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Hydrothermal System After the 1990-95 Eruption Near the Lava Dome of Unzen Volcano, Japan

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ABSTRACT

We have been conducted geothermal investigations on Unzen Volcano since 1999 as part of the Unzen Scientific Drilling Project. Using the result of our investigations, we constructed a conceptual model for a hydrothermal system after the 1990-95 eruption near the lava dome of Unzen Volcano.

This model shows that permeating rainwater makes dominant downflow and 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 lava dome. On the other hand, there is another conceptual hydrothermal model based on self-potential data presented by another group, which suggests the existence of hydrothermal circulation near the lava dome. Therefore, we constructed a 3-D numerical model of the Mt. Fugen area to investigate which conceptual model is reasonable.

A computer program called HYDROTHERM Version 2.2 was used for this numerical modeling. As a result of the numerical modeling of this study, we concluded that (a) there are two dominant flows, the upflow of high temperature gas in the conduit and the downflow of permeating rainwater, (b) the deeper part of the conduit of Unzen Volcano maintains a hot temperature, and (c) there is little possibility of geothermal fluid convection at a scale of a few hundred meters in Unzen Volcano in 13 years since the commencement of the 1990-95 eruption.

1. INTRODUCTION

Unzen Volcano is one of the active volcanoes in Japan. It is located in Shimabara Peninsula, Nagasaki Prefecture, Western Kyushu (Figure 1). The latest eruption began in 1990 and stopped in 1995. During the period of eruption, a lava dome appeared at a crater about 500 m east of the summit of Mt. Fugen, and as the lava dome grew, some disastrous pyroclastic flows occurred. The United Nation nominated Unzen as a Decade Volcano in 1991 (STA, 1999). Finally, the summit of the lava dome is about 130 m higher than that of Mt. Fugen, which was the highest peak of Unzen Volcano (Figure 2).

Since 1999, the Science and Technology Agency (STA) and the Ministry of Education, Culture, Sports, Science and Technology (MEXT) of Japan have conducted the Unzen Scientific Drilling Project (USDP). In Phase I of this project (April 1999 to March 2002), two flank drillings and a pilot drilling for a conduit drilling in Phase II were carried out. In Phase II (April 2002 to March 2005), the drilling to the conduit of the 1990-95 eruption is in progress as part of a joint project with the International Continental Scientific Drilling Program (ICDP). ICDP decided the financial support, totaling US$2.5 million for Phase II of USDP.

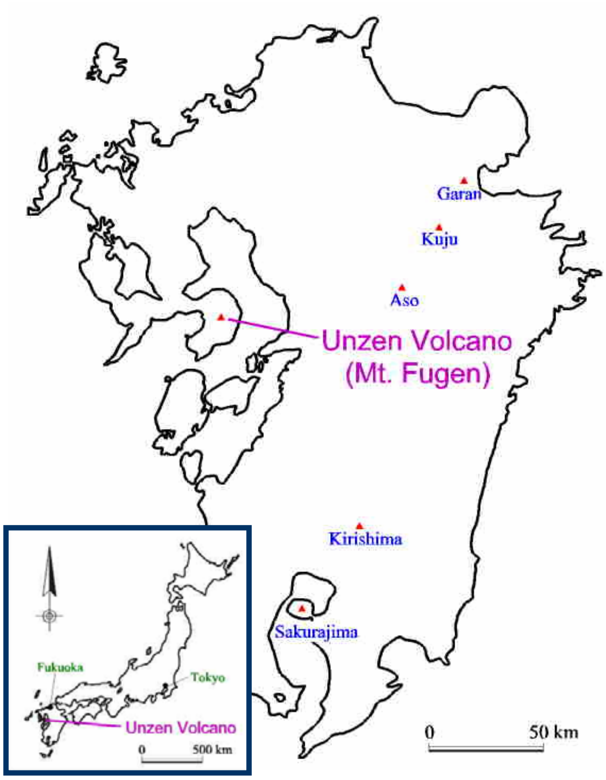

Figure 1: Location of Unzen Volcano (Mt. Fugen) and active volcanoes in Kyushu, Japan.

We have been participating in both phases of USDP. This paper shows a result of numerical modeling of the hydrothermal system in Unzen Volcano constructing in Phase II.

2. TWO CONCEPTUAL MODELS OF UNZEN VOLCANO

We have been conducting several kinds of observations and investigations, namely infrared imagery observation, 1 m-depth temperature, gamma-ray intensity investigation, repeat gravity measurements and remote observation of volcanic gases by FTIR spectrometer. These are mainly on heat discharge and ground temperature.

The cooling effect of groundwater upon the conduit using a 2-D thermal conductive numerical model of Unzen Volcano has already been discussed in the previous study (Fujimitsu et al., 2000). Using our previous numerical model study and the results of our geothermal surveys (Fujimitsu et al., 2002), we constructed a conceptual model of Unzen

Volcano in 2003 when the conduit drilling commenced (Figure 3). This model shows that permeating rainwater flows downward and 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.

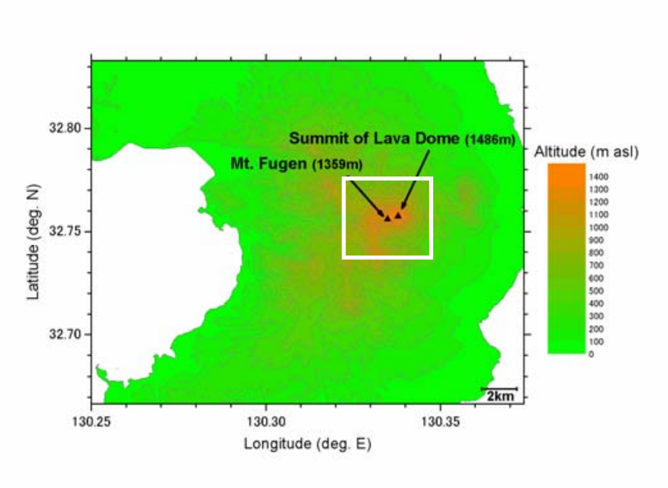

Figure 2: Location of the summits of Mt. Fugen and the lava dome formed by the 1990-95 eruption. A white rectangle indicates a horizontal extension of the modeling area.

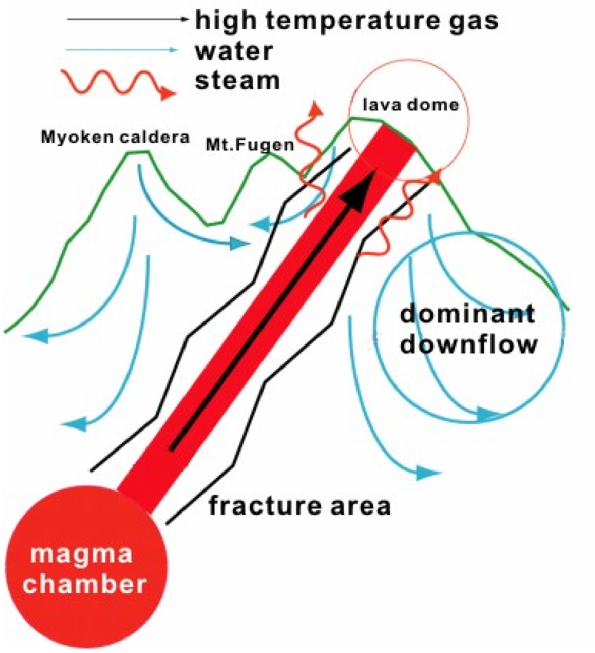

Figure 3: Conceptual model of Unzen Volcano constructed in this study.

On the other hand, there is another conceptual hydrothermal model based on self-potential (SP) data (Hashimoto, 1997), which suggests the existence of hydrothermal circulation near the lava dome (Figure 4). Hashimoto et al. (2002) show a 2-D numerical model which explains that a high temperature conduit generates a hydrothermal circulation which has a scale of a few hundred meters (Figure 5).

3. 3-D NUMERICAL MODEL OF UNZEN VOLCANO

We constructed a 3-D numerical model of the Mt. Fugen area to investigate which conceptual model is reasonable. A computer program called HYDROTHERM Version 2.2 (Hayba and Ingebritsen, 1994) was used for this numerical modeling. 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.

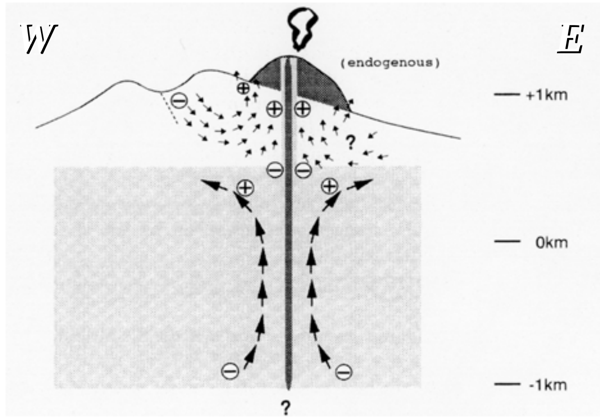

Figure 4: Hydrothermal model in the period from Dec. 1993 based on the result of SP survey (Hashimoto, 1997).

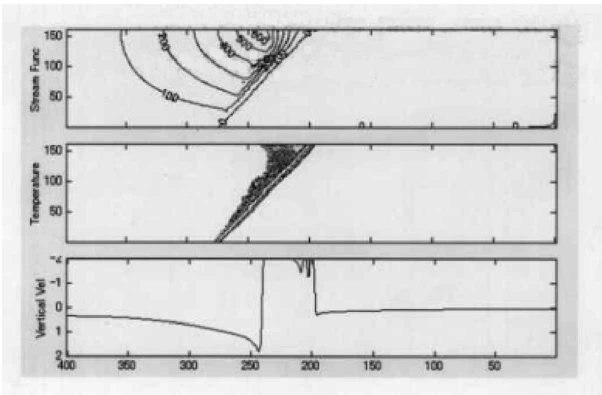

Figure 5: 2-D numerical model for the hydrothermal model by Hashimoto (1997) (Hashimoto et al., 2002).

3.1 Analytical Area

The summit of Mt. Fugen was set at the center of an analytical area that has a horizontal extent of 5 km (E-W) by 4.6 km (N-S) (a white rectangle in Figure 2) and a vertical extent of –3 km sea level to the ground surface (Figure 6).

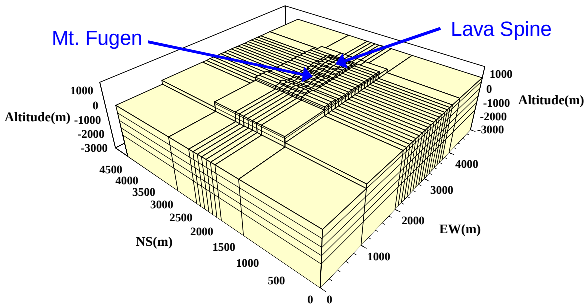

Figure 6: 3-D finite difference blocks for the numerical model of Unzen Volcano.

The analytical area was divided into two layers, made up of a volcanic rock layer (Layer I) and a basement rock layer (Layer II) (Figure 7). Each layer has some thermal and hydrological properties shown in Table 1. These values are based on the result of the geothermal development promotion survey by New Energy Development Organization (NEDO) (NEDO, 1988). In order to express the topography of the summit part of Unzen Volcano more precisely than the previous model by Fujimitsu et al. (2002), larger portion of the analytical area is divided into 100-meter cubes, which are the minimum size of the finite difference block. This model also expresses the E-W trending regional tectonic graben system formed by the basement rock (Unzen Graben) shown by Hoshizumi et al. (2002) (Figure 8).

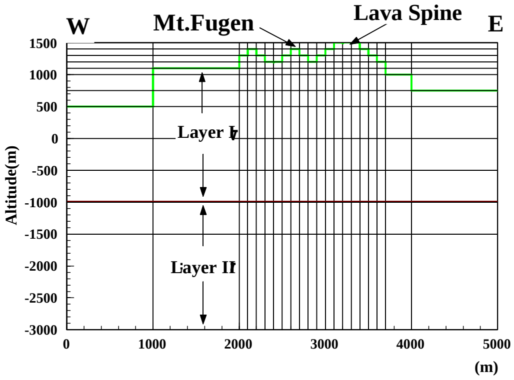

Figure 7: E-W slice No. 5 of the numerical model, which includes the summit of Mt. Fugen and the lava spine.

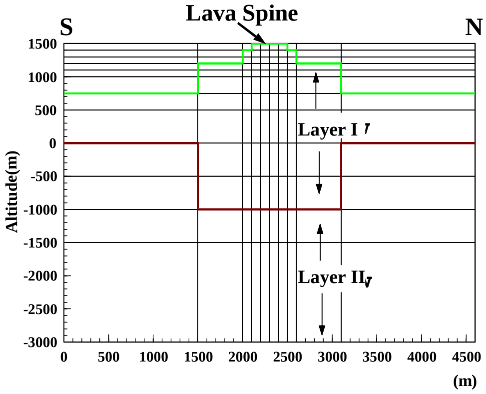

Figure 8: N-S slice No. 15 of the numerical model, which includes the lava spine.

Table 1: Rock properties for each layer.

	Layer I Volcanic Rock	Layer II Basement Rock
Specific Heat (J/kg K)	8.0×10^{2}	8.0×10^{2}
Density (kg/m³)	2.33×10^{3}	2.35×10^{3}
Permeability (darcy)	8.4×10^{-4}	8.4×10^{-4}
Porosity (-)	0.10	0.05
Thermal Conductivity (W/m K)	1.9	2.6

3.2 Calculation Parameters and Modeling Process

To begin with, we constructed a steady state model with no magma penetration in order to calculate the background temperature and pressure distributions. 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 four years from 1995 when the latest eruption stopped. We used the calculated background temperature and pressure distributions as an initial condition, and set the conduit to an initial temperature of 850 °C. The position of the conduit on E-W slice No. 5 is indicated in Figure 9 that is estimated by the distribution of the volcanic earthquakes during the eruption (Nakada et al., 2002). Shimizu et al. (2002) estimated that the N-S width of the conduit is about 200 to 300 m from seismic survey data. Therefore, we calculated for two cases, that is, the widths of the conduit at 300 m (Case 1) and 100 m (the smallest block size of this model) (Case 2). Other conditions were the same as those of the steady state model.

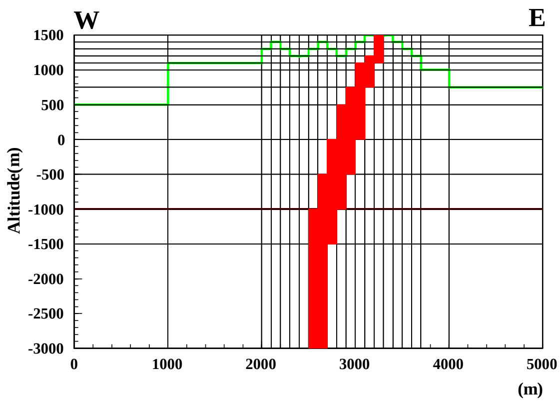

Figure 9: Block layout of the conduit (red blocks) on E-W slice No. 5.

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. The most suitable match occurred when the permeability was 50 times higher than the surroundings in both cases (Figure 10).

4. DISCUSSION

We tried to estimate the temperature distribution and geothermal fluid flow for 2003, when the conduit drilling commenced, using the model. The results of both cases are almost the same. Therefore, we will show the result of Case 1 in this paper. The velocities of water and steam are quite different, so the arrows in the flow pattern only indicate the flow direction.

The temperature distribution (Figure 11) shows that the shallow part of the conduit is cooled by groundwater, but still maintains a high temperature at depth. The projected flow pattern on Slice No. 5 for 2003 (Figure 12) shows that the downflow of permeating rainwater is dominant, with an upflow of high temperature gas in the conduit and there is no geothermal fluid convection at a scale of a few hundred meters near the lava dome.

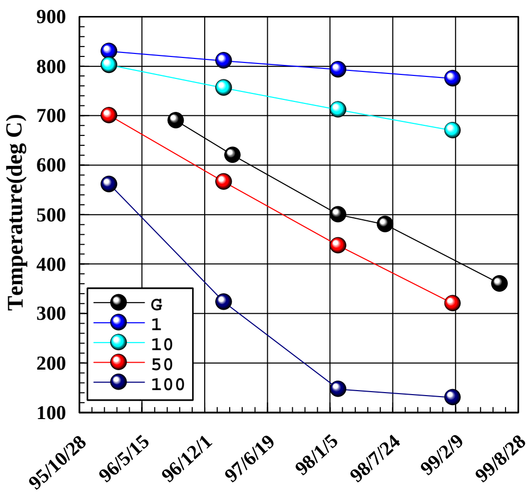

Figure 10: Temperature change of the hottest fumarole on the lava dome (G) and the calculated temperature variations at the summit of the lava dome in Case 1.

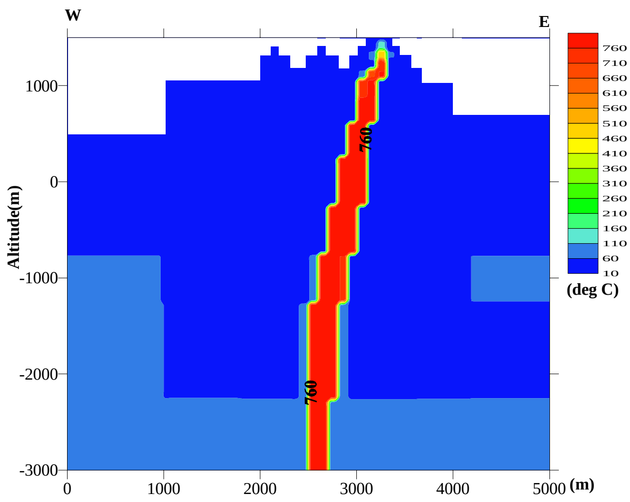

Figure 11: Calculated temperature distribution in 2003 on E-W slice No. 5 in Case 1.

These results mean 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. These results also indicate that the lava in the conduit is still at a high temperature when the conduit drilling commenced.

5. CONCLUSIONS

As the result of the numerical modeling of this study, we concluded that (a) there are two dominant flows, the upflow of gas in the conduit and the downflow caused by permeation of rainwater, (b) the deeper part of the conduit of Unzen Volcano is still at a high temperature, and (c) there is little possibility of geothermal fluid convection at a scale of a few hundred meters in Unzen Volcano in 13 years since the commencement of the 1990-95 eruption. These conclusions mean that our conceptual model is more reasonable, and we have to think another mechanism for generating SP anomalies observed by Hashimoto (1997).

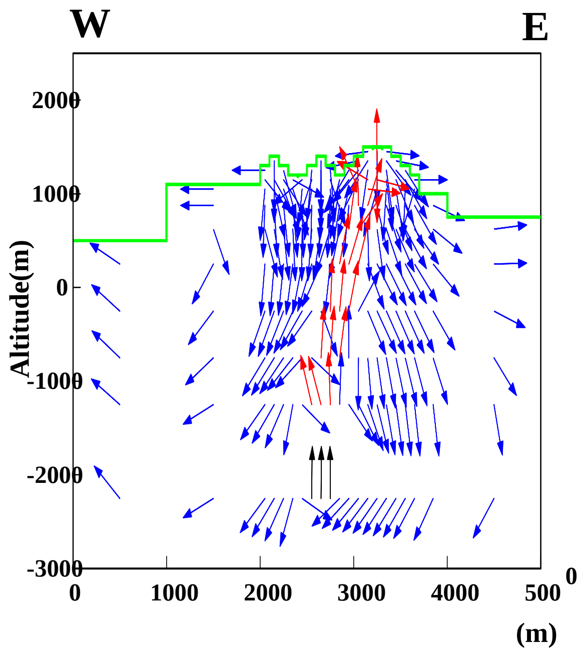

Figure 12: Calculated flow pattern of geothermal fluid in 2003 on E-W slice No. 5 in Case 1. Blue, red and black arrows indicate liquid water, steam and super-critical fluid, respectively.

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REFERENCES

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

Fujimitsu, Y., Ehara, S., Nishijima, J., Kanou, R. and Hirao, T.: Study on Hydrothermal System Development, Unzen Volcano, Japan: A Topic in Phase I of the Unzen Scientific Drilling Project, *Proceedings*, 24th New Zealand Geothermal Workshop 2002 (2002), 283-287.

Hashimoto, T.: Self-potential Changes and Subsurface Hydrothermal Activity Accompanying the 1990-95 Eruption of Unzen Volcano, *Journal of Geomagnetism and Geoelectricity*, **49**, (1997), 977-993.

Hashimoto, T., Tanaka, Y. and Kagiyama, T.: Developing Hydrothermal System and Self-potential Changes associated with Magma Intrusion, *Proceedings*, 2002 Japan Earth and Planetary Science Joint Meeting (2002), E016-008. (in Japanese with English abstract)

Hayba, D. O. and Ingebritsen, S. E.: 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* (1994).

Hoshizumi, H., Uto, K., Matsumoto, A., Xu, S. and Oguri, K.: Geology of Unzen Volcano and Core Stratigraphy of the Flank Drilling, *Proceedings*, Unzen Workshop 2002: International Workshop on Unzen Scientific Drilling Project (2002), 4-8.

Nakada, S., Motomura, Y. and Shimizu, H.: Aim of Conduit Drilling at Unzen Volcano, *Proceedings*, Unzen Workshop 2002: International Workshop on Unzen Scientific Drilling Project (2002), 21-24.

NEDO: Unzen-seibu Chiiki (Western Unzen Region), *Geothermal Development Promotion Survey Report*, **15**, (1988). (in Japanese)

Shimizu, H., Matsumoto, S., Uehira, K., Matsuo, N. and Onishi, M.: Seismic Experiment for Surveying Volcanic Conduit of Unzen Volcano, *Chikyu Monthly*, **24**, (2002), 878-882. (in Japanese)

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