QUICK COOLING OF KUJU VOLCANO, CENTRAL KYUSHU, JAPAN AFTER THE 1995 PHREATIC ERUPTION

S.EHARA, Y.FUJIMITSU, J.NISHIJIMA, K.FUKUOKA & M.OZAWA

Laboratory of Geothermics, Kyushu University, Fukuoka 812-8581, Japan

SUMMARY – A cooling of heat source after the 1995 phreatic eruption of Kuju volcano is discussed based on the thermal, magnetic and gravimetric measurements. Thermal and magnetic measurements showed a quick cooling of the volcano. It is suggested that the cooling heat source is not a new intrusive magmatic body but a pre-existing hot rock beneath the central part of the volcano. Results of thermal and gravimetric measurements indicate that the cooling of the heat source is not by conduction but by circulation of meteoric water.

1. INTRODUCTION

Kuju volcano is situated in central Kyushu, Japan. It has active fumarolic fields in the central part. The volcano began to erupt on 11 October, 1995 from some new craters about 300m south of the pre-existing fumarolic fields. It erupted again in the middle of December of the same year. A large amount of heat and mass is discharged from the new craters. After the eruptions, the pre-existing fumarolic fields continued to be active. There was no magmatic activity at shallow depth, even though vesiculated glass shards were detected from the ash (Hatae et al., 1997).

Ehara et al. (2000) analysed thermal, magnetic and gravimetric data recorded between 1995 and 1999. They concluded that a new magma body intruded the shallow crust and was quickly cooled down by cold meteoric'water circulation. A large amount of heat and steam is still discharging at present (August, 2002).

The geophysical data, including those recently measured, were analysed. The result suggests that the cooling heat source is not a new magma intrusion as previously suggested (Ehara et al., 2000), but a hot rock body beneath the pre-existing fumarolic fields.

2. KUJU VOLCANO

Kuju volcano, which is composed of many lava domes, is a typical andesitic arc volcano. The main rock type is hornblende andesite. The volcanic activity started 0.15Ma ago (Kamata, 1997). Several phreatic eruptions occurred in historic times at intervals ranging fiom a few tens to a hundred years. The active fumarolic field in the central part of the volcano is one of the most intense geothermal activities in Japan. The natural heat discharge rate was estimated about 100MW before the eruption (Ehara, 1992). Temperatures of fumaroles generally exceed 200 °C and the maximum observed temperature was 508 degrees °C prior to the recent eruption (Mizutani et al., 1986).

3. 1995 PHREATIC ERUPTION AND GEOPHYSICAL OBSERVATIONS

The volume of ash discharged by the eruption starting on 11 October 1995 is about 20000m^3. The following eruption in mid-December produced about 5000m^3 ash. Following these eruptions, a large amount of heat and mass (several hundreds to three thousands MW) started to discharge from the new craters and the pre-existing fumarolic fields. The discharge is still continuing at present (August, 20002). The eruption was considered a phreatic eruption, as there has been no magmatic activity near the surface.

4. CHANGES IN SURFACE TEMPERATURES AND HEAT DISCHARGE RATES

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.

4.1 Surface Temperatures

Temperature variations of some pre-existing fumaroles are presented in Fig. 1. The graphs

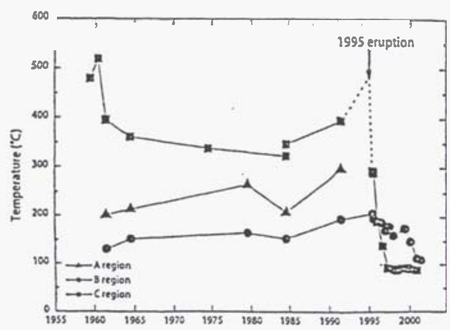

Figure 1. Representative patterns of the pre-existing fumarolic temperatures before and after the 1995 phreatic eruption of Kuju volcano.

show a quick cooling of surface thermal activity following the eruptions. The new craters also showed similar patterns except for a short period just after the eruption. Most of the surface temperatures decreased after the eruption, except those of the fumaroles at the central part of the pre-existing fumarolic fields. Here, the surface temperatures have increased gradually since, starting about one year after the first eruption.

4.2 Heat and Steam Discharge Rates

Figure 2 shows temporal variations of heat discharge rates from the new craters and the pre-existing fumaroles. Heat discharge rates during the two months after the first eruption were larger than 2000MW. However, after the second eruption they decreased suddenly to a few hundreds MW and then recovered to several hundreds MW. After that, heat discharge rates of several hundreds MW have been continuing until present (August, 2002).

4.3 Estimated Heat Source

Ehara et al., (2000) estimated the volume of the cooling heat source, assuming that the heat source is a new intrusive magma. The estimated radius of the heat source is about 500m, if a spherical shape is assumed. From the magnetisation of the heat source, they estimated the radius the spherical source body of 200m. Therefore they concluded that the equivalent radius of the heat source is about 200m to 500m.

A different type of. cooling heat source is suggested in this paper. Ehara (1992) calculated the temperature distribution beneath the central part of Kuju volcano based on the convection model. The model showsa high temperature in a central cylindrical permeable zone a diameter of about 500m and a thickness (vertical extent) of 2000m. The estimated temperatures inside and outside the central permeable zone are shown in Figure 3.

The relationships between the thickness (vertical extent) of the cylindrical cooling heat source and the time to cool the heat source, assuming different heat discharge rates, are shown in Figure 4. The average heat discharge rate at Kuju volcano is between several hundreds and one thousand MW. Therefore it is necessary to have a large body of cooling heat source to maintain such a heat discharge that continues to occur seven years after the eruption.

5. GEOMAGNETIC CHANGES

The subsurface temperature was monitored by continuous and repeat magnetic measurements. Six proton-precession magnetometers were set around the new craters and the pre-existing fumarolic field by Kyoto University and Kyushu University (Sakanaka et al., 2001). In addition, repeat measurements were conducted at more than twenty sites in the central part of Kuju volcano.

5.1 Geomagnetic Observations

The following changes of magnetic field were recognized (Ehara et al., 2000, Sakanaka et al., 2001).

(1) Linear changes of total magnetic intensity were observed at all sites for seven years after the eruption.
(2) The magnetic intensity decreased in the northern part but increased in the southern part.

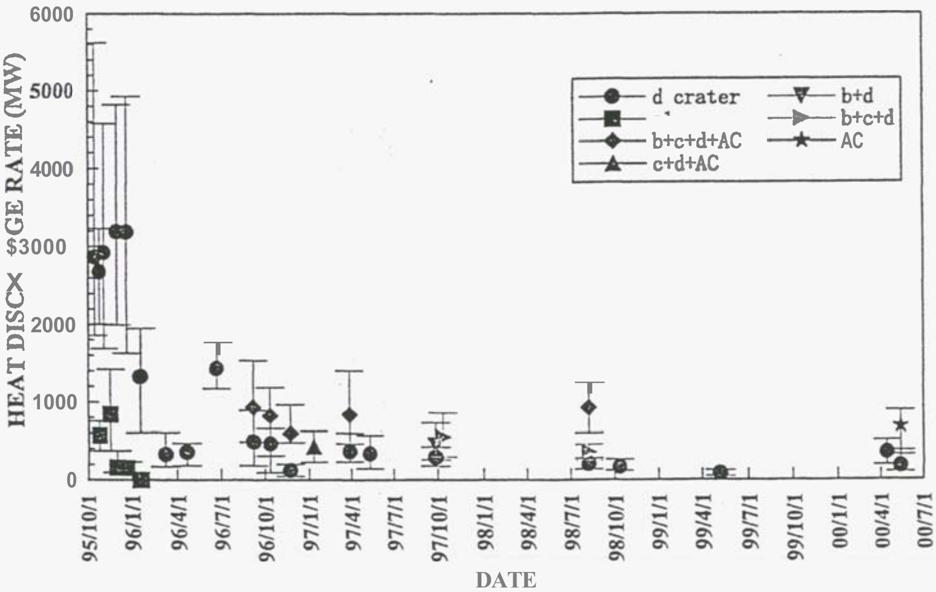

Figure 2. Temporal variations of heat discharge rate from the new craters (shown in small letters) and the pre-existing fumaroles (shown in capital letters).

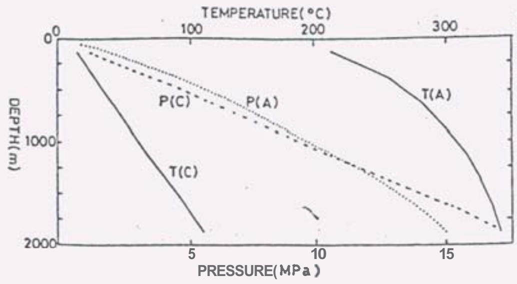

Figure 3. Temperature and pressure profiles in the central cylindrical permeable zone (T(A): temperature, P(A): pressure) and those outside the central zone (T(C):temperature, P(C):pressure).

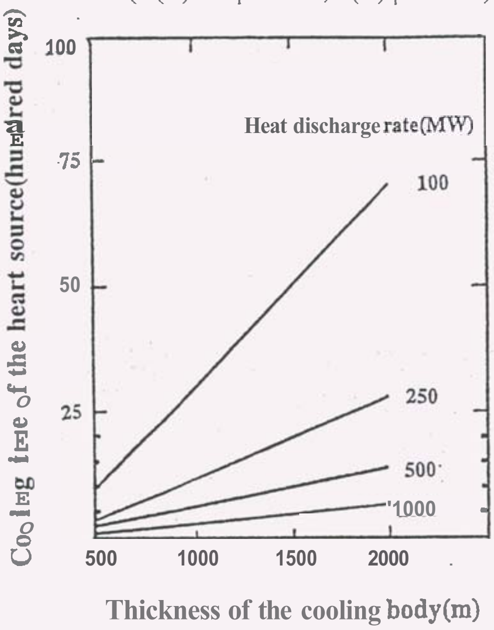

Figure 4. Relation between the thickness of the cylindrical cooling body with a radius of 250m and the cooling time of the heat source assuming constant heat discharge rates.

(3) Magnetic changes during the period seven years after the eruption were very large, up to more than 280nT.

Thermo-magnetic and piezo-magnetic effects and the electro-kinetic effects are generally considered as the source of magnetic changes in volcanic fields. The magnetic changes observed on Kuju volcano were probably caused by the thermo-magnetic effect.

5.2 Geomagnetic Model

Ehara et al. (2000) and Sakanaka et al. (2002) calculated geomagnetic models to explain the observed magnetic changes assuming a spherical magnetized body. They estimated the depth of the source is between a few and several hundreds meters.

In this paper, theoretical magnetic changes of several cylindrical models of the magnetic sources were calculated (Rikitake and Hagiwara, 1965, Singh and Sabina, 1978) and compared with the observed magnetic changes. A good fit between computed and observed magnetic variations (Figure 5) was obtained for a model with a diameter of 500m, top at 120m depth and bottom at 2000m depth. The model was assumed to have a magnetization of 1A/m.

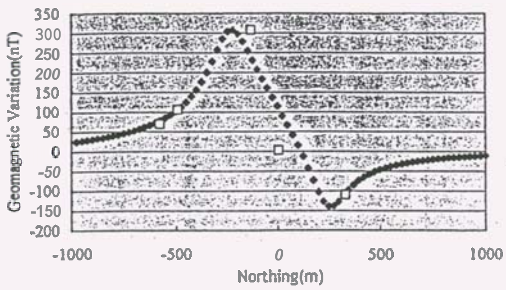

Figure 5. Calculated (solid squares) and observed (open squares) geomagnetic anomalies along the N-S direction.

Calculated values are not sensitive to the bottom's depth of the model. Models with depths to the bottom between 1000m and 2000m produce similar magnetic anomalies. Hence, the magnetic modelling suggests that the magnetized (cooled) part of the heat source extends from about 100m to between 1000m and 2000m depths.

6. DISCUSSIONS

There are two possibilities regarding the type of cooling heat source beneath Kuju volcano, i.e. a new magmatic intrusion or a pre-existing hot rock beneath the fumarolic field. As discussed previously, both models need a relatively large body of cooling heat source.

However, no remarkable ground deformation was observed before and after the eruption. This does not support the assumption of a large body of new magmatic intrusion, despite the detection of vesiculated glass shards in the ash (Hatae et al., 1997). The possibility. of a small magmatic intrusion cannot be excluded.

Ehara et al., (2000) also discussed the cooling mechanism of the heat source based on the changes in gravity and volcanic steam discharge rate. They concluded that the heat source (assumed as a new intrusive magma) was cooled more effectively by the increased recharge rate of meteoric water after the eruption. A similar mechanism of cooling can also be assumed for the pre-existing heat source suggested in this paper. Such increased recharge rate of meteoric water may originate fkom the pressure decrease by the phreatic eruption. Such a situation is very similar phreatic eruption. Such a situation is very similar to thermal fluid production from the geothermal reservoir without any reinjection of liquid water.

7. CONCLUSIONS

Even seven years after the 1995 phreatic eruptions, Kuju volcano is still discharging a large amount of steam, and its surface and subsurface temperatures are still decreasing. The cooling body concerned is not a new intrusive magma but a pre-existing body of hot rocks beneath the active fumarolic fields. The body of hot rocks is not cooled by conduction but by circulation of meteoric water. Much greater recharge of meteoric water occurred into the central part of the volcano following the 1995 eruptions. The increased recharge rate is caused by the quick pressure decrease after the phreatic eruptions. Such a situation is very similar to thermal fluid production fkom the geothermal reservoir without any reinjection of liquid water.

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