TEMPERATURE ESTIMATION AROUND THE CONDUIT OF THE 1990-95 ERUPTION AT UNZEN VOLCANO BY NUMERICAL SIMULATION.

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SUMMARY – Conduit drilling (Well USDP-4) was completed in 2004 in the Unzen Scientific Drilling Project (USDP). Some conduit materials of the 1990-95 eruption have been encountered at the bottom of Well USDP-4 (-150 m sea level), and a bottom temperature of 180° C was estimated using the logging data, although the temperature of about 700 ^oC had been inferred before the drilling. Accordingly, conduit cooling from the initial temperature (850 ^oC) to the observed temperature (180 ^oC) was evaluated by numerical simulation. The numerical model of our previous study was used for the initial model in this study, and revised by using the new information obtained from the conduit drilling. Drilling indicates that the N-S width of the conduit of the latest eruption is 20 to 30 m, and it occupies a zone of about 300 m, which includes the conduits of the past eruptions. However, the conduit width in the initial model was 100-300 m, which had been estimated by the result of seismic survey data. Therefore, the revised model has a conduit of 25 m width in the conduit zone of 300 m width in N-S direction. Two cases were calculated for the conduit width in E-W direction (100 and 300 m). In the simulation, the cooling process of the conduit, which has the initial temperature of 850 ^oC, from 1995 (the end of the eruption) to 2004 (completion of the conduit drilling) was calculated, and the temperatures of the conduit and the surroundings at -150 m sea level were monitored. To begin with, the permeability of the mountain body was fixed at 1 mdarcy and that of the conduit zone was set as a parameter and the values of 1, 10, 30 and 50 mdarcys were assigned. However, the temperature proved insensitive to the permeability of the conduit zone and was higher than the observed data. Therefore, the permeability of the mountain body was also treated as the parameter, and the same value with the conduit zone was assigned. As a result, the temperature of 180 ^oC was obtained in the conduit of the monitoring area under the permeability conditions of 10 mdarcys and 30 mdarcys in the case of the conduit width of 100 m in E-W direction.

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 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. The summit of the lava dome is about 130 m higher than that of Mt. Fugen (Figure 2).

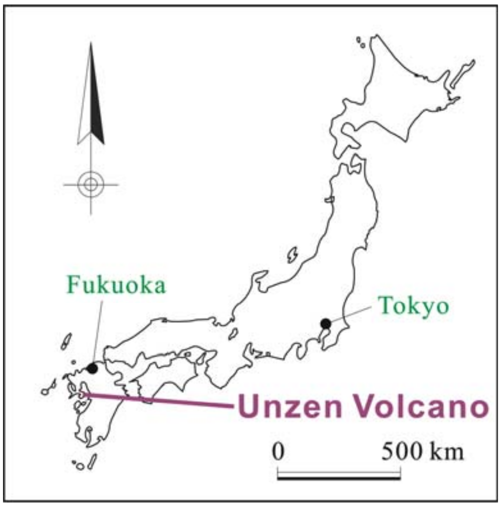

Figure 1 - Location of Unzen Volcano.

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. In Phase I (April 1999 to March 2002) of this project, two flank holes and a pilot hole were drilled in lead up to conduit drilling (Phase II). In Phase II (April 2002 to March 2005), Well USDP-4, the drilling of the conduit of the 1990-95 eruption, was completed in 2004. The wellhead exists about 1.3 km north of the summit of Mt. Fugen; the hole length is 1997 m (Figure 3). Some conduit materials of the

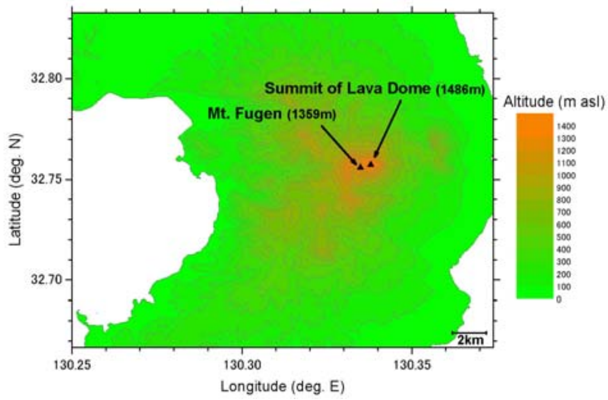

Figure 2 - Topographical map of Unzen Volcano in Shimabara Peninsula.

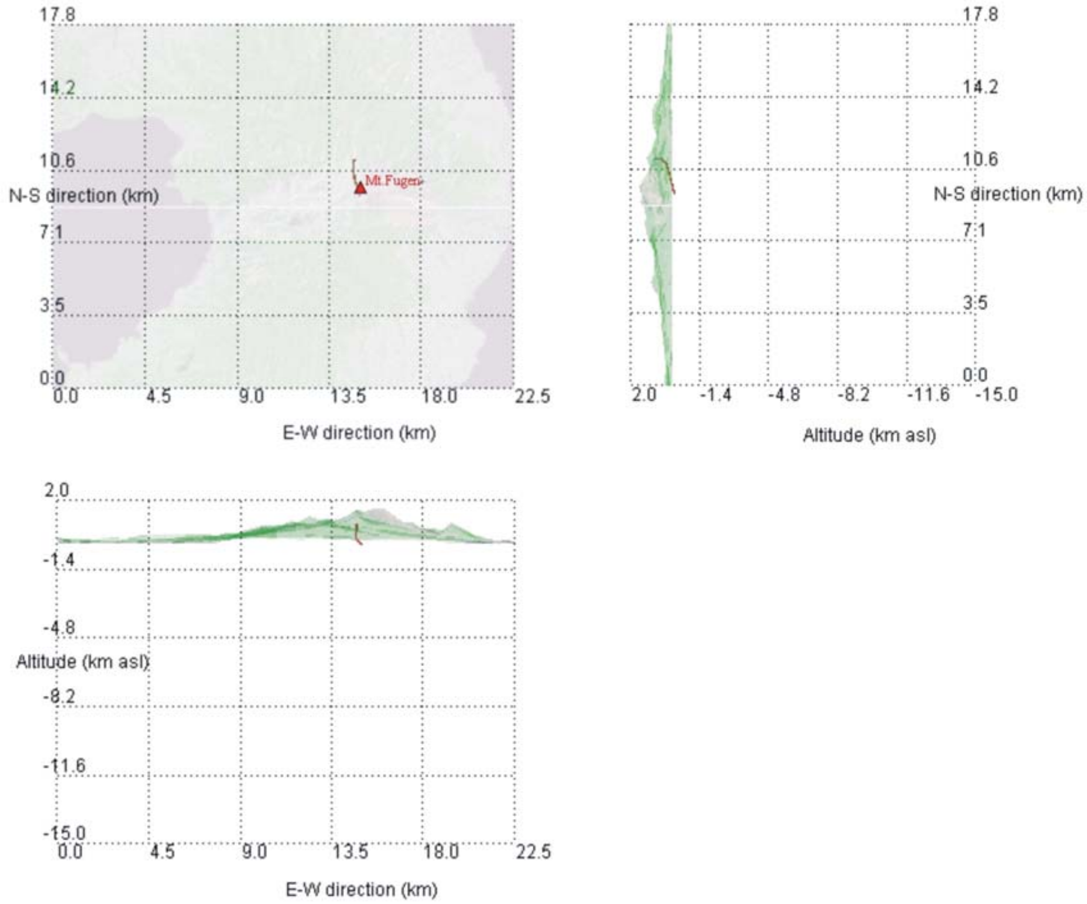

Figure 3 - Trace of Well USDP-4 in plan view (upper left), the projection on E-W section (lower left) and the projection on N-S section (upper right) of Shimabara Peninsula.

1990-95 eruption were encountered at the bottom of USDP-4 (-150 m sea level), and the bottom temperature of 180 ^{o}C was estimated from the logging data, although the temperature of about 700 ^{o}C had been inferred before the drilling.

We have been participating in both phases of USDP, and the purpose of this study is to evaluate the possibility of conduit cooling from the initial temperature (850 ^{o}C) to the observed temperature (180 ^{o}C) by using the numerical simulation.

2. NUMERICAL MODEL

In this study, we used HYDROTHERM Version 2.2 (Hayba and Ingebritsen, 1994) for numerical modelling, whereas before we used the numerical model proposed by Fujimitsu and Kanou (2003). The summit of Mt. Fugen was set at the centre of an analytical area that has a horizontal extent of 5 km (E-W) by 4.6 km (N-S) (Figure 4) and a vertical extent of -3 km sea level to the ground surface (Figure 5). The analytical area was divided into two layers, made up of a volcanic rock layer (Layer I) and a basement rock layer (Layer II). Layer I was divided into a vadose zone and a water-saturated zone in this study (Figure 6). Each layer has some thermal and hydrological properties shown in Table 1. These values are based on NEDO (1988). The vadose zone was simulated by setting low porosity for Layer I, because HYDROTHERM can treat the behaviour of liquid and gas water, only.

Before the transient analysis, we constructed a steady state model with no magma penetration in order to calculate the background temperature and pressure distribution of this region. 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. The lateral boundaries were thermally insulated and impermeable.

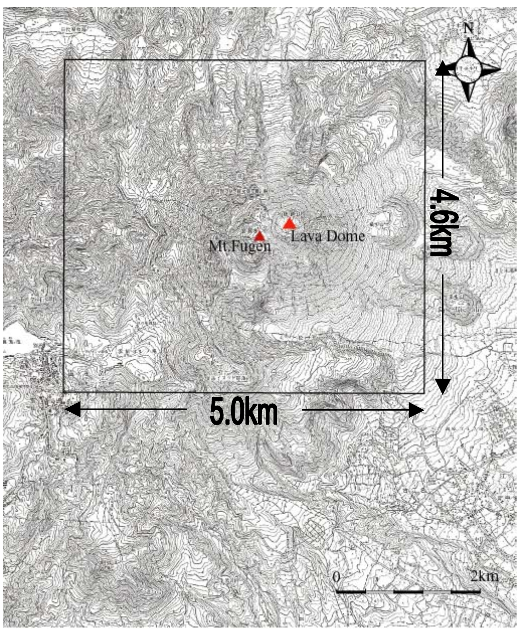

Figure 4 - Horizontal extent of modelling area.

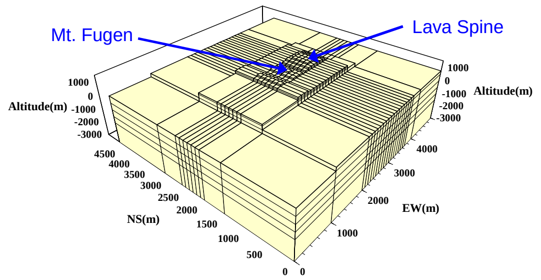

Figure 5 - 3-D finite difference blocks for the numerical model of Unzen Volcano.

We revised the initial model by using the new information obtained from the conduit drilling. Although USDP-4 did not pass through the conduit of the latest eruption completely, the result of the geological research on the core data of USDP-4 concluded that the latest conduit probably has the N-S width of about 20 to 30 m at -150 m sea level, and exists in the conduit zone of about 300 m, which includes the conduits of the past eruptions. The conduit width in N-S direction is 100-300 m in the initial model, because the width of the initial model is based on the result of seismic survey data (Shimizu et al., 2002). Therefore, the revised model has the latest conduit of 25 m width at the centre of the conduit zone of 300 m width in N-S direction.

3. TRANSIENT ANALYSIS PROCESS

In the transient analysis, the cooling process of the conduit, which has the initial temperature of 850 °C, from 1995 (the end of the eruption) to 2004 (completion of the conduit drilling) was calculated, and the temperatures of the conduit and the surroundings at -150 m sea level were monitored. Two cases were calculated for the conduit width in E-W direction (100 and 300 m), because there is no information for the width. The E-W width of the conduit zone was assumed to be the same as the conduit width. The position of the conduit on E-W slice No.6 is indicated in Figure 7, which was estimated from the distribution of the volcanic earthquakes during the eruption (Nakada et al., 2002). Other conditions were the same as those of the steady state model.

To begin with, the permeability of the mountain body was fixed at 1 mdarcy and that of the conduit zone was set as a parameter and the values of 1, 10, 30 and 50 mdarcys were assigned. However, the temperature of the monitoring area was insensitive to the permeability of the conduit zone and was higher than the observed data. Therefore, the permeability of the mountain body was also treated as a parameter, and the same value with the conduit zone was assigned.

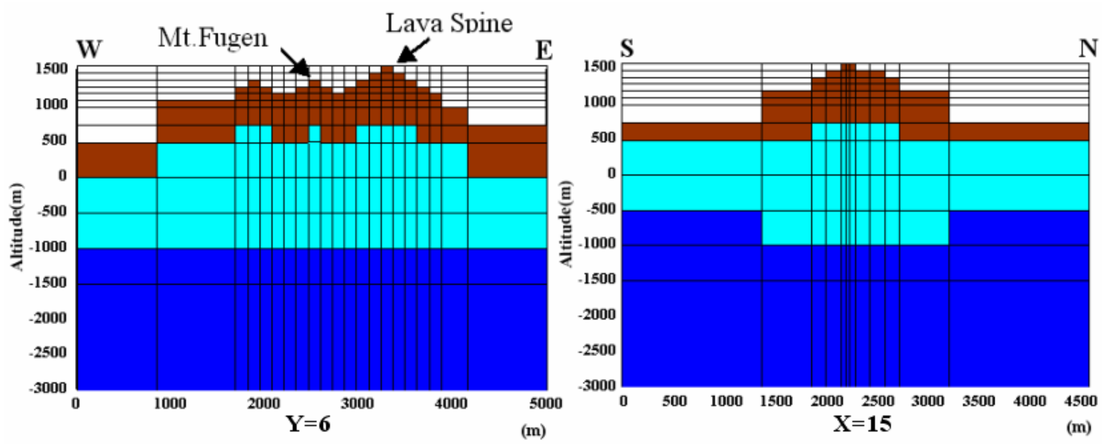

Figure 6 - E-W slice No. 6, which includes the lava spine and the summit of Mt. Fugen, and N-S slice No.15, which includes the lava spine, of the numerical model. Brown: vadose zone of Layer I; Light Blue: water-saturated zone of Layer I; Blue: Layer II.

Table 1 - Rock properties for each layer.

	Layer I (Volcanic Rock)		Layer II (Basement Rock)
	Vadose Zone	W-S Zone*	
Specific Heat (J/kg K)	$8.0x10^2$		$8.0x10^2$
Density (kg/m^3)	$2.5x10^3$		$2.5x10^3$
Thermal Conductivity (W/m K)	1.9		2.6
Porosity (-)	0.1, 0.05	0.2	0.1

*W-S Zone: Water-saturated Zone.

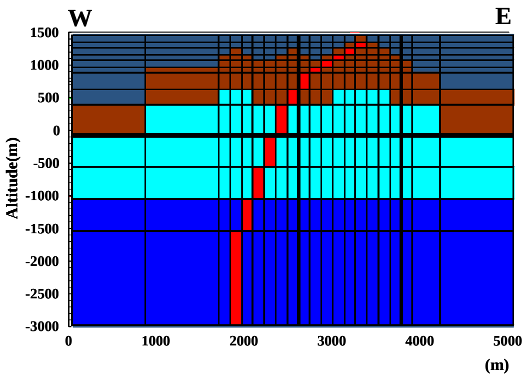

Figure 7 - Block layout of the conduit (red blocks) on E-W slice No.6 in the case of the conduit width in E-W direction of 100 m .

In the case of the conduit width in E-W direction of 300 m, the conduit temperature in the monitoring area did not cool down to the observed data even if the permeability of the mountain body was increased. Therefore, we evaluated only the case of 100 m wide conduit.

4. DISCUSSION

In the simulation, high permeability alone in the conduit zone was insufficient to cool the conduit in the monitoring area completely. Therefore, we infer that the mountain body also has higher permeability than was assumed. Moreover, the E-W width of 300 m was too large to obtain the measured temperature. Hence, we estimated that the conduit possibly has an E-W width of 100 m.

As a result, the temperature of 180 °C was obtained in the conduit of the monitoring area under the permeability conditions of 10 mdarcys (Figure 8) and 30 mdarcys in the case of the conduit width of 100 m in E-W direction. This result means that a highly permeable body and a small conduit are required to explain the measured temperature of 180 °C.

5. CONCLUSIONS

The evaluation of conduit cooling at Unzen Volcano from the initial temperature (850 °C) to the temperature observed at the bottom of USDP-4 (180 °C) was conducted by numerical simulation. As a result, a temperature of 180 °C was obtained in the conduit of the monitoring area under the permeability conditions of 10 mdarcys and 30 mdarcys for a conduit width of 100 m in E-W direction. This result means that a highly permeable mountain body and a small conduit are required to explain the measured temperature.

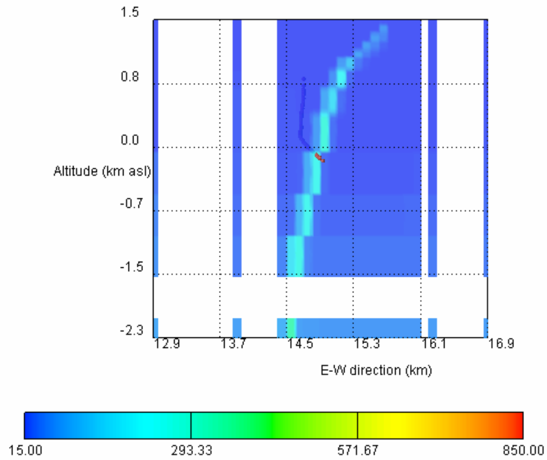

Figure 8 - Calculated temperature distribution for 2003 on E-W slice No. 6 in the case of 10 mdarcys. The unit of temperature is °C. The curved line at the centre of this figure shows the projected trace of Well USDP-4. The blue trace indicates the part of the well behind the slice, and the red trace indicates that before the slice.

6. ACKNOWLEDGMENTS

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