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).

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