GEOTHERMAL INVESTIGATIONS OF UNZEN VOLCANO, KYUSHU, JAPAN

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SUMMARY - Geothermal investigation of Unzen Volcano was conducted in 1999 as a part of the Unzen Scientific Drilling Project (USDP). The heat discharge rates fkom the lava dome during 5 months obtained by the infrared imagery observation show little variation. The 1-m depth temperatures near the lava dome and the summit of Mt. Fugen are lower than an extrapolated fine of the temperatures at the stations on the flank of Unzen Volcano. Some intensity anomalies of ^{214}Bi and ^{208}Tl were detected at the stations just near the estimated conduit location by the Gamma-ray intensity investigation. In some remote observation of volcanic gases by an FTIR spectrometer, CO and CO_2 were detected, and the equilibrium temperature of about 880 °C was estimated from the CO/CO_2 ratio. The result of the simulation using a simple 2-D conductive model showed that non-conductive effects are associated with conduit cooling, but that there is little possibility of extensive hydrothermal activity near the lava dome.

1. INTRODUCTION

Unzen Volcano is one of the active volcanoes in Japan. It is located in Shimabara Peninsula, Nagasaki prefecture, Western Kyushu (Fig. 1). The latest eruption began at a crater about 500 m east of the summit of Mt. Fugen in 1990. In 1991, a lava dome appeared at the crater, and as the lava dome grew, pyroclastic flows occurred creating a hazard. The United Nations nominated Unzen as a Decade Volcano in the same year. In 1995, this emption stopped. The summit of the lava dome is about 130 m higher than that of Mt. Fugen (Fig. 2).

Since 1999, the Unzen Scientific Drilling Project (USDP) has been conducted by the Science and Technology Agency (STA), Japan. In this project, two 1500m-deep wells will be drilled on the flanks (the first phase; April 1999 to March 2002). During the second phase (April 2002 to March 2005), the conduit in the 1990-95 eruption near the summit will be drilled as part: of the International Continental Scientific Drilling Program (ICDP). Many organizations, companies and universities in USDP have conducted scientific investigations. There are three main topics for the investigation. These are (a) conduit and eruption mechanism, (b) structure and

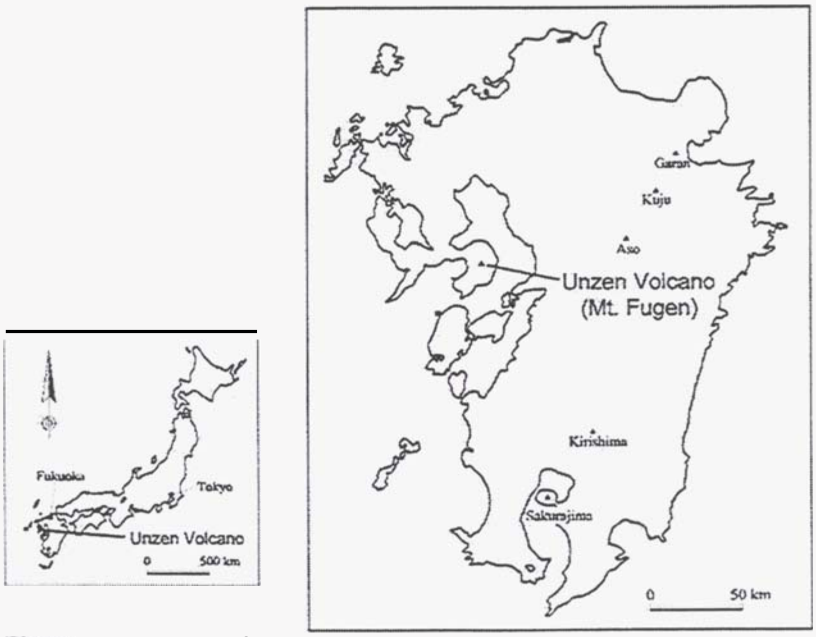

Figure 1 - Location of Unzen Volcano (Mt. Fugen) and active volcanoes in Kyushu, Japan.

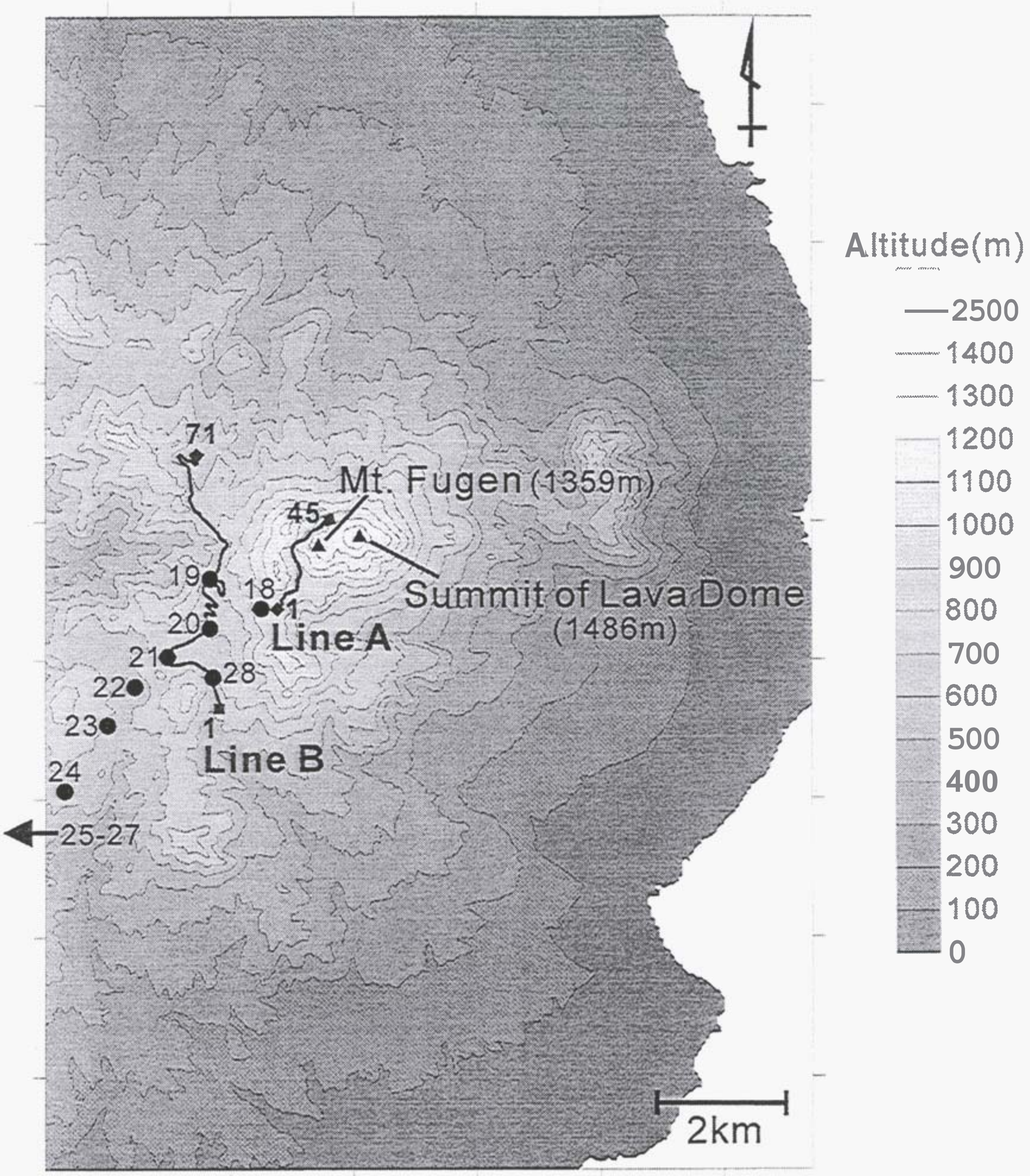

Figure 2 - Topographic *map* of Mt. Fugen and location of the observation stations. Solid circles indicate 1-m depth temperature stations. Line A and B are the measurement lines for *the* Gamma-ray intensity investigation.

evolution of volcano, and (c) technical development and optimizing of drilling and downhole measurement. We participate in a group investigating category "Cooling of the conduit and the geothermal system" in Topic (a). In this pager, we show the results of our observations and investigations in 1999.

2. RESULTS OF INVESTIGATIONS

We have made several observations and investigations mainly about *heat* discharge and ground temperature.

2.1 Infrared Imagery

We used an infrared camera (NEC San-ei Thermo Tracer TH3102) for observation of surface temperature distribution. The temperature measurement range of this camera is from -50 to 250 °C, and the temperature resolution is 0.1 °C. According to the infrared images of the lava dome, surface temperature of the lava dome is now cold. There are some fumaroles near the top of the lava dome, and they are detected as hot spots on the infrared images.

Figure 3 indicates temporal variation of the heat discharge rate from the lava dome calculated from the infrared image data by means of the heat balance technique (Sekioka and Yuhara, 1974; Sekioka, 1983) from June to November 1999. This figure shows a trend of decrease for the average value of each measurement. However, we reached the conclusion that there was little variation in the heat discharge rate, considering the error bars (Fig. 3).

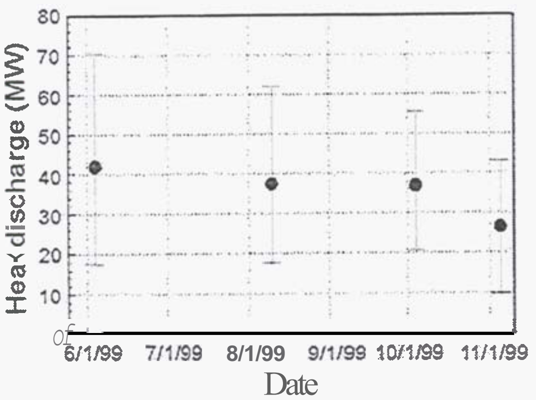

Figure 3 - Heat discharge from the fava dome of Mt. Fugen estimated from the infrared images.

2.2 1m-depth Temperature

We set 17 1m-depth temperature measurement stations (1-17) near the lava dome and 11 stations (18-28) along the road (Route 57) that runs from Mt. Fugen to ?he west (Fig. 2).

Figure 4 shows a good negative relation between altitude and 1m-depth temperature except the

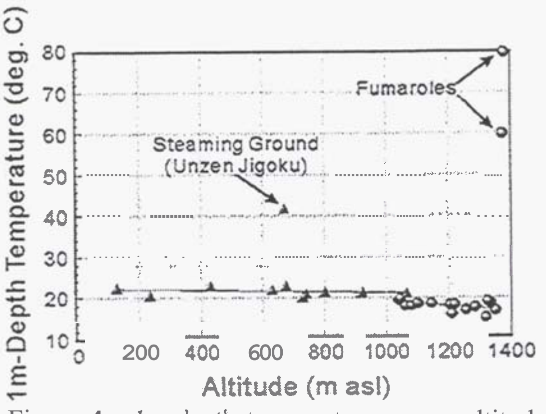

Figure 4 - 1m-depth temperature versus altitude plot for Unzen Volcano. The stations 1 to 17 are indicated by circles and the stations 18 to 28 by triangles.

stations at fumaroles and steaming grounds. However, the temperatures measured at the stations near the lava dome and the summit of Mt. Fugen are lower than an extrapolated line of the temperatures at the stations on the flank of Unzen Volcano along Route 57. In addition, the ratio of temperature decrease with altitude for the stations near the lava dome is larger than that for the stations along Route 57. We think that the lava dome and the top of Mt. Fugen exist in a caldera, and that this topography collects rainwater, effectively cooling the dome area.

2.3 Gamma-ray Intensity

In order to detect fractures near the ground surface and to try inferring the horizontal position of the conduit, we performed Gamma-ray intensity investigations by using a multichannel analyzer (NAIG E-560A) with 4 in. NaI(Tl) scintillation detector.

We estimate that the magma of the 1990-95 eruption rose from the west of Mt. Fugen because of the distribution of volcanic earthquakes and a result of an analysis of the ground deformation. Therefore, we set 2 measurement lines (Line A: around the summit of Mt. Fugen, Line B: along Route 389, see Fig. 2) across the estimated conduit position-

Some intensity anomalies of ^{214}Bi and ^{208}Tl were detected at the stations, which were just near the estimated location of the conduit, on Line A (Fig. 5). This result may mean the determination of the conduit location, so we think the anomalies must be confirmed by more investigations.

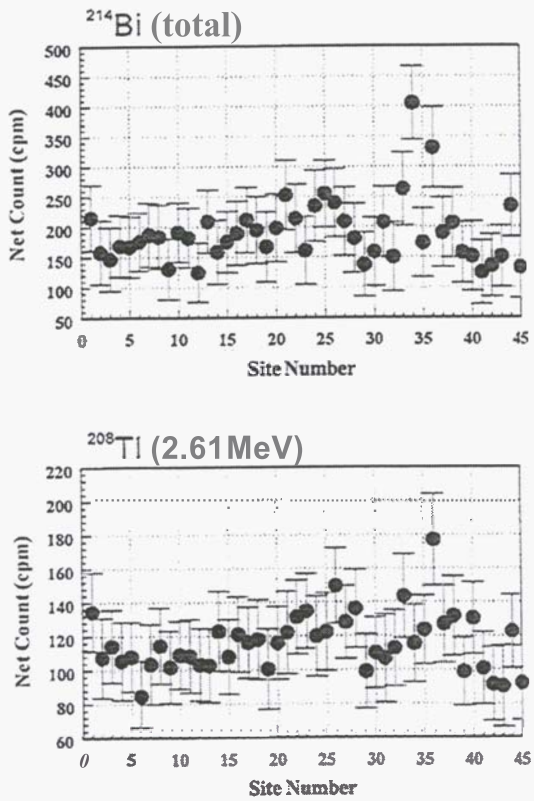

Figure 5 - Gamma-ray intensity distributions for ^{214}Bi and ^{208}Tl on Line A.

2.4 Remote Observation of Volcanic Gases

Remote observation of volcanic gases with a FTIR (Fourier Transform Infrared) spectrometer is still at a trial stage for volcanic observation. We used a FT-IR spectrometer (BOMEM MB100) with an InSb detector, and a Cassegrainian type telescope with an effective focal length of 130 cm and the field of view of 4.9 mrad. From an observation point about 1.5 km away from the lava dome, we detected CO and CO_2 in the discharge gas of a fumarole on the side of the lava dome. A value of CO/CO_2 was estimated by means of the quantitative analyzing method (Ono et al., 1999). From the CO/CO_2 value, the equilibrium temperature of about 880 °C was calculated by using a relationship shown by Mori et al. (1997).

3. 2-D CONDUCTIVE MODEL OF UNZEN VOLCANO

We constructed a two dimensional conductive model of Mt. Fugen area as a simplified model for the cooling process of the magma in the conduit. A computer code FINITEG (Lee et al., 1980), that calculates two dimensional steady or transient heat conduction by the finite-element method, was used for the numerical modeling.

3.1 Analytical Area

We set a vertical east-west section through the summit of Mt. Fugen as an analytical area which has an extension laterally of 5 km and verticalty fiom -3 km asl to the ground surface (Fig. 6). This analytical area was divided into 2 layers, made up of a basement rock layer and a volcanic rock layer.

3.2 Calculation Conditions and Modeling Process

First, we constructed a steady state model with no magma penetration in order to calculate the background temperature distribution of this area. A boundary condition at the bottom was a constant heat flux of this area (120 mW/m^2), and the annual average atmospheric temperature was assigned on the ground surface. Radioactive heat generation in the ground (3.0×10^{-6} W/m^3) was considered in this simulation.

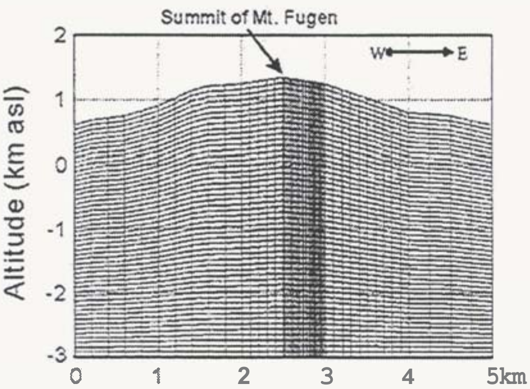

Figure 6 - 2-0 finite element grid for a numerical model of Unzen Volcano.

Next, we constructed a transient model of the conduit cooling. This model simulated the cooling process during 4 years from 1995 when the latest eruption stopped. We used the calculated background temperature distribution as an initial condition, and set a conduit with an initial temperature of 850 °C. The width ofthe conduit was a variable from 20 to 100 m. Other conditions were the same as those of the steady state model.

We tried to fit the calculated temperature change at the top of the conduit to that of gas from the fumarole which indicates the highest temperature value in the lava dome. However, even the smallest width of the conduit could not explain the rapid decrease of the fumarole temperature.

3.3 Revised Model and Discussion

In order to express cooling by non-conductive effects, we set 2 high thermal conductivity zones at and around the conduit. The thermal conductivity of the deeper zone was set two times higher than that of the surroundings, and the magnification of the thermal conductivity at the shallower zone was set as another variable from I to 20.

After calculations for all combinations of the two variables, we obtained the most suitable result when the conduit width was 40 m and the thermal

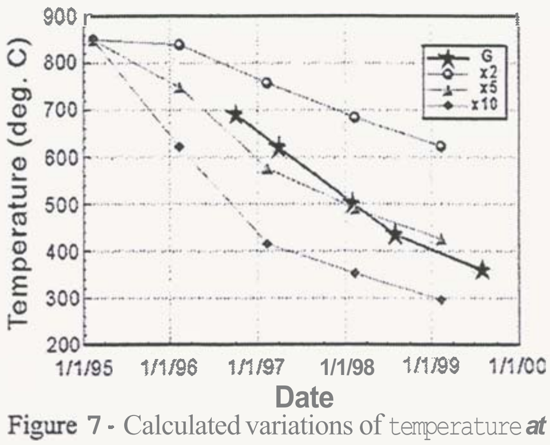

Figure 7 - Calculated variations of temperature at the s m i t of the lava dome. "G" indicates observed temperature of gas from the fumarole that is the hottest in the lava dome.

conductivity of the shallower zone was 5 times higher than the surroundings (Fig. 7).

The result of this simulation means that the non-conductive effects such as permeation of rainwater are implied in the cooling of the conduit. The effects are not so strong, because the the magnification of the thermal conductivity is not very large. Therefore, there is little possibility of extensive hydrothermal activity near the lava dome.

4. CONCLUSIONS

According to the results of the investigations and the numerical modeling in 1999, the non-conductive effects (e.g. permeation of rainwater) cool a shallow part of the conduit, while maintaining a high temperature in the deep part of the conduit. There is little possibility of extensive activity near the lava dome. We are continuing observations and investigations of Unzen Volcano. With more information, we will construct a more precise model.

5. ACKNOWLEDGMENTS

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