STUDY ON HYDROTHERMAL SYSTEM DEVELOPMENT, UNZEN VOLCANO, JAPAN. A TOPIC IN PHASE I OF THE UNZEN SCIENTIFIC DRILLING PROJECT

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SUMMARY – Some geothermal investigations on Unzen Volcano have been conducted since 1999 as part of the Unzen Scientific Drilling Project. The heat discharge rates fi-om the lava dome between 1999 to 2001, obtained by infrared imagery observations, show a trend of decreasing discharge. The 1 m-depth temperatures near the summit of Mt. Fugen are lower than an extrapolated line of the temperature-altitude relationships from the stations on the flank of the volcano. The temperatures near the summit of Mt. Fugen show seasonal changes, but those near the fumaroles on the lava dome maintain their values. Some Gamma-ray intensity anomalies of ^{214}Bi and ^{208}Tl were detected at the stations near the estimated location of the conduit. The result of repeat gravity measurements shows that the gravity values near the lava dome decreased while those of the western part of Mt. Fugen increased between 1999 to 2000. Remote observations of volcanic gases by an FTIR spectrometer detected CO and CO_2, and an equilibrium temperature of about 800°C was estimated fi-om the CO/CO_2 ratio. The result of a simulation, using a 3-D numerical model, showed that the downflow of permeating rainwater is dominant and the upflow of gas is limited in the conduit. This result means 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 the Shimabara Peninsula, Nagasaki prefecture, Western Kyushu (Figure 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, some disastrous pyroclastic flows occurred. The United Nation nominated Unzen as a Decade Volcano in the same year. The eruption stopped in 1995. The summit of the lava dome is about 130 m higher than that of Mt. Fugen (Figure 2).

Since 1999, the Unzen Scientific Drilling Project (USDP) has been conducted by the Science and Technology Agency (STA) and the Ministry of Education, Culture, Sports, Science and Technology (MEXT) of Japan. (MEXT is the ministry created by the amalgamation of the STA and the Ministry of Education of Japan established in 2001).

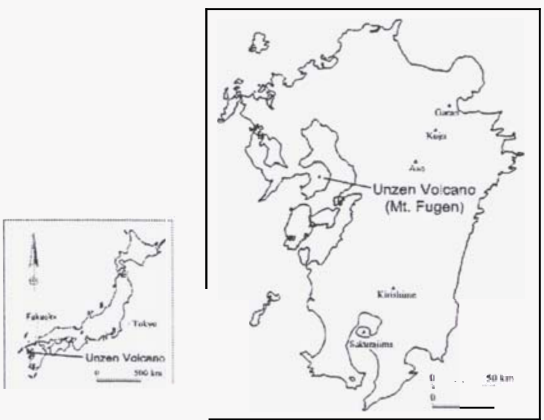

Figure 1 - Location of Unzen Volcano (Mt. Fugen) and active volcanoes in Kyushu, Japan.

In Phase I (April 1999 to March 2002) of this project, two vertical drillings were done on the northeastern and the eastern side of the volcano's flank, and pilot drilling was carried out about 1.5 km northwest of the summit of the lava dome.

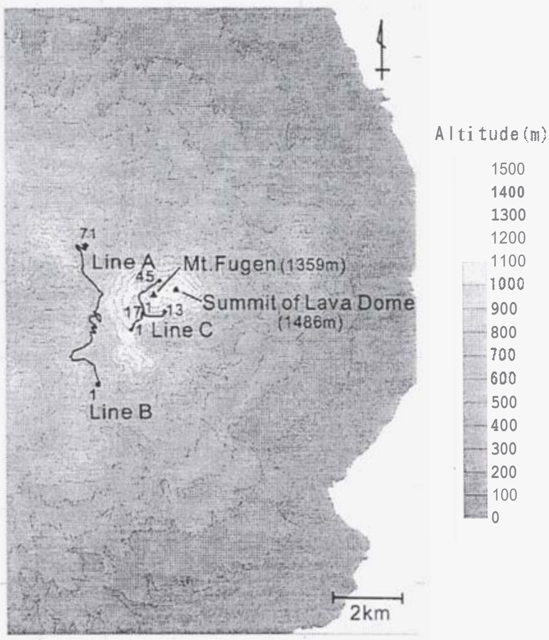

Figure 2 - Topographic map of Unzen Volcano and location of the measurement lines of Gamma-ray intensity investigation (Line A-C).

During Phase II (April 2002 to March 2005), the conduit of the 1990-95 eruption near the summit

(Fujimitsu et al., 2000) has already been discussed earlier.

Using our previous numerical model study and the results of our geothermal surveys, we constructed a conceptual model. This shows that permeating rainwater cools the body of the lava dome - except for a part of the conduit which is the pathway for high temperature gas - and that there is no strong hydrothermal circulation near the dome (Figure. 6). On the other hand, there is another conceptual hydrothermal model based on SP data (Hashimoto, 1997), which suggests the existence of hydrothermal circulation near the lava dome.

We constructed a simplified 3-D numerical model of the Mt. Fugen area to explain our conceptual model. A computer program called HYDROTHERM Version 2.2 (Hayba and Ingebritsen, 1994) was used for this numerical modelling. It calculates the three-dimensional, multiphase flow of pure water and heat, over a temperature range of 0 to 1200°C and a pressure range of 0.5 to 10000 bars, by the finite-difference method.

3.1 Analytical Area

The lava dome was set at the centre of an analytical area which has a horizontal extension of 5 km (E-W) by 4.6 km (N-S) and a vertical extension of -3 km (below sea level) to the ground surface (Figure. 7). This analytical area was divided into 2 layers, made up of a volcanic rock layer (Layer I), and a basement rock layer (Layer II) (Figure. 8).

3.2 Calculation Parameters and the Modelling Process

Firstly, we constructed a steady state model with no magma penetration in order to calculate the background temperature distribution of this area. Boundary conditions at the bottom had a constant heat flux of 120 mW/m^2 and an impermeable boundary. The atmospheric pressure, and annual average temperature of 15°C, were assigned to the ground surface, which was permeable. The lateral boundaries were thermally insulated and impermeable.

Next, we constructed a transient model of the conduit cooling and hydrothermal system development. In order to obtain the most suitable model, we matched the history to the change of gas temperature, using the fumarole that indicated the highest temperature in the lava dome during the 4 years from 1995 when the latest eruption stopped. We used the calculated background temperature distribution as an initial condition, and set the conduit to an initial temperature of 850°C. The width of the conduit was 100 m (the smallest block size of this model). 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 temperature by trial and error, by changing the permeability value of the shallow part of the lava dome (Figure 8). The most suitable match occurred when the permeability was 100 times higher than the surroundings.

4. DISCUSSION

We tried to estimate the temperature distribution and geothermal fluid flow for 2003, when the conduit drilling will commence, using the model.

The temperature distribution (Figure 9) shows that the shallow part of the Unzen volcano conduit is cooled by groundwater, but still maintains a high temperature at depth. The projected flow pattern for 2003 (Figure 10) shows that the downflow of permeating rainwater is dominant, with an upflow only of gas in the conduit. This result means that there is little possibility of extensive hydrothermal activity near the lava dome, despite the upflow of volcanic gas maintaining a high temperature in part of the conduit, it also means that the lava in the conduit will still be at a high temperature when the conduit drilling will commence.

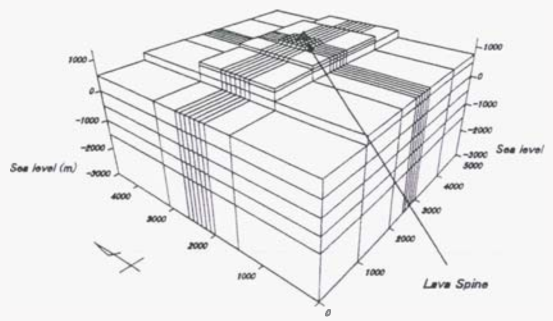

Figure 7 - 3-D finite difference blocks for the numerical model of Unzen Volcano.

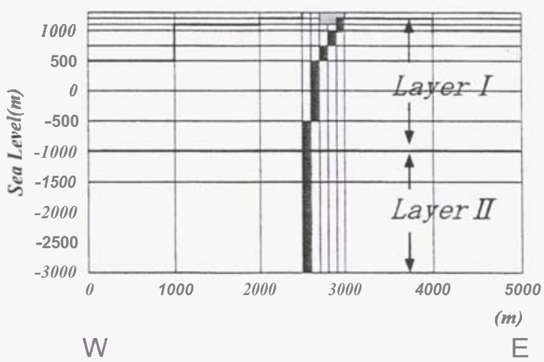

Figure 8 - E-W slice of the numerical model that includes the lava spine and the conduit,.

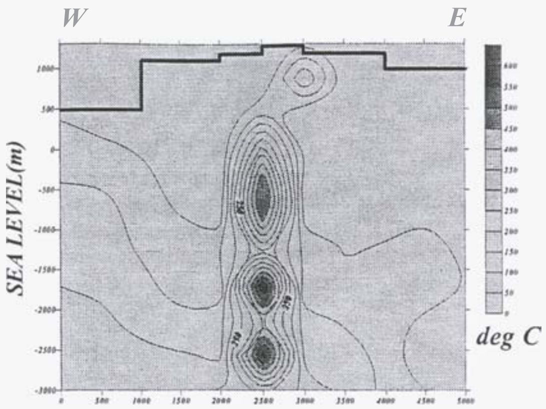

Figure 9- Calculated temperature distribution for 2003, on the same section as Figure 8

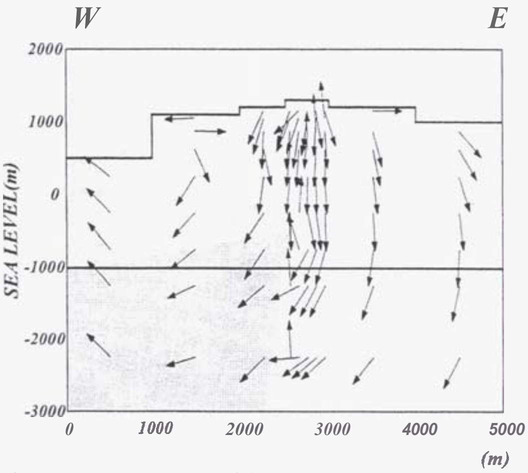

Figure 10 - Calculated flow pattern of geothermal fluid in 2003, on the same section as Figure 8

5. CONCLUSIONS

From the investigations and the numerical modelling in Phase I, we conclude that there is little possibility of extensive hydrothermal activity near the lava dome. On the other hand, there is another model that suggests hydrothermal circulation near the lava dome. We are continuing observations and investigations of Unzen Volcano in Phase 11, and will construct a model to explain the observed facts.

6. ACKNOWLEDGMENTS

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7. REFERENCES

Fujimitsu, Y., Ehara, S., Nishijima, J., Shibata, H., Sanematsu, K., Tashiro, H. and Daibo, T. (2000). Geothermal investigation of Unzen Volcano, Kyushu, Japan. Proc. *22nd New Zealand Geothermal Workshop 2000,* 183-187.

Hashimoto, T. (1997). Self-potential changes and subsurface hydrothermal activity accompanying the 1990-1995 eruption of Unzen Volcano. *J. Geoelectr.,* Vol. 49,977-993.

Hayba, D. O. and Ingebritsen, S. E. (1994). *The Computer Model HYDROTHERM, a Three-dimensional Finite-difference Model to Simulate Ground-water Flow and Heat Transport in the Temperature Range of 0 to 1,200 degrees Celsius.* USGS Water-Resources Investigations Report 94-4045.

Mori, T. and Notsu, K. (1997). Remote CO, COS, CO_2, SO,, HCl detection and temperature estimation of volcanic gas. *Geophys. Res. Lett.,* Vol. 24, 2047-2050.

Ono, A., Koya, M., Fujimitsu, Y. and Ehara, S. (1999). Remote observation of volcanic gases by Fourier Transform Infrared Spectroscopy (FT-IR) at Aso Volcano. *Bull. Volcanol. Soc. Japan,* Vol. 44, 123-130 (in Japanese with English abstract).

Sekioka, M. (1983). Proposal of a convenient version of the heat balance technique estimating heat flux on geothermal and volcanic fields by means of infrared Remote Sensing. *Memoirs of the National Defense Academy Japan,* Vol. **23**, 95-103.

Sekioka, M. and Yuhara, K. (1974). Heat flux estimation in geothermal areas based on the heat balance of the ground surface. *J. Geophysical Res.,* Vol. 79,2053-2058.

Shimizu, H., Matsumoto, S., Uehira, K., Matsuo, N. and Onishi, M. (2002). Seismic experiment for surveying volcanic conduit of Unzen Volcano, using controlled sources: *Proc.* 2002 *Japan Earth and Planetary Science Joint Meeting,* VO54-014 (in Japanese with English abstract).

STA (1999). *Unzen Volcano - International Cooperative Research with Scientific Drilling for Understanding Eruption Mechanisms and Magmatic Activity* -. Brochure of Science and Technology Agency, Japan.