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Reports on Volcanic Activities and Volcanological Studies in Japan for the Period from 1999 to 2002

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CONTENTS

Reports on Volcanic Activities and Volcanological Studies in Japan

for the Period from 1999 to 2003

I. Preface

The most significant events for volcanologists in Japan during this period are the Usu 2000 eruption and the Miyakejima 2000 eruption. The two eruptions have provided a test for volcanologists who faced the challenge of obtaining, conveying, and explaining the information needed by the Government and local officials charged for public safety. Also the two eruptions have provided volcanologists opportunities to learn more about the dynamics of volcanoes, and the studies of these eruptions will improve our knowledge and understanding of the eruptive mechanism.

The onset of the eruption was successfully predicted based on the detection of seismic activity and ground deformation, and more than 9000 people living near Usu volcano evacuated before the eruption. Phreatomagmatic eruption occurred on March 31; however, no casualties were reported because of the successful pare-eruption evacuation. Phreatic eruptions continued for several months and criptodome was formed yielding intense ground deformation.

In the early stage of the Miyakejima eruption, migration of magma was completely detected by seismic monitoring and tiltmeter measurement. Based on this observation, eruption within a short time was expected and was declared to the public. After the initial rather minor eruption, caldera formation was witnessed in July with complete description of the progress of the subsidence of the summit within the newly formed caldera. After several explosive events during August, all the residents evacuated from the island. Emission of huge amount of sulfur dioxide gas has continued for more than two years, and all the evacuated residents are still staying outside of the island. Brief description of both eruptions will be given in the following sections together with the results of investigation.

The sixth 5-years plan of the National Project for the Prediction of Volcanic Eruptions was proposed by the Geodetic Council of Ministry of Education, Science and Culture in 1998, and was started in 1999. The present plan will be completed at the end of this fiscal year, and another 5-years plan will be proposed to the Government within a few months.

In the latter parts of this report, the scientific activities related to volcanology in Japan are briefly reviewed for the period from 1999 to 2003, and the publication list of the related studies are included.

(Toshitsugu Fujii)

II. Eruptive Events

1. General Statement

Volcanic activity for the period 1999-2002 was characterized by the two large eruptive activities at Usu volcano and Miyakejima volcano, and other eruptions and phenomena.

Earthquake swarm began at Usu volcano on 27 March 2000. Remarkable ground deformation was accompanied at the summit and in the northwestern area of Usu volcano. Phreatomagmatic eruption took place about 4 km NW apart from the summit of Usu volcano at 13:07, 31 March 2000. Eruption continued at two crater areas, West-Nishiyama and Kompirayama, forming many new craters. Remarkable inflation occurred and a cryptodome was formed near the West-Nishiyama crater area during the eruptive activity. Eruptive activity and deformation gradually declined but small phreatic explosions continued at one of Kompirayama craters until September 2001. As the people living near the volcano and tourists were required to evacuate before the eruption, no people were injured. Detailed information is described in II-3.

Earthquake swarm began at Miyakejima volcano on 26 June 2000. The hypocenters of the earthquakes migrated westward and submarine eruption occurred off the western coast of Miyakejima island on 27 June. The hypocenters migrated more westward and vigorous earthquake swarm continued near Nii-jima and Kozu-jima. On the other hand, earthquake swarm began just beneath the summit of Miyakejima (Oyama) on 4 July and small eruption occurred at the summit on 8 July. After the summit eruption, a large collapsed crater, about 1 km across and about 200 m deep, was found on the summit. Collapse of the crater continued and a summit caldera of 1.4 km across and 450 m deep was formed until early August. Large eruptions occurred at the summit on 10, 18 and 29 August. Volcanic smoke from the eruption on 18 August reached 14 km height from the summit and low temperature pyroclastic flow from the eruption on 29 August reached the northern coast of Miyakejima. Active eruption continued until early September and SO_2 flux from the craters within the Miyakejima summit caldera continued in high level. Lahar sometimes occurred when it rained. All people who lived in Miyakejima island have been evacuated since September 2000. Detailed information is described in II-4.

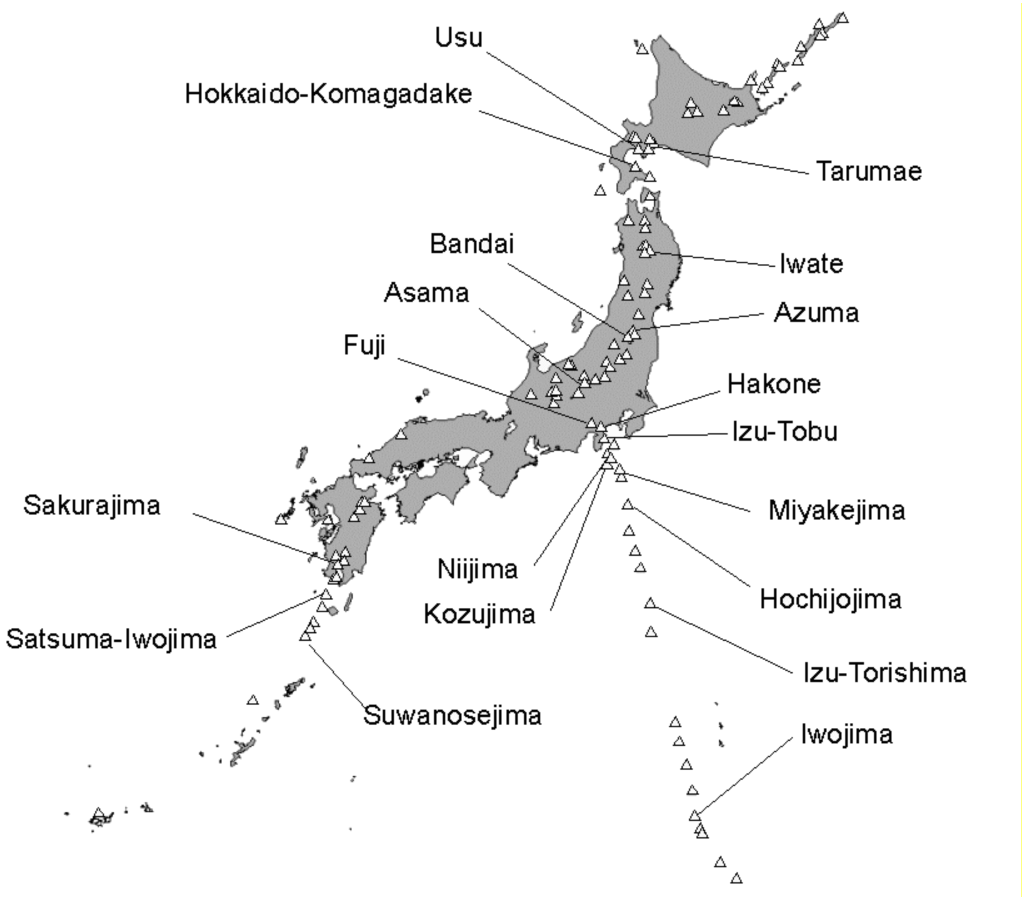

Fig. 1. Index map showing the location of active volcanoes listed in this report. Triangles represent active volcanoes in Japan. Japan Meteorological Agency has defined active volcanoes in Japan as "volcanoes which have erupted within 10,000 years or volcanoes with vigorous fumarolic activity".

Table 1. Chronology of volcanic eruptions and related events during 1999-2002.

1999	
May	Fumarolic activity at Iwate volcano became active.
2000	
27 March	Earthquake swarm began at Usu volcano.
31 March	Phreatomagmatic eruption started at Usu volcano.
May	Earthquake swarm at Bandai volcano, until 2001.
26 June	Earthquake swarm began at Miyakejima volcano.
27 June	Submarine eruption near Miyakejima volcano
4 July	Earthquake swarm began at the summit of Miyakejima volcano.
8 July	Small eruption and collapse at the summit of Miyakejima volcano
10, 18, 29 August	Large-scale phreatomagmatic eruptions at Miyakejima
August	High flux of SO_2 at Miyakejima volcano, until now
September	Small phreatic eruptions at Hokkaido-Komagadake volcano (until November)
October	Deep low frequency earthquakes at Fuji volcano, until May 2001
December	Eruptive activity became active at Suwanosejima volcano.
2001	
May	Earthquake swarm at Azuma volcano, until 2002.
21 September	Small submarine eruption near Iwojima
19 October	Small phreatic eruption at Iwojima

Two persistent active volcanoes in Japan, Sakurajima and Suwanosejima, also erupted. At Sakurajima volcano, explosive eruptive activity continued (see II-2). The volcanic activity at Suwanose-jima volcano became active since December 2000. At Satsuma-Iwojima volcano, intermittently discolored plumes were issued from the summit and high SO_2 flux continued.

Small phreatic eruptions occurred at Hokkaido-Komagadake volcano between September and November 2000. Small submarine eruption and phreatic eruption occurred at Iwojima in September and October 2001. Small eruption occurred also at Izu-Torishima in August 2002.

High volcanic activities without eruption were observed at several active volcanoes in Japan.

High seismicy and inflation began at Iwate volcano in March 1998. The seismicity gradually declined but continued for the period 1999-2002. Fumarolic activity at western Iwate volcano gradually became active since March 1999 and continued. Detailed information is described in II-3.

Seismicity that began since June 2000 near Nii-jima and Kozu-jima was the most active earthquake swarm in recent years. The number of earthquakes of the magnitude more than 4 was more than 600. Remarkable ground deformation occurred associated with the earthquake swarm. Seismic activity and ground deformation were observed also at Hakone volcano during June to August 2001, at Izu-Tobu volcanoes in May 2002, and at Hachijojima volcano in August 2002. At Hachijojima volcano, very long-period seismic events occurred (Ueno *et al.*, 2002). Seismicity became active at Bandai and at Azuma volcanoes since May 2000 and May 2001, respectively.

High temperature at the summit was observed at Tarumae volcano during the period 1999-2002.

B-type earthquake swarm intermittently occurred at Asama volcano since September 2000. Volcanic gas emission from the summit crater gradually increased since May 2002.

Deep low frequency earthquakes (deeper than 10 km) occurred beneath some active volcanoes. Seismicity of deep low frequency earthquakes beneath Fuji volcano became active since October 2000 to May 2001 (see II-5).

During the period 1999-2002 , no persons were killed by volcanic activity in Japan, excepting 1 person who was killed by an earthquake near Nii-jima and Kozu-jima region..

Preliminary reports on current eruptions in Japan were pasted in the internet web site;
"Current Eruptions in Japan";
http://hakone.eri.u-tokyo.ac.jp/vrc/erup/erup.html.
The information on Japanese volcanoes was given in the site of Japan Meteorological Agency;
http://www.jma.go.jp/. (revised everyday but in Japanese)
Additional information on eruptions in Japan was available in the following home pages;
Geological Survey of Japan; *http://www.gsj.jp/HomePage.html*,
Geographical Survey of Japan; *http://www.gsi.go.jp/ENGLISH/index.html*,
National Research Institute for Earth Science and Disaster Prevention; *http://www.bosai.go.jp/index.html*,

Tatsuro Chiba; *http://www.geo.chs.nihon-u.ac.jp/tchiba/chibah.html*, and
Yukio Hayakawa; *http://www.edu.gunma-u.ac.jp/~hayakawa/English.html*.

Internet web sites of volcano observatories in Japan are as follows;

Usu (UVO), Hokkaido Univ.; *http://uvo.sci.hokudai.ac.jp/*,
Res. Cent. Pred. Earthq. Volc. Erup., Tohoku Univ.; *http://aob-new.aob.geophys.tohoku.ac.jp/index_e.html*,
VRC, Earthq. Res. Inst., Univ. Tokyo; *http://hakone.eri.u-tokyo.ac.jp/vrc/VRC.html,*
Volcanic Fluid Research Center of Tokyo Institute of Technology; *http://www.ksvo.titech.ac.jp/index.html* #,
Res. Cent. Seism. Volcanol., Nagoya Univ.; *http://www.seis.nagoya-u.ac.jp/RCSVNU-E.html*,
Aso (AVL)-Kyoto Univ.; *http://w3.vgs.kyoto-u.ac.jp/* #,
Sakurajima (SVO)-Kyoto Univ.; *http://www.dpri.kyoto-u.ac.jp/~kazan/default_e.html*,
Unzen (SEVO)-Kyushu Univ.; *http://www.sevo.kyushu-u.ac.jp/index-e.html*.

open in Japanese

(Hitoshi Yamasato)

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Ueno, H., Ikeda, Y., Hasebe, D., Kamigaichi, O., Hoshiba, M. and Yoshida, Y. (2002) Earthquake activity and long-period events occurred around Hachijojima Island from August 2002. *Newsletter of Seism. Soc. Japan*, **14-4**, 3-5 (in Japanese).

2. Activity of Sakurajima Volcano

Sakurajima volcano is a post-caldera volcano, located at the southern rim of the Aira caldera in the southern Kyushu. The main magma reservoir is estimated to be located 10 km deep beneath the caldera, and the sub-reservoir is located a few kilometers under the volcano (Ishihara, 1990). In the historical time, large eruptions were originated three times in 1471-1476, 1779-1781 and 1914. Each eruption ejected lava and pyroclastic materials of 1 to 2 km^3 from the both flanks of the volcano.

The current eruptive activity, summit eruption, started in October 1955, and has continued for 48 years. The area 2 km around the summit crater has been specified as an off-limits area, where no one can enter. The activity is characterized with intermittent explosive eruptions of a Vulcanian type and emission of volcanic ash. The annual number of explosive eruptions is shown in Fig. 2. The cumulative number of explosive eruptions is 7842 as of the end of 2002. The amount of volcanic ash ejected each year since 1978 is shown in Fig. 3. The amount of volcanic ash ejected from June, 1978 to December, 2002 is estimated to be 190 millions tons by the Sakurajima Volcano Research Center, Disaster Prevention Research Institute of Kyoto University.

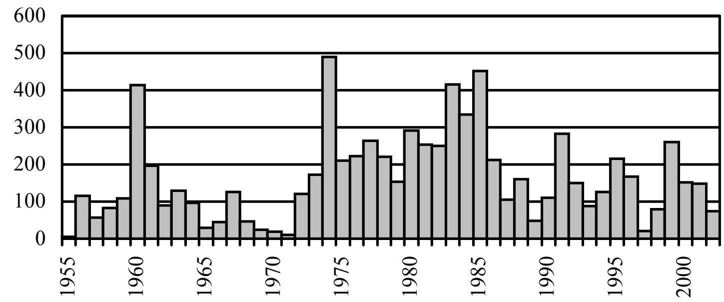

Fig. 2. Annual numbers of explosive eruptions at Sakurajima volcano (1955-2002)

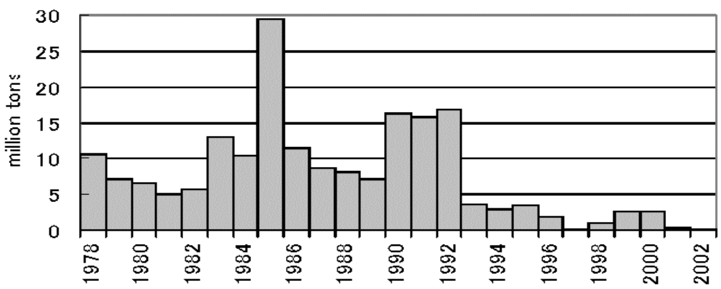

Fig. 3. Annual amounts of volcanic ash ejected from Sakurajima volcano (1978-2002)

Fig. 4. The summit crater of Sakurajima volcano on May 11, 2001. A small lava dome appears at the bottom of A-crater.

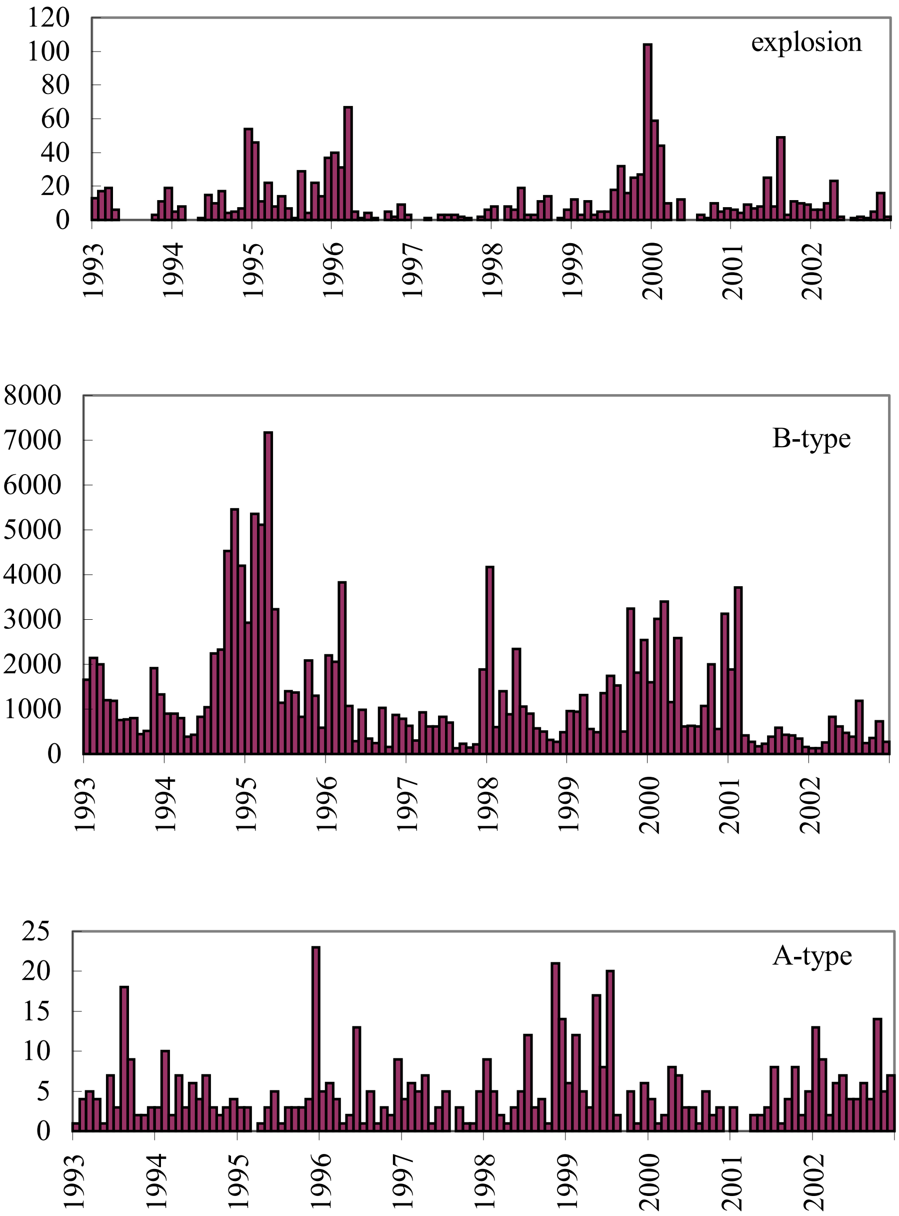

Fig. 5. Monthly numbers of explosive eruptions, B-type earthquakes and A-type earthquakes at Sakurajima volcano (1993-2002).

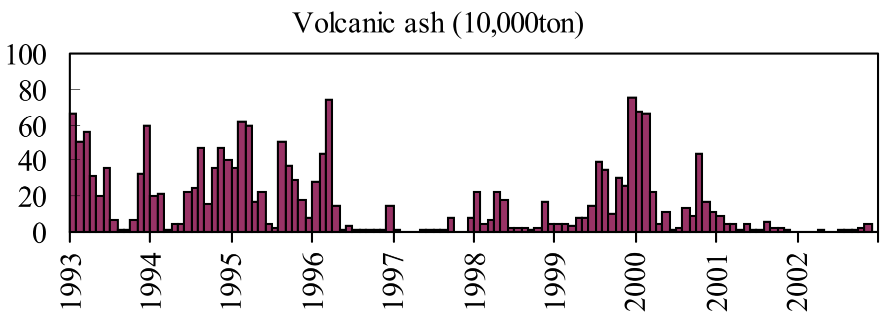

Fig. 6. Monthly amount of volcanic ash ejected from Sakurajima Volcano (1993-2002)

Fig. 7. A car damaged by lapilli stones on October 7, 2000

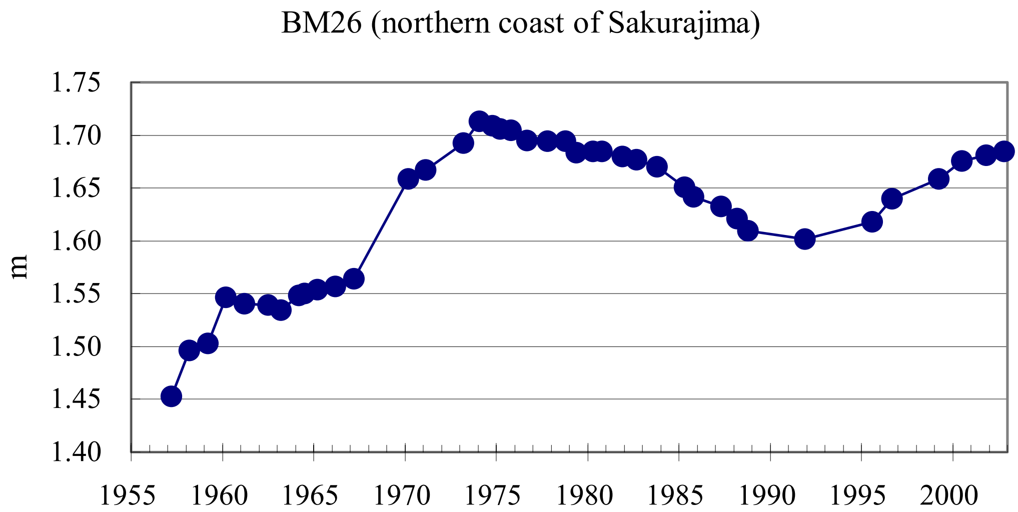

Fig. 8. Vertical ground deformation at Sakurajima volcano (Change in relative elevation of BM 26 at Sakurajima volcano). BM 26 is one of the nearest benchmarks to the center of the Aira caldera.

Explosive activity declined around 1993 (Ishihara, 1999). The amount of volcanic ash has rapidly decreased since 1993, though the number of explosive eruptions does not significantly decrease. This is related to a short duration of eruption, namely, most of recent eruptions ceased in a few minutes. Corresponding to the decrease in ejected ash, the ground deformation of the Aira caldera was turned into inflation in 1994. The summit crater became 250-300 m deep in 1995, which is the deepest record since 1955, and the flight distance of volcanic blocks ejected by recent eruptions became short (Ishihara, 1999). The summit crater has been still deep during the period from 1999 to 2002. Occasionally, a small lava dome, 20-40 m in diameter, appeared at the crater bottom, as shown in Fig. 4.

Monthly numbers of explosive eruptions, B-type earthquakes and A-type (volcano-tectonic) earthquakes during the recent 10 years are shown in Fig. 5. B-type earthquakes are low-frequency earthquakes related to extrusion of magma (Iguchi, 1994). Amounts of volcanic ash each month for the same period are illustrated in Fig. 6. During the period from 1999-2002, B-type earthquakes and ejection of volcanic ash increased in 1999 and 2000. A few strong eruptions however occurred, as indicated by a few numbers of volcanic advisories issued by the Kagoshima Meteorological Observatory: 4, 1, 0 and 0 times in 1999, 2000, 2001 and 2002, respectively. Two of 5 were issued associated with swarms of B-type earthquakes in 1999, which led to increase in explosive eruptions, and the others related to strong explosive eruptions in 1999 and 2000. The largest eruption occurred on October 7, 2000. In an hour, volcanic ash and lapilli of (3-4)x10^5 tons were ejected, and more than 35 cars were damaged by lapilli of 1 to 3 cm at a parking area 6 km away from the crater, as shown Fig. 7.

The emission rate of sulfur-dioxide from the summit has kept high level (1400-4900 ton/day) during the period from 1974 to 1996, even if eruptive activity became low (Ishihara, 1999). The emission rate observed by COSPEC in November, 1999 and November, 2001 was 2800 and 1900 ton/day (Kazahaya, 2001). No clear relationship between eruptive activity and emission of sulfur-dioxide has been recognized at Sakurajima volcano.

As mentioned above, the deflation of the ground around the Aira caldera was turned into inflation in 1994. At Sakurajima, leveling survey has conducted along a coast road since 1957. The change in the relative elevation of BM 26, close to the center of the caldera is illustrated in Fig. 8. The reference point is BM 17, 6 km southwest away from the benchmark. BM 26 indicated gradual uplift by 8.4 cm from December 1991 to November 2002. This suggests that storage of magma under the caldera is in progress for future eruption. However, the rate of uplift is much smaller than those in the former inflation stage during 1964-1974. This may suggests that magma supply rate to the caldera has decreased during the past 10 years.

(Kazuhiro Ishihara)

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Iguchi, M. (1994) A vertical expansion source model for the mechanisms of earthquakes originated in the magma conduit of an andesitic volcano: Sakurajima, Japan. *Bull. Volcanol. Soc. Japan*, **39**, 49-67.

Ishihara, K. (1990) Pressure sources and induced ground deformation associated with explosive eruptions at an andesitic volcano: Sakurajima volcano, Japan. In Ryan, M. P. (ed.), *Magma Transport and Storage*, John Wiley & Sons, 335-356.

Ishihara, K. (1999) Activity of Sakurajima Volcano, *Reports on Volcanic Activities and Volcanological studies in Japan for the period from 1995 to 1998*, 4-8.

Kazahaya, K. (2001) personal communication.

3. Activity of Iwate Volcano in 1998-2002

Iwate volcano is the active quaternary stratovolcano located in the northeastern Japan arc and consists of two subgroups (eastern Iwate volcano and western Iwate volcano) with several peaks. These subgroups, peaks and the caldera are aligned nearly east-west direction. This volcano has experienced two major eruptions in the historic times of 1686 and 1732. The former one accompanied lava flow, scoria emission and base surges from the summit crater. The second one did d a basaltic lava flow at the northeastern flank. Since the last eruption in 1732, the volcano has been quiescent conditions except several occurrences of small phreatic explosions at Oujigoku.

The volcano was in seismically calm until deep volcanic tremors with duration of 45 min were observed at depths of 8-10 km beneath the eastern flank in September, 1995. Since then, weak seismic activities and tremors have observed in the period from 1996 to 1997. The shallow and deep seismic activities and associated crustal deformations were started in middle February, 1998 and their activities increased with a lapse of times until September 5, 1998 when moderate tectonic earthquake with *M*6.1 occurred nearby Iwate volcano. After this earthquake, the number of shallow volcanic earthquakes started to gradually decrease with time. In consequence of decreases in number of the volcanic earthquakes, the volcanic unrest at this volcano is supposed to be over.

The long-term space-time plot of seismicity in and around Iwate volcano is shown in Fig. 9 for the period from 1976 to 2002, in which the long quiescence in seismicity around the eastern and western Iwate volcanoes (140.90E-141.02E) and stationary activity at a longitude around 140.88E can be recognized. The latter activity has been resulted by the exploration of deep geothermal energy at Kakkonda geothermal field.

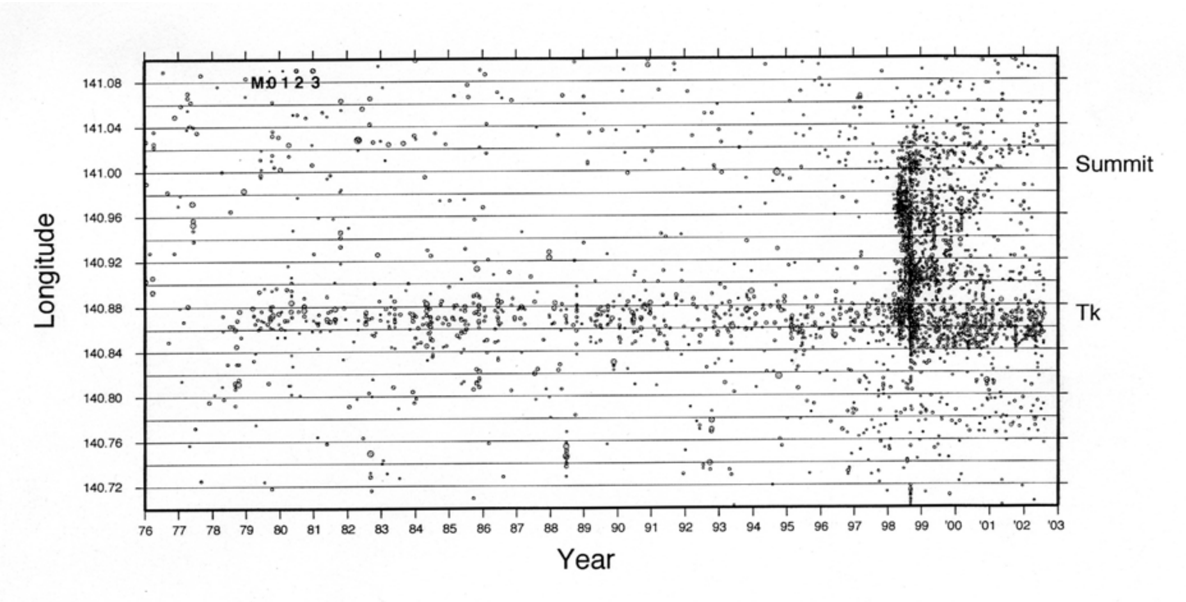

Fig. 9. The space-time diagram of seismicity in and around Iwate volcano in the period from 1976 to 2002. The epicenters are projected on the longitudinal direction between 140.72°E and 141.08°E. The positions for the summit of Iwate volcano and Kakkonda geothermal field (Tk) are indicated at the right margin.

The short-term space-time and magnitude-time plots in the period from 1998 to 20002 are shown in Fig. 10 (a) and (b), respectively. This figures reveal that (1) the number of volcano earthquakes increases with time until April 29, 1998, when large earthquake swarm occurred at nearby the western edge of caldera rim, (2) the seismic activity migrated intermittently westward from the eastern Iwate volcano, and (3) high seismic activity with relatively large events ($M > 3.5$) continued for about four months until the occurrence of the moderate tectonic earthquake of M6.1 on September 3. Hypocenters of high frequency (HF) volcanic earthquakes at depth above 6 km are distributed east-west direction from the eastern Iwate volcano to the western one (see Fig. 11). The spatial distribution of events can be divided into three groups. The eastern group is clustered beneath the summit crater and is characterized by relatively small events. The middle one beneath the caldera shows the highest activity and is distributed in the narrow belts. The western one is scattered onto north-south direction. Hypocenter of low frequency (LF) earthquakes is observed beneath the eastern flank of volcano at deeper depths of 6 - 12 km and at shallow depths of 0 - 4 km under the caldera (see Fig. 11). The deeper LF events have been active condition in the whole period of 1998-2002, whereas the shallow ones were mainly observed at the initial stage of seismic activity in the period from February to September, 1998.

Continuous ground deformations have been monitoring since 1994 by the Sacks-Evertson type strain meter and tilt meter that were deployed at the bottom of 300 m borehole at three stations around the volcano. In addition to the above monitoring, GPS has been operating at five stations in and around the volcano. These data were used to estimate the origin of the crustal deformations beneath the volcano. The detail of analysis and data sets were omitted in this report and only results are shown in Fig. 12 and discussed with reference to the associated seismic activity. Both the rectangular tensile crack source and the dilatational source (Mogi source) are required to interpret the data sets. Two sources are spatially separated by about 3 km. The tensile cracks that were located beneath the summit and caldera indicate that the magma intruded

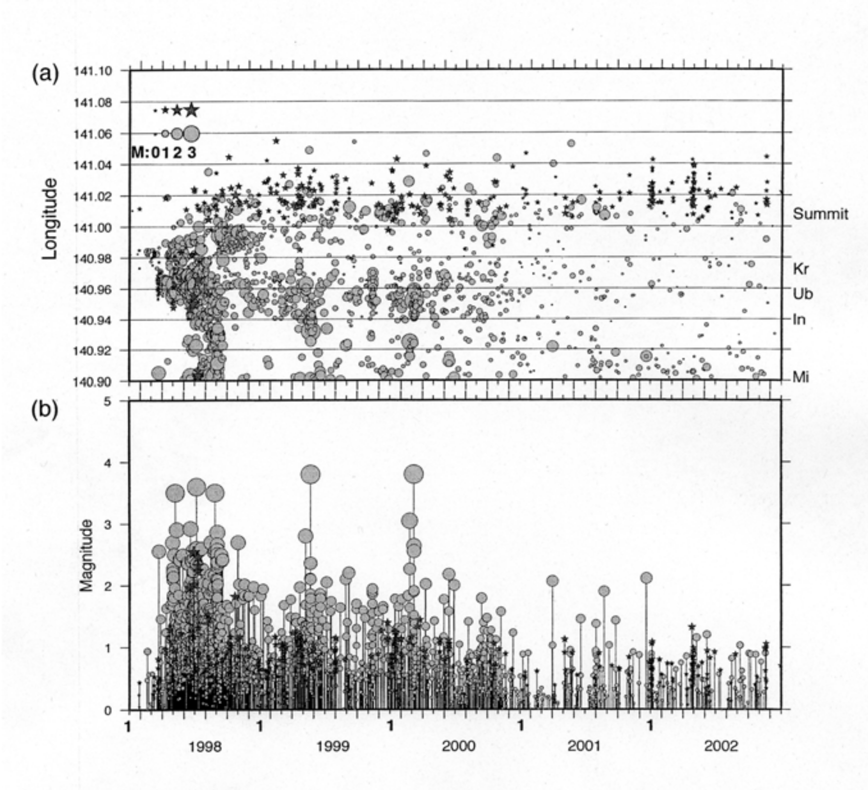

Fig. 10. (a) The space-time diagram of seismicity in Iwate volcano during the active period from 1998 to 2002. The circle and star indicate high- and low-frequency earthquakes, respectively. The codes in the right margin mean; summit, Kr, Ub, In and Mi are the peaks of Iwate volcano, Kurokura, Ubakura, Inukura and Mitsuishi , respectively. (b) The magnitude-time diagram corresponding (a).

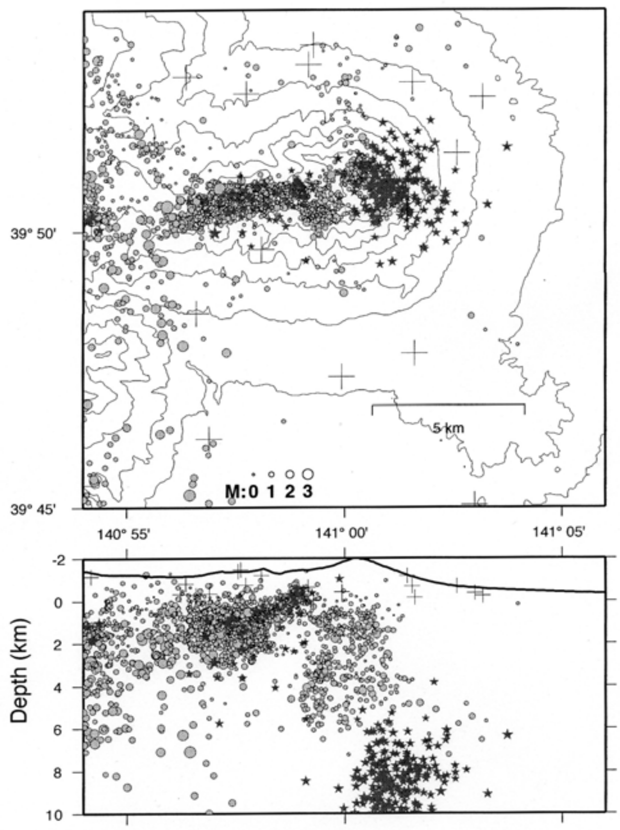

Fig. 11. The hypocenters in Iwate volcano during 1998-2002. Circle and star indicate high- and low-frequency earthquakes, respectively. Crosses are seismic stations.

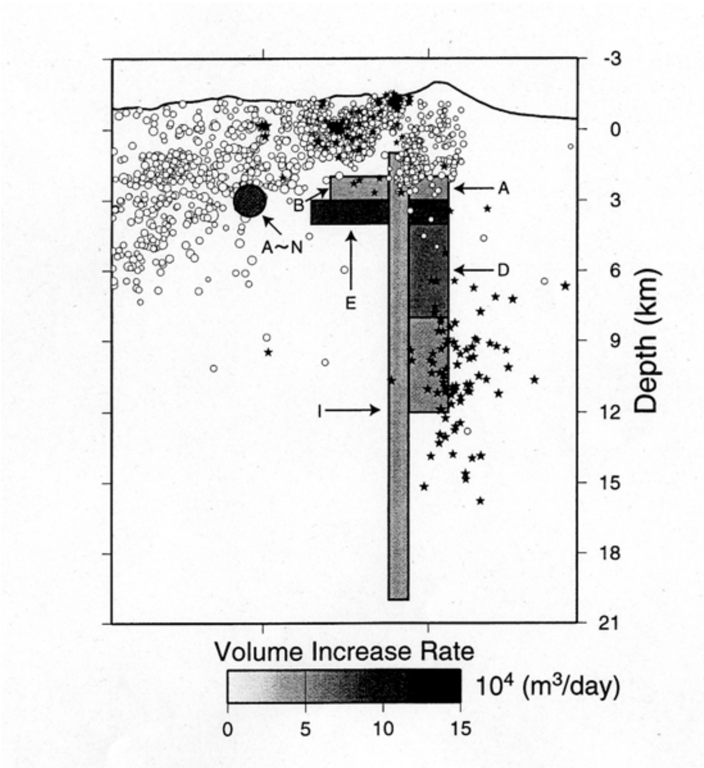

Fig. 12. The estimated origins of crustal deformations beneath the Iwate volcano together with the re-located hypocenters projected on to the E-W cross section. The circle is the dilatational source and the rectangles with marks (A to I) are a tensile crack corresponding different periods. Open circle and solid star indicate high- and low-frequency earthquakes, respectively. The volume increase rate is shown by a gray scale.

two times vertically and horizontally. The bottom of the HF and LF volcanic earthquake hypocenter limited the upper edge of tensile cracks. The eastern edge was close to the hypocenter of LF events, suggesting that intrusion processes of magma from a deeper part to a shallow one were closely relating the occurrence of volcanic earthquakes. On the other hand, the location of dilatational source was not changed during a lapse of time. The rate of dilatation increased exponentially at the initial stage of seismic activity and decreased gradually with time. These conditions suggest that the origin of dilatation at the fixed position was not magmatic but hydrothermal activity. This source was closely located at the northern edge of the faults associated with *M*6.1 earthquake on September 3, 1998. Based on the fracture function of the Coulomb failure criteria, it is concluded that the tectonic event of *M*6.1 was induced by the increases of shear stress of 0.7-0.8 MPa due to pressure increases of the dilatational source.

The present volcanic activity was marked by 350 deep low-frequency (DLF) events and 120 intermediate-depth low-frequency (ILF) events. The occurrence rate of the DLF events increased about 5 days before that of shallow events. The hypocenter of DLF events are located within three concentrated regions: the first is at a depth of 32 km about 10 km south of the summit, the second is at a depth of 33 km about 10 km northeast of the summit and the third is at a 37 km about 7 km northeast of the summit. ILF events are located within a vertical pipe-like region just beneath the summit, which sometimes shows a vertical migration of the focal depth. These results suggest that a complex magmas system may exist at a source regions of DLF and ILF events.

When the volcano-seismic activity was declined in 2000, the active seismic survey was conducted in and around the volcano in order to reveal the three-dimensional P velocity structure. Nine artificial explosions and 330 temporary seismic stations were operated in October, 2000 under the national project for the prediction of volcanic eruption. The most prominent feature of this survey is high P velocity column-like structure (V_P> 5.4 km/s) under the caldera, where the highest seismic activity was observed as pointed before.

In conclusion, Iwate volcano has experienced magma intrusion from the middle crust and the Moho region to a shallower part in 1998 and the volcano-seismic unrest was amplified in the period of 1998-2002. However, fortunately, there was no eruption.

(Hiroyuki Hamaguchi)

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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. 13).

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. 14) (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. 13b). As if to compensate for this, continuous shortening of a N-S baseline across Miyakejima Island (diameter of the island) was observed (Fig. 15) (Nishimura *et al*., 2001; 2002).

Summit Subsidence Stage (8 July-middle August): Following heavy seismicity beneath the island that resumed on 4 July (Fig. 13d), collapse of the summit area took place suddenly on the evening of 8 July (Fig. 16), 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. 13c) (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

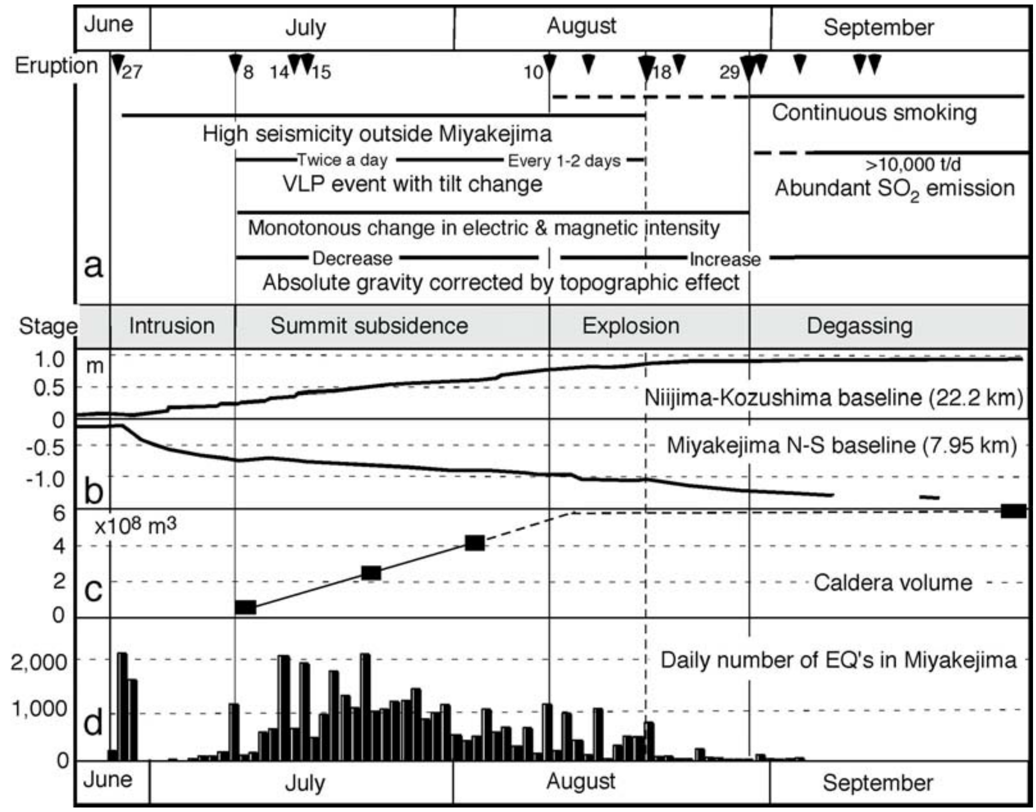

Fig. 13. Chronology of the 2000 eruption at Miyakejima volcano (Nakada *et al*., submitted, fig. 4). a) Stages of eruptive activity based on surface phenomena. Major eruptions are shown as vertical triangle with representative variations of geophysical and geochemical phenomena (modified from JMA, 2000; 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).

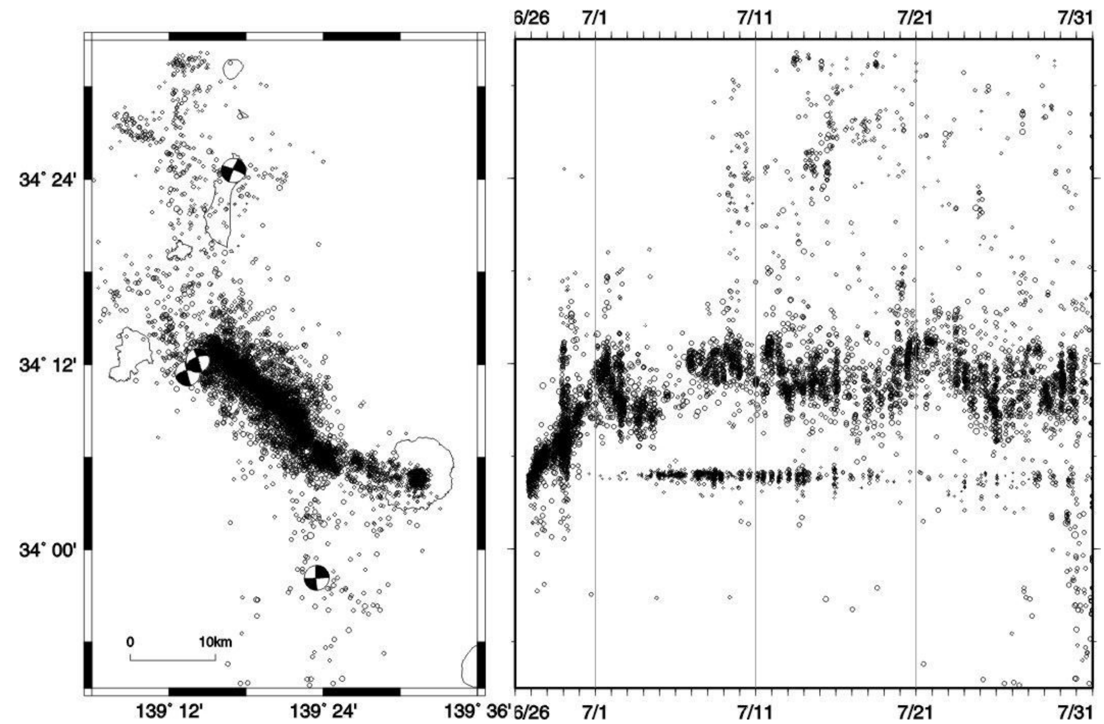

Fig. 14. Time-space distribution of swarm earthquakes that occurred on and around Miyakejima volcano during the period of 26 June to 31 July 2000 (Sakai *et al*., 2001).

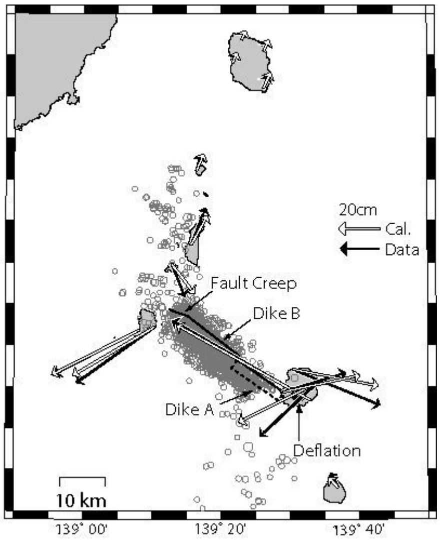

Fig. 15. Optimal fault model of ground deformation that accompanied the Miyakejima 2000 eruption. White and black arrows indicate calculated and observed displacements. Open circles are epicenters of earthquakes ($M \geqq 3.5$) (Nishimura *et al*., 2001).

Fig. 16. 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.

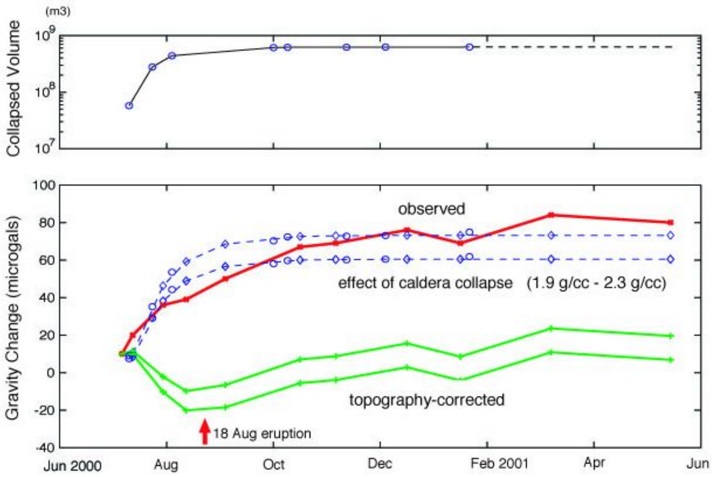

Fig. 17. Absolute gravity changes observed at the north coast of Niyakejinma.. Thick solid line indicates observed gravity and thin solid lines residual gravities after correction for the effect of caldera collapse (Furuya *et al*., 2003).

Fig. 18. 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.

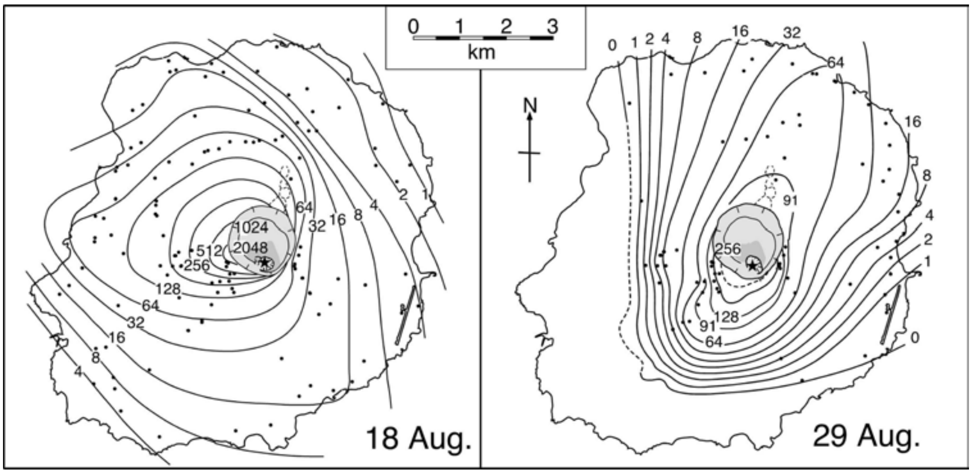

Fig. 19. Isopach map of the 18 and 29 August eruption products. Numbers of contours are in mm. The volumes of products are estimated to be 7.5 x 10^6 m^3 for 18 August and 3.4 x 10^6 m^3 for 29 August. According to M. Nagai (unpublished).

Fig. 20. 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. 13a).

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. 17). 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. 18). Abundant ballistics including volcanic bombs fell over the summit area and volcanic ash with pebbles covered thickly most parts of the island (Fig. 19). The last tilt change took place in this explosion. Eruption of low-temperature pyroclastic flows took place on the morning of 29 August (Fig. 20). 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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5. Activity of Fuji Volcano

Mt. Fuji is the largest active stratovolcano in Japan. It reaches 3776 m above sea level, making it the highest mountain in Japan. The diameter of its base is about 50 km. It is located about 100 km west of the Tokyo metropolitan area. Geologically, Mt. Fuji is a relatively young volcano, with two volcanic histories: the older Fuji (80,000 B.P. to 11,000 B.P.) and the younger Fuji (11.000 B.P. to the present) (Miyaji *et al*., 1992). Both eruptive materials are basically basaltic in composition (Takahashi *et al*., 1991). Historic records indicate 10 clear eruptions since 782 AD (Koyama, 1998). The most recent eruption is the "Hoei Eruption" occurring in 1707 AD, which was a plinian type eruption with total ejecta of about 1 km^3. No eruptions have been recorded in the approximately 300 years since the Hoei event.

Although surface volcanic activity has been quiet in recent years, swarm-like mid-crustal low-frequency earthquakes were observed in 2000 and 2001. Because they were not accompanied by any phenomena directly warning of eruption or the upward movement of magma, it was reasonably considered that this activity was limited to the mid-crustal depth. The Subdivision of Geodesy of the Council for Science and Technology, partly due to the high degree of public interest in the volcanic activity of Mt. Fuji, presented a report comprising a plan for the improvement of understanding the volcano which proposed the setting up of observational networks. This section briefly describes the low-frequency earthquake activity seen in Mt. Fuji in 2000 and 2001, based chiefly on observations made by the National Research Institute for Earth Science and Disaster Prevention (NIED).

Low-frequency earthquakes have been detected in Mt. Fuji since the early 1980s, when seismic stations were installed in the surrounding area as part of several earthquake prediction research programs (Ukawa and Ohtake, 1984; Kanjo *et al*., 1984; Shimozuru *et al*., 1986). They were located at depths ranging from 10 to 20 km around the summit. Those were the first clear observations of low-frequency earthquake activity in the mid-crust beneath a volcano in the subduction regime. Since then, low-frequency earthquakes in the depth range from mid-crust to the uppermost mantle have been reported in many volcanic areas in Japan and other countries (for example, Ukawa and Ohtake, 1987; Hasegawa *et al*., 1994; Hill, 1996; White, 1996). We call them deep low frequency (DLF) or deep long period (DLP) earthquakes.

The DLF earthquakes at Mt. Fuji have been continuously monitored by NIED, the Earthquake Research Institute of University of Tokyo (ERI) and the Japan Meteorological Agency (JMA) since the 1980s. The observation sites are shown in Fig. 21. Monitoring over the last 20 years has revealed that the ordinary activity of DLF earthquakes was low in both magnitude and occurrence number during the 1980s and 1990s. In the fall of 2000, however, the number of DLF earthquakes increased sharply, with the high activity lasting until May 2001.

A DLF event usually lasts several minutes or more, and consists of a series of small DLF earthquakes. Fig. 22 is an example of a seismogram of a DLF earthquake in comparison with an ordinary tectonic event in the same region. The amplitudes of the DLF earthquakes are in the micro-earthquake range, and since the start of the monitoring, no event larger than *M*3 has been observed. The predominant frequencies of most events range from 1 to 3 Hz, far lower than the expected predominant frequencies of tectonic earthquakes of the same magnitude range.

Since the DLF earthquakes at Mt. Fuji have a tendency to arrive in a series, it is difficult to count their number because the coda waves of successive events often overlap. For this reason, NIED treats one continuous vibration in a seismogram as a single event. We measure the duration time and maximum amplitude of each event and draw diamond diagrams to express the activity (Ukawa and Ohtake, 1984). Fig. 23 is a diamond diagram of activity since 1980 recorded by NIED, showing each event as a diamond (width=maximum amplitude and height=duration time).

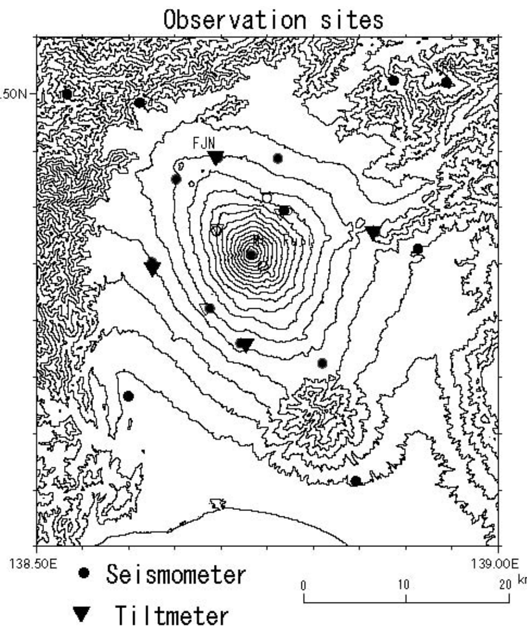

Fig. 21. Map showing permanent observation sites with seismometers and tilt-meters belonging to NIED, ERI and JMA. Solid symbols indicate stations installed before the 2000 high DLF earthquake activity, and open symbols are those installed from 2001 up to now (April 2003).

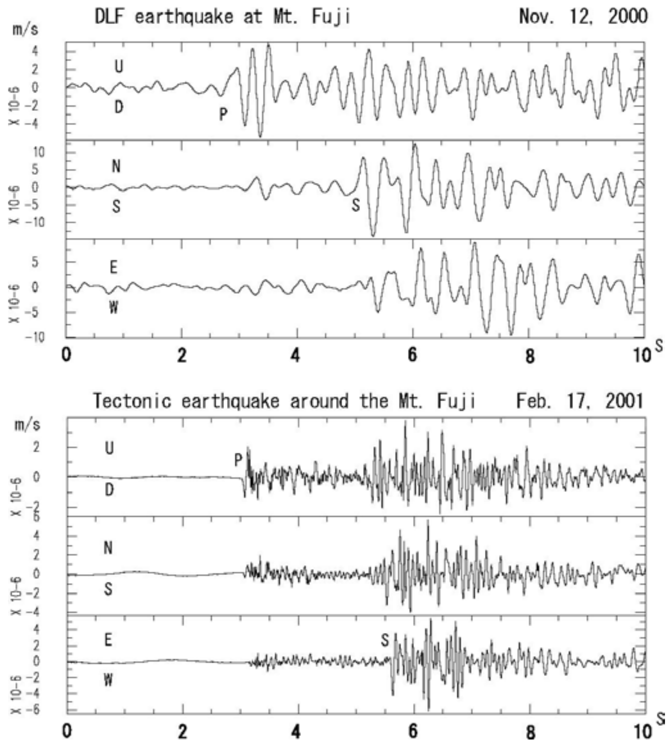

Fig. 22. Examples of three component seismograms of the DLF at Mt. Fuji in comparison with those of a tectonic earthquake around Mt. Fuji. The seismograms were recorded at FJN station of the NIED observation network.

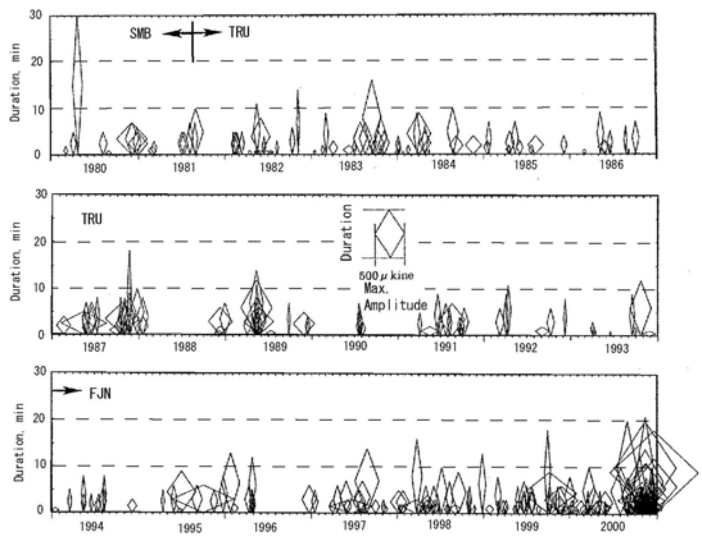

Fig. 23. A diamond-diagram showing the DLF earthquake activity during the period from 1980 to 2000 (NEID, 2002). The height of a diamond indicates the duration time of the successive DLF earthquakes, and the width indicates the maximum amplitude during the event. The duration time and maximum amplitude are measured on the seismograms of mainly TRU and FJN in Fig. 21.

During the period 1980-1999, the total number of DLF events was 274, while in 2000 and 2001 the DLF events numbered 180 and 172, respectively. The duration time of the longest event is 30 minutes and the magnitude of the largest event is in the *M*2 class. Fig. 24 shows the cumulative number of DLF events, indicating that the occurrence rate in the 1980s and in the early 1990s is fairly constant with some small step-like increases, seen for example in 1987 and 1989. The rate slightly increased from the middle of 1990s. This change is due to the improvement of observational networks around Mt. Fuji. The abrupt increase from October 2000 to May 2001 is the most distinctive change since the start of the observation.

The DLF events have been located at 2–4 km northeast of the summit in the depth range 10–20 km. Fig. 25 compares the hypocenter distribution from April 1995 to July 2000, pre-swarm period, with that from August 2000 to July 2001. No significant change is recognized either in the epicenter or focal depth.

In the active period of the DLF earthquakes, tectonic earthquake activity in the Mt. Fuji area increased slightly. In Fig. 25, clusters of

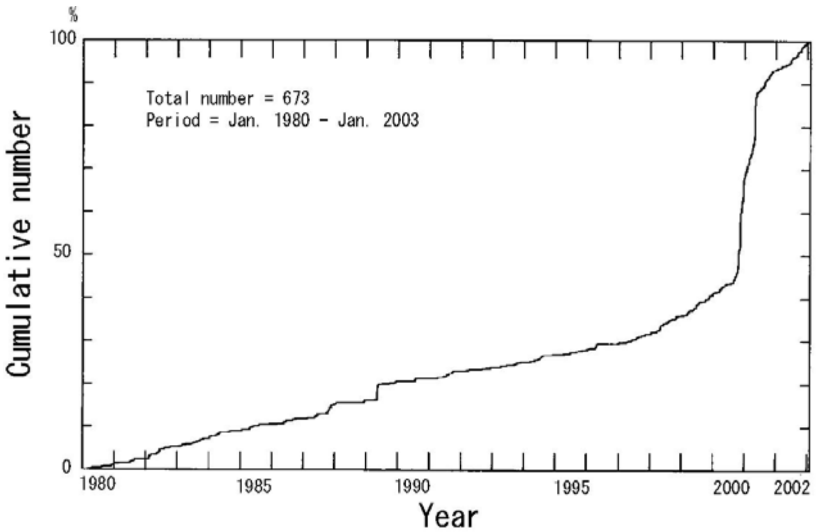

Fig. 24. Cumulative number of the DLF events from Jan. 1980 to Jan. 2003. The dataset is the same as those in Fig. 23.

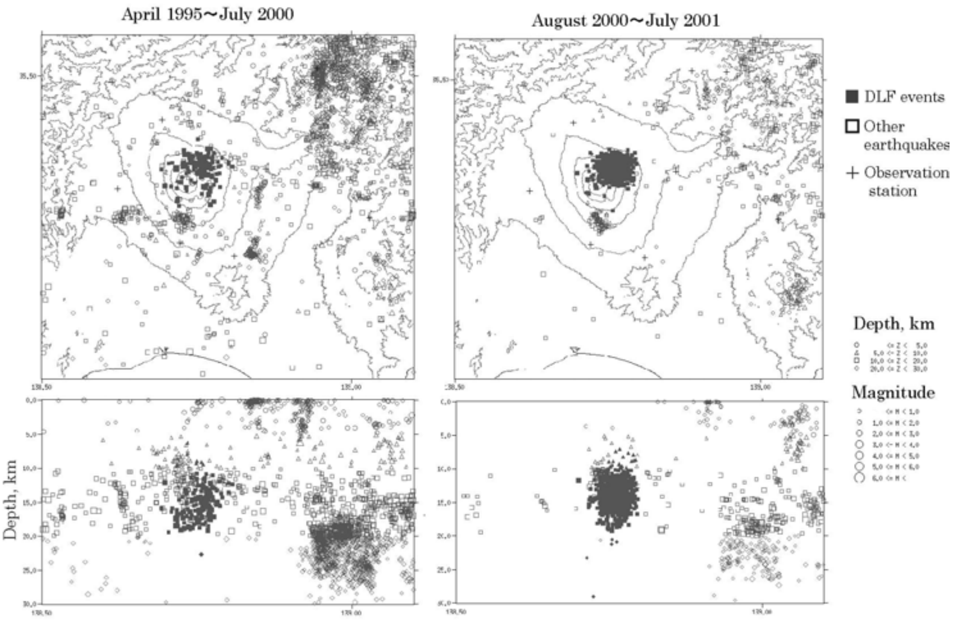

Fig. 25. Hypocenter distribution maps around Mt. Fuji determined by the NIED. The left is the hypocenters from April 1995 to July 2000, and the right is those from August 2000 to July 2001, which includes the period of the high DLF earthquake activity. The solid symbols indicate the DLF earthquakes.

tectonic earthquakes can be seen at the southwestern flank of Mt. Fuji. The focal depths range from 8 to 12 km. The low-level activity of these tectonic events probably indicates minor stress change beneath the volcano. No volcanic tremors, large earthquake swarm activity or abnormal crustal deformations were detected in or around Mt. Fuji in this or any other period. Since the abnormal activity was limited to the mid-crustal depth beneath the volcano, we concluded that magma did not migrate upwards.

In response to the report on the observation plan of Mt. Fuji presented by the Council for Science and Technology in 2001, the JMA has installed new seismic stations in high altitude areas, and the ERI is constructing three borehole stations with seismometers and/or a tilt-meter on the northeastern middle flank. The GSI has installed several GPS stations around Mt. Fuji, including the summit, and the NIED is constructing two borehole observational sites with tilt-meters and seismometers on the mid-flank of the volcano. This development of observational networks is undoubtedly contributing to the improvement of monitoring volcanic activity and of research into the volcano. The Coordinating Committee for Prediction of Volcanic Eruption has formed a working group to address topics related to expected phenomena if future eruptions occur, especially focusing on the potential for Hoei-type eruptions, and on the recommendation of a suitable observation network.

Concerning the hazard mitigation aspects of Mt. Fuji, the Committee for the Hazard Map of Mt. Fuji has carried out a two-year project, starting in 2001, to study past volcanic hazards around Mt. Fuji and to establish methods for hazard mitigation in the Mt. Fuji area. A variety of volcanic hazards is expected during future eruptions of Mt. Fuji, including lava flows, ash falls, pyroclastic flows and debris flows. To evaluate these volcanic hazards, the committee has summarized previous studies and carried out onsite geological research to improve the database. Hazard mitigation plans for affected local governments will be designed based on the Committee's final report.

(Motoo Ukawa)

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6. The 2000 Eruption at Usu Volcano

Nakada (2001) and Ui *et al*. (2002a) reported the sequence of Usu 2000 eruption. The eruption started at 1:07 PM, March 31 following 3-and-a-half days precursory activities of earthquakes and ground cracking. Initial explosion took place at the western lower slope of the volcanic edifice discharging ash plume. Ballistics were thrown at least 1.2 km away from the source. The initial vigorous phreatomagmatic explosion moved gradually into phreatic eruption with vertical cock's tail jets in early April. Hot lahars were discharged from some of the craters. The phreatic eruption was replaced by intermittent small explosion in mid-April and by continuous steaming that often included ash emissions. A small-scale and flat-topped cryptodome was formed during this stage. Graben-like fault swarms were formed above the cryptodome. More than 60 explosion craters were formed by late April. Then the eruptive activity concentrated on a few craters and bursting-type explosion with air shock wave frequently occurred at the water-saturated crater floor. Geothermal activity became clear on and around the cryptodome since middle May and then amount of steam decreased with time.

Event of the March 31 phreatomagmatic eruption was analysed in detail correlating video footage and analysis of the proximal deposit (Takarada *et al*., 2002). Totally 11 sandy coarse layers and 9 silty matrix-supported layers were identified 90 m away from the crater rim. These layers are correlated with each eruption event observed from 13:07 to 17:25 on March 31. The deposit consists of fresh juvenile fragments up to 20 mm in diameter, accessory fragments, accidental fragments and aggregate of ash (Tomiya *et al*., 2001; Nagai *et al*., 2002). The deposit is interpreted as a product of dry pyroclastic surge derived from the collapse of low eruption column (Ui *et al*., 2002b). Maximum travel distance was 1-2 km (Yamamoto, 2001). Wet pyroclastic surge deposits was also identified during phreatic eruption stage. Maximum travel distance of wet surge was about 600 m away from the source (Ui *et al*., 2002). Ash sample from the ejecta during March 31 to early April contain Miocene altered felsic volcanic rocks suggesting that the fragmentation by the eruptions occurred at depths below ca. 1000 m and more (Yahata, 2002). Yahata (2002) also suggested that fragmentation occurred shallower than several hundred meters below after middle April.

Takarada *et al*. (2001) estimated total amount of ash discharged by April 4 as 1.24×10^8 kg judging from tephra fall data at proximal and medial region. However, Ohno *et al*. (2002) concluded amount of the pyroclastic deposits from the entire Usu 2000 eruption is more than 6.4×10^8 kg.

Hirose and Tajika (2002) described three different types of surface ruptures, compressional, tensional and strike-slip regimes. Miura and Niida (2002) suggested by means of aerial photograph interpretation that formation of the cryprodome is due to the two stage growth, consisting of initial dike intrusion and subsequent shallow inflation and lateral extension of magma from the dike tip.

Chemical composition of juvenile fragment is slightly less differentiated than those of 1977-78 eruption (Tomiya *et al*., 2001; Nakagawa *et al*., 2002). This suggests that distinct and/or modified magma system has been active in the 2000 eruption (Nakagawa *et al*., 2002). Tomiya and Miyagi (2002) proposed magma-feeding system for Usu 2000 eruption by petrological and experimental data. The 2000 eruption is inferred to have started by an ascent of magma from 10-km chamber, followed by its injection to the 5-km depth chamber, as well as other historical eruptions. The magma ejected during the 2000 eruption shows no evidence of magma mixing, indicating that this magma was derived from only top layer of the shallower chamber. Suzuki and Nakada (2001, 2002) made bubble size distribution analysis and measurement of water content in groundmass glass. They concluded that magma ascent rate was slow to allow gas escape up to 5-km depth chamber. Then disequilibrium in water exsolution can be caused by acceleration of magma ascent and fragmentation of juvenile material may have been caused by water quenching.

(Tadahide Ui)

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III. Geophysical Study

The works on geophysics done in the last 4 years in Japan are summarized according to the following five categories: (1) monitoring of volcanic activity, (2) structure of volcanoes, (3) source processes of volcano earthquakes and tremor, (4) dynamics of volcanic eruptions, and (5) mantle dynamics and magma migration

Monitoring of Volcanic Activity

Various kinds of techniques based on seismology, geodesy, electricity and magnetisms and so on have been applied to clarify the volcanic activities in Japan. In the last 4 years, high-quality data from dense geophysical networks have been utilized for evaluating magma activities on and beneath the volcanoes.

Dense seismic networks consisting of broadband and short-period seismometers and high resolution data acquisition systems enable us to determine precise hypocenters of VT, LP, VLP, tremor and/or to clarify magma transport system at Usu, Towada, Iwate, Bandai, Miyakejima, Unzen, Kuju, Aso, Satsuma-Iwojima, Kuchierabujima, Nevado del Ruiz volcanoes (Ueno *et al*., 2002; Ohtani *et al*., 2002; Tanaka *et al*., 2002b; Nishimura *et al*., 2002; Fujita *et al*., 2001; Yoshikawa *et al*., 2000; Yoshikawa *et al*., 2002; Umakoshi *et al*., 2001, Umakoshi *et al*., 2002; Sudo and Ikebe, 2001; Iguchi *et al*., 1999; Iguchi *et al*., 2001; Londono and Sudo, 2001). Shallow volcanic and tectonic earthquake activities are discussed with the static change of the stress field due to the magma intrusions and migrations (Nishimura *et al*., 2001a; Ueki and Miura, 2002). Regional seismic networks deployed in and around volcanoes captured deep low frequency events beneath Tohoku district and Miyakejima and Yakedake volcanoes (Okada and Hasegawa, 2000; Fujita and Ukawa, 2000; Ohmi *et al*., 2001). Temporal ocean bottom seismographic observations determine precise hypocenters relating magma intrusions around Miyakejima-Kozushima-Niijima islands in 2000 (Nishizawa *et al*., 2001; Nishizawa *et al*., 2002a). Software for monitoring running spectrum of real-time seismic data is also developed (Aoyama *et al*., 2000).

Dense geodetic networks have been temporally and/or permanently deployed around volcanoes to detect magma intrusions and migrations. GPS networks around Usu, Iwate, Miyakejima, Kozujima, and Kuju volcanoes, Izu islands and Hachobaru geothermal area are utilized for determining the locations and amounts of dike intrusions (Kimata *et al*., 2002; Okazaki *et al*., 2002; Fujiwara *et al*., 2002; Takahashi *et al*., 2002a; Miura *et al*., 2000; Terai *et al*., 2001; Sato *et al*., 2002b; Kimata *et al*., 1999; Nishimura *et al*., 2001a; Sakamura *et al*., 2001). GPS and EDM observation revealed inflation/deflation process of volcanoes or downward flow of lava dome on the slope (Nakaboh, 2002; Matsushima and Takagi, 2000; Nishi *et al*., 1999). Tilt measurements captured crustal deformation relating magma intrusions at Miyakejima (Fujita *et al*., 2002b) and lava dome extrusions at Unzen volcano (Yamashina and Shimizu, 1999). Leveling detected upheaval of ground before the M6.1 earthquake took place southwest area of Iwate volcano (Doi *et al*., 1999). Strain offsets associated with monotonous damped oscillations during the 1986 Izu-Oshima volcano are observed by geodetic measurements with a high sampling rate (Fujita *et al*., 2000). Photograph analyses and theodolite measurements are utilized for measuring the ground deformation and detecting the volume source at Unzen and Usu volcanoes (Saito and Suto, 2002; Suto *et al*., 2002; Takagi, *et al*., 2002; Koarai *et al*., 2002). A new convenient method using time-differential stereoscopy is proposed to detect volcanic deformation and is applied at Unzen and Usu volcanoes (Yamashina *et al*., 1999; Yamashina and Nishimura, 2001). SAR is used for measuring topographic changes associated with the 2000 caldera formation of Miyakejima volcano (Sato *et al*., 2002a), spatial distribution of pylocrastic flow of Merapi volcano (Koike, *et al*., 2002), and volcanic inflation of Iwate volcano (Nishimura *et al*., 2001a). Absolute and relative gravitational observations succeeded to detect a caldera formation process associated with the 2000 activity of Miyakejima (Furuya *et al*., 2001). Precise gravity change is detected by correcting accurate ocean tide loading at Sakurajima volcano (Yamamoto *et al*., 2001). Volcanic activities of Sakurajima influenced by periodic anomalous vertical crustal movement are studied (Tanaka, 2000).

Electric and magnetic observations are utilized for detecting temporal and spatial changes of shallow volcanic systems at active volcanoes in Japan. A precursory magnetic anomaly, which is ascribed to be thermal demagnetization, is reported at the 2000 volcanic activity of Miyakejima (Sasai, *et al*., 2001ab). Geomagnetic observations detect heat discharging process at shallow parts of Iwoyama and Kuju volcanoes (Hashimoto *et al*., 2002; Sakanaka *et al*., 2001) and are utilized for monitoring of activity of Aso volcano (Hashimoto *et al*., 2001). Continuous monitoring system of geomagnetic total intensity using satellite telecommunication is deployed at Kuchinoerabujima volcano (Kanda *et al*., 2001). Temporal change of geoelectric difference is observed at Niijima volcano prior to the volcanic activity around Izu islands (Tanaka, 2000). Thermal infrared analysis is applied to the eruptive activity of the 2000 eruption of Usu (Kaneko *et al*., 2002) and multitemporal observations using airborne multispectral scanners are conducted for the 2000 Usu eruption (Jitsufuchi, *et al*., 2002).

Infrasound data are utilized for determining the source location and/or monitoring the volcanic activities of Usu (Yamasato *et al*., 2002; Aoyama *et al*., 2002) and Sakurajima volcano (Garcez *et al*., 1999). Eruption clouds are studied from a geostationaly meteorological satellite (HIMAWARI) images (Sawada, 2002).

Recent activities of Satsuma-Iwojima, Kuchierabujima, Kuju, Miyakejima, Unzen volcanoes are discussed through multiparameter measurements based on seismic, geodetic, heat, gravitational observations and/or geological field works (Iguchi *et al*., 2002ab; Ehara *et al*., 2000; Fujimitsu *et al*., 1999; Nakada *et al*., 1999; Ukawa *et al*., 2000; Voight *et al*., 2000).

Structure of Volcanoes

Three dimensional seismic structures of volcanoes are revealed by tomography methods using natural eartqhaueke data at Aso (Sudo and Kong, 2001), Kuju (Yoshikawa *et al*., 2002), Usu (Onizawa *et al*., 2002b) and Nevado del Ruizu (Londono and Sudo, 2002). A simultaneous seismic wave velocity and crustal density inversion is applied to the shallow structure of Izu-Ooshima (Onizawa *et al*., 2002a). Arrival times and pulse width are used for tomographic inversion of P-wave velocity and Q-structures of Kirishima volcano (Tomatsu *et al*., 2001). Artificial seismic experiments are conducted for determining the 3D shallow structure of Iwate and Unzen volcanoes (Tanaka *et al*., 2002a; Nishi, 2002), and air-gun sources in the ocean are utilized for clarifying the velocity structure around submarine volcanoes and Shimabara peninsula (Nishizawa *et al*., 1999, Nisihzawa *et al*, 2000, Nishizawa *et al*., 2002b; Takahashi *et al*., 2002b). Receiver function analysis is applied to the crustal structure beneath Iwate volcano (Nakamichi, *et al*. 2002). Converted phases are used for determining boundary of a shallow structure of Kuju volcano (Tanaka *et al*., 2000), and distinct reflected S reflector is observed in the uppermost mantle beneath Osoresan volcano (Hori and Hasegawa, 1999). Temporal changes of seismic structure are studied around Iwate volcanoe by using artificial seismic sources (Nishimura *et al*., 1999), and new techniques for measuring slight change of the structure are developed (Yamaoka *et al*., 2001; Yamaoka *et al*., 2002). Three dimensional thermal structure of the crust beneath Nikko volcano group is determined by comparing the tomography results with laboratory velocity data (Adachi *et al*., 1999). Autoregressive modeling is used for determining complex travel times (arrival times and pulse width) (Hasada *et al*., 2001), and a new algorithm for calculating shortest path of seismic ray in 3D is developed (Nishi, 2001).

Detailed gravitational studies are conducted at Toga and Sakurajima volcanoes and Hida mountains (Kiztsunezaki *et al*., 2002; Miyamachi *et al*., 2000; Gennai *et al*., 2002).

Magnetotelluric soundings detected low-electric resistivity zones representing magma chambers, melting zones, and/or ground water layers beneath Tateyama volcano, Aso caldera, and Taupo volcanic zone (Ogawa *et al*., 2002; Handa and Tanaka, 1999; Ogawa *et al*., 1999). Electric resistivity structure is also investigated for Usu and Norikura volcanoes (Matsushima *et al*., 2001; Fujita *et al*., 1999). Electric self-potential measurements are conducted at Sakurajima and Aso volcano to detect hydrothermal systems (Hashimoto *et al*., 1999; Hase *et al*., 2000). Three-dimensional geomagnetic tomography method is applied to the data obtained before the 2000 Miyakejima eruption (Ueda *et al*., 2001b). A helicopter-borne electromagnetic survey is conducted to better understand the subsurface structure of Usu volcano (Okuma *et al*., 2002).

Geophysical structure of the Myojinsho caldera is investigated from acoustic-sounds, geomagnetic and gravity data and topography (Ueda *et al*., 2001). Zeta-potential is also measured for various rock samples of Aso (Hase *et al*., 2002).

Source Process of Volcano Earthquakes and Tremor

Source mechanisms of very long period seismic events observed at Usu, Iwate and Aso volcanoes are investigated through waveform analyses to clarify the magma and hydrothermal system beneath the volcanoes (Yamamoto *et al*., 2002; Nishimura *et al*., 2000; Yamamoto *et al*., 1999, Kawakatsu *et al*., 2000; Legrand *et al*., 2000). Sources of very long period signals associated with caldera formations of Miyakejima volcanoes are examined through analyses of broadband seismograms (Kumagai *et al*., 2001) and step signals recorded by tilt meters (Fujita *et al*., 2002a). Source mechanisms of explosion earthquakes at Sakurajima volcano and long period events at Asama and Usu volcanoes are studied by moment tensor analyses (Tameguri *et al*., 2002; Aoyama and Takeo, 2001; Yoshida *et al*., 2002). Hydrothermal system is studied through the analyses of complex frequencies and moment tensors of long-period events at Kusatsu-Shirane volcano (Kumagai *et al*., 2002ab). Pilsative seismic events observed at Tsurumi volcano are studied by using dense seismic array data (Mori *et al*. 2000). Seismic observation at Iwo-jima detected small earthquake activity triggered by surface waves of teleseismic events (Ukawa *et al*., 2002). Relations between volcanic eruptions, inland earthquakes, and great tectonic earthquakes in and around north-eastern Japan island arc is discussed (Churei, 2002). Acoustic properties of a crack including magmatic or hydrothermal fluid (Kugamai and Chouet, 1999, 2000, 2001) and low attenuation resonance of a spherical magma chamber (Fujita and Ida, 1999) are theoretically studied.

Dynamics of Volcanic Eruptions

Laboratory experiments on fragmentation of a porous viscoelastic material are conducted to understand magma fragmentation (Ichihara *et al*., 2002). Field explosion experiments are conducted for examining the effects of explosion energy and depth on the nature of explosion cloud and pressure-wave forms (Ohba *et al*., 2002; Goto *et al*., 2001), and the results are utilized for understanding the 2000 Usu phreatic explosions (Yokoo *et al*., 2002). Motions of vapor/gas bubbles in a fluid flow are numerically investigated to evaluate their effects to the hydrothermal system (Kawashima *et al*., 2001). Blast waves caused by explosions are simulated by using a three dimensional computational code (Saito *et al*., 2001), and tsunami is calculated for the Nuuanu and Wailau giant landslide, Hawaii (Satake *et al*., 2002). A dynamical model is proposed to explain the periodic nature of the 2000 Usu eruption (Maeda, 2002).

Mantle Dynamics and Magma Migrations

Magmatism beneath the Japan arc are studied based on the results of numerical simulations, and seismic structures and/or geologic data (Iwamori and Zhao, 2000; Furukawa *et al*., 1999; Tamura *et al*., 2001; Tamura *et al*., 2002; Zhao *et al*., 2000). Experimental study on Rayleigh-Taylor instability is conducted to understand interaction and spacing of diapers (Kumagai and Kurita, 2000). Effect of the viscosity ratio on entrainment and stirring of mantle plume are studied (Kumagai, 2002). Deflection of volcanic chains towards backarc is discussed with lower temperature due to subducting plates (Iwamori 2000). Observed magma supply rate and magma partitioning in various volcanoes are discussed with tectonic settings (Takada *et al*., 1999). Numerical simulations examine influence of a magma chamber on thermal structure of the surrounding crust (Tomiya, 2000).

(Takeshi Nishimura)

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IV. Geological Study

1. Regional Geology and Physical Volcanology

Researches on various aspects of regional geology of Quaternary, Tertiary, and Cretaceous volcanic areas in Japan have been published since the previous report. Regional geological studies of Quaternary volcanoes in Japan were reported for Tyatya volcano (Nakagawa *et al*., 2002a), Rausudake volcano (Miyaji *et al*., 2000), Daisetsu volcano (Nakamura and Hirakawa, 2000), Rishiri volcano (Ishizuka, 1999), Hokkaido-Komagatake volcano (Okuno *et al*., 1999), Osore volcano (Kuwabara *et al*., 2001), Okiura caldera (Nozawa, 2001), Iwate volcano (Doi, 1999; 2000, Doi *et al*., 2002), Hachimantai volcano (Ohba and Umeda, 1999; Takashima *et al*., 2001), Toga volcano (Kano *et al*., 2002), Chokai volcano (Ban *et al*., 2001), Kurikoma volcano (Fujinawa *et al*., 2001b), Aoso volcano (Toya and Ban, 2001), Shirataka volcano (Mimura and Kano, 2000), Adatara volcano (Fujinawa *et al*., 2001a; Yamamoto and Sakaguchi, 2000), Bandai volcano (Chiba and Kimura, 2001), Nekoma volcano (Kimura *et al*., 2001; Mimura, 2002), Sunagohara caldera (Mizugaki, 2000), Takahara volcano (Takashima, 1999), Kinunuma volcano (Yamamoto, 1999a), Shirouma-Oike volcano (Oikawa *et al*., 2001), Yakedake volcano (Oikawa, 2002; Oikawa and Kioka, 2000; Oikawa *et al*., 2000; 2002), Ontake volcano (Matsumoto and Kobayashi, 1999; Matsumoto Basin Collaborative Research Group, 2002), Fuji volcano (Takada, 2000a; Yamamoto *et al*., 2002), Hakone volcano (Kobayashi, 1999; Mannen, 1999a; Mannen and Sugiyama, 2000), Higashi-Izu monogenetic volcanoes (Hasebe *et al*., 2001; Shimada, 2000), Izu-Oshima volcano (Nakada *et al*., 1999), Miyakejima volcano (Tsukui *et al*., 2001), Daisen and Sambe volcanoes (Kimura *et al*., 1999), Yufu-Turumi volcano (Fujisawa *et al*., 2002; Saito *et al*., 2000), Aso volcano (Baba *et al*.1999; Miyabuchi and Watanabe, 2000; Miyabuchi and Takada, 2002), Unzen volcano (Hoshizumi at al., 1999; Shimao *et al*., 1999; Tateyama *et al*., 2002), Ojika-Jima volcano (Yamamoto, 2001), Aira caldera (Fukushima and Kobayashi, 2000; Sudo *et al*., 2000), submarine volcano off the north-east of the Iriomote Island (Watanabe, 2000), and submarine Myojin-Sho caldera (Ueda *et al*., 2001). Tephrostratographic studies have been reported for Late Pleistocene widespread tephras (Fujii *et al*., 2001; Kawai and Miyake, 1999), Middle Pleistocene tephras (Suzuki, 2001; Yamamoto, 1999a), and Early Pleistocene tephras (Kataoka, 2001; Kataoka and Nakajo, 2002; Kataoka *et al*., 2001; Nagahashi *et al*., 2000; 2002; Satoguchi *et al*., 1999; 2000). Regional geological studies of Pre-Quaternary volcanism were published for the Miocene high-Mg volcanism in SW Japan (Furukawa and Tatsumi, 1999; Tatsumi *et al*., 2001), the late Neogene volcanism in SW Japan (Kamata, 2000; Kamata and Kodama, 1999), the Late Miocene alkalic volcanism in Oki-Dozen island (Tiba *et al*., 2000) and Oki-Dogo island (Kobayashi *et al*., 2002), the Pliocene-Pleistocene volcanism in NE Honshu (Umeda *et al*., 1999), and the late Neogene volcanism in Hokkaido (Hirose and Nakagawa, 1999; Hirose *et al*., 2000; Nakagawa *et al*., 1999). Geological studies in foreign countries were published for the Tertiary volcanism in Sikhote Alin, Russia (Tatsumi *et al*., 2000), the Quaternary volcanism in Philippines (Sudo *et al*., 2000), the submarine structure of Hawaii (Lipman *et al*., 2000; Naka *et al*., 2002), and the Quaternary volcanism in Flores Island, Indonesia (Muraoka *et al*., 2002; Takashima *et al*., 2002).

Hazard maps have been prepared for Meakan volcano in 1999, Atosamupuri volcano in 2001, Esan volcano in 2001, Chokai volcano in 2001, Azuma volcano in 2001, Adatara volcano in 2002, Bandai volcano in 2001, Nasu volcano in 2002, Ontake volcano in 2002, and Yakedake volcano in 2002 by individual local governments. Total numbers of published volcanic hazard maps are 28 in Japan. Geologic maps (1:50,0000) with explanation including Quaternary volcanoes have been published for Tonohetsuri caldera (Yamamoto, 1999b), Kenashi volcano (Yanagisawa *et al*., 2001), Shirouma-Oike volcano (Nakano *et al*., 2002), Tateyama volcano (Harayama *et al*., 2000), Oe-Takayama volcano (Kano *et al*., 2001), and Kirishima volcano (Imura and Kobayashi, 2001) by the Geological Survey of Japan.

Geological researches on historical eruptions were published for the 1707 Fuji eruption which was a dacitic-basaltic sub-Plinian eruption (Ui *et al*., 2002a), the 1888 Bandai eruption which generated a phreatic density currents and a debris avalanche (Yamamoto *et al*., 1999), the 1986 Izu-Oshima eruption which was a basaltic sub-Plinian fissure eruption (Mannen, 1999b), the 1990-95 Unzen eruption which produced a dacitic lava dome and numerous block-and-ash flows (Fujii and Nakada, 1999; Kaneko and Wooster, 1999; Kaneko *et al*., 2002a; Miyabuchi, 1999; Nakada *et al*., 1999; Saito and Suto, 2002; Ui *et al*., 1999; Watanabe *et al*., 1999a; 1999b), the 1996, 1998 and 2000 Hokkaido-Komagatake eruptions which were phreatic explosions (Hirose *et al*., 2002; Nakagawa *et al*., 2001), the 2000 Usu eruption which was a shallow dacitic intrusion with many phreatomagmatic to phreatic explosions (Kaneko *et al*., 2002b; Koarai *et al*., 2002; Miura and Niida, 2002; Nagai *et al*., 2002; Nakada, 2001; Nakagawa *et al*., 2002b; Ohno *et al*., 2002; Suto *et al*., 2002; Suzuki and Nakada, 2002; Takada *et al*., 2001; Takagi *et al*., 2002; Takarada *et al*., 2001; 2002; Tomiya and Miyagi, 2002; Tomiya *et al*., 2001; Ui *et al*., 2000; 2002b; 2002c; Urai *et al*., 2001; Yahata, 2002; Yamamoto, 2001; Yokoo *et al*., 2002), and the 2000 Miyakejima eruption which started as a submarine basaltic flank eruption and was succeeded by caldera collapse with phreatomagmatic explosions and gigantic SO_2 emission (Geshi *et al*., 2002a; 2002b; Kaneko *et al*., 2001; Miyagi and Tomiya, 2002; Nakada *et al*., 2001; Uto *et al*., 2001).

Various studies on physical volcanology were reported since the previous report. Tamura *et al*. (2002) discussed the relationship between Quaternary volcanoes in NE Japan arc and hot fingers in the mantle wedge using seismic tomographic data. Tomiya (2000) estimated thermal effect of a magma chamber in the crust. Magma transport mechanism through dike system was examined by observation data of fissure eruptions (Takada, 1999), physical properties of magma (Takada, 2000b; Takeuchi and Nakamura, 2001), and field occurrences of dikes (Geshi, 2000; Wada and Aoki, 2002; Wada and Iwano, 2001; Wada *et al*., 2000). Caldera formation processes were studied by Miura (1999, 2000) and Takada (2001). Ohba *et al*. (2002) showed effect of explosion energy and depth on the nature of explosion clouds by field experiments. Specific researches on debris avalanches were reported for field occurrences (Takarada *et al*., 1999) and experiments (Iizawa *et al*., 1999; Kamata *et al*., 2002; Suda *et al*., 2002).

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2. Petrology and Mineralogy

In the period from 1999 to 2002, many studies on petrology and mineralogy have been made by Japanese earth scientists as well as the previous period.

Significant progress has been made at the Japanese-USA cooperative studies on Hawaiian volcanoes (Naka *et al*., 2000; see section VII of this report), including deep-sea survey with the submersible "Shinkai 6500", the world's most advanced deep-sea probe. Major part of the outcome was published as a monograph (Takahashi, E. *et al*., 2002), including petrological and geochemical studies on products collected by the deep-sea survey (Kaneoka *et al*., 2002; Sherman *et al*., 2002; Shinozaki *et al*., 2002; Tanaka *et al*., 2002) and melting experiments on basalt+peridotite (Takahashi, E. and Nakajima, 2002). Other studies on the Hawaii project were appeared as individual papers (e.g., Lipman *et al*., 2000).

Research on Unzen volcano also progressed significantly after its eruption of 1990-1995 (Chen, C. H. *et al*., 1999; Kusakabe *et al*., 1999; Nakada and Motomura, 1999; Sato *et al*., 1999; Tateyama *et al*., 2002; Watanabe, Ko. *et al*., 1999). At the volcano, international scientific drilling project (Unzen volcano Scientific Drilling Project) is going on (Sakuma and Nakada, 2002; Sakuma and Saito, 2000; Uto *et al*., 2000; see section VII of this report) and many publications will be appeared in the next period.

Research on subduction-zone magmatism around Japan was made energetically. As for Northeast Japan, spatial distribution of volcanoes was noticed (Umeda *et al*., 1999), and a new concept of "hot fingers" in the mantle wedge was proposed (Tamura, Y. *et al*., 2001, 2002). The magmatism in this region was summarized (Yoshida, 2001) and compared with Southern Chile arc (Takahashi, M. *et al*., 2002b). Also Cenozoic volcanism on Hokkaido area (Hirose, W. *et al*., 2000; Hirose, W. and Nakagawa, 1999; Ikeda, Y. *et al*., 2000; Nakagawa, 1999; Nakagawa *et al*., 1999a; Okamura *et al*., 2000; Takagi *et al*., 1999) was discussed in connection with its tectonic setting. As for Southwest Japan, many geochemical studies were made especially on the Setouchi volcanics or related rocks (Furukawa and Tatsumi, 1999; Hanyu *et al*., 2002; Nakashima *et al*., 2000; Seno and Matsuura, 2000; Shimoda and Tatsumi, 1999; Sumii, 2000; Tatsumi, 2000b, 2001; Tatsumi *et al*., 2002), including contemporary adakitic rocks in central Japan (Takahashi, T. and Shuto, 1999). Also studies on the region before (Kagami *et al*., 1999a, 2000) and after (Ikeda, Y. *et al*., 2001; Kamata and Kodama, 1999; Shukuno and Arai, 1999) the opening of the Japan Sea were made. Studies on premature arcs and active back-arc basins, such as Izu-Bonin arc (Hochstaedter *et al*., 2000; Ishii *et al*., 2000a-b; Ishizuka, O. *et al*., 2002), Mariana arc (Ishikawa and Tera, 1999; Ohara *et al*., 2002), Ryukyu arc (Shinjo and Kato, 2000; Shinjo *et al*., 2000; Watanabe, Ka., 2000, 2001) and West Philippine back-arc basin (Fujioka *et al*., 1999), were made mainly by deep-sea survey. In connection to the above studies, it was proposed that continental crust with andesitic composition was generated by delamination (Tatsumi, 2000a), and that silicic magma in oceanic arc was generated by remelting of an andesitic crust (Tamura, Y. and Tatsumi, 2002). Analyses on light elements in subduction-zone magma, such as boron (Sano, T. *et al*., 2001b), beryllium (Shimaoka and Kaneoka, 2000) and carbon (Nishio and Sano, 2000), were made to investigate contribution of recycled elements from subducting sediment. There were studies on high-pressure melting experiments for related rocks (see later) and numerical simulation for wedge-mantle convection (Iwamori, 1999a-b, 2000a-b, 2001a-b, 2002a-b; Iwamori and Zhao, 2000a-b; Zhao *et al*., 2000). A textbook on subduction-zone magmatism was published by Takahashi, M. (2000). Research on plume-origin magmatism (Hanyu and Nakamura, 2000; Hirano *et al*., 2001; Tatsumi *et al*., 1999b, 2000a-b) was also progressed in addition to the Hawaii project.

There were two major eruptions during this period, on which many studies were made (see section II of this report). One was the 2000 eruption of Usu volcano, Hokkaido (phreatomagmatic/phreatic). In this eruption, it was pointed out that detailed petrographical research was needed for detection of essential materials of phreatomagmatic eruptions (Tomiya *et al*., 2001) because apparently fresh and clear volcanic glass from this eruption was found to be accidental fragment. Studies on the magmatic process of the eruption in comparison with the past eruptions (Tomiya, 2001; Tomiya and Miyagi, 2002), on vesiculation of the magma during ascent (Suzuki and Nakada, 2001, 2002), on fragmentation of country rocks due to explosion within the conduit (Yahata, 2002) and on petrographical and geochemical analyses of the volcanic ash (Nakagawa *et al*., 2002b; Nogami *et al*., 2002; Shimano *et al*., 2001) were also made. The other major eruption in this period was the 2000 eruption of Miyakejima volcano, Izu Islands (phreatomagmatic/phreatic). Again, the detection of essential materials in the eruptive products required detailed and complex researches (Miyagi, I. and Tomiya, 2002a-b; Miyagi, I. *et al*., 2001a-c). Studies on mechanism of the voluminous emission of SO_2 gas (Uto *et al*., 2001; Yasuda *et al*., 2001, 2002), on magmatic process of the eruption (Amma-Miyasaka and Nakagawa, 2002; Geshi *et al*., 2002) and on formation history of the volcano (Tsukui *et al*., 2001) were also made.

Petrological studies of other individual volcanoes (volcanic areas) around Japan include: Abu Monogenetic Volcano Group (Kakubuchi *et al*., 2000), Adatara (Fujinawa *et al*., 2001b), Akagi (Kobayashi, K. and Nakamura, 2001), Akan (Ikeda, Y., 2002), Akusekijima (Furuyama *et al*., 2002), Aoso (Toya and Ban, 2001), Aso (Obata *et al*., 2001), Bishamon-dake (Ujike *et al*., 1999), Chokai (Ban *et al*., 2001), Daikonjima basalt (Morris *et al*., 1999), Daisen (Tamura, Y. *et al*., 2000), Daisetsu (Nakamura, Y. and Hirakawa, 2000), Fuji (Fujibayashi *et al*., 1999; Ui *et al*., 2002), Hachijo-Nishiyama (Tsukui and Hoshino, 2002), Hachimantai (Ohba and Umeda, 1999), Hakone (Hirata *et al*., 2001), Higashi-Izu Monogenetic Volcano Group (Suzuki, 2000; Takahashi, M. *et al*., 2002a), Iwate (Nakagawa and Togari, 1999), Kikai and Satsuma-Iwojima (Maeno *et al*., 2002; Saito *et al*., 2002), Kita-Hakkoda Volcano Group (Kudo *et al*., 2000), Kurikoma (Fujinawa *et al*., 2001a), Myojin-sho (Ueda *et al*., 2001), Nasu (Ban and Yamamoto, 2002), Nekoma (Kimura *et al*., 2001, 2002b), Norikura (Kimura *et al*., 1999), Numazawa (Numazawa Volcano Research Group, 1999), Ontake (Kimura and Yoshida, 1999), Rausu (Miyaji *et al*., 2000), Rishiri (Ishizuka, Y. and

Nakagawa, 1999; Kuritani, 1999a-b, 2001), Sannome-gata (Yoshinaga and Nakagawa, 1999), Toga (Kano *et al*., 2002), Towada (Kuri and Kurita, 1999), Tyatya (Nakagawa *et al*., 2002a) and Ueno volcano (Ueno basalts) (Kimura *et al*., 2002a; Nakano, S. *et al*., 2000; Ujike and Stix, 2000).

Studies focused on a special eruption include: the 1929 eruption of Hokkaido-Komagatake (Takeuchi, 2000; Takeuchi and Nakamura, 2001), the 1813 eruption of Suwanose (Shimano and Koyaguchi, 2001) and the 100-ka eruption of Hijiori (Matsu'ura *et al*., 2002).

Studies on volcano-related geothermal areas include: Yuzawa-Ogachi-Doroyu area (Takashima *et al*., 1999; Zhang *et al*., 1999), Hachimantai-Appi area (Takashima *et al*., 2001) and Yanaizu-Nishiyama (Okuaizu) area (Mizugaki, 2000).

Studies on volcanics of around Neocene, besides those described above (e.g., Setouchi volcanics), include: Anamizu Formation (Lopez and Ishiwatari, 2002), Beppu-Shimabara graben (Kita, I. *et al*., 2001; Yokose *et al*., 1999), Daiyama and Nisshou areas (Shimakura *et al*., 1999), Hahajima (Yajima *et al*., 2001), Hamamasu area (Aoki *et al*., 1999), Hisatsu area (Nagao *et al*., 1999), Inaniwadake (Yasui and Yamamoto, 2000), Masuda basanite (Sawada and Takasu, 1999), Oki-Dogo (Kobayashi, S. *et al*., 2002), Shimane Peninsula (Iizumi *et al*., 1999), Shirogishi Tuffs (Imaoka *et al*., 1999) and southern Fossa Magna region (Miyagi, S. and Kanai, 2002). Studies on volcanics and granites of Paleogene or older (Aoya, 2001; Ikawa *et al*., 1999; Kagami *et al*., 1999b; Kanayama *et al*., 1999; Kawano, Y. and Kagami, 1999; Owada *et al*., 1999; Rezanov *et al*., 1999; Sugii and Sawada, 2000; Tsuchiya *et al*., 1999a) were made to investigate the relation between the arc crust and felsic magmatism in Japan.

Volcanic fields outside Japan were also studied, such as: Ruapehu volcano (Nakagawa *et al*, 1999b, 2002c), Flores island (Muraoka *et al*., 2002; Otake *et al*., 2002), East African Rift Zone and related areas (Kabeto *et al*., 2001a-b; Orihashi *et al*., 2001; Sawada *et al*., 2001; Tadesse *et al*., 1999), Deccan trap (Sano, T. *et al*., 2001a), Korea (Kim *et al*., 1999), China and Mongolia (Kanisawa, 1999; Liu and Taniguchi, 2002; Nozaka and Liu, 2002; Zheng *et al*., 2002), Siberia (Agashev *et al*., 2001; Hasenaka *et al*., 1999; Litasov, K. and Taniguchi, 2002; Litasov, K. *et al*., 2000, 2001c-d, 2002; Litasov, Y. *et al*., 2002; Morikiyo *et al*., 2000), Sikhote Alin (Shimazu and Kawano, 1999; Tatsumi *et al*., 2000c) and Kokchetav 'lamproite' (Zhu *et al*., 2002).

Research on peridotite/ophiolite masses of various fields was made, such as Horoman peridotite (Kaneoka *et al*., 2001; Morishita and Arai, 2001a-b; Takazawa *et al*., 1999; Yoshikawa and Nakamura, 2000), Iwanaidake peridotite (Kubo, 2002), Nikanbetsu peridotite (Takahashi, N., 2001), Shiokawa peridotite (Uesugi and Arai, 1999), Oeyama peridotite (Tsujimori, 1999), Oman ophiolite (Ahmed and Arai, 2002; Ishikawa *et al*., 2002; Kawahata *et al*., 2001), Ronda peridotite (Morishita *et al*., 2001), Harzburg intrusion (Sano, A. *et al*., 2002), Elistratova ophiolite (Miyashita and Sokolov, 1999) and other Japanese peridotites (Abe *et al*., 1999; Kadoshima and Arai, 1999; Matsumoto and Arai, 2001; Tamura, A. *et al*., 1999). Volcanics closely related to ophiolites were also studied (Imanaka and Miyashita, 1999; Ishiwatari, 1999; Kawabata and Kiminami, 1999; Kiminami *et al*., 1999; Miyashita, 1999; Miyashita and Kiminami, 1999; Niida and Kito, 1999; Ozawa, H. *et al*., 1999; Sakakibara *et al*., 1999; Tsuchiya *et al*., 1999b). In addition, mantle xenoliths (Arai *et al*., 2000, 2001; Hattori, K. H. *et al*., 2002; Yamamoto *et al*., 1999) and inclusions in diamonds (Akagi, 1999; Wang *et al*., 2000) and Cr-spinel (Shimizu, K. *et al*., 2001) were investigated for mantle studies.

There was mass production of papers in the field of high-pressure experiment on mantle mineralogy (Chen, J. *et al*., 2002; Hattori, T. *et al*., 2000; Hirose, K. *et al*., 1999, 2001a-b; Katsura, 2002; Kuroda *et al*., 2000; Miura *et al*., 2000; Miyajima *et al*., 1999, 2001; Murakami *et al*., 2002; Nakatsuka *et al*., 1999a-b; Oguri *et al*., 2000; Ono, 2000; Ono *et al*., 2001a-b, 2002a; Shinmei *et al*., 1999; Shirasaka *et al*., 2002; Suito *et al*., 2001) and melting experiments on MORB-like or mantle-related rocks (Aizawa *et al*., 1999; Chung and Kagi, 2002; Funamori *et al*., 2000; Hirose, K., 2002; Hirose, K. and Fei, 2002; Inoue *et al*., 2000; Kogiso and Hirschmann, 2001; Litasov, K. *et al*., 2001a-b; Niida and Green, 1999; Okamoto and Maruyama, 1999; Ono, 1999; Pati *et al*., 2000; Singh *et al*., 2000; Sumita, 2000; Tatsumi *et al*., 1999a; Wang and Takahashi, 1999, 2000) including diamond-forming experiments with carbonate melt (Arima *et al*., 2002). There was also an experimental study on water solubility in natural rhyolite melt at crustal pressure (Yamashita, 1999).

Various types of analytical or experimental techniques were improved, such as electron microprobe (Geshi and Yoshida, 2001; Kato, 1999; Sugawara, 2001a; Ujike, 2000), ICP-MS (Fukuda and Nakai, 2002; Nakai *et al*., 2001), FT-IR (Ogo and Yamashita, 1999; Okumura *et al*., 2000), TL measurement (Shimao *et al*., 1999), Pb-isotope measurement (Nohda, 1999) and 1-atm gas-mixing furnace (Sugawara, 1999). New types of analyses of rock texture were introduced such as X-ray CT (Nakano, T. *et al*., 2000; Ohtani *et al*., 2000, 2001; Tsuchiyama *et al*., 2000), high-resolution TEM (Hiraga, 1999) and polarized laser-scanning microscope (Shimizu, I. and Shimada, 2002).

Fluid connectivity (wetting angle) in porous rocks and its role on various processes were noticed. Mibe *et al*. (1999, 2000) suggested that the generation of arc magma and, therefore, the location of the volcanic front may be controlled by aqueous fluid connectivity in the mantle. The connectivity of fluid was also thought to be important on water transport within mantle (Ono *et al*., 2002b), crust (Nakamura, M., 2000; Nakamura, M. and Watson, 2001; Yoshino *et al*., 2002) and metamorphic rocks (Hiraga *et al*., 2001, 2002). Connectivity of melt in crystal-rich magma was also studied in relation to the textural development of igneous rocks in the stage of their crystallization (Ikeda, S. *et al*., 2002).

There were various types of studies on dynamics of magma from petrological points of view, such as, melt migration within dikes (Geshi, 2000, 2001), crystallization and cooling history of magma (Miyake and Shimobayashi, 2000; Nishimura and Yanagi, 2000; Sano, Y. *et al*., 2002), solidification of lava domes (Smith *et al*., 2001), and formation of layered structure of gabbro (Akatsuka *et al*., 1999) and peridotite

(Toramaru *et al*., 2001). A series of analogue experiments on crystallization of magma within meltable material (a binary eutectic system) was carried out (Kaneko and Koyaguchi, 2000) in order to discuss evolution of a magma chamber within the crust (Koyaguchi and Kaneko, 1999). There was also a numerical experiment of crystallization for a binary eutectic system for the purpose of applying to igneous textures (Toramaru, 2001). A textbook on dynamics of petrogenesis was published by Banno *et al*. (2000). Theoretical approach to viscosity of magma (Taniguchi, 2000) and a review on magma science (Taniguchi, 2001) was made.

Thermodynamical and mineralogical research was made on mixing properties of Ca in olivine (Kawasaki, 1999, 2001a-b), phase relations of enstatite at high temperatures (Jiang *et al*., 2002), behavior of Sr in CaAl-silicates (Enami, 1999), fine structure of amphiboles (Ishida *et al*., 2002) and oxybiotite (Kogure and Nepolo, 2001), partition of Mg between olivine/orthopyroxene and melt (Sugawara, 2000a), Fe and Mg between plagioclase and melt (Sugawara, 2000b, 2001b) and trace-elements within mantle materials (Kanzaki, 2000; Taura *et al*., 2001) in even open magmatic systems (Ozawa, K., 2001). Studies on other kinetic processes include: diffusion in garnet (Nishiyama, 1999) and biotite (Utsuki, 2002), equilibrium form of negative crystals in quartz (Asada *et al*., 2002), and weathering/hydration of volcanic glass or minerals (Kawano, M. and Tomita, 2001; Kita, S. *et al*., 1999; Nakamura, Y. *et al*., 2002).

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(* In Japanese with English abstract. ** In Japanese)

V. Geochemical Study

1. Monitoring of Active Volcanoes Before and After the Eruption

Usu volcano, Hokkaido, Japan erupted on March 31, 2000, after a dormancy of 22 years. Various geochemical studies have been reported related to the eruption. Prior to the 2000 eruption, several geochemical anomalies were identified. Soil CO_2 degassing from the summit area increased before and significantly decreased after the 2000 eruption (Hernandez *et al*., 2001b). Systematic water-level decreases were observed for a several month prior to the eruption at two wells (Shibata and Akita, 2001). Abrupt and large rises in well water levels were observed three days prior to the 2000 eruption (Matsumoto *et al*., 2002a). The constituents of the 2000 volcanic ashes were shown to be the alteration products of the volcaniclastics of the historic eruptions (Nogami *et al*., 2002a) and water-soluble components on volcanic ash are documented (Murayama and Ogino, 2002; Nogami *et al*., 2002b). Distribution maps for Boron and Ammonia concentration in the soil in 1999 showed anomalies at Nishiyama area where the 2000 eruption took place (Perez *et al*., 2002). Arsenic on ash and mudflow deposits is investigated (Yahata *et al*., 2001). Continuous soil CO_2 emission monitoring was carried out at the summit of Usu after the onset of the eruption and observed decreasing trend similar to the decreasing eruptive activity (Mori *et al*., 2002a). Satellite data are used for monitoring thermal activities (Kaneko *et al*., 2002) and ash fall distributions (Urai *et al*., 2001).

Miyakejima volcano started to erupt in June 2000; one of the eruptive activities that deserve special mention is continuous high SO_2 emission from the volcano. SO_2 flux as high as 230 ktons/day was observed using COSPEC and convective transport of magma model are proposed to explain the observed continuous high SO_2 flux (Kazahaya, 2001; Kazahaya *et al*., 2001; Uto *et al*., 2001). Sulfur dioxide and acid rain due to the Miyakejima eruption were observed and reported at many locations even on the Honshu Island, Japan (Yamakawa and Yamagami, 2001; Yokota, 2001; Katsuno *et al*., 2002; Matsumoto *et al*., 2002b), and dispersion of volcanic gas from the volcano is simulated (Chino, 2001). Reason for the high SO_2 emission of the Miyakejima 2000 eruption was discussed by analyzing sulfur, chloride, and fO_2 in melt inclusions inside phenocrysts (Yasuda *et al*., 2001; 2002). Soil CO_2 survey was performed in 1999 before the eruption (Hernandez *et al*., 2001c). Kinoshita (2001) reviewed geochemistry and effects of the volcanic gas.

Takahashi *et al*. (2000) reports on Koshimizu thermal spring formed in the 1986 eruption of Izu-Oshima volcano. Nogami *et al*. (2001) discussed the relationship between the chemical composition of volcanic ash and the contents of the water-soluble components adhering to it for the early stage of the 1990-1995 Unzen eruption. Related to the 1995 phreatic eruption of Kuju volcano, entrainment of atmospheric air into volcanic system was observed (Ohsawa *et al*., 2000a) and HCl emission rate variations are reported (Itoi *et al*., 2000). Hydrothermal processes of the 1997 phreatic eruption of Akita-Yakeyama volcano were revealed using geochemical data of fumarolic gases and ejecta of the eruption (Nogami *et al*., 2000).

2. Studies on Gas and Water Related to Volcanic Activity.

Special issue of “Earth, Planets and Space” (Vol. 54, No. 3) for Satsuma-Iwojima volcano, which is continuously degassing high temperature volcanic gas, is published in 2002. The issue has 15 manuscripts (12 by Japanese authors) on the volcano (Hamasaki, 2002; Iguchi *et al*., 2002; Kanda and Mori, 2002; Kawanabe and Saito, 2002; Kazahaya *et al*., 2002; Mori *et al*., 2002b; Saito *et al*., 2002b; Sato *et al*., 2002; Shimoike *et al*., 2002; Shinohara *et al*., 2002; Uchida and Sakai, 2002; Urai, 2002). Results from the fourth and fifth IAVCEI volcanic gas field workshop held respectively at Vulcano Island, Italy, and Java, Indonesia were evaluated (Giggenbach *et al*., 2001). Ossaka and Nogami (2001) reported the history and gas chemistry on Tyatya volcano as a result of Japan-Russia joint scientific study held in 1999. Ohba (2000) reviewed chemical approach for the prediction of volcanic eruptions.

Saito *et al*. (2002a) collected up to 15 fumarolic gas samples at Satsuma-Iwojima and Kuju volcanoes and showed that careful sampling and analyses provide reliable geochemical data. Trace gas species in fumarolic and volcanic gases are studied for light hydrocarbons (Igari *et al*., 2000) and halocarbons (Jordan *et al*., 2000). Sulfur isotope ratios of volcanic gases from Satsuma-Iwojima and Sakurajima volcanoes are obtained (Kasasaku *et al*., 1999).

Hydrothermal system and water chemistry and isotope compositions are discussed for crater lakes of Kusatsu-Shirane (Ohba *et al*., 2000a; Ohba *et al*., 2000b) and Patuha volcano, Indonesia (Sriwana *et al*., 2000), Kawah Lien volcano, Indonesia (Delmelle *et al*., 2000). Nishimura *et al*. (1999) surveyed crater lake, Lake Towada, for methane concentration and carbon isotopic composition profiles. An in-situ monitoring system for aqueous polythionate in Yugama crater lake, Kusatsu-Shirane volcano is developed (Takano *et al*., 2000b). The crater lake water from Mary Semiachik volcano was used for the analytical inter laboratory comparison for its chemistry (Takano *et al*., 2000a). Takano (2001) reviewed geosciences on active crater lakes. Geochemistry and/or disaster prevention at Lake Nyos, Cameroon is reported and discussed (Kusakabe *et al*., 2000b; Kusakabe, 2001a; Kusakabe, 2001b; Kusakabe, 2002). Sulfur isotope effects during the SO_2 disproportionation reaction were experimentally determined for hydrothermal conditions (Kusakabe *et al*., 2000a).

Lanthanoid abundances in hot spring waters are reported (Kikawada *et al*., 1999) and hydrothermal alternation of rocks by acidic hot spring water was reported and experimented (Kikawada *et al*., 2000a; Kikawada *et al*., 2001). Chemistry and/or isotope ratios of hot spring waters are studied at Manza area (Kikawada *et al*., 2002), Kagusa hot spring (Kikawada *et al*., 2000b), Tateyama-Jigokudani (Mizutani *et al*., 2000), Shimabara Peninsula (Ohsawa *et al*., 2002b), and Tamagawa hot spring (Muto and Matsubaya, 2002). Helium and/or carbon isotopic composition of hot spring gases are reported for Unzen volcano (Notsu *et al*., 2001), Kirishima volcano (Sato *et al*., 1999a), Tibet Plateau (Yokoyama *et al*., 1999) and Tatun volcano (Yang *et al*., 1999). Chemical and isotopic compositions for water, CO_2 and noble gases in groundwater are reported for Bioko, Principe, Sao Tome and Annobon Islands off the western coast of Africa (Aka *et al*., 2001). Origin of CO_2 from Nagayu hot spring is discussed (Iwakura *et al*., 2000). Anomalously high $\delta^{13}C$ values up to +2.8‰ for CO_2 in fumarolic gases from Ogasawara-Iwojima is reported (Ohsawa and Yusa, 2001). Using chemistry and isotopic information of inorganic carbon in ground water system of Unzen volcano, Ohsawa *et al*. (2002c) showed that volcanic gas is escaping into ground water system.

Carbon dioxide emissions through ground surface of volcanic flanks have been measured at various volcanoes: Usu (Hernandez *et al*., 2001b; Mori *et al*., 2002a), Tarumae (Hernandez *et al*., 2001a), Miyakejima (Hernandez *et al*., 2001c), Satsuma Iwojima (Shimoike *et al*., 2002) volcanoes in Japan and Teide, Spain, (Hernandez *et al*., 2000) and Cerro Negro volcanoes, Nicaragua, (Salazar *et al*., 2001). Remote measurements on chemical composition of volcanic gas using FTIR spectral radiometer were carried out. The CO/CO_2 ratios were obtained at Aso volcano (Ono *et al*., 1999), and anomalously high SiF_4/HF ratio was identified at Satsuma-Iwojima volcano (Mori *et al*., 2002b). Urai *et al*. (1999) showed that it is possible to measure distributions of SO_2 emission from volcanoes using the ASTER launched on EOS AM-1 satellite. Gas or fluid velocity from boreholes were measured based on temperature data (Umeda *et al*., 1999; Igarashi *et al*., 2000). An in-situ method for CO_2 flux measurements from fumaroles using tracer gas is established (Mori *et al*., 2001). Natale *et al*. (2000) developed a system to measure pressure gradients in the soil at locations of ground gas emissions. A method for Carbon-isotope composition for extremely low concentration CH_4 was established and successfully applied to volcanic gases from Satsuma-Iwojima volcano (Sato *et al*., 1999b). A continuous monitoring system for measuring fumarolic gas composition was developed and applied to a steam-well at Izu-Ohsima volcano (Shimoike and Notsu, 2000). Colors of the waters or hot spring deposits are used to understand volcano-hydrothermal systems: Ohsawa *et al*. (2002a) showed that blue color of thermal waters are related to Rayleigh scattering by colloidal silica; Ossaka *et al*. (2000) reported discolor of sea water during the 1986 eruption of Izu-Oshima volcano; Oue *et al*. (2002) revealed the reason for the change in the color of the hot spring deposit at Chinoike-Jikoku in Beppu geothermal area.

Geochemistry and exploration of Geothermal and hydrothermal systems are studied at various locations: Kawayu spa (Suzuki *et al*., 2000), Matsukawa (Ozeki *et al*., 2001), Hachimantai (Kobayashi *et al*., 1999), Uenotai (Takeno, 2000), Kakkonda (Ehara *et al*., 2001), Hakone (Ohsawa *et al*., 2000b), Kusatsu-Shirane (Ohba *et al*., 2000b), Hachijojima (Matsuyama *et al*., 1999; Matsuyama *et al*., 2000), Fushime (Okada *et al*., 2000), Beppu (Yusa *et al*., 2000), Kirishima (Fujita *et al*., 2000; Fujita and Sakamoto, 2001a), Kagoshima city (Fujita and Sakamoto, 2001b), Sumikawa (Kato *et al*., 2001; Ueda *et al*., 2001). Polymerizations of silicic acids in geothermal and low temperature waters are discussed (Sugita and Yamamoto, 1999; Fujita and Sakamoto, 2001c). Yoshida (2000) reviewed and recommended procedures for chemical analyses of geothermal fluids.

Global volcanic fluxes of Nitrogen, Helium carbon are discussed based on elemental and isotopic compositions of the volatile species (Sano, 2001; Sano *et al*., 2001). Many studies on noble gas chemistry and isotope compositions in lavas or xenolithes were carried out to understand volcanism, and magma and mantle systems (Tedesco *et al*., 1998; Xu *et al*., 1998; Hanyu *et al*., 1999; Sumino *et al*., 2000; Sumino *et al*., 2001; Hanyu *et al*., 2001; Matsumoto *et al*., 2001; Orihashi *et al*., 2001; Yamamoto *et al*., 2001; Matsumoto *et al*., 2002c).

3. Geochemical Studies of Hydrothermal Activities on Oceanic Bottoms

Ishibashi and Gamo (1999) summarized the chemical aspects of submarine hydrothermal systems. A review article by Gamo (1999) focused on the behavior of methane gas associated with cold seepage from sediment of the Nankai Trough. New techniques for surveying trace amount of metals in seawater have been developed: Okamura *et al*. (1998, 2001) developed in-situ Mn analyzer using chemiluminescence and applied for hydrothermal plume observation; Obata *et al*. (2000) developed Al flow-through analysis method using fluorometric detection for collected samples from oceanic hydrothermal regime.

The chemical characteristics of hydrothermal fluids from the Indian Ocean have been revealed for the first time (Gamo *et al*., 2001). The concentration and stable carbon isotopic composition of methane in water related to seafloor hydrothermal venting of Myojin Knoll Caldera, Izu-Bonin arc, have been measured, and results showed the microbial methane oxidation in the effluent plume (Tsunogai *et al*., 2000). The hydrothermal petroleum has been investigated at the submarine Wakamiko caldera in northern Kagoshima Bay (Yamanaka *et al*., 2000). The pore fluids from Ocean Drilling Program (ODP) Leg 169 were analyzed for He and carbon gas geochemistry (Ishibashi *et al*., 2002), and the fluid was also compared with the fluid chemistry of ODP Leg 139 (Gieskes *et al*., 2002).

Various elements including rare earth element (REE), Yttorium, Tungsten and Molybdenum in hydrothermal fluids and deposits have been extensively studied (Douville *et al*., 1999; Hongo and Nozaki, 2001; Sohrin *et al*., 2002). Shikazono and Kusakebe compared the chemical and mineralogical characteristics of sulfate-sulfide chimney in backarc basin and mid-ocean ridge. Differentiated volcanic glasses dredged from the Manus Basin were analyzed for volatiles and Marty *et al*. (2001) suggest that most of the volatiles are lost continuously during the fractional crystallization.

(Toshiya Mori)

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VI. National Project for Prediction of Volcanic Eruptions

1. Outlines of National Project for Prediction of Volcanic Eruptions

(Brief History)

National Project for Prediction of Volcanic Eruptions was initiated in 1974, according to the recommendation of the Geodetic Council of Ministry of Education, Science and Culture. The aims of the project are to improve volcano monitoring, to promote research on volcanic activity and mechanism of volcanic eruptions and to obtain the ability of forecasting volcanic eruptions. Since then, the project has repeated 6 times as 5-years plan. The project has been carried out by 9 national universities (Appendix 1), Japan Meteorological Agency (JMA), Geographical Survey Institute (GSI), Japan Coast Guard (JCG), National Research Institute for Earth Science and Disaster Prevention (NIED), Geological Survey of Japan (GSJ) and Communication Research Laboratory (CRL).

The Coordinating Committee for Prediction of Volcanic Eruptions (CCPVE) was organized in 1974 in order to exchange information and knowledge, to adjust research programs among institutions and to evaluate volcanic activity and contribute mitigation of volcanic disaster. Since 1974, many volcanic crises have been experienced at Tokachidake, Usu, Iwate, Izu-Oshima, Miyakejima, Unzen, Aso, Sakurajima and so on. For each volcanic crisis, CCPVE has evaluated volcanic activity and issued official statements on activity before eruptions and activity in progress.

The outlines of NPPVE until the fifth 5-years plan were summarized by Watanabe (1999). Now the sixth 5-years plan (1999－2003) is going.

(The Sixth 5-years Plan)

The sixth 5-years plan was proposed in 1998 after reviewing on the achievement of project since 1974. The proposal of the plan is consist of three parts: (1) Reinforcement of volcano monitoring and observational research at volcanoes, (2) Promotion of basic research for higher-grade prediction of volcanic eruptions and (3) Strengthening of the scheme for the prediction of volcanic eruptions.

The Geodetic Council was reconstructed into the Subdivision on Geodesy and Geophysics, Council for Science and Technology in 2000. The sixth 5-years plan was reviewed by the subdivision in 2002 and evaluated by experts in the fields of volcanology, seismology, social science, and civil engineering. The main volcanic crises in Japan during the past 5 years were (1) Volcano-seismic crisis at Iwate volcano (1998-2000), (2) Eruption at Usu volcano (2000) and (3) Eruption and active gas emission at Miyakejima volcano (2000-). The main achievements of the current 5-years plan are as follows:

(1) Reinforcement of volcano monitoring and observational research at volcanoes

Universities have carried out every year at two target volcanoes the Joint Experiment on Subsurface Structure of Volcanoes and Comprehensive Joint Volcano Observations, respectively, (Appendix 2) and universities and institutions have done the tentative and collaborative observations at volcanoes which indicated volcano crisis, those are, Iwate, Usu and Miyakejima volcanoes.

At Usu and Miyakejima volcanoes, precursory phenomena before eruptions were clearly detected by several kinds of observations, borehole seismometers and tiltmeters, GPS and so on. CCPVE and JMA succeeded in prediction of eruptions at the two volcanoes, and a quick evacuation of inhabitants were executed with no loss of life by local governments. However, it was difficult to predict how volcanoes behave after the onset of eruptions, when the volcano changed the style of activity like the Miyakejima which caused subsequently the collapse of the summit caldera and has continues active gas emission.

It was revealed at Iwate volcano that high-accuracy instruments, bore-hole seismometers, tiltmeters and strainmeters could detect clearly minor movements of intruded magma even at dormant volcanoes when they are waking up.

(2) Promotion of basic research for higher-grade prediction of volcanic eruptions

The Joint Experiment on Subsurface Structure of Volcanoes including seismic sounding has provided information on detail structure of volcanoes shallower than 3 km, and the determination of location of volcanic earthquakes was highly improved at Iwate, Bandai, Unzen and Kirishima volcanoes. It, however, is a future problem to detect the magma chamber and study the interior structure by seismic sounding.

At some volcanoes, ground deformation and geo-electromagnetic changes associated with volcanic earthquakes and tremors were observed and the mechanism of volcano-seismic events was discussed in relation to volcanic fluid.

At Fuji volcano, seismic activity of deep low-frequency earthquakes increased in fall of 2000, and the Subdivision on Geodesy and Geophysics, Council for Science and Technology reported a proposal on the reinforcement of monitoring and research at Mt. Fuji (2001). According to the proposal, a collaborative study among different institutions, including social science, was initiated in 2001 as 3-years plan. The aims are how to evaluate eruption potential at dormant volcanoes and how to inform of volcanic activity to publics. The research plan includes (1) the reinforcement of volcano monitoring, (2) research on volcanic structure and history of volcanic activity by geophysical methods, drilling of volcanic edifice and geological survey, and (3) analysis and design of volcanic information from viewpoint of social science .

(3) Strengthening of the scheme for the prediction of volcanic eruptions.

JMA established four regional centers for volcano monitoring and volcanic information in 2002 by reconstructing volcano sections at meteorological observatories and weather stations in order to improve the ability on monitoring and evaluation of volcanic activity. In case of volcano crises at Usu and Iwate volcanoes, communication among scientists, local governments and inhabitants has been frequently and effectively done through social education and making volcanic hazard maps before crises, and evacuation was quickly and smoothly executed at Usu volcano.

In summer of 2003, the recommendation of seventh 5-years (2004-2008) will be proposed from the Subdivision on Geodesy and Geophysics, Council for Science and Technology.

Appendix 1. Institutes and Observatories of National Universities Participating in the National Project for Prediction of Volcanic Eruptions

1) Research Center of Seismology and Volcanology, Hokkaido University (Usu Volcano Observatory)
2) Earthquake and Volcano Observatory, Hirosaki University
3) Research Center for Prediction of Earthquakes and Volcanic Eruptions, Tohoku University
4-1) Volcano Research Center, Earthquake Research Institute, University of Tokyo
4-2) Laboratory for Earthquake Chemistry, University of Tokyo
5) Volcanic Fluid Research Center, Tokyo Institute of Technology (Kusatsu-Shirane Volcano Observatory)
6) Research Center for Seismology and Volcanology, Nagoya University
7-1) Aso Volcanological Laboratory, Institute for Geothermal Science, Kyoto University
7-2) Sakurajima Volcano Research Center, Disaster Prevention Research Institute, Kyoto University
8) Institute of Seismology and Volcanology, Kyushu University (Shimabara Earthquake and Volcano Observatory)
9) Nansei-toko Observatory for Earthquakes and Volcanoes, Kagoshima University

Appendix 2. Target Volcanoes for the Joint Experiment on Subsurface Structure of Volcanoes and the Comprehensive Joint Volcano Observations in the Sixth 5-years Plan

Fiscal year	Joint Experiment		Comprehensive Joint Observation
1999	Izu-Oshima	Iwate	
2000	Iwate		Satsuma-Iwojima & Kuchinoerabujima
2001	Usu		Unzen
2002	Hokkaido-Komagatake	Fuji	
2003	Fuji		Kusatu-Shirane

(Kazuhiro Ishihara)

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**Subdivision on Geodesy and Geophysics, Council for Science and Technology (2002) Reviews on the Sixth 5-years plan for Prediction of Volcanic Eruptions, 79p.
(* in Japanese with English abstract ** in Japanese)

2. Joint Volcanological Experiment on Volcanic Structure and Magma Supply System

Since 1994, joint experiments have been conducted in several volcanoes in Japan to reveal the structure and the magma supply system by the scientist group of national universities under the National Research Project for Prediction of Volcanic Eruptions (Fig.26). The experiments were conducted in Izu-Oshima Volcano in 1999, Iwate Volcano in 2000, Usu Volcano in 2001 and Hokkaido-Komagatake Volcano in 2002. The experiments were carried out by seismological, electromagnetic and other geophysical methods. These experiments succeeded in detecting some anomalous regions related to magma activity. The results of the previous experiments are briefly presented as follows.

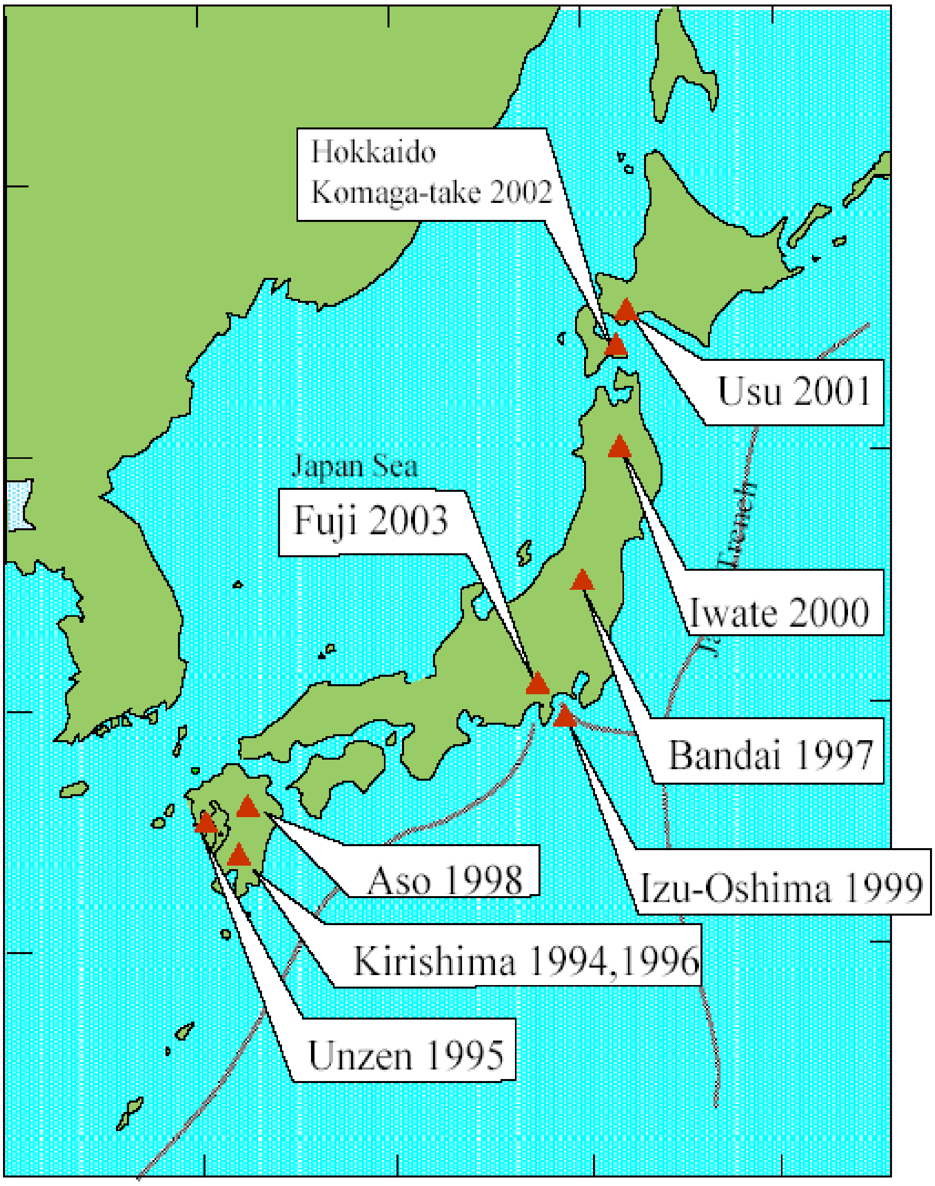

Fig. 26. Joint volcanological experiment on volcanic structure and magma supply system in Japan.

Experiments in Izu-Oshima Volcano in 1999

The 6th experiment was conducted in Izu-Oshima Volcano during 27 October - 5 November 1999. The purpose of the experiment is to clarify the subsurface structure of the volcano including the location of magma reservoir, and to understand the magma feeding system and its temporal change. Observations were made along a 30-km major line lying in the NNW-SSW direction and other sub-lines which across the major line at the center of Izu-Oshima. Survey lines and 2-dimensional arrays cover about 160 and 60 seimometers, respectively. Along these lines, 6 shots with a charge size of 200-250 kg were fired in the island, and 6 dinamite shots and air-gun shots and OBS observation were also included in the sea-area. All shots were successfully fired and significant data were obtained by most of the loggers.

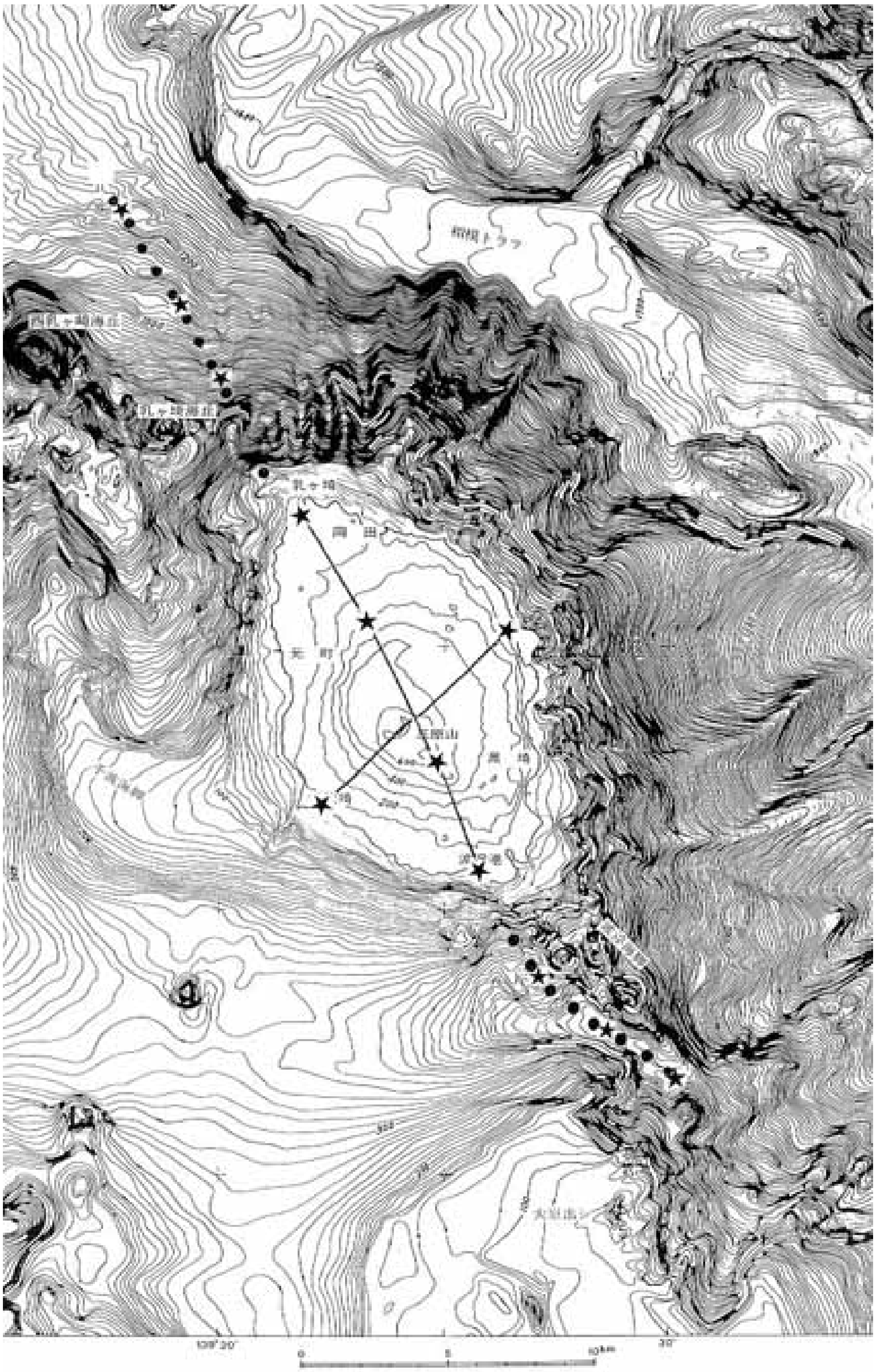

Fig. 27. Map of Izu-Oshima and the surrounding sea bottom.
Star: dynamite explosion
Dots in the sea=OBS sites

Experiment in Iwate Volcano in 2000

The 7th seismic survey of the volcanic structure was conducted around the Iwate volcano, northeastern Japan, in October 2000. The outline of the experiment and the arrival times of first motions were reported by Tanaka *et al*. (2002a). Here we show a brief summary of the survey and its scientific result. Seventy scientists participated in the active seismic survey from 11 national universities of Japan (Tohoku, Hokkaido, Hirosaki, Akita, Iwate, Tokyo, Tokyo Institute of Technology, Nagoya, Kyoto, Kyushu, and Kagoshima), the National Institute of Polar Research (NIPR) and the Japan Meteorological Agency (JMA). Fig. 28 shows a geographical configuration of the survey. Nine chemical explosions using dynamite charges of 200-250 kg excited seismic waves. The seismic signals were recorded at 330 temporary seismic stations deployed around the volcano within 20 km from the summit (study area 40 x 40 km2). Each station consisted of a vertical short-period seismometer with a natural frequency of 2 Hz and a small data logger. More than 3000 seismograms were acquired with sampling interval of 4 ms, and they showed good signal-to-noise ratios. Additional seismograms with sampling interval of 10 ms from 33 permanent stations established to monitor volcano-seismic activity by Tohoku University, JMA and the National Research Institute for Earth Science and Disaster Prevention (NIED) are also collected.

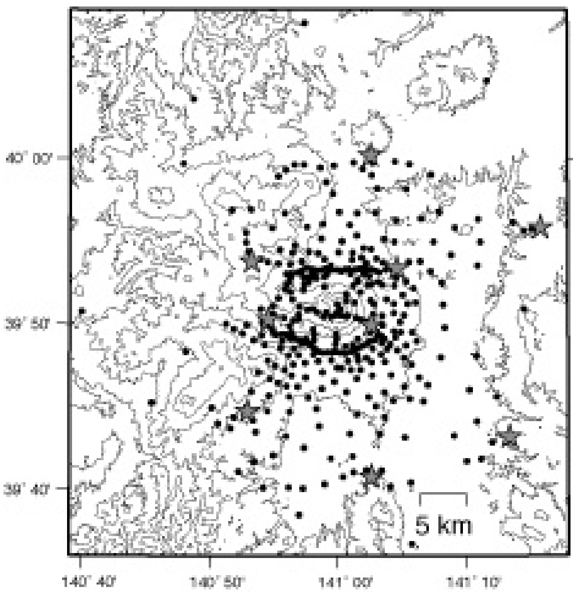

Fig. 28. Geographical configuration of the seismic survey at Iwate volcano in 2000. Starts are 9 shots. Dots are 330 temporary seismic stations deployed during the survey and 33 permanent stations by Tohoku University, NIED, and JMA.

The three-dimensional P-wave velocity structure of the volcano is determined to depths of 2 km through seismic tomography using the approximately 2700 travel-time data (Tanaka *et al*., 2002b). Fig. 29 shows the vertical cross-section of tomographic image of the volcano passing through the summit in the east-west direction. The most prominent discovery is an existing of column-like high-velocity body (V_P > 5.4 km/s) that extends vertically for 2 km beneath the caldera. While the western part of the volcano extending from the caldera is characterized by a moderate-velocity region (4.8 < V_P < 5.4 km/s), the summit and eastern flank of the volcano are covered with very low-velocity material (V_P < 4 km/s) that represent relatively younger volcanic edifices. The spatial difference in the velocity structures between the western and eastern parts of the volcano is explained by the evolutionary history of the volcano. And we find that the western structure may give constraints on the volcanic unrest in 1998.

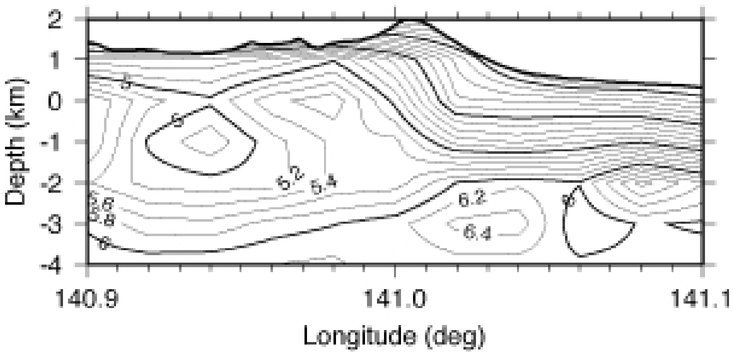

Fig. 29. Vertical cross-section of tomographic image of Iwate volcano passing through the summit in the east-west direction. Contour interval is 0.1 km/s.

Experiment in Usu Volcano in 2001

Mt. Usu erupted four times during 100 years, in 1910, 1943-1945, 1977-1982, and 2000. Noticeable characteristics common to these four eruptions are formation of a new mountain (lava dome or cryptdome) with remarkable ground deformation and violent earthquake swarm due to dacitic magma. These four eruptive activities, however, have different features. The 1977-1982 eruption occurred at the summit crater, whereas the 1910, 1943 and 2000 eruption took place at the northern foot, the eastern foot and the western foot of the volcano respectively. The duration of precursory earthquakes and eruptive activities are also different among them.

The 2000 eruption was accompanied by remarkable lateral migration of precursory earthquakes with drastically increases in number and intensity. A seismic tomography using precursory earthquakes and the following earthquakes suggests that these earthquakes mainly occurred within the layer with V_P = 6 km/s (Onizawa, *et al*., 2002a). This implies that magma intrusion and the resultant seismic activity are affected by the subsurface structure.

In order to investigate subsurface structure in more detail and discuss the magma intrusion processes, a seismic exploration using active sources was conducted on November 5, 2001. We deployed 290 seismic stations with vertical-component seismometer (a natural frequency of 2 Hz) and a compact data-logger with precise GPS clock in the volcano and its surrounding region. Dynamite charges of 200-250 kg were fired at 7 shot points around the volcano. The seismic signals were acquired with sampling interval of 4 ms (Onizawa *et al*., 2003).

A 3D tomographic inversion reveals the south dipping well-layered P wave velocity structure (Fig. 30). The structure is consistent with resistivity structure obtained by a magnetotelluric soundings (Matsushima *et al*., 2001) and geological structure. The high velocity region ($V_P >$ 6 km/s) is correlated with the Pre-Neogene system with high resistivity (1000-10000 ohm-m). The moderate velocity region (3 km/s $< V_P <$ 6 km/s) corresponds to the Neogene-Tertiary system with low resistivity (< 500 ohom-m). The obtained velocity structure also reveals the focal cluster extending from the source of long period tremors suggesting vibration of a magma chamber at about 5.5 km to the pressure source causing inflation of the volcano edifice at about 3.5 km deep. This focal cluster implies the path of magma intrusion within the Pre-Neogene system beneath Usu volcano, although there remain unsolved problems such as the magma ascent from the pressure source and the lateral migration of the hypocenters.

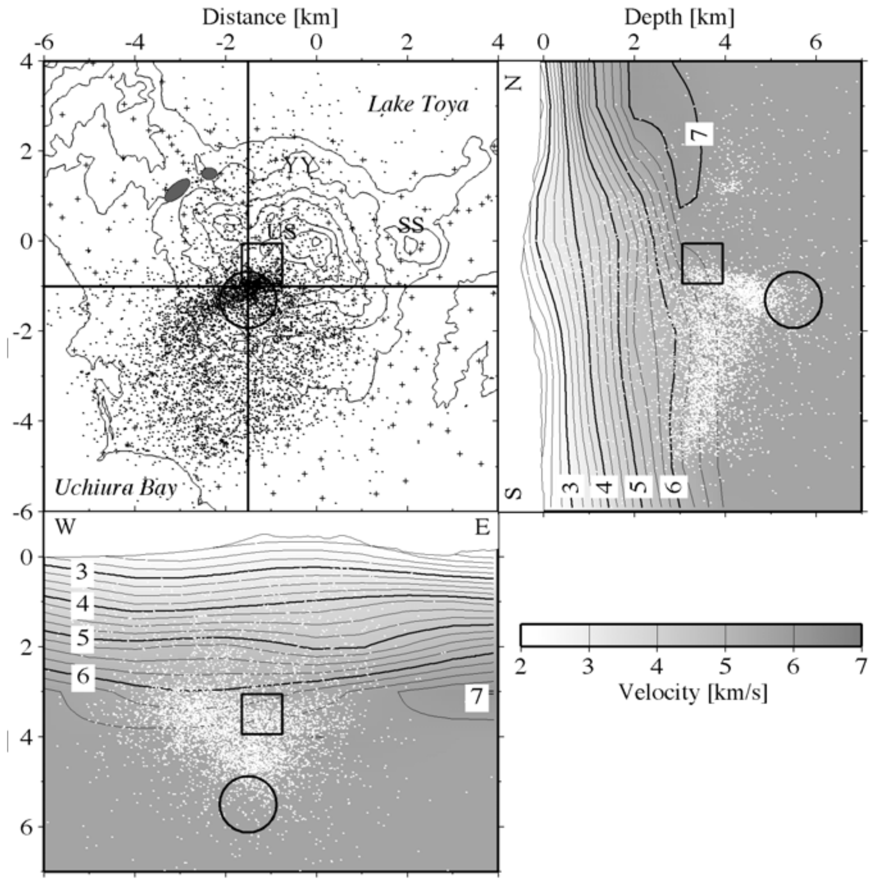

Fig. 30. N-S and E-W cross section of P wave velocity obtained by the 3D tomographic inversion and hypocenters of precursory earthquakes re-located with this velocity model (Onizawa *et al*., 2002b). The open circle and square denote the source of long period tremors (Yamamoto *et al*., 2002) and the pressure source of the vertical deformations (Mori *et al*., 2000) respectively. Shaded ellipses represent the west of Nishiyama (N) and Kompirayama (K) craterlets group. MS, SS, US show Meiji-shinzan cryptodome formed in 1910, Showa-shinzan lava dome in 1943-1945 and 77 new mountain in 1977-1982.

Experiment in Hokkaido-Komagatake Volcano in 2002

Mt. Komagatake (1133 m), one of the most active volcanoes in Japan, is located in southwest Hokkaido. It is a truncated stratvolcano crowned with a horseshoe-shaped crater at the summit. The edifice consists andesite lavas and pyroclastic rocks and is covered by pyroclastic falls, flows, surges and debris avalanche deposits.

From March 1996, after 54 years of dormancy since the 1943 phreatomagmatic eruption, Mt. Komagatake have repeated a small phreatic explosion on the summit, which is regarded as intermediate-term precursor of the coming major eruption because several minor eruption took place during 1919-1924 prior to the 1929 Plinian eruption.

In order to make monitoring of volcanic activities more accurate and to understand magma-plumbing system, a seismic exploration using active sources was conducted on 30 September 2002. A three-component seismometer (a natural frequency of 2 Hz) was installed at 129 stations to observe S phase or later phases, and 92 stations was equipped with a vertical-component (a natural frequency of 2 Hz) (Fig. 31)..

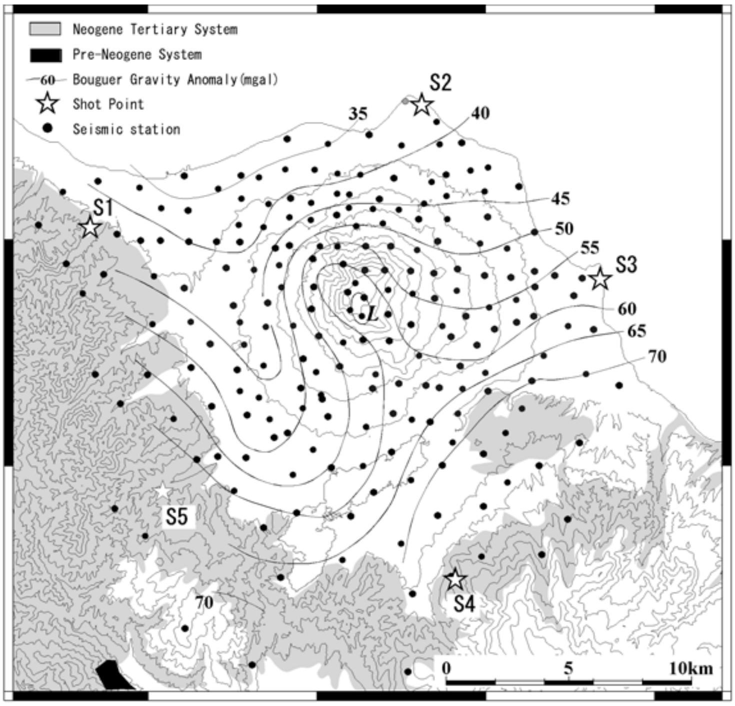

Fig. 31. Map showing topography of komagatake volcano, geological sketch, bougour anomaly, temporal seismic stations (solid circles) and shot points (open stars).

Seismic wave excited by the 300 kg charge explosion at five shot point, were recorded on compact data-logger with precise GPS clock at each station

The Preliminary time term analysis for first P arrival-times reveals that a ridge of the basement extends from the southeastern mountain region to the summit of Komagatake volcano. The NW-SW trending high velocity zone corresponding to the ridge is also imaged by a 3D tomographic inversion, and the low velocity region invading from Achier bay lies in the west of it (Fig. 32). Such P wave velocity distribution reflects the geological structure in Mt. Komagatake and the surrounding district. Thick Neogene-Tertiary system occurs in the low velocity region, and the high velocity zone corresponds with the uplift zone of Pre-Neogene system presumed from gravity anomaly and geology of thermal water wells.

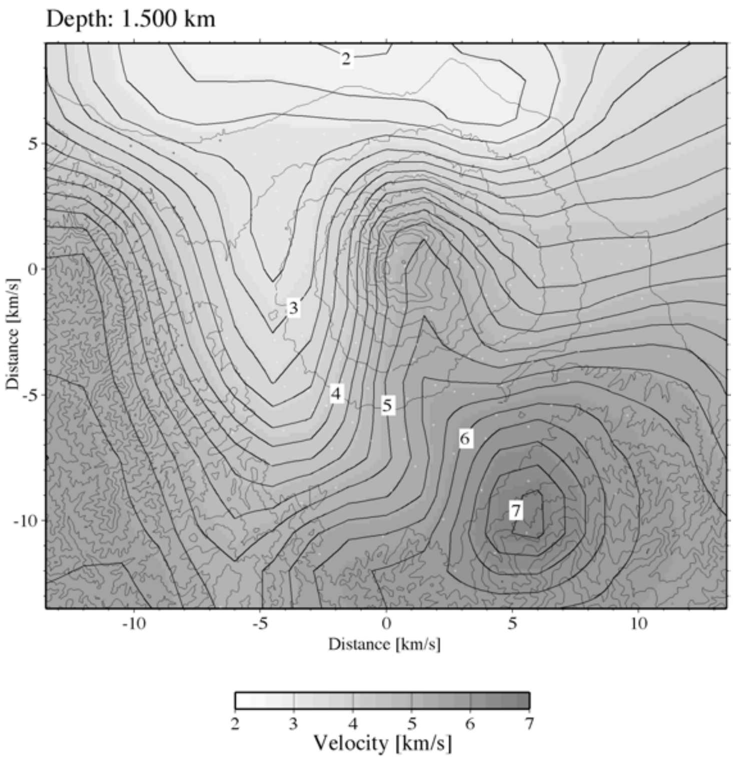

Fig. 32. Distribution of P wave velocity at the depth of 1.5 km b.s.l. obtained by the 3D tomographic inversion. The grid interval is 1 km in the vertical direction, and is 3 km in the horizontal direction.

(Tsuneomi Kagiyama, Satoru Tnaka and Hiromitsu Oshima)

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(* in Japanese with English abstract ** in Japanese)

3. Comprehensive Joint Volcano Observations

The comprehensive joint geophysical- and geochemical-observations have been carried out at active volcanoes in Japan, in order to reveal the volcanic activities and evaluate the eruption potential. In the sixth 5-years plan of the national project for prediction of volcanic eruptions, the joint observations were conducted at Iwate Volcano in 1999, Satsuma-Iwojima and Kuchierabujima Volcano in 2000, Unzen Volcano in 2001, Fuji Volcano in 2002, and the observation at Kusatsu-Shirane Volcano is planned in 2003. The participants were from national universities (e.g. Hokkaido University, Hirosaki University, Akita University, Iwate University, Tohoku University, University of Tokyo, Tokyo Institute of Technology, Shizuoka University, Nagoya University, Kyoto University, Tottori University, Kyushu University, Kagoshima University) and other institutes (e.g. National Research Institute for Earth Science and Disaster Prevention, Geographical Survey Institute, National Institute of Advanced Industrial Science and Technology, Japan Meteorological Agency, Geothermal Research Institute of Kanagawa Prefecture).

Observation at Iwate Volcano in 1999

The comprehensive joint volcano observation of 1999 was carried out at Iwate volcano, northeastern Japan, where significant activation in seismicity and ground deformation had been observed in 1998. The seismic activity and ground deformation observed in 1998 were interpreted to be caused by magma intrusion in a shallow part beneath the volcano. To evaluate the state of the volcano in 1999, observations were executed on seismic activity, ground deformation, gravity change, volcano-magnetic effect, self potential, geothermal activity and geochemistry of gases. Seismic experiments using controlled sources were also repeated to reveal temporal change in internal structure of the volcano. The results of the observations revealed that the geothermal activity was activated about one year later compared to the seismic activity and ground deformation. The seismic activity and ground deformation similar to those in 1998 but with smaller magnitude were observed at least till the middle of 1999. The repot on the observations is now in editing.

Observation at Satsuma-Iwojima Volcano in 2000

Continuous emission of gas has continued at the summit crater of Iwodake and its eruptive activity increased in 1996. Associated with the event in 1996, a volcanic earthquake (M2.9) occurred. Temporary seismic observation was conducted by installing 21 seismic stations at the summit and on the flank of Iwodake. A-type earthquakes are distributed around Iwodake and B-type events are concentrated beneath the summit crater. Focal mechanism of the A-type earthquakes is normal fault type and B-type earthquakes have an expansion source. Remarkable deflation around the summit crater was observed after 1996 due to emission of gas, and deflation of Kikai Caldera was also detected by GPS campaigns. Around the summit, positive SP anomaly caused by continuous gas emission is observed. Heat discharge rate was estimated and the rate decreased after the event in 1996. Emission rate of SO_2 is almost 500ton/day and temperature of fumarole attained more than 800 °C. SO_2 flux, maximum and equilibrium temperatures of volcanic gas from the summit crater also increased before the event and decreased after that.

Observation at Kuchierabujima Volcano in 2000

The volcano has repeated phreatic or phreato-magmatic eruption in and around the summit crater of Shindake. Last eruption occurred in 1980 and recently seismicity sometimes in creased in 1996 and 1999. Temporary seismic observation was conducted by using 4 short-period, 2 broadband seismometers and 2 accelerometers. HF events with normal fault-type are concentrated western part of the summit at very shallow depths of 100-500 m. Associated with increase in seismicity, inflation around the summit crater was detected by GPS. The source is located east of Shindake at a depth of 1 km. Change of geomagnetic total force was observed and it suggests demagnetization beneath the summit crater due to increase in temperature. Airborne survey of geomagnetic total force was conducted. Intensity of magnetization is weak at shallow depth of eastern part of the summit. This anomaly corresponds to the inflation source of the ground deformation. We also conducted VLF and ELF-MT surveys, airborne geothermal survey, temperature measurements and geochemical analysis volcanic gas from fumarole and hot spring, chemical analysis of underground water, paleomagnetic study on lava flows from Shindake and Furudake, and radio carbon age measurement of tephra.

The results of the joint observations in 2000 are summarized in “Reports of Geophysical and Geochemical Joint Observations at Satsuma-Iwojima and Kuchierabujima (2002), Sakurajima Volcano Research Center, Disaster Prevention Research Institute of Kyoto University, 184p.” and the reports can be downloaded from the following site; http://www.dpri.kyoto-u.ac.jp/~kazan/iwo-kuc.html

Observation at Unzen Volcano in 2001

The 2001 joint observation was the first comprehensive observation at Unzen Volcano after the 1990-1995 eruption. In the observation, we investigated seismic activity, ground deformation, gravity change, geomagnetic total force, resistivity structure, and temperature and geochemistry of volcanic gases. The low seismicity, deflation and recovery of magnetization intensity at shallow depth of the summit indicate that no magma newly intrudes at the shallow conduit and/or volcanic edifice after the last eruption. However we detected re-inflation of the pressure sources which had been deflating associated with lava effusion during the eruption. This suggests that the supply of magma to the deep reservoirs has started again.

During the 2001 observation at Unzen Volcano, a seismic reflection experiment was conducted using vibratory energy sources in order to detect the volcanic conduit as a program of the Unzen Scientific Drilling Project. The survey line is crossing over the Unzen graben and the magma ascent path inferred from geophysical observations. The experiment revealed the depression structure of the Unzen graben, and detected the strong reflection corresponding to one of the pressure sources inferred from the geodetic measurement. Moreover the narrow area, in which the strength of reflection is extremely weak, extends almost vertically from the sea level down to the pressure source. Volcanic earthquakes occur along the narrow area. Thus the area is interpreted as the volcanic conduit or dike intrusion in the volcanic edifice.

Observation at Fuji Volcano in 2002

In the joint observation at Fuji volcano in 2002, a dense seismic observation was started by installing 30 seismometers around the volcano in addition to the permanent stations operated by several institutions, in order to clarify the mechanism of low-frequency earthquakes originating deep beneath the volcano and to make 3D seismic imaging of the subsurface structure. Scientists of national universities also conducted an advanced hybrid gravity survey around the volcano by integrating absolute and relative gravity measurements, self-potential and MT surveys across the volcano, and CO_2 flux measurements at the summit.

(Hiroshi Shimizu, Sadato Ueki, Masato Iguchi and Hidefumi Watanabe)

VII. International Activities

1. Collaboration Study on Volcanic Activity between Indonesia and Japan

Geophysics

In 1993, the Disaster Prevention Research Institute (DPRI), Kyoto University and the Directorate General Geology and Mineral Resources, Ministry of Mines and Energy, Indonesia reached an arrangement for the joint research program in the field of volcanic activity to migrate volcanic hazards in Indonesia and in relation to IDNDR. Kyoto University has made survey and observations at Indonesian volcanoes in cooperation with Volcanological Survey of Indonesia (reorganized to Directorate of Volcanology and Geological Hazard Mitigation in 2002). In 1998, the arrangement of cooperation was extended until 2003 and the arrangement will be extended 5 years more until 2008.

1) Guntur Volcano

Guntur volcano repeated eruptions with lava flows, ejection of volcanic bomb and pyroclastic flows until the middle of 19th century. After the last eruption in 1843, no eruption has occurred, however, several tens volcanic earthquakes had been observed per month. Kyoto University and DVGHM have continued seismic observation. In May 1997, seismic activity at Guntur Volcano suddenly increased and the seismicity was concentrated beneath the summit, especially at depths of 2-4 km, and the hypocenters were aligned from NW to SE, that is, direction of alignment of craters and domes in the summit area (Suantika and Iguchi, 2000). When the volcanic earthquakes successively occurred, reverse fault type earthquakes were dominant. Upward tilt toward the summit crater was observed by a tiltmeter installed 2 km south of the summit crater associated with the seismicity increase from May 1997. The tilt change suggests inflation of the ground around the summit crater. The inflation around the summit crater was detected by precise leveling along bench marks on the southeastern and south flanks of the volcano (Hendrasto *et al*., 2000). Referred to benchmark at southeastern flank, the benchmark closed to the summit was elevated 5 mm during the period from August 1996 to November 1997. The vertical deformation was inverted to deflation in 1998 when seismicity declined. On May 6, 1999, two felt earthquakes (M = 2.7 and 2.8) occurred at Guntur volcano and 60 after-shocks were observed. The hypocenters were concentrated beneath Gandapura caldera NW of the summit crater area at depths of 4 km. Focal mechanism of the earthquakes is reverse fault type. Associated with increase in the seismicity, inflation around the summit area was detected by precise leveling again. The benchmark closed to the summit was elevated by 5mm during the period from August 1998 to May 1999. Similar relations between increase in seismicity and uplift of the ground around the summit crater were also found in August 2000 (Hendrasto *et al*., 2000) and December 2002 (Fig. 33).

2) Merapi Volcano

Merapi volcano has repeated growth of lava domes and their collapse generating pyroclastic flow. During the period from 1990-1991, volcano tectonic earthquakes originated beneath the summit. After the seismicity, lava dome growth and collapse were repeated in time interval of a year. Inflations associated with the dome growth were observed by tiltmeters around the summit prior to generation of pyroclastic flows (Voight *et al.*, 2000). Pyroclastic flows in July 1998 entered in rivers the southwestern flank. Koike *et al* (2002) estimated the area and the volume of the pyroclastic deposites to be 10 km^2 and 9 x 10^6 m^3, respectively, by using SAR data. Merapi volcano became dormant for two years after the pyroclastic flow. In August 2000, the seismicity of volcano tectonic earthquakes resumed beneath the summit and continued to January 2001 when frequent rock-fall started from the lava dome. During the activity, pyroclastic flow on February 10, 2001

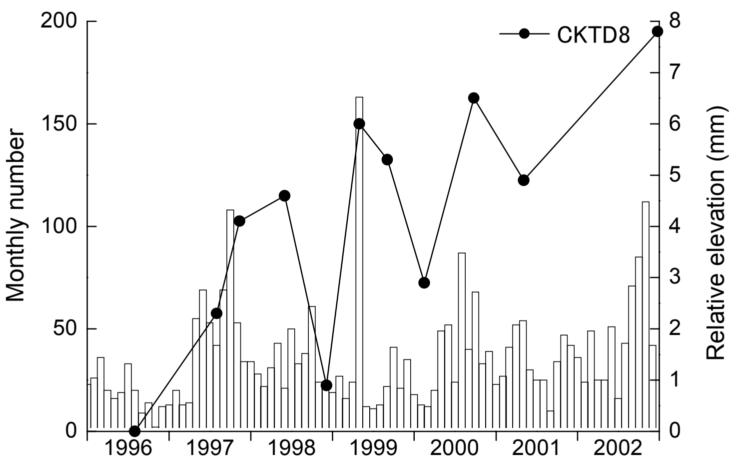

Fig. 33. Relation of relative elevation and monthly number of volcanic earthquakes at Guntur volcano, West Java, Indonesia. The benchmark CKTD8 is located on the southeastern flank of the volcano.

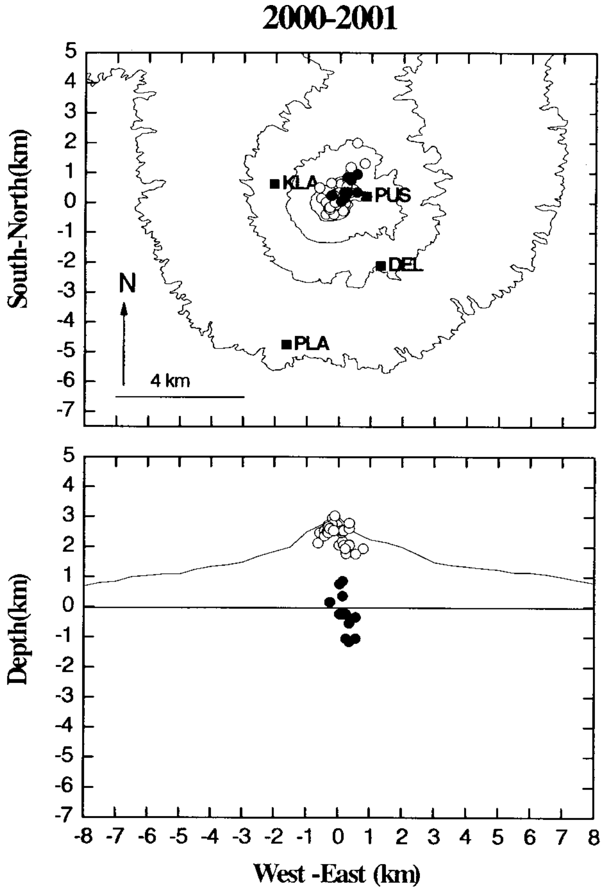

Fig. 34. Hypocentral distribution of volcano tectonic earthquakes at Merapi volcano. Closed and open circles denote VTA and VTB type events. Aseismic zone is recognized between the types of the events. Top: epicenter. Bottom: vertical cross-section in EW direction.

is the biggest, and the front of the pyroclastic flow reached 7 km from the summit. Hidayati (2003) determined the hypocenters and focal mechanisms of the volcano tectonic earthquakes. Deep volcano tectonic earthquakes are located at depth 2-4 km beneath the summit, and the mechanism is normal fault type. Shallow volcano tectonic earthquakes have shallower hypocenter of less than 1 km and reverse-type mechanism (Fig. 34).

3) Other Volcanoes

Anak Krakatau volcano in Sunda Straight resumed Strombolian activity in February 1999. Kristianto *et al.* (2000) observed air-shocks caused by the eruptions and compared the characteristics with Suwanosejima volcano. Iguchi *et al.* (2001) applied tensile shear crack model to monochromatic events at Papandayan volcano where mud eruptions have repeated and magmatic eruption occurred in November 2002. Monochromatic events may be related with shallow hydrothermal system of the volcano.

Geology

Kagoshima University started to collaborate with DVGHM on chronology of Tangkubanparahu volcano, West Java. The volcano is situated north of Bandung. The chronology of 100 ka has been made clear (Kartadinata *et al.*, 2002) and started study on eruption in Sunda Caldera Period. They studied on chronology and formation mechanism of Batur caldera, Bali, Indonesia. Batur caldera has double rim and central stratovolcano and many maars are distributed inside the caldera. The chronology of the caldera was made clear from radiocarbon dating of burned woods in several layers (Sutawidjaja *et al.*, 2003).

"Research Cooperation Project on the Exploration of Small-scale Geothermal Resources in the Eastern Part of Indonesia" was jointly conducted by Volcanological Survey of Indonesia, and Geological Survey of Japan, and NEDO during 1997- 2002. Mataloko area, Flores island was selected as a project site. Based on geological mapping, and geophysical explorations, two holes were drilled. Steam production test confirmed the geothermal reservoir under the site.

In order to evaluate the time-space relationship of large volume eruptions in comparison with Japanese calderas, the cooperation project on geological study for caldera forming eruption in Indonesia has started between Volcanology and Geological Hazard Mitigation and Geological Survey of Japan in 2002. The geology of Rinjani volcano, Lombok island was studied in 2002.

(Masato Iguchi)

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2. Cooperative Observations at Nyiragongo Volcano in D.R. of Congo

Volcano Nyiragongo belongs to the Virunga volcanic group and is located in the central part of the western rift of the East African Rift System, just to the north of Lake Kevin in the Rep. Dem. Congo. Among the 8 volcanoes in the Virunga, Nyiragongo and its neighboring volcano Nyamuragira have bee presently active condition. Nyiragongo had a long-lived lava lake in the summit crater since 1928. After the eruption in 1977, the lava lake in the summit was not seen for about 5.5 years. However the lava lake re-appeared at the bottom of crater on 21 June 1982 and, thereafter, the surface of lake has ascent intermittently with the small eruptions in the crater. During the period from June 1994 to September 1996, the surface in the crater was elevated about 120 m and the supplied magma volume was about 1.3×10^8 m^3.

The 13 days prior to the Nyiragongo eruption on January 2002, the moderate felt shocks and also felt volcanic tremors were observed by local habitant at Rusayo village, where is located about 5 km south of the volcano. The Nyiragongo eruption was always preceded by the occurrence of tremors with large amplitudes. On January 10th, one week before the eruption, the forecast that new volcanic eruption is acute and that lava flows might direct their course toward Goma or Sake was issued to the local habitant and the foreign people in the Goma area by the Goma volcano observatory (GVO), the Centre de Rechereche en Sciences Naturelles (CRSN). This is the first successful prediction of volcanic eruption at Nyiragongo volcano based on the monitoring of seismo-volcanic activities, temperature measurements at fumaroles along the old fissure near the Shaheru cone and the surface observation of lava lake in the crater.

Fig. 35. The fissure on the mountainside at the elevation of about 2835 m with two fumaroles activity, the Shaheru crater buried by the new lava, and lava flows at foothill. (Photo taken by M. Kasereka, Nov. 11, 2002)

Fig. 36. Small spatter corn near the end of fissure, from which huge amount fluid lava was poured out and directed its course toward the Goma city. (Photo taken by H. Hamaguchi, Feb. 6, 2002)

The eruption started at 8:35 local time on January 17 along the fissure on the mountainside at the elevation of about 2835 m (Fig. 35). According to eyewitnesses of local habitants who are living at about 4 km NW outskirts of Goma, a rising of black plume was observed at about 10 o'clock near the foot of Shaheru cone and black rain and scoria came down after about 30 min latter. The present eruption was

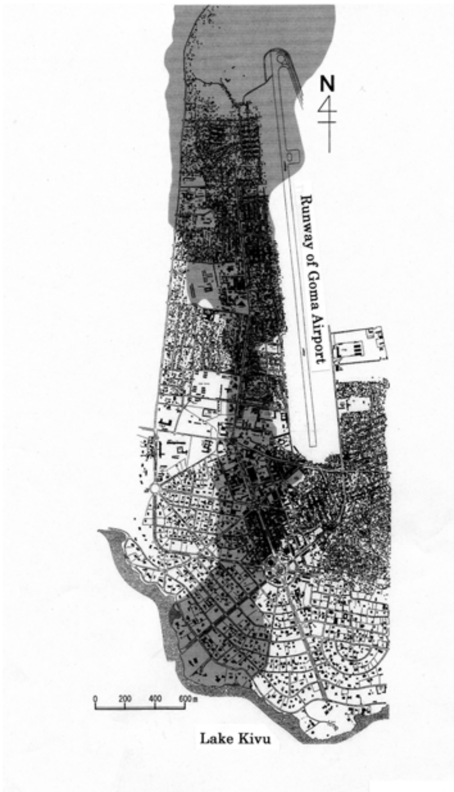

Fig. 37. The lava flow (shaded area) passed through the downtown of Goma. The original map is on the scale of one to two thousand prepared in 1998.

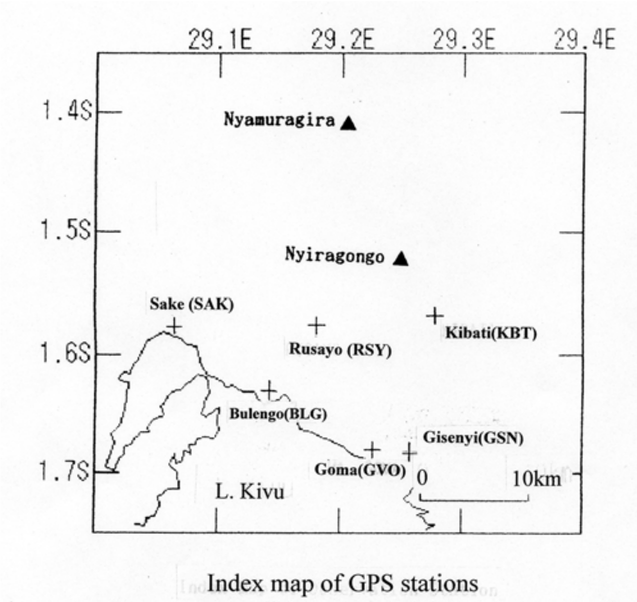

Fig. 38. Index map of GPS stations (cross) around the Nyiragongo volcano. Solid triangle is active volcano.

characterized by exceptionally long fissures (ca 13 km) that stated at the side of Nyiragongo mountainside (elevation 2835m) and ended at the outskirts of Goma (elevation 1600 m). A huge amount of lava was poured out from the three spatter cones (Fig. 36) at the southern end of fissure, which is close to the Goma International airport and inundated the suburbs and the central part of Goma city. The extremely fluid lava flows and strong emission of CO2 gas caused many fatalities. The more than 4500 houses and buildings in the city of Goma were collapsed and/or buried by lava flow, of which thickness in the downtown was over 2 m (see Fig. 37).

Immediately after the eruption stopped, large number of felt earthquakes was observed around Goma and Gisenyi area. This swarm activity continued for about three months and caused a collapse of local houses in and around Gisenyi. In order to continues monitor the crustal deformations due to fissuring, volcanic activity and/or rift movements, we constructed the GPS network at the southern part of Nyiragongo volcano. The network consisted of 6 fixed stations and one mobile station at the top of Nyiragongo (Fig. 38). The GPS monitoring sensor is a type MG-2110 (Furuno Electric Co.) with low power consumption and single frequency detection. A sampling time interval is

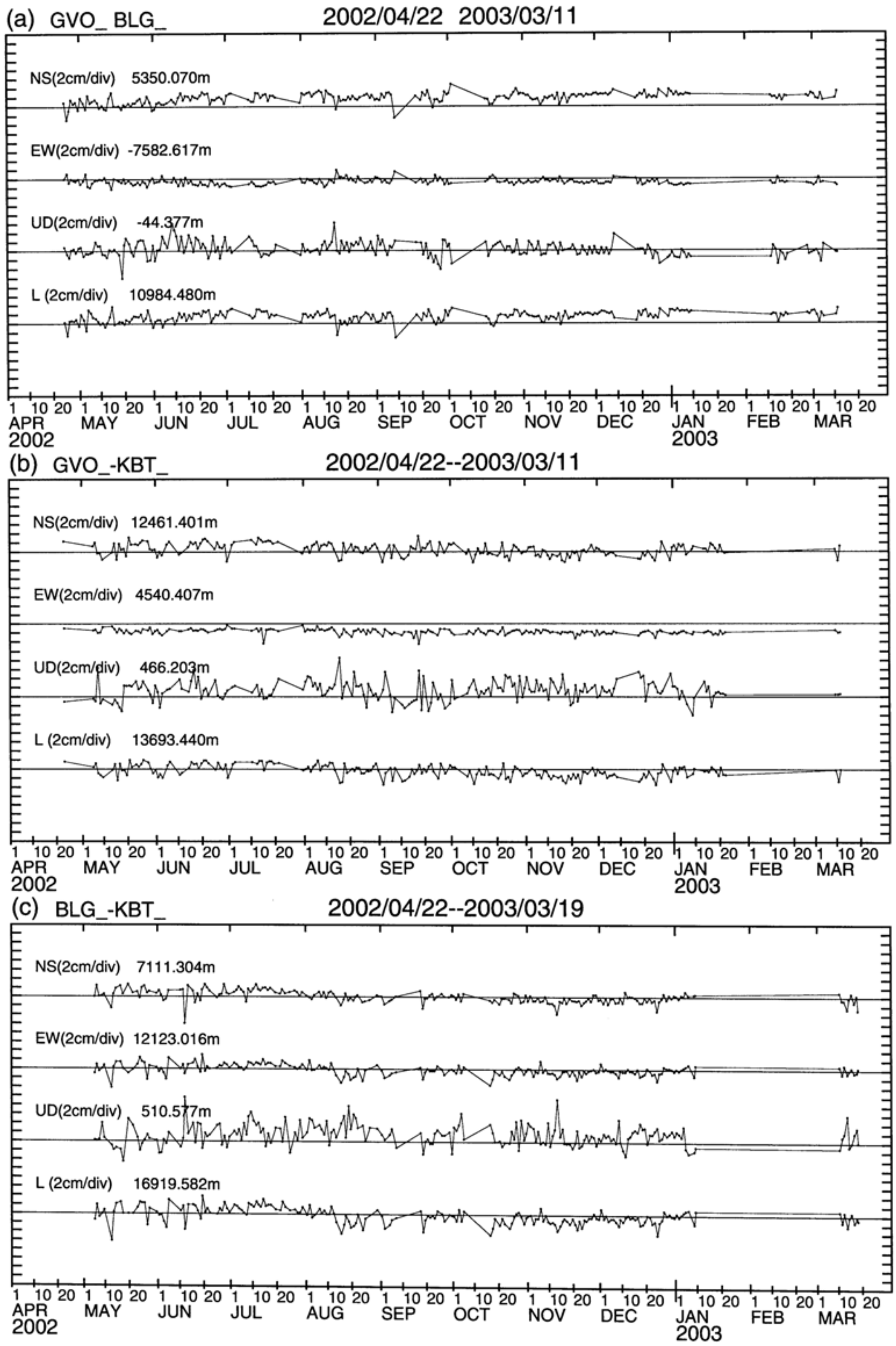

Fig. 39. Temporal changes of the horizontal (NS, EW) and oblique distances and height differences at three baselines; (a) GVO-BLG, (b) GVO-KBT and (c) BLG-KBT. The unit in the vertical axis is 2 cm/div.

fixed to be 30 sec. The cooperative observation between CRSN and Tohoku University was started at April 22, 2002. The data analyses reveal that the horizontal and vertical variations along all baselines for about one year from April 2002 to March 2003 were within the accuracy of the sensor (Fig. 39), suggesting that, even though new lava lake activity already re-appeared in the crater, there have been neither significant magma supply or drain-back nor a magma intrusion into the volcanic region.

(Hamaguchi Hiroyuki)

3. Japan-US Joint Study on Hawaiian Hot Spot Volcanoes 1998-2002

Purpose of the Joint Study

Hawaii is the most active hot spot on Earth and is the classical locality of modern volcanology. Although numerous research papers have been written on Hawaiian volcanoes and their current activities those exposed on land, very little is known on their submarine roots. In 1998, a collaborative Japan-USA program was initiated to explore the evolution of Hawaiian volcanoes including their growth and degradation, making use of the deep-sea research capabilities of the Japan Marine Science and Technology Center (JAMSTEC). During a four week cruise in 1998, the ROV *Kaiko* (Remotely Operated Vehicle), supported by its mother ship RV *Kairei*, made 10 dives at depths to 5,200 m for direct sampling and video observations, supplemented by dredging, piston cores, and SeaBeam bathymetric surveys. During a seven week cruise in August-September 1999, the *Shinkai 6500* submersible made 29 dives from the RV *Yokosuka* for sampling and direct observations as deep as 5,560 m, and further SeaBeam surveys were obtained. A third cruise in 2001, the initial part of the current project, utilized the *Kairei* and *Kaiko* to make 17 ROV dives and collected about 300 outcrop samples, obtain 10 new piston cores, made several dredge hauls, and generated additional SeaBeam coverage. Finally fourth cruise of this series has been carried out in summer of 2002 again with the *Shinkai 6500* submersible and the RV *Yokosuka.* In total, 30 submersible dives were carried out in 2002 on to the newly discovered volcanic field SW of Oahu, submarine rifts of Haleakala and Kilauea, and submarine landslides from Mauna Loa, Kohala and Hualalai. Altogether 20 scientists from Japanese side, consisting of JAMSTEC, Geological Survey of Japan and 7 universities (Titech., Tokyo Univ., Hokkaido Univ., Shizuoka Univ., Osaka Univ., Shimane Univ., and Kumamoto Univ.) collaborated with 15 US scientists from US Geological Survey, University of Hawaii, Rice Univ., Bishop Museum and the Monterey Bay Aquarium Research Institute. Part of research results of this project have been published as collective papers in the AGU Geophysical Monograph vol. 128, *Hawaiian Volcanoes: Deep underwater perspectives*, in Feb. 2002.

Our knowledge of the submarine region around Hawaiian volcanoes has changed dramatically in the last few years as a result of these JAMSTEC expeditions to Hawaiian waters. These expeditions have generated improved images of sea-floor bathymetry (Naka *et al*., 2000; Smith *et al*, 2002), utilized ROV and submersible vehicles to collect a large suite of precisely located samples for petrologic study, and acquired detailed photo and video images for many critical areas. Such materials, supplemented by petrologic, geochronological, and other laboratory studies, provide the basis for investigating a wide variety of geophysical phenomena. These include the sources for and extent of plume magmatism, processes associated with active and ancient landslides on oceanic island volcanoes, seismic structure and tectonic processes on active volcanoes, nature of rift zone and other submarine volcanism, growth of oceanic island volcanoes, and hydrothermal processes. In concert with the field and laboratory studies, recent theoretical investigations have explored the causes and consequences of Hawaiian plume magmatism and the landslides associated with these unstable volcanoes.

One major objective of this JAMSTEC cooperative program is to explore the evolution of oceanic islands including their growth and degradation. Giant landslides are now widely recognized along the flanks of many oceanic volcanoes, such as Hawaii, Marquesas, La Reunion, Galapagos, and Canary Islands. The landslides form during the growth of the volcano as it is centered over the hot spot and after it drifts off. The abundance of landslides demonstrates that mass-wasting processes play an important role in the construction and evolution of oceanic-island volcanoes. Not only do such processes modify the surfaces and slopes of the islands, they also are closely linked with major geologic hazards, including earthquakes associated with slope failure, large-scale submergence or emergence of coastlines, and massive tsunamis, which can destroy life and property. Due to the unpredictable and sporadic nature of such massive landslides, the processes and timing associated with these events remain poorly understood. Yet the significance of landslide features in the evolution of volcanic islands, and their extraordinary destructive potential, make it imperative that we understand their history and behavior, and assess their impact on human development of volcanic islands and adjacent coastal areas.

Another major goal of the JAMSTEC program is to reconstruct the growth history of Hawaiian volcanoes through study on deep exposure of the volcanic edifices. The landslide blocks themselves are collapsed and dismembered interiors of the volcanoes, which is inaccessible by ordinal means. As discussed below, our study shed lights on early alkalic stage of Kilauea volcano through intensive survey on deep submarine Hilina slumps on the south flank of Kilauea volcano. We also found the multiple growth history of 3 Ma old Koolau volcano on Oahu through reconstruction of the giant Nuuanu landslide. Our result showed that this volcano has experienced at least three magma types, Kilauea-type, Mauna Loa-type and Koolau-type in its growth history. In this way, our joint research program demonstrated the importance of submarine geologic study to understand the long term evolutional history of ocean island volcanoes. Such study gives comparable but quantitatively different information in its special coverage to those obtained by deep drilling of a volcanic edifice (e.g., Hawaiian Scientific Drilling Project).

Early Growth Stage of Kilauea Volcano

In contrast to the dominantly constructional volcanic morphology along the crest of the Puna Ridge, the offshore south flank has more diverse morphologic, structural, and petrologic features. Visual observations during the 1998-99 JAMSTEC cruises, combined with sample characterization, indicate that the 3 km-deep mid-slope bench and lower scarp consist entirely of well-bedded volcaniclastic rocks: massive sandstone, debris-flow breccia, siltstone, and mudstone (Lipman *et al*., 2002). High-S compositions of many alkalic basalt clasts and some sandstone glasses indicate derivation from a submarine "Loihi" stage of ancestral Kilauea, prior to growth of its tholeiitic shield. In contrast, all observed outcrops above and east of the mid-slope bench, are massive pillow lava and broken pillows of transitional basalt, which define the initial submarine flank of subalkaline Kilauea. These features indicate that ancestral Kilauea was a sizeable submarine alkalic volcano, where recurrent slope failures generated a flanking apron of clastic debris that was subsequently overgrown by the modern tholeiitic Kilauea shield.

Compositions of submarine-erupted glass from the lower scarp (Sisson *et al*., 2002), which encompass a range far greater in silica, alkalis, and other elements than that known for Loihi Seamount, record magma-generation processes during early stages of volcanic growth, prior to tholeiitic shield-stage Kilauea. The general compositional sequence on the south flank of Kilauea and on other Hawaiian volcanoes is compatible with genetic models of increasing degrees of partial melting in the mantle source, but the diverse compositions preserved in the volcaniclastic sediments of the south flank cannot have been derived entirely from a homogeneous source. The volcaniclastic apron on the south flank of Kilauea thus provides a broad petrologic sampling of an early stage in Hawaiian hotspot volcanism, much like that sought for Mauna Kea volcano by the in-progress Hawaii Scientific Drilling Project. Recently acquired underwater and drill-hole samples have also documented greater compositional diversity than previously known for other Hawaiian volcanoes, such as Mauna Loa and Koolau. Compositional differences among tholeiitic basalts, previous considered characteristic of individual Hawaiian volcanoes (e.g., Kilauea, Mauna Loa, Koolau), now appear more likely to represent a general evolutionary sequence sampled to different extents during growth of Hawaiian shields.

The offshore observations, in conjunction with previously reported subaerial geologic information, provide new perspectives on the growth of Kilauea and other ocean-island volcanoes. Many previous studies have interpreted on-land features of Kilauea's south flank and adjacent offshore region as products of large-scale block-slumping and volcano spreading since growth of the tholeiitic shield. The new data obtained by submersible operations suggest a more complex compositional evolution and prolonged history of slope failures. Meanwhile, the success of JAMSTEC cruises in obtaining representative materials from the early alkalic growth stage of Kilauea volcano suggest that similar sampling strategies may be applicable to other ocean-island volcanoes, especially where flanks are disrupted by slumping and landsliding associated with volcano spreading.

Giant Landslides NE of Oahu Island

The presence of giant landslides on the flanks of numerous ocean island volcanoes including Hawaii, Reunion, and the Canary islands is well documented. The catastrophic failure associated with some of these giant landslides appears to be a common feature of ocean island volcanoes. Ocean island collapses are now recognized as important global erosional agent. The rapid growth (~1 to 1.5 million years) and enormous size of Hawaiian volcanoes (individually, up to 8.5 km of relief and 100,000 km^3 volume) causes them to be particularly unstable. The collapse of Hawaiian volcanoes has generated some of the largest landslides on Earth and colossal tsunami waves. Dozens of major landslides, some with volumes >1000 km^3 and large blocks >1 km in height, have been recognized along the Hawaiian Ridge. On average, a major landslide has been identified every 32 km along the ridge. Based on an average ~10 cm/year northwest motion of Hawaiian volcanoes, a giant landslide occurs about every 320 thousand years, and smaller slides must have occurred much more frequently. The wealth of information on Hawaiian landslides has led to Hawaii becoming the type example for ocean island landslides.

A major obstacle in gaining a better understanding of when, why and how giant landslides form in Hawaii has been the limited detailed bathymetric and side-scan sonar imagery coverage for Hawaii. This dramatically changed following the detailed surveying northeast of the island of Oahu during JAMSTEC cruises to Hawaii in the summers of 1998 and 1999. This new bathymetric data allow for comprehensive reconstructions of the Nuuanu and Wailau landslides. Moore and Clague (2002) conclude that the volume inequities between the size of the "holes" left by these slides and the volume of the blocks indicate that there was long-term bulging on the slopes of Koolau volcano before the landslide. Yokose (2002) enhances our understanding of the products and processes for both these landslides by combining the new bathymetric data with detailed submersible observations of landslide debris outcrops.

How big were the tsunamis associated with the Nuuanu and Wailau landslides? Satake *et al*. (2002) answered this question by determining the volume change associated which each landslide. Tsunami generation and propagation for these slides were computed using a kinematic landslide model. They calculate that mammoth waves were formed from these slides. For the Nuuanu slide, some waves would have been >100 m high and would have struck the Hawaiian islands within minutes. The tsunami from this slide was directed towards California. Waves up to 70 m high would have reached the shores of southern California in about 5 hours.

Another major obstacle to our understanding of giant Hawaiian landslides was the lack of sampling of the landslide debris. This was due in part to the landslide debris being in water depths of 3-5 km below sea level, which is outside the range of most submersibles. The JAMSTEC deep submergence vehicles are ideal for exploring the landslide debris because they can explore the full depth range of the debris.

The papers by Shinozaki *et al*. (2002) and Tanaka *et al*. (2002) examine petrology and geochemistry of rocks recovered from the landslide debris. Using the geologic reconstruction of the landslide debris, these authors demonstrated that 3 Ma Koolau volcano had experienced multiple growth history. The main shield building stage of the volcano consists of olivine tholeiite lavas similar to modern Kilauea and Mauna Loa, successively. At the final growth stage of this volcano, the magma change abruptly to very silica-enriched tholeiite composition with distinct isotope signature.

Takahashi and Nakajima (2002) simulated melting processes in the Hawaiian plume consisting of peridotite and entrained oceanic crust (eclogite), they conducted series of high-pressure melting experiments. They showed that high-silica tholeiite characteristic of the subaerial Koolau volcano could be produced by direct partial melting of recycled eclogite at temperatures slightly below the peridotite dry solidus. On the other hand, Garcia (2002) studied submarine picrite lavas taken from northern flank of Koolau volcano, and he showed that primary magma of this volcano had picritic composition similar to those in modern Kilauea and Mauna loa. Distinct anomalies in rare-gases (e.g., $^{3}He/^{4}He$ in lavas from Loihi Seamount is up to 35 times that in the atmosphere) are a key signature of mantle-plume magmas that originated from a deep undegassed reservoir in the mantle. Kaneoka *et al*. (2002) reported new analyses of rare gas isotopes (He, Ne, Ar, Xe, and Kr) for deep-ocean samples from Loihi, Kilauea, and Koolau volcanoes. The new data and their previous studies document large variations in He isotopes among volcanoes in the Hawaiian hot spot. The highly variable He values are interpreted to represent different degrees of interaction between the rising plume magma and the uppermost asthenosphere.

(E. Takahashi, P.W. Lipman, M.O. Garcia and J. Naka)

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4. Unzen Scientific Drilling Project

Unzen volcano is one of the active volcanoes in Japan, located in Southwest Japan behind the volcanic front of the Ryukyu Arc. 1990-95 eruption caused the $ 2 billion damage and took 44 lives. A large-scale collapse of an old lava dome, Mayuyama, during the 1972 eruption results in death of 15,000 peoples around the volcano. The volcano has become the focus of international volcanological attention through its designation as a Decade Volcano by IDNDR (International Decade of Nature Disaster Prevention). In May 1997, an international workshop was held in Shimabara to discuss not only what volcanologists learned from Unzen eruption, but also the feasibility and importance of drilling into the edifice of Unzen, particularly to the conduit of 1990-95 magma (Nakada *et al*., 1997). Following discussions at the workshop, a project was submitted to the Japanese Government to initiate a project using the scientific drilling as a main research tool to understand the growth history, subsurface structure and magma ascending mechanism of the Unzen Volcano. The research team also submitted a proposal to the International Continental Scientific Drilling Project (ICDP) to obtain a partial financial support.

Unzen Scientific Drilling Project (USDP) started in April 1999 as an international scientific research. The project includes not only scientific drillings but also related geological, geophysical and geochemical studies to totally understand Unzen volcano. USDP is a six-year term project and is divided into two phases. Phase I consists of drilling of three boreholes on the northeastern and eastern flanks and at the northern slope of Unzen Volcano, and conducting associated researches mainly to reveal the three-dimensional structure and the growth history of the volcano. Phase II is drilling into the conduit of the 1990-95 magmas to clarify the ascending and degassing mechanism of magmas and to evaluate geophysical and geological models made for the 1990-95 eruptions. Phase I is fully sponsored by the Ministry of Education, Sports, Culture, Science and Technology (MEXT), Japan,whereas the Phase II is a joint venture between MEXT project and ICDP. More than 25 research institutes from Japan, USA, Germany, UK and Taiwan are participating this project.

In Phase I, two vertical drillings (USDP-1: 752 m and USDP-2: 1462 m) were conducted at the northeastern and eastern flanks of Unzen volcano (Fig. 41). These drillings were aimed to reveal the growth history of Unzen volcano and related tectonic background. A third drilling (USDP-3) was conducted at the northern slope as a pilot hole for the conduit drilling in Phase II. USDP-3 is a 45-degree slant hole of 350 m. USDP-1 is located at the northern edge of the Unzen graben, where the base of the Unzen volcano is assumed to have subsided about 600 m beneath the surface. USDP-2, on the other hand, is situated in the middle of the graben, where Unzen products have accumulated as thick as more than 1000 m beneath the surface. As USDP-2 is also within a main course of transportation of volcanic materials form the center of Unzen Volcano, it is expected to recover the continuous record of its eruption history in USDP-2. Total core recovery for two wells was more than 90%, and it was possible to perfectly reconstruct the volcanic history of both sites. Against the expectation of thick piles of lava flows before drilling, many layers of pyroclastic flows and related debris flows were encountered in both wells by drilling. Vesicularity of essential blocks in block-and-ash flow deposits tends to increase with the increasing depth, suggesting more explosive eruptions in the past. The oldest pyroclastic materials of Unzen include vesiculated pumices that are rarely found on the modern surface, revealing very explosive eruptions took places in the beginning of Unzen volcano. Beneath the base of the Unzen products about 680 and 1200 m below the surface in the USDP-1 and 2 sites, respectively, pre-Unzen pyroxene andesite of 0.5 Ma was recovered. Systematic ^{14}C, K-Ar and ^{40}Ar/^{39}Ar dating, major and trace element geochemistry, and Sr, Pb and Nd isotopic analyses have been conducted on core samples of both wells, and detailed geologic and geochemical evolution history of Unzen volcano is now under construction. Geophysical measurements were also conducted using these wells, and results are now utilized to construct the geophysical structure of the volcano. During Phase I, intensive geological, geophysical and geochemical studies have been conducted beside drillings. Emphases were put to reveal three-dimensional geological, geophysical and hydrological structure of Unzen volcano and Shimabara Peninsula, and to understand the magma degassing and cooling processes.

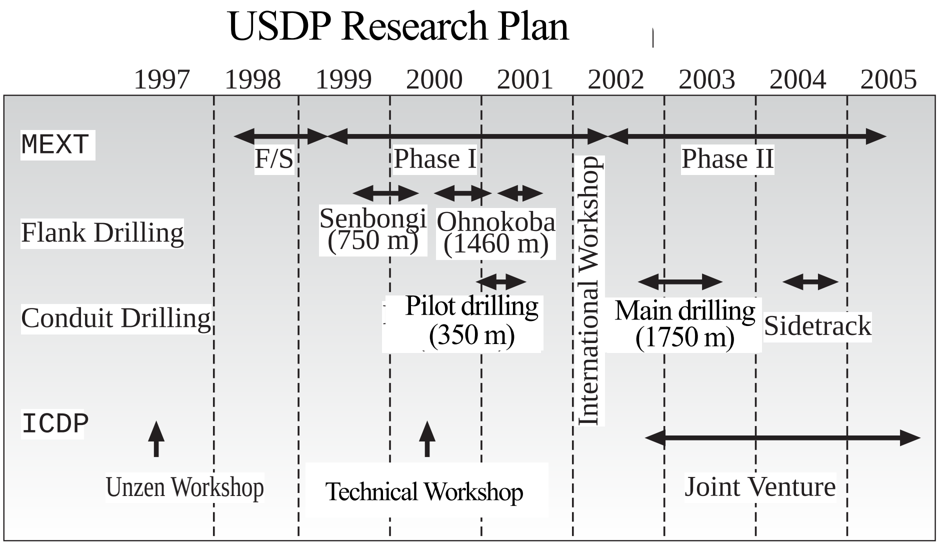

Fig. 40. Research schedule of Unzen Scientific Drilling Project

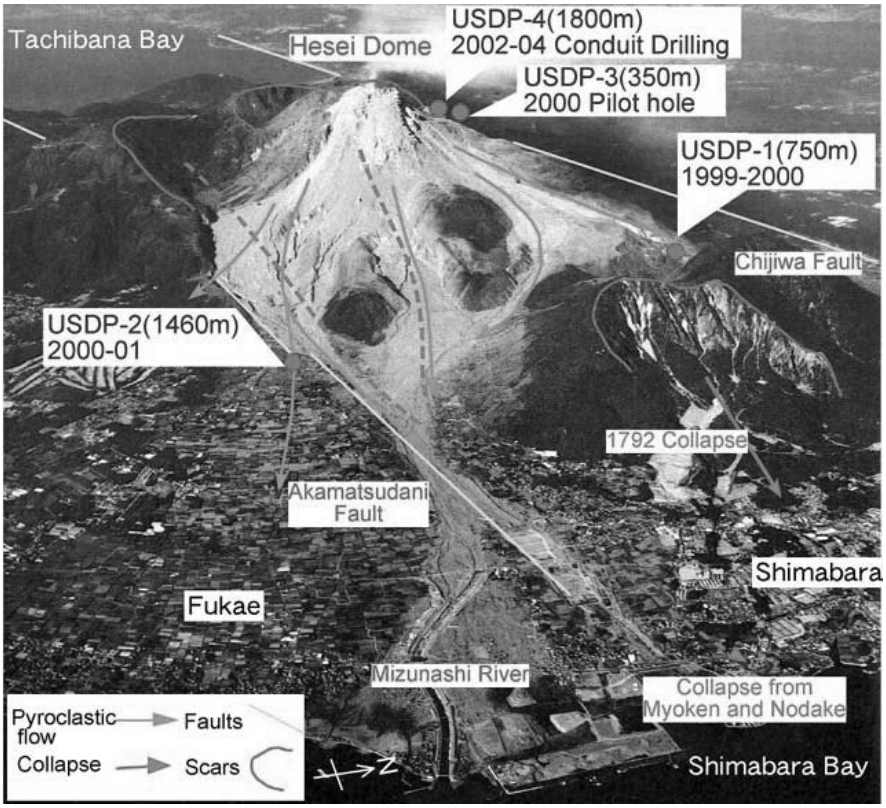

Fig. 41. Locations of drilling sites of USDP

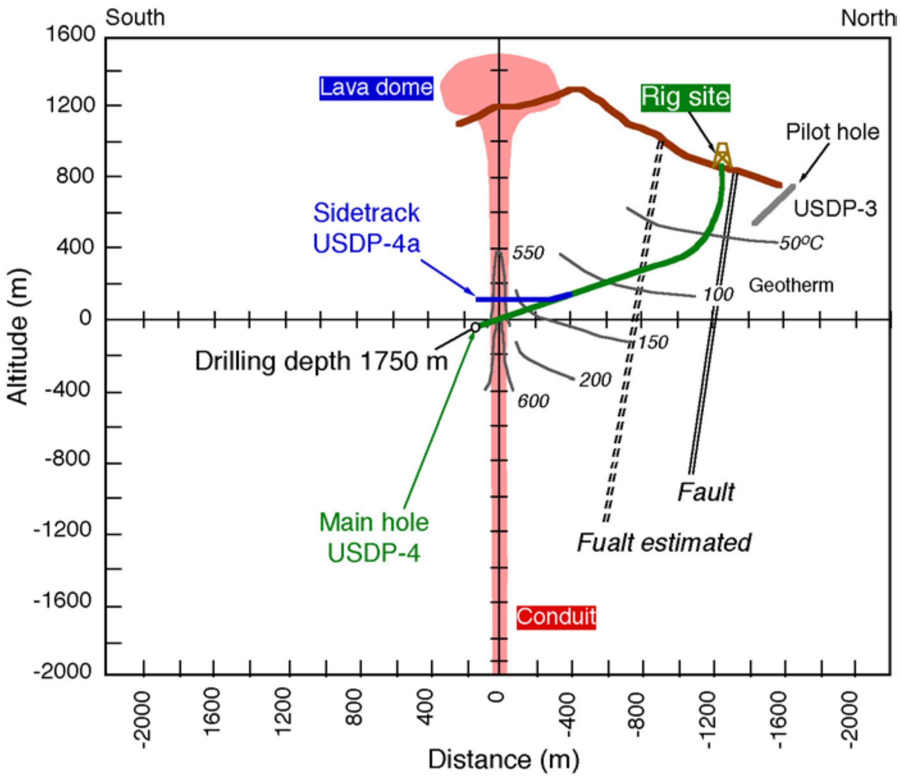

Fig. 42. Trajectory plan of the conduit drilling.

Phase II, started in April 2002, targets the upper part of the conduit through which the lava domes of 1991-1995 eruption were emerged. In the last kilometer of ascent, magma is subjected to an order of magnitude decrease in solubility of water in melt together with more than an order of magnitude increase in melt viscosity, more than two order of magnitude decrease in vapor density, and the onset of crystal growth. This in turn causes huge changes in magmatic properties and is responsible for a number of geophysical phenomena and signals prior or during eruption; i.e., isolated tremor events (1.5-0.5 km deep), low-frequency earthquake events (0.5-0 km), sources of vulcanian explosions and deformation-and-inflation in 1.2 to 0.5 km-depths. These phenomena and signals are thought to reflect magmatic degassing during ascent and interaction of magma with groundwater in an aquifer below 0.5 km depth. Direct drilling into the conduit in this depth range is critical in order to verify interpretation of monitoring data during eruptions and to understand these important magmatic processes. The conduit is considered to be an east-west trending dike with a length as large as several hundred meters and a thickness of 10-20 m. A 50 m-high rotary rig was constructed at the northern slope of Unzen, 840 m above sea level, and drilling was started normal to the dike in February 2003. The drilling was initiated vertically and increased its inclination with depth, which is the best choice to drill the hot and challenging target at the sea level. The temperature of the conduit center is estimated as high as 600 °C. The hole-bottom temperature during operation of conduit drilling can be controlled at rather low values with a special casing program and mud circulation system, so that we can use the logging tools (temperature probe, bore hole televiewer, etc) even at considerable depth of the conduit. The drilling, associated borehole measurements and sampling will be ended by March 2005.

(Kozo Uto and Setsuya Nakada)

5. Tokyo Volcanic Ash Advisory Center

Most of the volcanoes around the world are known to be potential threats to local inhabitants due to lava flows, volcanic bombs, pyroclastic flows, and ash falls during an eruption that may cause the loss of life and property. However, a lesser-known fact is that volcanic ash thrown high into the atmosphere by an eruption may threaten flights with floating ash clouds of tiny particles. Volcanic ash damages engines and bodies of aircraft and is not only a threat to flight safety but also cause of severe economical damages for airlines and aviation organization. Therefore, timely provision of information of drifting volcanic ash is very important for the aviation safety.

The International Civil Aviation Organization (ICAO), a special organization of the United Nations launched the International Airways Volcano Watch (IAVW) with the assistance of international organizations such as the World Meteorological Organization (WMO, a special organization of the United Nations). Thereafter, ICAO and WMO stipulated that Meteorological Watch Offices (MWO) in individual countries should issue information about volcanic ash cloud as Significant Meteorological Information (SIGMET): information about meteorological weather conditions that may be significant or threatening to flights. ICAO also recommended the establishment of volcanic ash advisory centres that provides Volcanic Ash Advisories (VAA) to help MWO to issue SIGMETs about volcanic ash cloud.

The Japan Meteorological Agency (JMA) established the Volcanic Ash Advisory Center in the Tokyo Aviation Weather Service Center in April 1997 as one of nine VAAC in the world, and started services for the issuance of VAAs in the area of responsibility (see Fig. 43).

Monitoring of Volcanic Ash Cloud

(1) Collection of information about eruptions, volcanic activities and witnessed volcanic ash cloud

a) In the event of the eruption of a volcano in Japan, the observation data is reported from Volcanic Observations and Information Centers of JMA, and additional information is reported from pilots about eruptions and volcanic ash cloud.

b) In the event of the eruption of a volcano outside Japan, the volcanic activity reports from both volcano observatories overseas and pilots are important information sources. In addition to this information, Tokyo VAAC also exchanges information about eruptions of volcanoes and divergence of volcanic ash cloud with the adjacent VAACs in Anchorage, Washington, and Darwin. Information from the Web sites is also used as a reference.

(2) Monitoring of volcanic ash cloud using satellite image analysis system

Tokyo VAAC monitors volcanic ash cloud using the satellite image analysis system of visible images and infrared images of the Meteorological Satellite GMS-5 and infrared images of the Earth Observation Satellite of the National Oceanic and Atmospheric Administration.

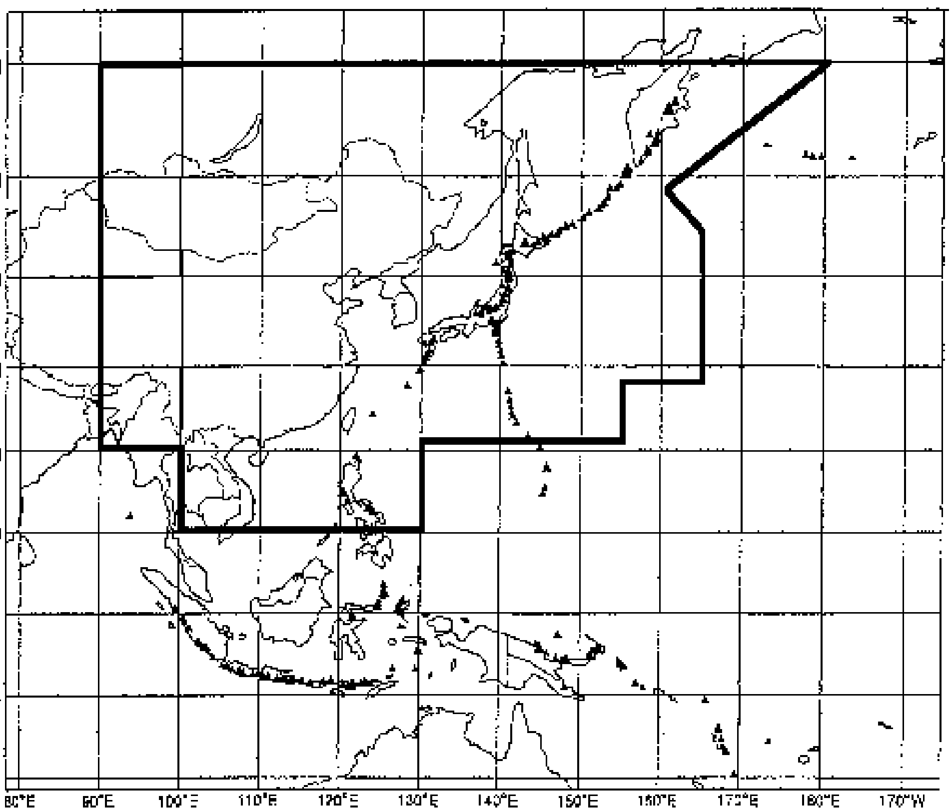

Fig. 43. The area of responsibility of the Tokyo VAAC.
(▲: volcanoes in and around the responsibility area)

Forecasting volcanic ash cloud dispersion

The Tokyo VAAC forecasts volcanic ash cloud dispersion based on the calculation taking the monitored results into account for volcanic ash cloud. The forecasts are issued in the VAA with the monitored results and are also available in a volcanic ash cloud forecast chart.

Issuance of Volcanic Ash Advisories

The issuance criteria for VAA from the Tokyo VAAC are as follows:

a) When the height of volcanic ash cloud reaches 5,000 meters above sea level as estimated from the relevant information about volcanic ash cloud,

b) When volcanic ash cloud is detected on satellite imagery and the height of the eruption plume or volcanic ash cloud reaches 5,000 meters above sea level, and

c) Any time when aircraft in flight may be affected by volcanic ash.

Unless remarkable changes in the situation do occur, VAA update will be issued at 00, 06, 12, and 18 UTC.

If Tokyo VAAC detects or is notified of a volcanic eruption from a volcano in Japan, VAA will be issued in spite of a plume height for the domestic aviation authorities and airlines. JMA will eliminate the criteria mentioned above and to provide low level VAAs for the other volcanoes in the area of responsibility than ones in Japan.

VAAs for volcanic ash clouds over 5,000 m above sea level provided by Tokyo VAAC in these six years are as follows;

Years	number of issuance of VAAs	
1997	28	
1998	30	
1999	22	
2000	104	
2001	87	
2002	39 (for over 5,000 m plume)	290 (for below 5,000 m plume)

(Keiji Doi)