4. The 2000 Eruption at Miyakejima Volcano

Introduction

Miyakejima is a volcanic island of about 8 km across, located about 180 km south of Tokyo, on the volcanic chain of Izu-Ogasawara (or -Mariana). Including the body under the sea level, the base of the volcano has the diameter of about 13 km and the height is about 1,000 m. It is a stratovolcano, consisting largely of basaltic rocks. The summit area is characterized by double calderas, 3.5 and 1.5 km across, in which a scoria cone "Oyama" is located. Near the coastal line, there are many craters formed by phreatomagmatic eruptions.

During these 500 years, twelve eruptions occurred at intervals of 21 to 69 years. The volume of each eruption ranges from 20 to 30 million cubic meters. In the 20-th century, eruptions occurred in 1940, 1962 and 1983. The precursory seismic activity was generally short, less than 6 hours. That of the 1983 eruption was as short as 1 hour and a half. Historic eruptions had begun with effusion of lava and lasted for the period as short as several days, except for the 1940 eruption, which continued for about a month. Basaltic lavas had been effused along fissures extending radially from the summit .

The manner of the 2000 eruption was largely different from what had been experienced during the last hundred years. Lateral migration of magma away from Miyakejima generated the summit subsidence, associated with explosive eruptions from the summit in the summer of 2000. Huge amount of SO_2 (as high as $4x10^7$ kg/day) had been continuously emitted from the crater in the newly formed caldera (Oyama Caldera) after the major eruptions were over. All islanders (about 3,000) had been forced to continue evacuation from Miyakejima for more than two and one half years. According to geological studies (e.g. Tsukui *et al*., 2001), Miyakejima had experienced the summit collapse about 2.5 ka, resulting in the formation of the Hatchodaira Caldera with a size similar to the Oyama Caldera. Therefore, for Miyakejima caldera-forming eruption may repeat once every 2,500 years. Brief summaries of various aspects of this eruption were reported by Nakada *et al*. (2001), Uto *et al*. (2001) and so on.

Volcano Monitoring and Precursors to the 2000 Eruption

In the 1990's various kinds of geophysical observations were strengthened in Miyakejima volcano, including seismic array observation, repeat precise leveling and gravity surveys, GPS, borehole tilt measurements and so on by the related organizations: Tokyo Metropolitan Government-JMA-University of Tokyo (seismic observation), National Institute for Earth Science and Disaster Prevention (seismic and tilt observations), Geographical Survey Institute (GPS observation), university group (GPS), and cooperation among researchers in Japanese universities, French LGO-OPGC and USGS (electromagnetic observations). Leveling surveys by Tokyo Metropolitan Government and GSI, and GPS observation by GSI and the university group that were conducted since 1990, clearly detected an inflation of the island with a pressure source in the south part of the island (Mikada *et al*, 1996; Nishimura *et al*., 2002). The results of the electromagnetic observation also indicated the thermal demagnetization at a shallow depth beneath the south of Oyama cone (Sasai *et al*., 2001). These were the precursors to the 2000 eruption.

Chronology of the 2000 Eruption

Volcanic activity of the 2000 eruption at Miyakejima can be divided into four stages based on surface phenomena: magma intrusion, summit subsidence, explosion, and degassing stages (Fig. 1).

Magma Intrusion Stage (26 June-7 July): A seismic swarm activity started at shallow depths beneath the summit in the evening of 26 June 2000 (JMA, 2000). Eruption did not occur, although magma seemed to have approached to the summit as shallow as up to 200 m below the sea level as suggested by tilt observation (Fujita *et al*., 2002). Hypocenter of earthquakes moved westward about the midnight of 26-27 June, associated with ground deformation indicating the intrusion of dike in EW direction at the western coast (Fig. 2) (Sakai *et al*., 2001). Submarine eruption occurred on the morning of 27 June, soon after the seismic swarm passed through the eruption points (JMA, 2000). Since then, felt earthquakes occurred mainly outside Miyakejima. Bursts of earthquakes including Magnitude 6 class were repeated in the sea between Niijima-Kozushima and Miyakejima from 27 June until the middle August. GPS data of Geographical Survey Institute showed that a steady increase in the baseline length between the Niijima and Kozushima started in this stage and continued by August (Fig. 1b). As if to compensate for this, continuous shortening of a N-S baseline across Miyakejima Island (diameter of the island) was observed (Fig. 3) (Nishimura *et al*., 2001; 2002).

Summit Subsidence Stage (8 July-middle August): Following heavy seismicity beneath the island that resumed on 4 July (Fig. 1d), collapse of the summit area took place suddenly on the evening of 8 July (Fig. 4), accompanied by a small phreatic eruption. An integration of seismic, gravimetric and geomagnetic observations revealed the precursory processes leading to the summit collapse. Subsidence of the summit area had continued by middle August (Fig. 1c) (Hasegawa *et al*., 2001). Phreatomagmatic eruptions occurred on 14 and 15 July. Tiltmeters installed along the hillside road by National Institute of Earth Science and Disaster Prevention indicated steady and continuous deflation of the summit area, periodically broken by sudden inflation (Ukawa *et al*. 2000). Synchronously, the number of volcanic earthquakes increased for a few hours and stopped with occurrence of a very-long-period seismic event (VLP pulse) whose pulse width was as long as 50 s. Waveform analyses of these signals show that the source mechanism of these pulses is characterized by a large volume expansion of 10^7 m^3. Several models have been proposed. One is an intermittent subsidence of a piston in the volcanic conduit (Kumagai *et al*., 2001). Another is an

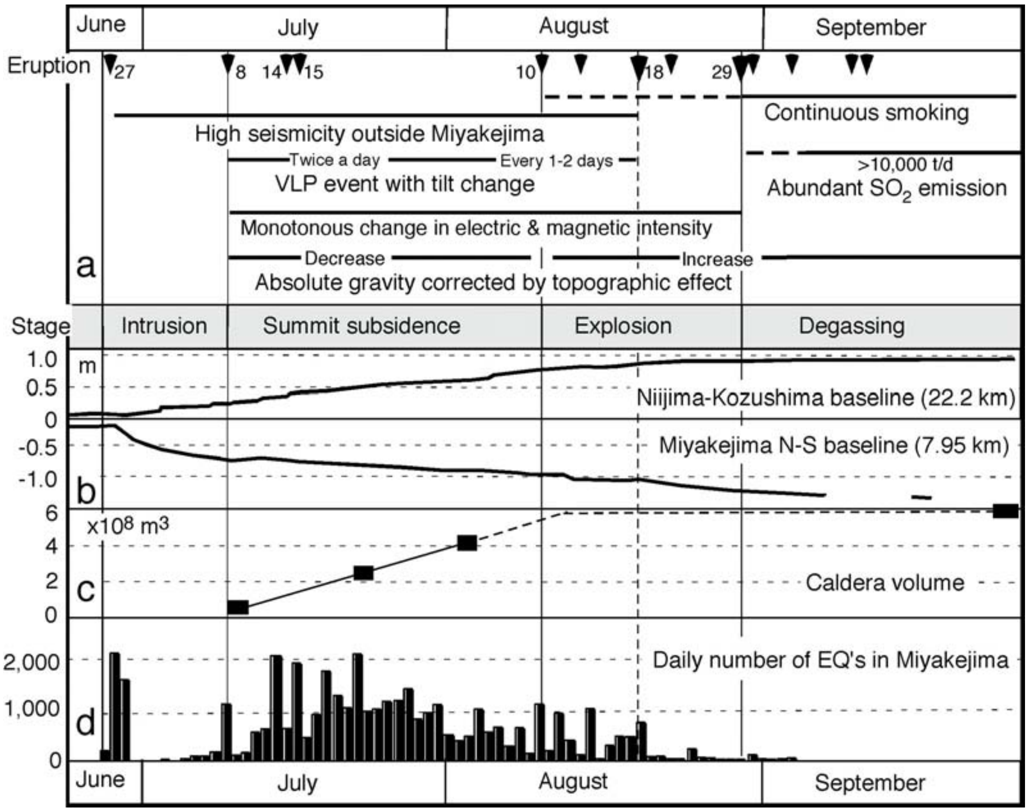

Fig. 1. Chronology of the 2000 eruption at Miyakejima volcano (Nakada *et al*., submitted, fig. 2). a) Stages of eruptive activity based on surface phenomena. Major eruptions are shown as vertical triangle with representative variations of geophysical and geochemical phenomena (modified from JMA, 2000; Kikuchi *et al*. 2001; Sasai *et al*. 2001; Furuya *et al*. 2003; Kazahaya *et al*. 2001). b) GPS data for baselines of Niijima-Kozushima and south-north coast of Miyakejima (after Nishimura *et al*., 2001). c) Temporal change in volume of the summit subsidence (Hasegawa *et al*., 2001). d) Daily number of earthquakes that occurred only in the Miyakejima island (data from JMA, 2000).

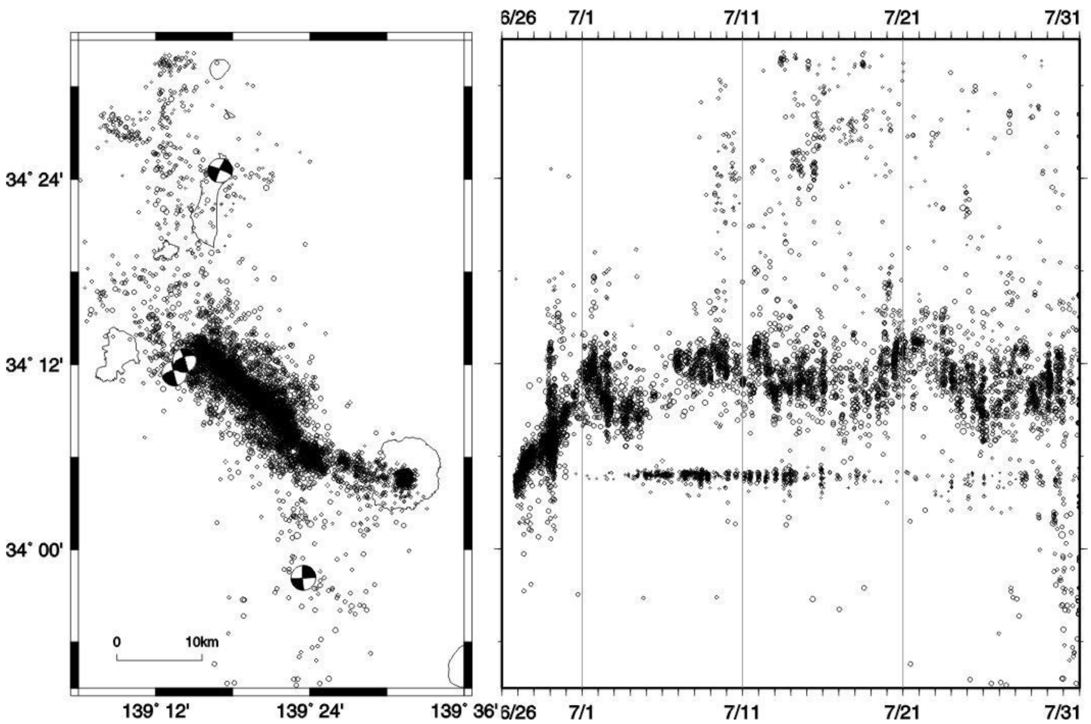

Fig. 2. Time-space distribution of swarm earthquakes that occurred on and around Miyakejima volcano during the period of 26 June to 31 July 2000 (Sakai *et al*., 2001).

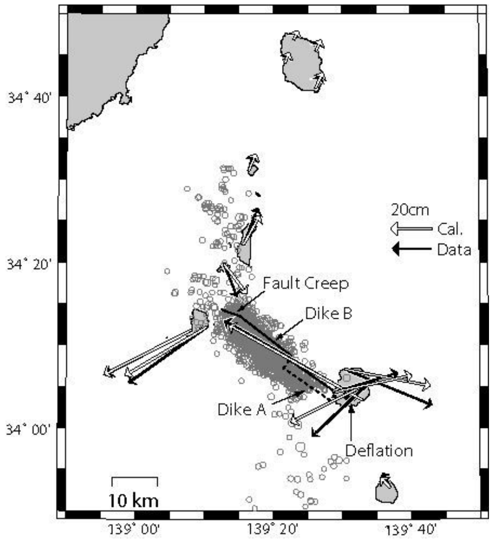

Fig. 3. Optimal fault model of ground deformation that accompanied the Miyakejima 2000 eruption. White and black arrows indicate calculated and observed displacements. Open circles are epicenters of earthquakes ($M \geqq 3.5$) (Nishimura *et al*., 2001).

Fig. 4. Southwestern view of the summit subsidence at Mt. Oyama, Miyakejima volcano. Left: Initial stage of subsidence (1.0 x 0.8 km with 0.2 km depth), taken by S. Nakada on 9 July 2000. Right: Smokes including abundant sulfur dioxides were emitted from the Oyama Caldera (1.6 km across and 0.5 km deep), taken by T. Kaneko on 4 June 2001. Both were take in the similar angles and directions.

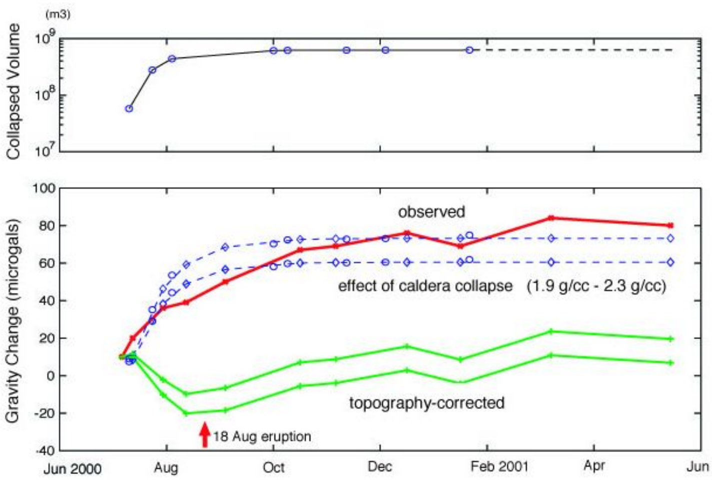

Fig. 5. Absolute gravity changes observed at the north coast of Niyakejinma.. Thick solid line indicates observed gravity and thin solid lines residual gravities after correction for the effect of caldera collapse (Furuya *et al*., 2003).

Fig. 6. Photo of explosion on 18 August 2000. Ash was sent up to 16 km above the crater. Taken from the Mikurajima Island about 20 km south of Miyakejima on the 18 August evening. By courtesy of K. Takeiri.

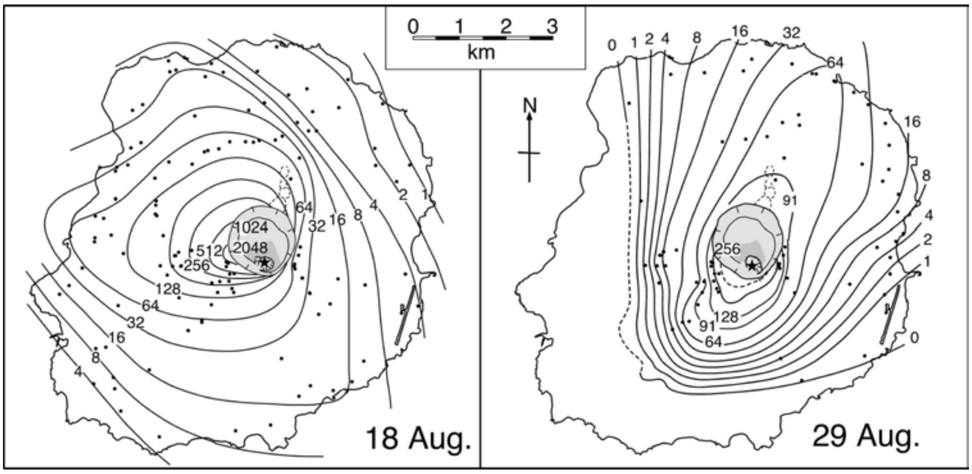

Fig. 7. Isopach map of the 18 and 29 August eruption products. Numbers of contours are in mm. The volumes of products are estimated to be 7.5 x 10^6 m^3 for 18 August and 3.4 x 10^6 m^3 for 29 August. According to M. Nagai (unpublished).

Fig. 8. Photograph of ash-cloud surge attacking the northern part of Miyakejima, Taken from northwest of Miyakejima by S. Nakada around 5:30 a.m., 29 August 2000.

underground hydrothermal expansion model (Kikuchi *et al*., 2001). The periodical tilt changes were repeated with time intervals ranging from half a day to 2 days until 18 August 2000 (Fig. 1a).

The combined use of an absolute gravimeter FG5 with LaCoste-Romberg gravimeters enabled us to trace the accurate and high-resolution spatio-temporal gravity variations caused by the volcanic activity (Furuya *et al*., 2003). It was noted that the topography-corrected gravity data showed a clear decrease during the period of active subsidence and eruptions until middle August (Fig. 5). This was the essential information on the cause of repeated hydromagmatic eruptions that continued till August. Remarkable changes in the electric self-potential and geomagnetic total intensity in the island were also observed in this stage.

Explosion Stage (10 August-29 August): Explosive eruptions started on 10 August, and continued intermittently by 29 August. Caldera had grown up to about 1.5 km in diameter by early August, and was widened later by gravitational collapse of its steep walls. The largest explosion occurred on the evening of 18 August, and the eruption column reached the stratosphere (Fig. 6). Abundant ballistics including volcanic bombs fell over the summit area and volcanic ash with pebbles covered thickly most parts of the island (Fig. 7). The last tilt change took place in this explosion. Eruption of low-temperature pyroclastic flows took place on the morning of 29 August (Fig. 8). The residential area where islanders remained was enveloped by thick but not-hot and slow-moving ash cloud. However, nobody was injured by this eruption. Possibility of more explosive explosions forced the head of the Miyakejima Village to order all islanders evacuation to the main land on 3 September.

Degassing Stage (after 29 August): Plumes including abundant SO_2 had been emitted from the summit crater. The value measured with COSPEC from helicopters had increased, following the 29 August eruption. The SO_2 flux was peaked over $4x10^7$ kg/day in the end of 2000 (Kazahaya *et al*., 2001; Shinohara *et al*., 2003). Spewing of volcanic ash took place several times in the degassing stage, accompanied by continuous volcanic tremor. According to JMA, the temperature of the craters measured from helicopter had increased up to about 400 °C by the end of 2000. Glow of the summit in night was observed in December 2000-January 2001 and November-December 2001.

Eruption Products

The total volume of deposits in July and August eruptions was about 1.7×10^7 m^3 (2.3×10^{10} kg). It is much smaller than the subsidence volume of the Oyama Caldera (about 6×10^8 m^3) (Hasegawa *et al*., 2001). The estimated eruption rates were between 10^6 and 10^7 kg/s for the 18 and 29 August eruptions. The latter is a surprisingly high value for eruption of low temperature pyroclastic flows. Products of the 2000 eruptions show enrichment of fine materials ranging from 6 to 8 in phi scale. They have high fragmentation/dispersion ratios and the nature of phreatomagmatic eruptions. Only the product of the 18 August eruption is near vulcanian to subplinian in nature.

Fine ash of the eruptions contains abundant hydrothermal minerals of kaolinite and smectite (Yasuda *et al*., 2002). Proportion of juvenile materials in the products is as high as 60 % for the 18 August eruption (rather magmatic), and is scarce for the 8 July, and 10, 14 and 29 August eruptions (close to phreatic). There are two kinds of juvenile materials in the 2000 eruption; aphyric glassy basaltic andesite erupted as spatters under the sea on 27 June and phyric basalt erupted as volcanic bomb on 18 August (Uto *et al*., 2001; Yasuda *et al*., 2001). It is likely that juvenile materials was replaced with from basaltic andesite to basalt in the middle of August (Geshi *et al*., 2002).

(H. Watanabe and S. Nakada)

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