Water Discharge and Recharge Balance of Kuju Volcano, Japan, Deduced from Thermal and Gravity Measurements

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ABSTRACT

Repeat thermal and gravity measurements have been conducted at Kuju volcano, an erupting volcano in central Kyushu, Japan, in order to monitor the underground geothermal fluid flow system.

A very high level of heat discharge rate, over 2000 MW, had been maintained after the first phreatic eruption which created some new craters in October, 1995. However after the second eruption in December, 1995, the heat discharge rate from the new craters decreased rapidly. Nevertheless, the heat discharge rate from all fumarolic areas, in which the new craters are included, has maintained its value of 600 to 800 MW since September, 1996 to date.

Gravity decreased rapidly just after the first eruption, and then decreased gradually. After some assumptions, underground water mass balance can be estimated by using the mass decrease data based on the Gauss's theorem and the steam discharge data. Estimation of mass balance of underground water shows that the recharge of ground water from the region around the new craters and the fumarolic areas was increasing after the eruption, and then, the underground water flow is gradually approaching a new equilibrium state.

Introduction

There are many geothermal fields in Kyushu, Japan. In order to monitor the underground geothermal fluid-flow system and to understand the effects of development on the geothermal system, we have been conducting gravity and thermal measurements in several geothermal fields in Kyushu (Ehara *et al.*, 1998). The places are Hatchobaru, Takigami, Oguni and Yamakawa in which geothermal power plants are in operation or under construction (Figure 1). We are applying the same method to Kuju volcano in central Kyushu in order to estimate the balance of discharge and recharge accompanied with its volcanic activity.

There were three main fumarolic areas (called A, B and C-region) in Kuju volcano before the 1995 eruption, and the first eruption began with the creation of some new craters on October 11, 1995. The area in which the new craters appeared is called D-region (Figure 2). The second eruption with ash occurred in December, 1995. After that, no eruptions occurred up to now (April, 1999), but the new craters and the fumarolic areas are still in activity. At present, most scientists consider that the 1995 eruption of Kuju volcano is essentially phreatic,

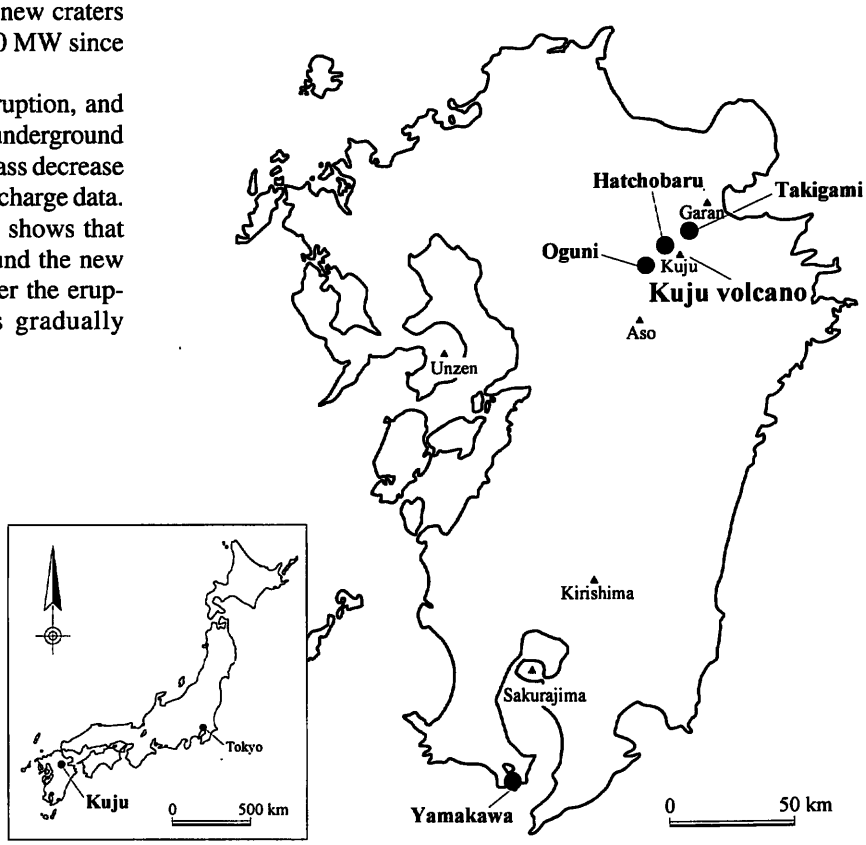

Figure 1. Geothermal fields in Kyushu, Japan.

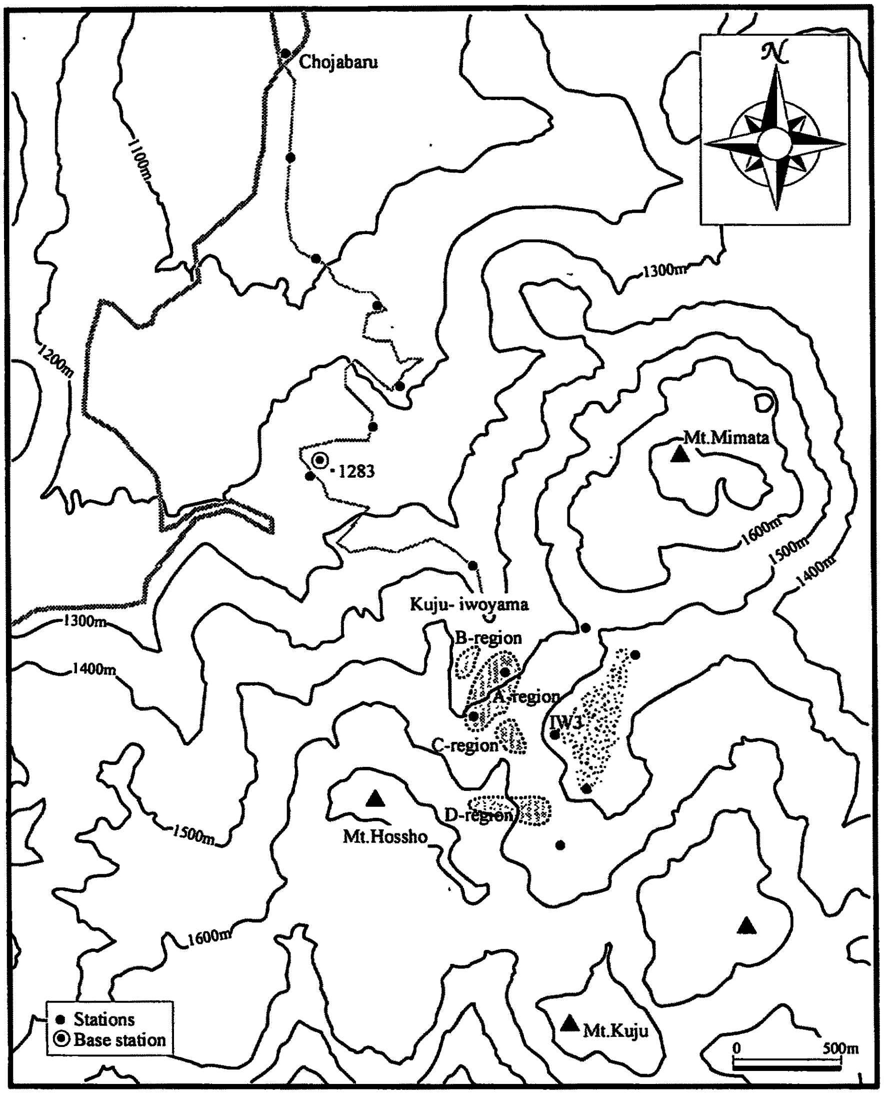

Figure 2. Location of the fumarolic areas (A, B, C-region), the new craters (D-region) and observation stations of gravity measurement in the central part of Kuju volcano.

although some small magmatic intrusion may exist beneath the new crater zone.

Thermal and Gravity Measurements in Kuju Volcano

We started repeat thermal and gravity measurements around the new craters just after the first eruption.

Figure 3 shows heat discharge rate by steam from A, B, C and D-regions since the first eruption in 1995 by means of a remote sensing measurement method of steam and heat discharge rates by using the maximum diameter of a volcanic steam plume (Jinguuji and Ehara, 1996). Just after the first eruption, activity of the new craters was overwhelming. Therefore, we measured heat discharge rates from D-region only. However, after the second eruption, as the heat discharge from the new craters declined, that from the fumarolic areas increased. Therefore, since September 1996, we have measured the discharge rate from all regions.

A very high level of heat discharge rate, over 2000 MW, had been maintained during two months after the first eruption. However after the second eruption, the heat discharge rate from the new craters decreased rapidly. On the other hand, the heat discharge rate from all regions has kept its value of 600 to 800 MW since September, 1996. That value is 6 to 8 times larger than that before the eruption, about 100 MW (Ehara *et al.*, 1981).

The observation stations for gravity measurement had been distributed as seen in Figure 2. We set a reference point on the mountainside at 1283m asl. The gravity meters we have been using are the Scintrex CG-3 and CG-3M.

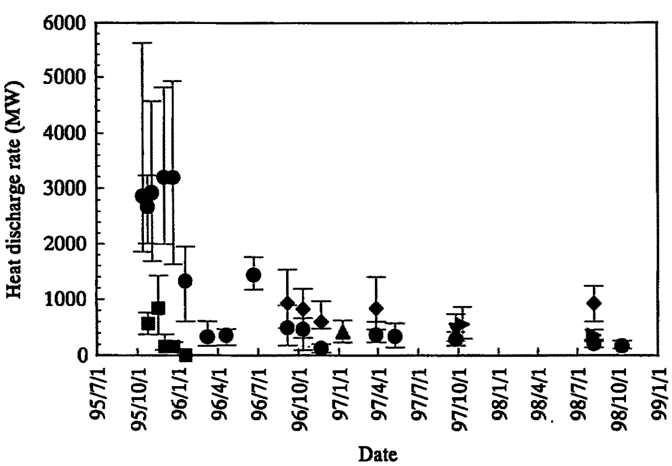

Figure 3. Temporal variations of heat discharge rates from the new craters and the fumarolic areas. ◆▲: all regions, others : D-region.

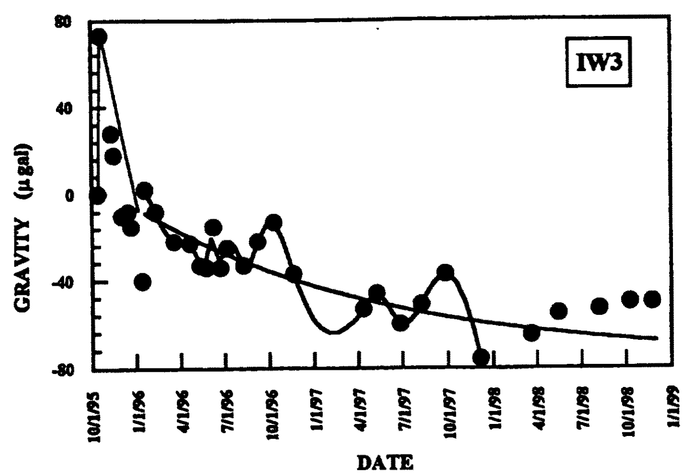

Figure 4. Gravity change of IW3, that is near the new craters and the fumarolic areas. In this figure, the gravity value of the first measurement is set as zero.

As a result of these measurements, we detected remarkable changes in gravity. For example, we indicate gravity values of station IW3, just beside C-region, in Figure 4, that shows a typical pattern of gravity change at the observation stations around A, B, C and D-region. According to this figure, the pattern is divided into three periods. In the first period (from the first eruption to mid-October, 1995), the gravity value continued to increase suddenly just after the first eruption. In the second period (from mid-October, 1995 to January, 1996), gravity around the active regions decreased rapidly. In the third period (from January, 1996 to November, 1998), accompanying the decrease in the heat discharge rate from the new craters, the rate of gravity decrease becomes smaller. The gravity change curve of this period is formed by the long-term trend of decrease and the annual change. By establishing a comparison between this annual change and precipitation data of Kuju area, it is inferred that the precipitation causes the annual change of gravity value.

Figures 5 and 6 show the distribution of gravity change along the long-term trend during the second and third period, respectively. The contours of both figures are limited by lack of the observation stations, however it seems that a center of the gravity decrease exists in the area of the fumaroles and the new craters. Thus it is able to be thought that steam discharge from the new craters and the fumaroles causes the long-term trend of gravity decrease.

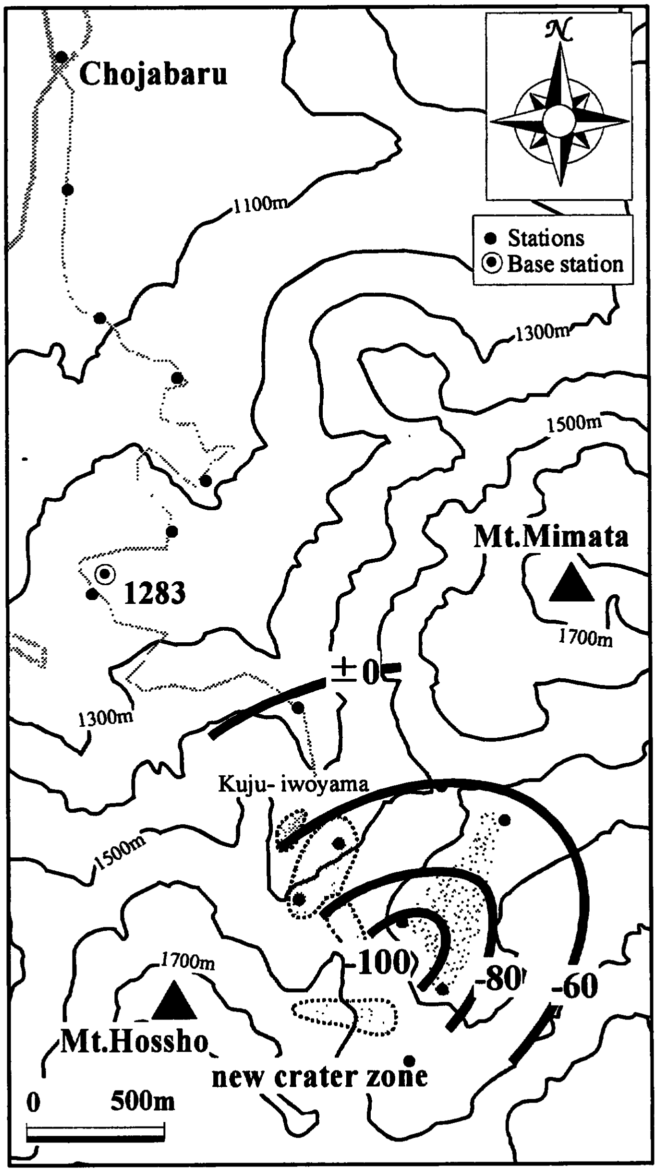

Figure 5. Distribution of gravity change during the second period (from mid-October, 1995 to January, 1996). The unit is μGal.

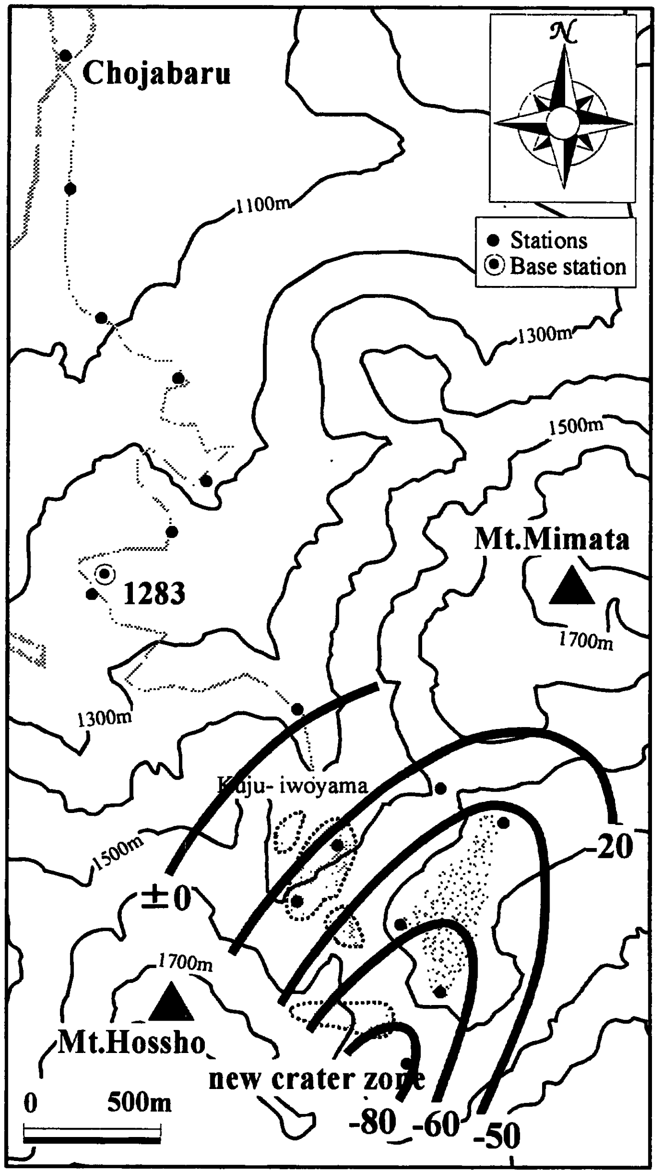

Figure 6. Distribution of gravity change during the third period (from January, 1996 to November, 1998). The unit is μGal.

Estimation of Underground Water Mass Balance

When we assume that each contour line in Figures 5 and 6 is an ellipse, mass decrease (mainly underground water) based on the Gauss's theorem can be estimated. And in addition to the mass decrease, mass balance of underground water may be estimated if we assume that the steam discharge rate that is calculated simultaneously with the heat discharge rate mentioned above.

During the second period, the mass decrease calculated by using the Gauss's theorem amounts to 4.70 Mt and the mass decrease rate is about 55000 t/day. On the other hand, steam discharge rate during the same period is estimated at about 89000 t/day. It is thought that 65% of the steam mass has originated from meteoric water and the rest from magmatic water (Kazahaya *et al.*, 1997). Therefore, the mass supplied from the ground water that was reserved in the mountain body is 58000 t/day. A difference between 55000 t/day and 58000 t/day is thought to be the recharge of ground water from the region around the new craters and the fumarolic areas (Figure 7).

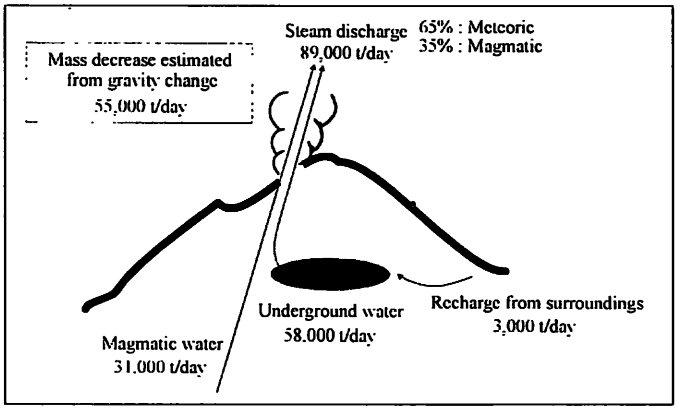

Figure 7. Mass balance of underground water during the second period.

Similarly, during the third period, the mass decrease amounts to 2.85 Mt and the mass decrease rate is about 2800 t/day. The steam discharge rate is about 26000 t/day and the mass supplied from the ground water is 17000 t/day. Therefore, the recharge of ground water from the surroundings is estimated at 14200 t/day (Figure 8).

Estimation of the mass balance of underground water shows that the recharge of ground water from the region around the new craters and the fumarolic areas is increasing since the eruption, and about three months after, the underground water flow is gradually approaching a new equilibrium state.

Conclusion

The 1995 eruptive activity is analogous to thermal fluid production in the geothermal field. The phreatic eruption seems to correspond to a kind of thermal fluid production without reinjection. The frequent repeat thermal and gravity measurements in Kuju volcano after the eruption will give new insights to monitoring of the underground fluid flow in geothermal fields.

We are also conducting another repeat gravity measurement in some non-geothermal fields to monitor shallow ground water flow. For the purpose of clarifying the changes in underground water-flow systems in geothermal fields, it is necessary to compare the observational results of geothermal fields, volcanos and non-geothermal fields.

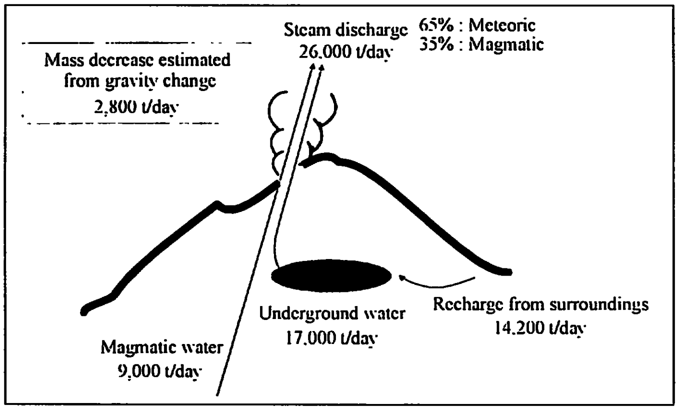

Figure 8. Mass balance of underground water during the third period.

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