kyushu, Japan. It is a typical andesitic island arc volcano. The main rock type is hornblende andesite. The volcanic activity started 0.15 Ma (Kamata, 1997). In historic times, only phreatic eruptions have occurred several times in interval of several tens to one hundred years. An active fumarolic field in the central part of the volcano shows the most intense geothermal activity in Kyushu Island. The natural heat discharge rate was estimated at about 100MW before the eruption (Ehara, 1992). Temperatures of fumaroles generally exceed 200 degree C and the maximum observed temperature was 508 degree C before the eruption (Mizutani et al.,1986).

The thermal model beneath Kuju volcano was presented before the eruption, based on the geological, geophysical and geochemical data and the numerical modeling (Ehara, 1992). Magmatic fluids discharged from the cooling magma body rise upward through the fractures in the basement rocks and mix with the meteoric water at about 2 km depth. Two-phase volcanic reservoir (diameter:500m, thickness:2km)is formed between the surface and 2km depth. The temperature at the bottom of the reservoir was estimated at about 340 degree C. The contribution of the magmatic water to the discharged water at the surface was about 75%.

1995 PHREATIC ERUPTION AND RECENT ACTIVITY

Kuju volcano began to erupt on 11 October, 1995 from the new craters about 300m south of the pre-existing fumarolic field(The volume of the erupted ash is about 20000m^3.). It erupted again in the middle of December of the year (The volume of the erupted ash is about 5000m^3). After that, huge heat and mass discharges from the new craters and the pre-existing fumarolic field have been continuing, which is very similar to production without reinjection of geothermal fluids. The eruption is phreatic one and there have been no magmatic activity at the surface even though the vesiculated glass shards were detected from the ash (Hatae et al.,1997)

CHANGES IN SURFACE AND SUBSURFACE TEMPERATURES

An Infrared imagery apparatus and an infrared radiation thermometer were used to monitor the surface temperatures of the new craters and the pre-existing fumaroles after the 1995 eruption. As a result, it became clear that all the observed temperatures were decreasing after the eruption, although the temperatures of the pre-existing fumaroles were increasing before the 1995 eruption.

The subsurface temperature was monitored by the repeat magnetic measurements. Six proton-precession magnetometers were set around the new craters and the pre-existing fumaroles by Kyoto University and Kyushu University. The following changes are recognized in the geomagnetic field :

(1) Linear changes of total magnetic intensity were observed at all stations.
(2) The magnetic intensity at the northern part decreased but that at the southern part increased.
(3) Magnetic changes during the past four years after the eruption are very large, to more than 160 nT.

Generally, the thermo-magnetic effect, the piezo-magnetic effect and the electro-kinetic effect must be taken into account as a source for these magnetic changes. However, such changes in the magnetization on Kuju volcano are probably caused by the thermo-magnetic effect. Based on the above data, the position and the intensity of the source magnetic moment can be determined. The source position and intensity are estimated to minimize the square sum of deviations between theoretical and observed values of the magnetic field. The location of the magnetic source model estimated is not in the new crater zone but in the pre-existing fumarolic field. The source of magnetic changes lies at a depth of 500m. As a result, a spherical source body of radius 150m is obtained assuming the magnetization of 2A/m (Sakanaka et al., 2001). If we have such a newly intruded magma in the shallower depth, we will see large crustal movement. However, we could not see such crustal movement. Then it is reasonable to assume that equivalent volume of a spherical shell (The radius is about 200m.) with a thickness of a few tens meter was cooled, which means that the cooling body after the eruption is not the newly intruded magma but the hot rock which existed before the eruption.

CHANGE IN THE HYDROLOGICAL STATE

The heat discharge rates from the new craters and the pre-existing fumaroles were estimated by the remote sensing technique in interval of one week to several months after the first eruption. The total steam discharge was calculated by integrating the steam discharge rate at different periods. We also estimated the rate of vaporized ground water by the hot magmatic fluid, by using the stable isotope data of the discharged steam(about 35% of the discharged water is magmatic origin).

Repeat gravity measurements around the new craters and the pre-existing fumaroles have been conducted in interval of one week to several months after the first eruption by using the SCINTREX CG-3M gravimeter. Gravity values at all the stations around the new raters and the pre-existing fumaroles decreased rapidly during two months after the first eruption and thereafter gradually decreased. The average daily net mass decrease rates during two periods (mid-October 1995 to January 1996 and January 1996 to November 1998) were estimated at 55,000 tons/day and 2,800 tons/day, respectively, by applying the Gauss's potential theorem to the maps of gravity change. This shows that deficiency of the underground water mass around the new craters and the pre-existing fumaroles is compensated gradually.

Steam discharge rates from the new craters and the pre-existing fumaroles and the net water mass changes around the new craters and the pre-existing fumaroles were estimated above. Here, we assume that the discharged water (steam) from the new craters and the pre-existing fumaroles is mixture of magmatic water and groundwater, which means that part of groundwater is vaporized by the uprising hot magmatic water (gas). The ratio of the magmatic water to the discharged water from the new craters is about 35% and it did not change so much after the eruption (Hirabayashi et al.,1996). Based on the above discussions, we estimated the mass balance at different two periods(One is from mid-October 1995 to January 1996 and another is from January 1996 to November 1998.) as follows:

(1) from mid-October 1995 to January 1996

Steam discharge rate:	89,000 tons/day
(magmatic water:	31,000 tons/day)
Vaporized groundwater:	58,000 tons/day
Net mass change:	-55,000 tons/day
Recharged water from the surroundings:	3,000 tons/day

(2) from January 1996 to November 1998

Steam discharge rate:	26,000 tons/day
(magmatic water:	9,000 tons/day)
Vaporized groundwater:	17,000 tons/day
Net mass change :	-2,800 tons/day
Recharged water from the surroundings:	14,200 tons/day

We estimated the rate of the recharged water from the surroundings before the eruption is about 1000 to 2000 tons/day before the eruption (Ehara et al.,1981, Ehara,1992). The recharged water just after the eruption is about 3000 tons/day which is slightly larger than that before the eruption. However, the recharged water in the later stage is 14,200 tons/day which is several to ten times larger than that before the eruption. On the other hand, the rate of the magmatic water supply after the eruption increased about three times larger than that supplied before the eruption. These facts show the subsurface hot body beneath the new craters and the pre-existing fumaroles was cooled much more quickly by the large amount of the cold recharge water.

A CONCEPTUAL MODEL OF GEOTHERMAL FLUID FLOW BEFORE AND AFTER THE 1995 ERUPTION

Through multiparameter measurements, especially, thermal, magnetic and gravimetric measurements in this paper, we estimated the changes in thermal and hydrological processes after the 1995 phreatic eruption of Kuju volcano. After the eruption three times of the magmatic water is supplied comparing with the magmatic water supplied before the eruption.
However, much more (several to ten times larger than that before the eruption) cold water was recharged to the subsurface hot rock. Then the hot rock body beneath the new craters and the pre-existing fumaroles was cooled much more quickly. Such processes are very similar to the case of geothermal fluid production without reinjection. The conceptual thermal model was constructed based on the above discussions as follows:

The supplied rate of magmatic water increased about three times after the eruption. However, the cold groundwater recharged from the surroundings increased much more (up to ten times). Therefore, the subsurface hot rock body was cooling much more quickly than before the eruption. As a result, we observed clear changes in the surface and subsurface temperatures after the eruption. Such a process is very similar to the geothermal fluid production without reinjection.

CONCLUSION

Multiparameter measurements were conducted after the 1995 phreatic eruption of Kuju volcano. As a result, a large amount of cold water recharge(up to ten times larger than that before the eruption) was deduced after the eruption. This is a reasonable interpretation of rapid cooling of the subsurface hot rock body beneath the new craters and the pre-existing fumaroles of Kuju volcano.

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