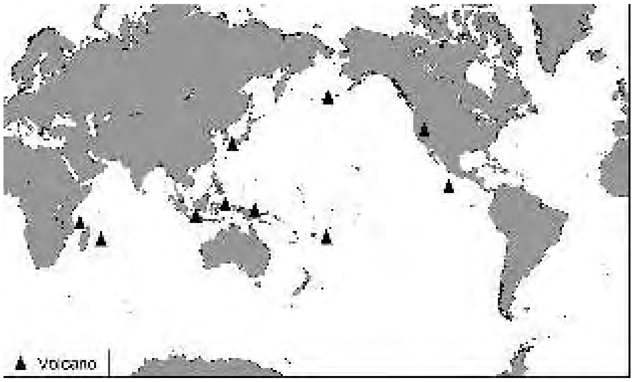
Bulletin of the Global Volcanism Network



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Editors: Rick Wunderman, Edward Venzke, Catherine Galley, and Sally Kuhn

Volunteer Staff: Zahra Hirji, Robert Andrews, Jerome Hudis, Veronica Bemis, Jackie Gluck, William Henoch, and Stephen Bentley

Global Volcanism Program · National Museum of Natural History, Room E-421, PO Box 37012 · Washington, DC 20013-7012 · USA
Telephone: (202) 633-1800 · Fax: (202) 357-2476 · Email: gvn@volcano.si.edu · URL: http://www.volcano.si.edu/

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Merapi

Java, Indonesia
7.542°S, 110.442°E; summit elev. 2,968 m

During mid-March through July 2006, scientists at Merapi noted variations in seismicity, the number and size of explosions, and the abundance of pyroclastic flows and incandescent rockfalls. This led to changes in Alert Levels and, during April and May, thousands of evacuations. The source of *in-situ* information for this report was Merapi Volcano Observatory and the Center of Volcanology and Geological Hazard Mitigation (CVGHM; formerly VSI, the Volcanological Survey of Indonesia, and still informally referred to in that way). Satellite images collected by the Advanced Spaceborne Thermal Infrared and Reflection Radiometer (ASTER) complemented the ground observations.

Although events of 28 April to 22 June 2006 were previously discussed in more detail (*BGVN* 31:05), they are presented here in the context of ASTER and summaries of CVGHM field reports. CVGHM observations from 28 June to 25 July revealed an interval of limited significant rockfalls, sparse pyroclastic flows (only one was reported, to 3 km runout distance), and modest gas plumes.

Activity during 28 April to 22 June 2006. About eight images from 28 April to 22 June were collected over Merapi by the ASTER satellite and processed by Michael Ramsey. Temperatures over the lava dome and flanks were extracted from daytime and nighttime images; in some cases the contents of plumes were assessed. The temperature and distribution of thermal anomalies were consistently in agreement with ground observations from CVGHM.

ASTER consists of three instrument sub-systems covering fourteen bands over three wavelength regions with various spatial (pixel) resolutions. Three visible and near-infrared (VNIR) bands cover 0.52-0.86 µm at 15 m spatial resolution. Six short-wavelength infrared (SWIR) bands cover 1.60-2.45 µm at 30 m resolution. Five thermal infrared (TIR) bands cover 8. 125-11.65 µm at 90 m resolution.

A temperature data point from a pixel is the average temperature for that 30 x 30 m (SWIR) or 90 x 90 m (TIR) pixel area. Temperature data are extracted from the TIR region, unless the pixels are saturated (temperatures greater than 100°C over the 90 m pixel). In those cases, temperatures are extracted from SWIR images. Cross-track pointing of the sensors ± 116 km from nadir allows for repeat times of less than sixteen days. For a target near the equator at a 24° pointing angle, repeat times can average four days. During the Merapi crisis, investigators tasked the satellite to collect more frequent images.

A nighttime TIR image from 28 April showed a weak thermal anomaly over the summit. Approximately 8 pixels were thermally elevated above background, to a maximum temperature of ~ 25.9°C. Further processing of the emissivity spectra from the hottest pixels demonstrated that over 5% of the sub-pixel temperatures may be on the order of 100's of degrees C. SWIR data from the same time showed temperature of no more than ~ 200°C. One small anomaly was visible ~ 650 m SW from the summit. CVGHM reported that volcanic material traveled ~ 1.5 km SW towards the Lamat River on 28 April.

On 12 May, a daytime SWIR image demonstrated increased activity with a larger thermal anomaly than the 28 April image and a pixel average maximum temperature of 213°C. Emissivity spectra collected in the TIR region corroborated the temperature data in the SWIR region. On 11 May, CVGHM reported a sharp increase in eruptive activity and on 13 May, raised the Alert Level from 3 to 4 (the highest level). As noted in *BGVN* (31:05), about 4,500 people living near the volcano were evacuated.

A significant thermal anomaly was present in the 14 May TIR and SWIR nighttime images. Three pixels in the SWIR region had a maximum average pixel temperature of 442°C. An area of elevated temperature to the SW was interpreted as a pyroclastic flow. On 15 May, CVGHM reported that pyroclastic flows had traveled as far as 4 km W.

A clear nighttime SWIR image acquired on 30 May showed a maximum derived temperature of 447°C and 11 pixels with temperatures greater than 400°C. Two zones of

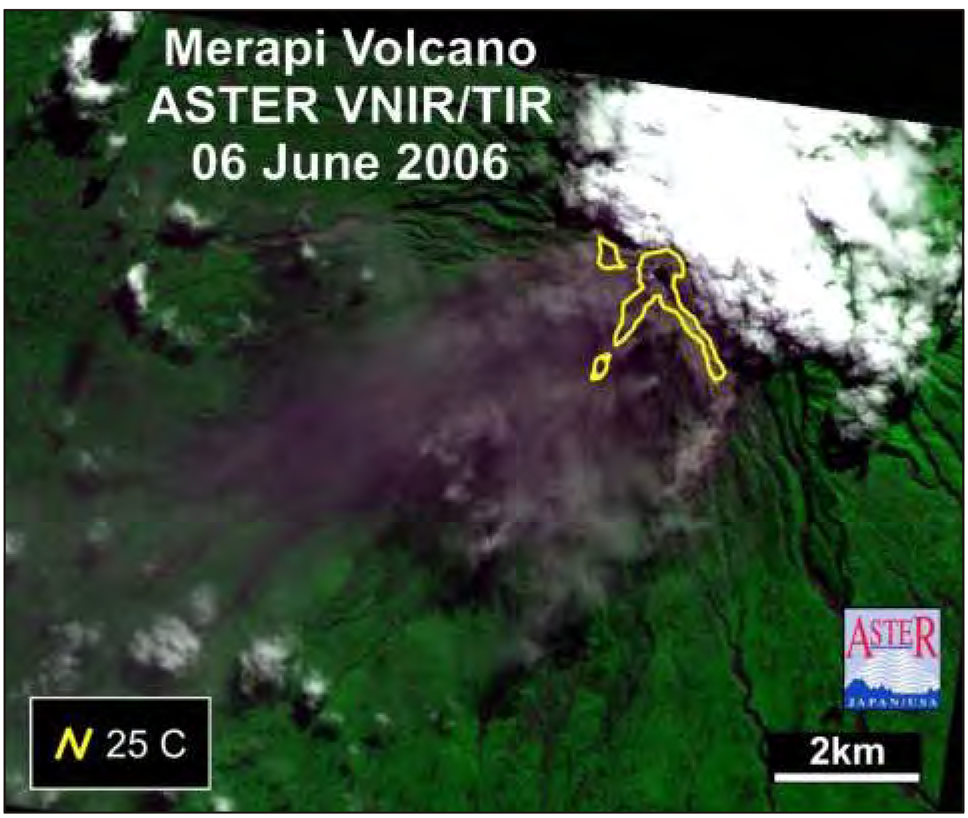

Figure 1. Composite ASTER image of Merapi acquired on 6 June 2006. A large ash-rich plume drifting over 40 km SW of the summit is evident in this visible near-infrared ASTER image (15 m pixel size) taken during daylight hours. Temperature data from a nighttime thermal infra-red image acquired 12 hours later is superimposed on the image as contour lines. Those on and around the summit represent the minimum extent of elevated temperatures (~ 25°C) from hot material such as pyroclastic flows. Courtesy Michael Ramsey, University of Pittsburgh.

thermally elevated pixels were evident about 600 m SE of the dome and 2 km SW of the summit. Consistent with the imagery, CVGHM reported that during 28-30 May, multiple pyroclastic flows reached a maximum of 3 km SE toward the Gendol River and 4 km SW toward the Krasak and Boyong Rivers.

On 6 June, daytime VNIR, nighttime SWIR, and TIR images were collected. The daytime image shows a large ash-rich plume extending SW over 40 km from the summit (figure 1). Preliminary analysis of the plume by Vince Realmuto (using a decorrelation stretch of the daytime TIR data) indicated a mixture of ash and steam, and low SO_2 content. Thermal anomalies over the summit and on the flanks (outlined in white), interpreted as possible pyroclastic flows, extended~ 3 km SE and SW, and ~ 1 km NW. SWIR temperature data showed a maximum average pixel temperature of 420°C and two summit pixels over 400°C. According to CVGHM, on 6 June lava avalanches and two pyroclastic flows reached ~ 2 km SE and lava avalanches traveled 2 km SW.

A thermal anomaly, interpreted as cooling pyroclastic flows, that extended ~ 6.4 km S of the summit region was evident on a TIR and SWIR image set acquired on 22 June. The SWIR data showed two pixels greater than 425°C over the summit similar to the 6 June data. Based on interpretation of seismic data, CVGHM reported almost daily occurrences of rockfalls and pyroclastic flows during 21-25 June. Visual observations were mostly inhibited by cloud cover.

Activity during 28 June-25 July 2006. Pyroclastic flows and rockfalls decreased in frequency and intensity during 28 June-4 July. Pyroclastic flows were observed during 28-30 June and reached a maximum distance of 3 km SE along the Gendol River. Gas plumes were observed during 28 June-1 July and reached a maximum height of 1 km above the summit (~ 4 km altitude) on 28 June.

During 5-11 July, gas plumes reached a maximum height of 1.2 km above the summit on 6 July. Due to a decrease in activity, on 10 July the Alert Level was lowered one level to 3 in all areas except the S slope.

Incandescent material reached a maximum distance of 2 km SE along the Gendol River from 12 to 18 July. Gas plumes were also observed daily and reached heights of 1 km above the crater (~ 4 km altitude) On 17 July, CVGHM lowered the Alert Level to 3 for the S slope. During 19-25 July, gas plumes reached maximum heights of 400 m above the summit (~ 3.3 km altitude). Flows of incandescent material were observed daily, advancing at a maximum distance of 1.5 km SE toward the Gendol River. Pyroclastic flows were not observed during 12-25 July.

Geologic Summary. Merapi, one of Indonesia's most active volcanoes, lies in one of the world's most densely populated areas and dominates the landscape immediately N of the major city of Yogyakarta. The steep-sided modern Merapi edifice, its upper part unvegetated due to frequent eruptive activity, was constructed to the SW of an arcuate scarp cutting the eroded older Batulawang volcano. Pyroclastic flows and lahars accompanying growth and collapse of the steep-sided active summit lava dome have devastated cultivated and inhabited lands on the volcano's western-to-southern flanks and caused many fatalities during historical time.

Information Contacts: *Center of Volcanology and Geological Hazard Mitigation (CVGHM)*, Jalan Diponegoro 57, Bandung 40122, Indonesia (URL: http://www.vsi.esdm.go.id/); *Michael Ramsey and the Image Visualization and Infrared Spectroscopy (IVIS) laboratory*, University of Pittsburgh, 200 SRCC Building, Pittsburgh, PA 15260, USA (URL: http://ivis.eps.pitt.edu/; Email: ramsey@ivis.eps.pitt.edu); *Vince Realmuto*, Jet Propulsion Laboratory, Mail Stop 168-514, 4800 Oak Grove Drive, Pasadena, CA 91109, USA (Email: Vincent.J.Realmuto@jpl.nasa.gov); *Advanced Spaceborne Thermal Infrared and Reflection Radiometer satellite* (URL: http://asterweb.jpl.nasa.gov/).

Dukono

Halmahera, Indonesia
1.68°N, 127.88°E; summit elev. 1,335 m

During 2004 and 2005, Dukono continued to emit ash plumes as it has for many decades. This report first summarizes available reports from Indonesia's Center of Volcanology and Geological Hazard Mitigation (CVGHM).

David Rothery and Charlotte Saunders previously discussed MODIS thermal alerts up to April 2004 in our last report (*BGVN* 29:06). Since that time, and as recently as 1 August 2006, the only MODIS thermal alerts were detected on 4 October 2004.

CVGHM observations, 2004-2005. During this interval, the volcano's hazard status stood at Level 2 (Yellow).

During 31 May to 31 August 2004 small explosions were accompanied by rumbling sounds and the release of white to gray-black ash. The emissions occurred at a relatively constant frequency and intensity. The ash-bearing clouds reached up to ~ 500 m above the summit. Ash discharges and rumbling were constant.

Eruptive behavior continued throughout 2005. From 24 to 30 January explosions often ejected ash, and dark gray ash plumes reached 200-600 m above the summit. On 9 May an ash eruption was accompanied by an explosive sound repeated 27 times. Ejections the week of 26 September-2 October contained ash and, occasionally, larger pyroclastic material. Explosions occurred about 15 times a day, sending plumes 100-400 m high. Thousands of explosions were documented during the next two weeks (table 1). Ash columns rose 100-950 m above the summit.

Aviation reports, 2004-2006. A large table contains aviation observations from 31 December 2003 through 12 January 2006 from the Darwin VAAC (table 2), although not all the VAAC's original reports were inspected. Some of the reported eruptions during that time generated plumes visible on satellite imagery to distances as far as 200 km. Plumes often rose to ~ 3 km altitude.

Geologic Summary. Reports from this remote volcano in northernmost Halmahera are rare, but Dukono has been

Date (2005)	A-type	B-type	Explosions	Tectonic
26 Sep-02 Oct	27	18	146	22
03 Oct-09 Oct	42	32	1,471	5
10 Oct-16 Oct	10	1	2,068	3

Table 1. Summary of types and numbers of seismic/volcanic events occurring at Dukono during late September through mid-October 2005. Courtesy of CVGHM.

one of Indonesia's most active volcanoes. More-or-less continuous explosive eruptions, sometimes accompanied by lava flows, occurred from 1933 until at least the mid-1990s, when routine observations were curtailed. During a major eruption in 1550, a lava flow filled in the strait between Halmahera and the N-flank cone of Gunung Mamuya. Dukono is a complex volcano presenting a broad, low profile with multiple summit peaks and overlapping craters. Malupang Wariang, 1 km SW of Dukono's summit crater complex, contains a 700 x 570 m crater that has also been active during historical time.

Information Contacts: *CVGHM* (see Merapi); *Darwin Volcanic Ash Advisory Center (VAAC)* (URL: http://www.bom.gov.au); *HIGP Thermal Alerts Team*, Hawai'i Institute of Geophysics and Planetology (HIGP) / School of Ocean and Earth Science and Technology (SOEST), University of Hawai'i, 2525 Correa Road, Honolulu, HI 96822, USA (http://hotspot.higp.hawaii.edu/).

Manam

NE of New Guinea
4.080°S, 145.037°E; summit elev. 1,807 m

In the past year Manam issued energetic eruptions. In contrast, Rabaul Volcanological Observatory (RVO) described milder behavior during March-July 2006.

Although steam emissions from Main and Southern craters dominated in early March, small eruptions occurred on 3 and 6 March 2006. A 7 March pyroclastic flow descended SE valley halting at 500 m elevation. Scoria and ashfall affected the E part of the island between the coastal settlements of Warisi and Bokure (see annotated image in *BGVN* 30:02). Fine ashfall was reported along the SW part of the island at night. On 22, 24-25, and 28-31 March, Main Crater emitted thick white vapor, while Southern Crater released white and blue vapor. Pale gray ash clouds were reported 30-31 March.

Glowing-lava fragments discharged from Southern Crater late on 31 March. During 4-20 March there was low-to-moderate seismicity. Audible noises, weak to roaring, were reported from Main Crater on 13 April, but no glow was seen at night. Clear weather on 14 April revealed both craters releasing diffuse white vapor.

During 26 April to 2 May, ash was observed on satellite imagery at ~ 3 km altitude On 24 and 25 May, an ash plume extended ~ 100 km WNW. Another ash plume was visible on 26 May, reaching an altitude of ~ 3 km altitude and drifting 48 km WNW.

According to Darwin VAAC, a pilot reported that an ash cloud from Manam reached altitudes of ~ 4.6 km on 17 July and drifted N. Ash was not visible on satellite imagery due to local cloud cover. The Darwin VAAC reported an ash cloud on 18 July moving N at an unknown altitude. On 29 July an ash cloud was visible on satellite imagery drifting WNW at an altitude of ~ 3 km.

Geologic Summary. The 10-km-wide island of Manam, lies 13 km off the northern coast of mainland Papua New Guinea. Four large radial valleys extend from the unvegetated summit of the conical basaltic-andesitic stratovolcano to its lower flanks. These "avalanche valleys," regularly spaced 90 degrees apart, channel lava flows and pyroclastic avalanches that have sometimes reached the coast. Five small satellitic centers are located near the island's shoreline on the northern, southern and western sides. Two summit craters are active, although most historical eruptions have originated from the southern crater, concentrating eruptive products during the past century into the

Dates	Event(s)	Plume characteristics (heights above sea level)
31 Dec 2003-06 Jan 2004	low-intensity eruptions	low levels, extended to ~185 km SE
07 Jan 2004-13 Jan 2004	low-intensity eruptions	low levels, extended to ~120 km SSW
20 Feb 2004-22 Feb 2004	—	thin ash plumes visible on satellite, extended predominately E to max. of 90 km
25 Feb 2004-27 Feb 2004	—	thin ash plumes visible on satellite, extended max. of 160 km E at height of ~3 km
14 Mar 2004	—	ash plume visible on satellite imagery at height of ~4.6 km, extended SE
17 Mar 2004-01 Jun 2004	—	ash plumes sometimes visible on satellite imagery reaching max. height of ~3 km; on 24 Mar one plume extended ~185 km E
07 Jun 2004	—	thin ash plume visible in satellite imagery extended ~75 km ESE at ~3 km
08 Jun 2004	—	thin ash plume seen in satellite imagery extended ~65 km ESE at altitude of ~2 km
09 Jun 2004-15 Jun 2004	—	low-level plumes occasionally emitted, visible on satellite imagery
01 Sep 2004	—	thin ash plume visible on satellite imagery at height of ~3 km, drifting NW.
26 Sep 2004	eruption	satellite imagery showed plume extended WNW at a height of ~3 km
24 Jan 2005-30 Jan 2005	ash explosions	ash plumes rose 200-600 m above summit
21 May 2005	—	satellite data showed thin ash plumes; height not reported
29 May 2005-31 May 2005	—	small low-level ash plumes visible on satellite imagery
01 and 04 Jun 2005	—	ash plumes visible on satellite imagery
20 Jun 2005-21 Jun 2005	—	ash visible on satellite imagery, drifting NW; height not reported
02 Sep 2005	—	plume observed on satellite imagery, height of ~3 km, extended NW.
26 Sep 2005-09 Oct 2005	explosive activity	ash rose 100-950 m above the summit and mostly drifted ENE
10 Oct 2005-16 Oct 2005	explosions, pyroclastic ejections	ash columns rose 100-950 m above summit and mainly drifted SE
19 Oct 2005	—	thin low-level plume visible on satellite imagery extended to the ENE
27 Oct 2005	—	ash plume visible on satellite imagery extended to NNW
12 Jan 2006	—	ash visible on satellite imagery at height of ~3 km, extended SW

Table 2. Events reported for Dukono for the interval 31 December 2003-12 January 2006 (as taken from summaries of collaborative Darwin VAAC and CVGHM reports presented in USGS-Smithsonian Weekly Reports). Courtesy of Darwin VAAC and CVGHM.

SE avalanche valley. Frequent historical eruptions have been recorded at Manam since 1616. A major eruption in 1919 produced pyroclastic flows that reached the coast, and in 1957-58 pyroclastic flows descended all four radial valleys. Lava flows reached the sea in 1946-47 and 1958.

Information Contacts: *Ima Itikarai* and *Herman Patia*, Rabaul Volcano Observatory (RVO), P.O. Box 386, Rabaul, Papua New Guinea.

Tofua

Tonga Islands, SW Pacific
19.75°S, 175.07°W; summit elev. 515 m

Fieldwork at Tofua during 11 May-1 June 2006 was accomplished by a group led by John Caulfield (Macquarie University). The work involved detailed lithological mapping of the island, with specific focus on the N side. It is hoped that correlation of geological units and U-Series disequilibria will help to unravel the eruptive history.

The active vent, Lofia, was degassing throughout the visit. Fumaroles were located at the bottom of the vent and on the lower half of the inside of the vent. There was no degassing on the flanks of Lofia. Expelled gases were brownish-blue, with a strong sulfurous smell. The "chugging" sounds reported by Tim Worthington (*BGVN* 26:12) were still occurring at a rate of once every few minutes to bursts of up to four, one after the other. The highest point on the rim of Lofia was very unstable, probably weakened by the large earthquake that occurred on 4 May. A large crack (~ 30 cm wide), trending roughly WNW-ESE had opened across the thick ash and spatter deposits in the caldera, several hundred meters N of Lofia.

When the gas was periodically cleared by wind gusts, three craters could be seen at the bottom of the 150-200-m-deep vent. Of these craters, one was fumarolic, one was quiet, and one contained an orange glow. Although the depth and angle of the vent meant that the magma itself was not visible, the strong glow suggested that lava had ponded there. There was abundant spatter around the rim and abundant bombs on the flanks, the latter most likely resulting from eruptive activity in 1958. The pH of the large crater lake was determined to be 5.5-6.

Geologic Summary. The low, forested Tofua Island in the central part of the Tonga Islands group is the emergent summit of a large stratovolcano that was seen in eruption by Captain Cook in 1774. The first Caucasian to set foot on the 515-m-high island was Capt. William Bligh in 1789, just after the renowned mutiny on the "Bounty." The volcano's summit contains a 5-km-wide caldera whose walls drop steeply about 500 m. Three post-caldera cones were constructed at the northern end of a cold fresh-water caldera lake, whose surface lies only 30 m above sea level. The easternmost cone has three craters and produced young basaltic-andesite lava flows, some of which traveled into the caldera lake. The largest and northernmost of the cones, Lofia, has a steep-sided crater that is 70 m wide and 120 m deep and has been the source of historical eruptions. The fumarolically active crater of Lofia has a flat floor formed by a ponded lava flow.

Information Contacts: *John Caulfield* and *Heather Cunningham*, ARC National Key Centre for Geochemical Evolution and Metallogeny of Continents (GEMOC), Department of Earth & Planetary Sciences, Macquarie University, NSW 2109, Australia (URL: http://www.es.mq.edu.au/GEMOC/, Email: jcaulfield@els.mq.edu.au); *Graham Smith*, Department of Earth Sciences, University of Cambridge, Downing Street, Cambridge CB2 3EQ,United Kingdom (Email: gcs27@esc.cam.ac.uk).

Unnamed

East Pacific Rise
9.82°N, 104.30°W; summit elev. ~ -2,500 m

Scientists verified a recent seafloor eruption at 9°50'N on the E Pacific Rise (EPR) between ~ 104°16'00"W and 104°18'58"W (figure 2). This area was visited during cruises of the Research Vessel (RV) *Knorr*, 24-26 April 2006, and of the RV *New Horizon*, 10-17 May 2006. In early April 2006 some ocean bottom seismometers deployed in the area failed to return to the ocean surface when instructed. As a result, scientists suspected that a seafloor eruption may have buried the seismometers with lava (*Venture Deep Ocean* website).

The *Knorr* recovered samples of new seafloor by dredging along the EPR axis in response to this possible eruption. The first seafloor images, collected several weeks later in May 2006 by *RV New Horizon*, showed fresh and older lavas interspersed along the dredge track (figures 3 and 4). The images also documented young lavas spanning nearly 13 km (between 9º47' and 9º54' N), an area known to cover a significant range in neovolcanic lava compositions.

Tolstoy (2006) discussed heightened seismicity detected by ocean-bottom instruments along this part of the EPR. The most pronounced seismicity occurred in the time period of late January 2006. In addition, the U.S. Geological Survey's Earthquake Hazards Program reported an M 5. 4 earthquake on the EPR at 2345 UTC on 30 July 2006. It was at 10.06°N, 104.21°W and at a depth of 10 km. Another nearby EPR earthquake, also M 5.4, struck at 0124 UTC on 31 July, centered at 10.01°N, 103.89°W and a depth of ~10 km. Both epicenters were within several kilometers of the eruption site.

Ken Rubin and Mike Perfit suggested (Rubin and Perfit, 2006) that the new eruption (Bowles and others, 2006) provided an opportunity to define the temporal-spatial evolution of new volcanic seafloor. Such an analysis would provide information not only on how the eruption progressed, but would also form a baseline to subsequent biological, geochemical, and geological observations. According to Rubin and Perfit, sample collection and subsequent radiochemical analysis must be conducted within 1-2 months of the eruptive event because of the ^{210}Po-^{210}Pb radiometric dating method they employ, with a ^{210}Po half-life 138 days. Generation of a detailed surface-age map (with resolution of 2-3 weeks) would require multiple, small, geographically dispersed samples (tens of grams) with known geological context, collected and analyzed within several months after an eruption. Such sampling would be best conducted from a submersible. This dating scheme is not possible more than ~1.5 years after the eruption.

Geologic Summary. Evidence for an eruption was detected during a series of dives in the submersible vessel *Alvin* in 1991 on the East Pacific Rise in water depths of ~2.

5 km. This spot sits ~500 km S of the Clipperton fracture zone and ~ 900 km SW of Acapulco, México. At this location fresh lava flows previously estimated as less than roughly 50 years in age had been found (Haymon and others, 1991). Dive observations (Haymon and others, 1993) and rock dating (Rubin and others, 1994; *BGVN* 30:10) showed that the 1991-92 eruption lasted close to a year, and eruption locales migrated through the flow field. The eruption, or at least the effects of diking, may have affected areas as far S as the 9°37'N small ocean spreading center (OSC) (Smith and others, 2001). Hot-vent animal communities that had been documented in 1989 had been buried by fresh basaltic lava flows, and the scorched soft tissues of partially buried biota had not yet attracted bottom scavengers. Fresh black smoker chimneys were draped by new lava flows. Bottom photographs taken in 2006 show fresh lava flows overlying older ones, and thermal instrument tows along the seafloor identified areas of hydrothermal venting.

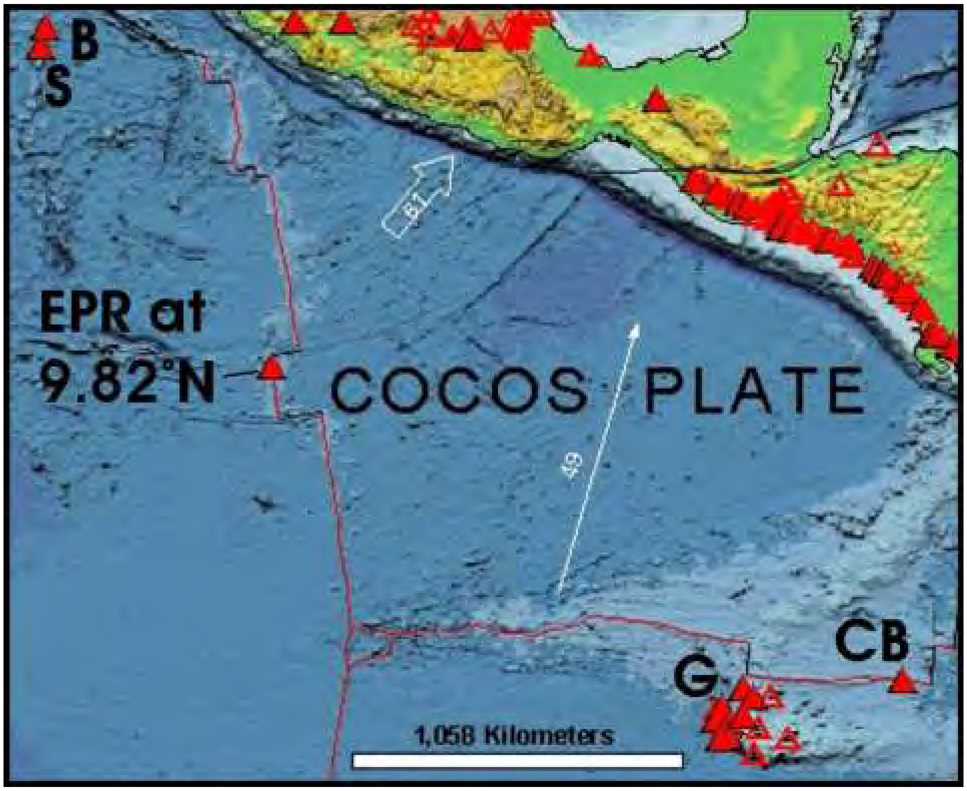

Figure 2. Map showing the EPR off Central America. Solid triangles show Holocene volcanoes, and the sub-vertical (N-S) line shows the axis of the EPR (with this volcano at 9.82°E labeled). The Galapagos islands (G) lie in the cluster of known volcanoes there. The Clam Bake (CB) vent zone sits farther E along the Galapagos ridge. The Revillagigedo Islands (Barcena and Socorro) appear at upper left (B and S). Courtesy of the *This Dynamic Planet* website (Simkin and others, 2006).

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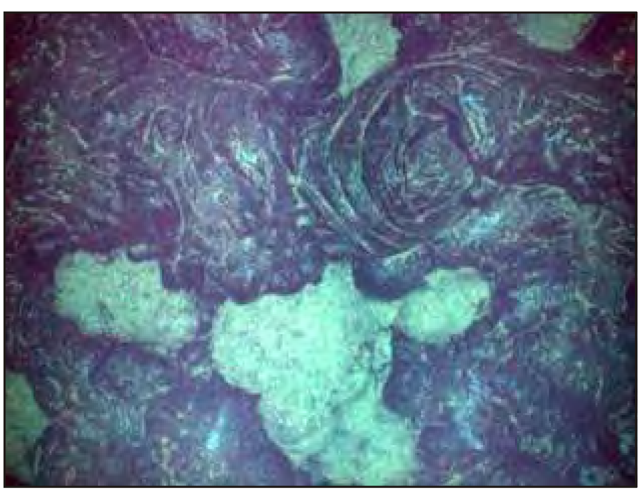

Figure 3. Towed-camera view along the crest of the EPR from the *New Horizon*, 11 May 2006, of a newly erupted (2006?) glassy lobate lava flow overlying older lava. Based on comparisons with images from the submersible *Alvin* in March 1992, it appeared to be a recent eruption. Cruise scientists tentatively suggested, based on the character of the lava surfaces compared with the underlying lava, that the eruption may have occurred 1 to 6 months earlier. Cast 2, TowCam Run 1, 9°50.2'N, 104°17.5'W, seafloor depth 2,498 m. Courtesy of the Ridge 2000 Program.

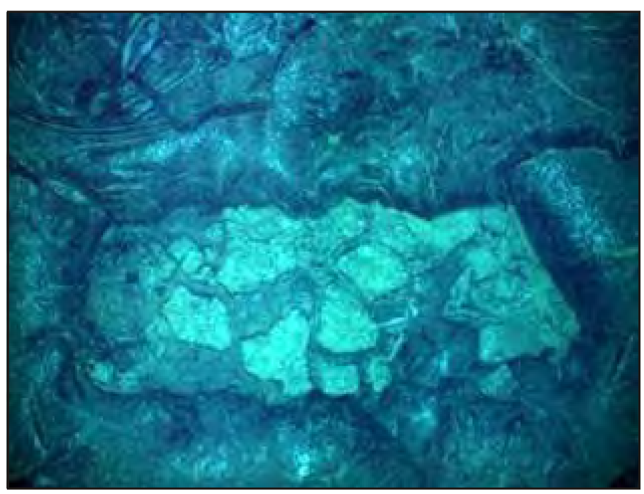

Figure 4. Towed-camera view on the EPR from the *New Horizon*, 11 May 2006, showing a new lava flow framing an exposure of lava that appeared older. The latter (center of frame) was lighter-colored and lobate. Preliminary analysis of the photos suggested that a new lava flow was present at 9°47' N, but perhaps not farther S. In many places (on this and TowCam Run 1) the new flow appeared less than 1 m thick. Cast 4, TowCam Run 2, ~ 9°47' N, ~ 104°17' W, seafloor depth ~ 2,500 m. Courtesy of the Ridge 2000 Program .

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Information Contacts: *Kenneth H. Rubin*, School of Ocean and Earth Science and Technology, University of Hawai'i at Manoa, 1680 East-West Road, Honolulu, HI 96822, USA (Email: krubin@hawaii.edu); *Michael R. Perfit*, Dept of Geological Sciences, Univ of Florida, 365 Williamson Hall, Gainesville, FL 32606, USA (Email: perfit@geology.ufl.edu); *Ridge 2000 Program*, EPR 9N Integrated Studies Site (ISS) Latest Updates, 22 May 2006 (URL: http://www.ridge2000.org/science/tcs/epr06activity.html); *Venture Deep Ocean*, website by the Education & Outreach team of Ridge 2000 Program Office, Scripps Institution of Oceanography, University of California, San Diego, 9500 Gilman Drive, La Jolla, CA 92093-0225, USA (URL: http://venturedeepocean.org/expeditions/epr/0605rapid_response.html); *U.S. Geological Survey Earthquake Hazards Program* (URL: http://earthquake.usgs.gov/).

Long Valley

California, USA

37.70°N, 118.87°W; summit elev. 3,390 m

During May 2005 to June 2006, Long Valley caldera was relatively quiet with hazard status remaining at green, the lowest level. During this time, there were two to three small, shallow earthquakes daily; these rarely reached a maximum of M 3 (figure 5). The earthquakes primarily occurred in the Sierra Nevada, an area S of the caldera, S of Mammoth lakes, and W of Tom's Place. The earthquakes were shallow, with focal depths less than 4 km. Deformation was slight. According to geodetic data from June 2006, the largest range of variability was ~ 13 mm, at Hot Creek.

During the second half of 2005, long-baseline tilt measurements revealed little N-S shift. In contrast, there was considerable E-W shift, with a fluctuation from -1.5 µrad around July up to 1.5 µrad in December (figures 6 and 7). The instrument responsible for these measurements, the long-baseline tiltmeter, measures levels in fluid reservoirs separated by ~ 500 m and connected by buried pipes. It records tidal tilts and shows minimal response to diurnal temperature changes along with little secular drift.

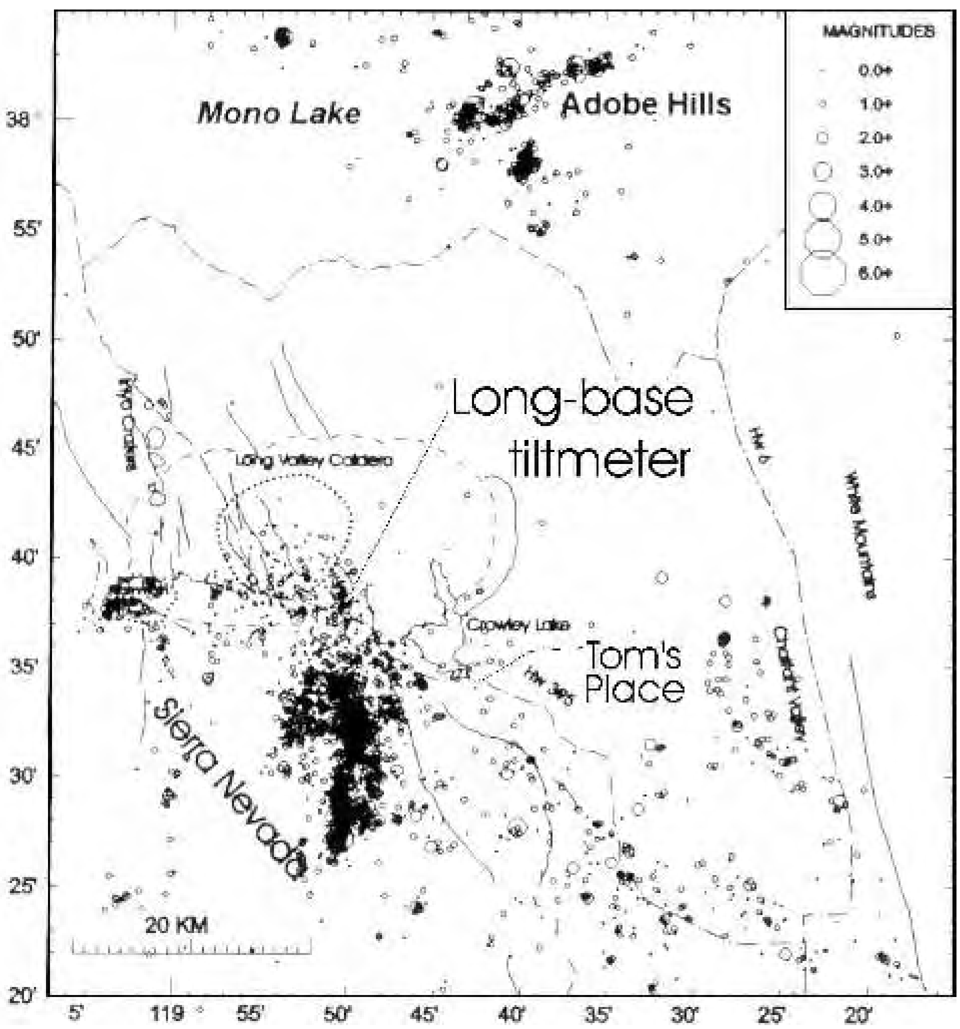

Figure 5. A map of epicenters during 2005 in the area of Long Valley caldera. Courtesy of the Long Valley Observatory (LVO) (combined July-December 2005 and annual summary for 2005 report).

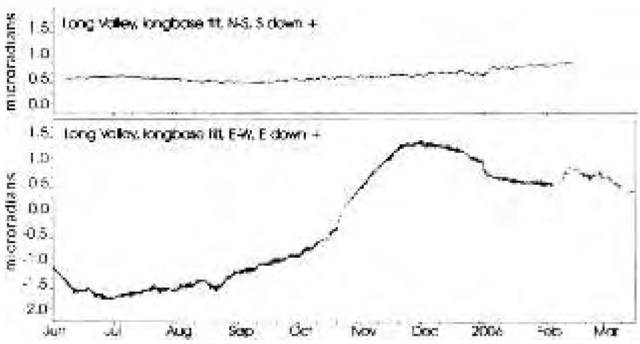

Figure 6. A plot showing the E-W and N-S components of float data from the long-base tiltmeter for 1 June 2005-12 March 2006. Courtesy of LVO.

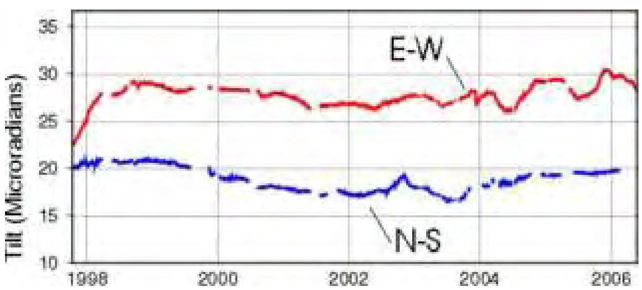

Figure 7. A plot of long-base E-W tilt and N-S tilt versus time from 16 October 1997 to 25 May 2006. Courtesy of LVO.

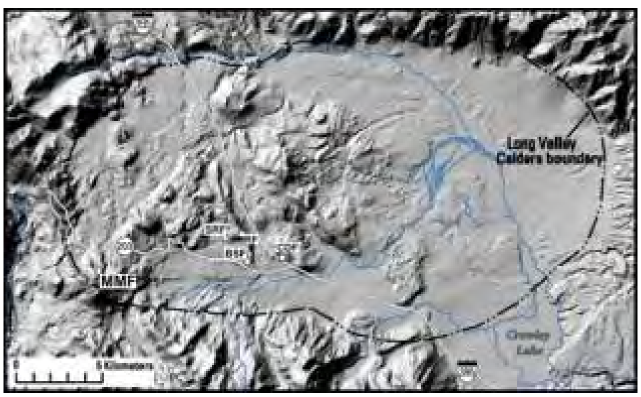

Figure 8. Map of the Long Valley Caldera with fumaroles indicated. The fumarole involved in the ski patrol tragedy, discussed below, is identified as MMF (for Mammoth Mountain fumarole). Courtesy of LVO.

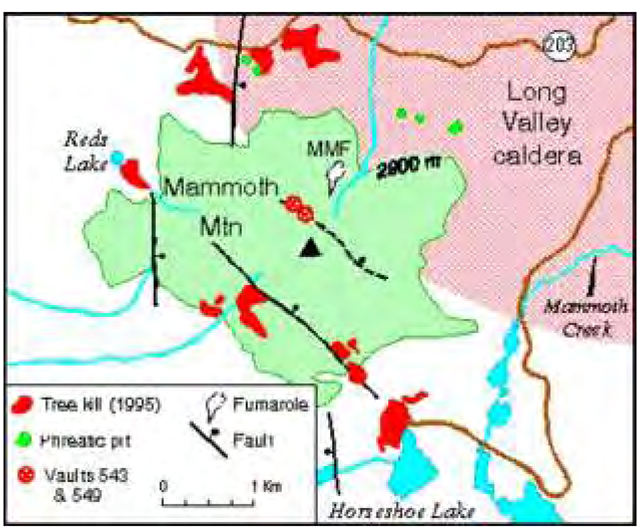

Figure 9. Map of the Mammoth Mountain complex showing both fumaroles and tree-kill areas. Courtesy of LVO.

The caldera's CO_2 flux rate was closely monitored, in some cases hourly. CO_2 levels have been high since 1996, and the effects have included the killing of thousands of trees (figures 8 and 9). At Horseshoe Lake the tree-kill area underwent CO_2 discharge rate of 50-150 tons per day.

Ski-area accident. On 6 April 2006, three ski-patrol officers died when they fell into a 6.4-m-deep hollow, a snow cave, at the Mammoth Mountain ski resort (figure 10). The accident occurred "on Christmas Bowl run, E of Chair 3" explained Mammoth Mountain chief executive officer Rusty Gregory. Geophysicist Dave Hill, from Long Valley Observatory, noted that "the fumarole is roughly 200 m left (looking uphill) of the midpoint along the Chair 3 lift," and "one gets a whiff of H_2S when riding on the chair lift if the wind is right" (figure 10).

Hill further said, "the accident was more weather related than due to any changes in the fumarole. The exceptionally heavy spring snow fall completely covered over the vent, so that the ~ 85°C gases melted a snow cave above the vent (normally the heat from the vent keeps pace with the snow-fall so that the vent is marked by an open hole in the snow several meters in diameter). With no clear sign of the vent at surface, the ski patrol guys evidently didn't realize that, as they were attempting to re-set the fencing around the vent, they were standing directly over the cavity melted by the hot gas. When the roof gave way . . . [they fell] into

Figure 10. Mammoth Mountain fumarole (MMF) as seen during the summer with Chair lift 3 in the background. Vent temperature is measured each hour and recorded on an electronic data logger. Gas chemistry and the isotopic composition of the water have been determined on several occasions. The rationale behind monitoring vent-gas temperatures at MMF is that they may reflect changes in the volcanic system. (MMF is located at 36.38°N, 119.01°W, 3,000 m elevation). Courtesy of LVO.

an atmosphere that was very likely over 90% CO_2. " A third ski-patroller died trying to rescue them.

It was reported by Brendon Riley of the *Tahoe Daily Tribune* that seven other ski patrollers in a rescue party were injured due to the inhalation of dangerous gases from the fumarole. All were recovering.

At an undisclosed date after the accident, Mitch Weber, took pictures of the fenced-off hollow (figure 11). Weber posted these and a narrative regarding the incident in the online magazine he produces, Telemarktips.com, as part of a memorial to the victims.

Hill explained that the LVO's follow-up action, "has been to collect another series of gas samples from the fumarole, which show no change from earlier measurements." Hill also noted that "the ski area has taken steps to fence off a much wider area around the fumarole than before the accident."

The temperatures of all the fumaroles in Long Valley caldera are monitored (figure 12). Although this plot ends in 2005, Hill indicated that the data suggested normal conditions at the fumarole (MMF) at the time of the accident.

Long Valley Observatory posts hazard status as a color code in one of four categories: green, yellow, orange, and red (the most serious response). Details of their response plan appear on the *USGS-Long Valley* website and in a 2002 publication (USGS, 2002).

Figure 11. Photos of the fenced off accident site at Mammoth Mountain ski area adjacent to Long Valley caldera (date unknown). A photo of the lower portion of the hollow (bottom) indicates that at that time the lower walls were steep and the floor was rock. Courtesy of Mitch Weber.

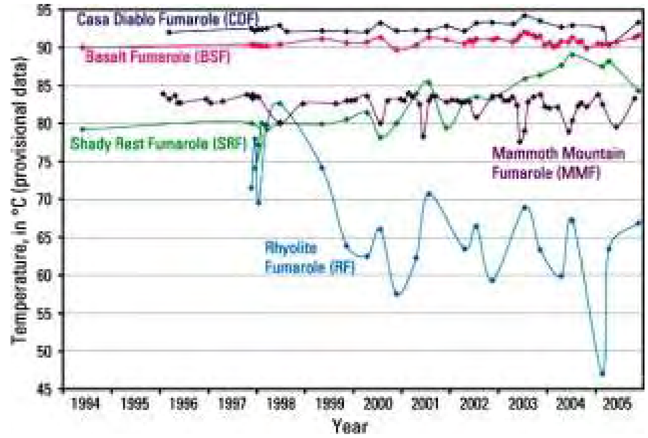

Figure 12. Long Valley fumarole temperatures shown from 1994 to 2005. Courtesy of LVO.

Reference: U.S. Geological Survey, 2002, USGS Response Plan for Volcanic Hazards in the Long Valley Caldera and Mono Craters Region, California: U.S. Geological Survey.

Geologic Summary. The large 17 x 32 km Long Valley caldera E of the central Sierra Nevada Range formed as a result of the voluminous Bishop Tuff eruption about 760,000 years ago. Resurgent doming in the central part of the caldera occurred shortly afterwards, followed by rhyolitic eruptions from the caldera moat and the eruption of rhyodacite from outer ring fracture vents, ending about 50,000 years ago. During early resurgent doming the caldera was filled with a large lake that left strandlines on the caldera walls and the resurgent dome island; the lake eventually drained through the Owens River Gorge. The caldera remains thermally active, with many hot springs and fumaroles, and has had significant deformation, seismicity, and other unrest in recent years. The late-Pleistocene to Holocene Inyo Craters cut the NW topographic rim of the caldera, and along with Mammoth Mountain on the SW topographic rim, are W of the structural caldera and are chemically and tectonically distinct from the Long Valley magmatic system.

Information Contacts: *Dave Hill*, Long Valley Observatory, U.S. Geological Survey, 345 Middlefield Rd., MS 977, Menlo Park, CA 94025, USA (URL: http://lvo.wr.usgs.gov/); *Mammoth Local* (URL: http://www.mammothlocal.com/); *Tahoe Daily Tribune* (URL: http://www.tahoedailytribune.com); *Mitch Weber*, c/o Telemarktips.com, 3 San Bittern Lane, Aliso Viejo, CA 92656, USA (URL: http://www.telemarktips.com/TeleNews55.html, Email: mitch@telemarktips.com).

Cleveland

Aleutian Islands, USA
52.825°N, 169.944°W; summit elev. 1,730 m
All times are local (= UTC -10 hours)

Since an ash cloud was detected on 6 February 2006 (*BGVN* 31:01), observers have documented two brief spurts of activity. On the morning of 2 May beginning at 0101, a thermal anomaly and continuous plume were seen on satellite imagery. The plume extended ~ 50 km SW and was visible on imagery for ~ 6 hours. Satellite data suggested a maximum height of ~ 1 km altitude There was no indication of ash in the cloud. No further activity was detected for several weeks after the 2 May plume. In this interval Cleveland was not assigned a Concern Color Code because there is no real-time seismic network at the volcano.

The second episode took place on 23 May 2006. AVO reported that an astronaut aboard the International Space Station observed an ash plume from Cleveland at 1500. At 1507 satellite imagery showed a plume that drifted SW and reached an altitude of ~ 6.1 km. At 1700, an image showed the detached ash plume 130 km SW of Cleveland. The Concern Color Code was raised to Yellow.

The ash plume had mostly dissipated by 24 May. On 26 May, AVO downgraded the Concern Color Code from Yellow to "Not Assigned."

Geologic Summary. Beautifully symmetrical Mount Cleveland stratovolcano is situated at the western end of the uninhabited, dumbbell-shaped Chuginadak Island. It lies SE across Carlisle Pass strait from Carlisle volcano and NE across Chuginadak Pass strait from Herbert volcano. Cleveland is joined to the rest of Chuginadak Island by a low isthmus. The 1730-m-high Mount Cleveland is the highest of the Islands of the Four Mountains group and is one of the most active of the Aleutian Islands. The native name for Mount Cleveland, Chuginadak, refers to the Aleut goddess of fire, who was thought to reside on the volcano. Numerous large lava flows descend the steep-sided flanks of the volcano. It is possible that some 18th to 19th century eruptions attributed to Carlisle should be ascribed to Cleveland (Miller and others, 1998). In 1944 Cleveland produced the only known fatality from an Aleutian eruption. Recent eruptions from Mount Cleveland have been characterized by short-lived explosive ash emissions, at times accompanied by lava fountaining and lava.

Information Contacts: *Alaska Volcano Observatory* (AVO), a cooperative program of the U.S. Geological Survey, 4200 University Drive, Anchorage, AK 99508-4667, USA (URL: http://www.avo.alaska.edu/; Email: tlmurray@usgs.gov), the Geophysical Institute, University of Alaska, P.O. Box 757320, Fairbanks, AK 99775-7320, USA (Email: eisch@dino.gi.alaska.edu), and the Alaska Division of Geological and Geophysical Surveys, 794 University Ave., Suite 200, Fairbanks, AK 99709, USA (Email: cnye@giseis.alaska.edu); *Earth Observatory*, National Aeronautics and Space Administration (NASA) (URL: http://earthobservatory.nasa.gov/NaturalHarards/).

Sakura-jima

Kyushu, Japan
31.585°N, 130.657°E; summit elev. 1,117 m
All times are local (= UTC + 9 hours)

According to Yukio Hayakawa, on 4 June 2006 Sakura-jima erupted. The vent, which was outside the summit crater, was near or within the crater which issued the 1946 (Showa) lava flow, on the E slope of Minami-dake summit. The eruption continued intermittently until the next morning. A small amount of ash fell in Kagoshima city. In the following days it became calm.

Aviation reports noted that ash clouds that reached unknown heights. No ash was visible on satellite imagery.

On 10 June, the Sakura-jima Volcano Research Center reported an increase in low-frequency earthquakes since mid-March and in small tremors with a less than 2 minute duration since mid-May 2006. A thermal anomaly at the volcano grew in size after February 2006.

This was the first reported Sakura-jima eruption from a vent outside the summit crater in 58 years. The 1946 vent was the source of major lava flows that reached the E and S coasts of the former island.

Our last Sakura-jima report noted the frequent ash plumes and eruptions through May 2004 (*BGVN* 29:05). The Tokyo Volcanic Ash Advisory Center's reports enabled an overview of ash plumes during mid-2005 to mid-2006 (table 3).

Geologic Summary. Sakura-jima, one of Japan's most active volcanoes, is a post-caldera cone of the Aira caldera at the northern half of Kagoshima Bay. Eruption of the voluminous Ito pyroclastic flow accompanied formation of the 17 x 23 km wide Aira caldera about 22,000 years ago. The smaller Wakamiko caldera was formed during the early Holocene in the NE corner of the Aira caldera, along with several post-caldera cones. The construction of Sakura-jima began about 13,000 years ago on the southern rim of Aira caldera and built an island that was finally joined to the Osumi Peninsula during the major explosive and effusive eruption of 1914. Activity at the Kita-dake summit cone ended about 4850 years ago, after which eruptions took place at Minami-dake. Frequent historical eruptions, recorded since the 8th century, have deposited ash on Kagoshima, one of Kyushu's largest cities, located across Kagoshima Bay only 8 km from the summit. The largest historical eruption took place during 1471-76.

Information Contacts: *Hayakawa Yukio*, Gunma University, 4-2 Aramaki-machi, Maebashi City, Gunma, 371-8510, Japan (Email: hayakawa@edu.gunma-u.ac.jp); *Tokyo Volcanic Ash Advisory Center (VAAC)*, Japan Meteorological Agency (JMA), 1-3-4 Ote-machi, Chiyoda-ku, Tokyo 100, Japan (URL: http://www.jma.go.jp/JMA_HP/jma/jma-eng/jma-center/vaac/; Email: vaac@eqvol.kishou.

Date	Event	Plume Type, Height, and Drift
02 Jun 2005	explosion	ash; unknown height
08 Jul 2005	explosion	—
10 Jul 2005	explosion	—
13-19 Jul 2005	explosion	~ 1.8 km height; drifting N
21 Jul 2005	explosion	—
22 Jul 2005	explosion	—
02 Sep 2005	eruption	ash; ~ 2.1 km high; drifting NW
09 Dec 2005	explosion	~ 2.7 km height; drifting S
05 Feb 2006	explosion	~ 1.8 km height; drifting N
19 Apr 2006	explosion	~ 2.4 km height; drifting NE
28 Apr 2006	explosion	ash; 2.1 km height
01 May 2006	explosion	unknown
04-05 Jun 2006	intermittent eruptions	ash clouds; 200-300 m height, unknown drift
07-12 Jun 2006	—	ash; unknown height, drift
14, 16, 19 Jun 2006	—	ash; 2.1 km height

Table 3. Sakura-jima plumes during 2 June 2005-19 June 2006. Courtesy of the Tokyo VAAC.

go.jp); *Sakura-jima Volcano Research Center, Disaster Prevention Research Institute (DPRI),* Kyoto University, Gokasho, Uji, Kyoto 611-0011, Japan (URL: http://www.dpri.kyoto-u.ac.jp).

Karthala

Comoros, western Indian Ocean
11.75°S, 43.38°E; summit elev. 2,361 m
All times are local (= UTC + 3 hours)

Karthala generated two strong eruptions in 2005 (*BVGN* 31:01). This report, based on information from *Kashkazi* (a newspaper in the Comores), discusses the interval May to late July 2006. *Kashkazi* reported that a magmatic eruption on 28 May occurred inside the Chahalé caldera. Lava fountains were seen inside the lava lake. No lava flow was observed outside the caldera. Some bubbling continued in the crater lake through 31 May (figure 13), but the surface on the SE part had solidified.

The news media reported several other events that occurred by the afternoon of 1 June. The lava lake had completely crusted over. Seismicity had returned to background levels. Some gas and ash was released.

According to available sources, the volcano was relatively quiet until a brief 16-18 July eruption. In that eruption a lava lake again formed in the crater and ash was discharged.

A UN official stated in an *IRINnew.org* article, ". . . contamination of the water supply raises serious concerns about the availability of potable water in the areas exposed to smoke and ash." As of 22 July, about 2,000 people had evacuated and 123,000 people lacked clean water supplies.

Geologic Summary. The southernmost and largest of the two shield volcanoes forming Grand Comore Island (also known as Ngazidja Island), Karthala contains a 3 x 4 km summit caldera generated by repeated collapse. Elongated rift zones extend to the NNW and SE from the summit of the Hawaiian-style basaltic shield, which has an asymmetrical profile that is steeper to the S. The lower SE rift zone forms the Massif du Badjini, a peninsula at the SE tip of the island. Historical eruptions have modified the morphology of the compound, irregular summit caldera. More than twenty eruptions have been recorded since the 19th century from both summit and flank vents. Many lava flows have reached the sea on both sides of the island, including during many 19th-century eruptions from the summit caldera and vents on the northern and southern flanks. An 1860 lava flow from the summit caldera traveled ~ 13 km to the NW, reaching the western coast N of the capital city of Moroni.

Figure 13. The lava lake in Karthala's Chahalé caldera, 31 May 2006. The lava lake's surface contained both a churning zone of degassing lava (right center) and a larger adjacent zone largely composed of cooled floating crust. Photo by Julie Morin.

Information Contacts: *IRINnews.org*, United Nations, Office for the Coordination of Humanitarian Affairs (URL: http://www.irinnews.org/);*Kashkazi* .

Piton de la Fournaise

Western Indian Ocean
21.231°S, 55.713°E; summit elev. 2,632 m
All times are local (= UTC + 4 hours)

Piton de la Fournaise exhibited dynamic activity in February and October-December 2005 (*BVGN* 30:11). This report covers January to July 2006. According to the Observatoire Volcanologique du Piton de la Fournaise (OVPF), following the 2005 activity was an eruptive period during 3-18 January 2006. During this time there were lava flows leaving the Plain of Osmondes and descending into the Grandes Pentes.

Seismicity was low from mid-January through March. From March until mid-July, seismicity gradually increased (figure 14), reaching 80 earthquakes on 2 July. From 1 March to the end of June, instruments detected up to 5 cm of horizontal movement at many stations (figure 15).

Although there was a decrease in seismicity on 17 July, on 20 July at 0218 seismicity spiked. At 0400, the summit began erupting (figure 16). A 50-m-long fissure opened on the SW flank and a lava flow went E of Rivals crater. A second 50-m-long fissure opened on the S flank between Rivals and Fort Chateau craters.

On 24 July a small pyroclastic cone formed and lava fountains were visible (figure 16). One lava flow destroyed a new seismic station near Fort Chateau. On 31 July, a 200-m-long lava flow was visible S of the erupting cone. The eruption continued through the end of July. Figure 16 presents a series of photos from the eruption.

Geologic Summary. The massive Piton de la Fournaise basaltic shield volcano on the French island of Réunion in the western Indian Ocean is one of the world's most active volcanoes. Much of its >530,000 year history overlapped with eruptions of the deeply dissected Piton des Neiges

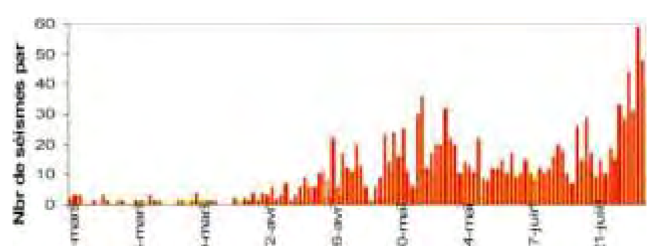

Figure 14. Daily earthquakes at Piton de la Fournaise during 1 March to 1 July 2006. Courtesy of OVPF.

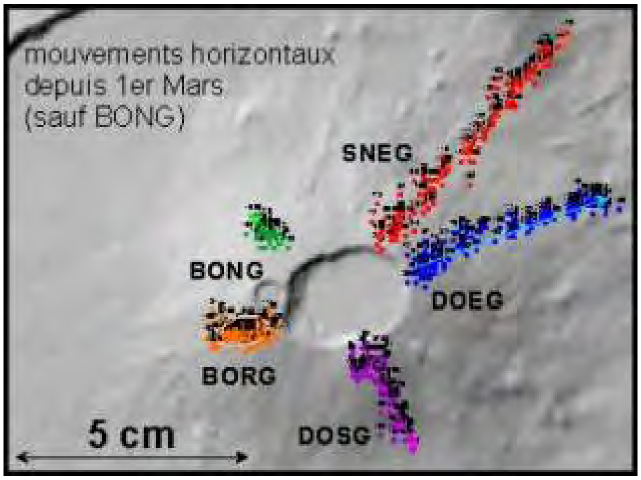

Figure 15. Plot of the horizontal movement of Piton de la Fournaise's stations from 1 March to the end of June 2006. All of the stations had moved horizontally except for BONG, which had shifted in a circular motion during the months of observation. Station SNEG had the greatest horizontal shift, up to 5 cm. Courtesy of OVPF.

shield volcano to the NW. Three calderas formed at about 250,000, 65,000, and less than 5000 years ago by progressive eastward slumping of the volcano. Numerous pyroclastic cones dot the floor of the calderas and their outer flanks. Most historical eruptions have originated from the summit and flanks of Dolomieu, a 400-m-high lava shield that has grown within the youngest caldera, which is 8 km wide and breached to below sea level on the eastern side. More than 150 eruptions, most of which have produced fluid basaltic lava flows, have occurred since the 17th century. Only six eruptions, in 1708, 1774, 1776, 1800, 1977, and 1986, have originated from fissures on the outer flanks of the caldera.

Information Contacts: *Observatoire Volcanologique du Piton de la Fournaise (OVPF)*, Institut de Physique du Globe de Paris, 14 route nationale 3, 27 ème km, 97418 La Plaine des Cafres, La Réunion, France (URL: http://www.ovpf.univ-reunion.fr/); *Serge Gélabert*, 85, rue juliette Dodu, 97400 Saint-Denis, Ile de La Réunion (Email: gelabert.serge@wanadoo.fr; URL: http://www.gelabert.com).

Figure 16. Lava flows and eruptive processes at Piton de la Fournaise, July 2006. The scanty available information about the photos is discussed below. a) Lava flow on the morning of 20 July 2006, the first day of the eruption; courtesy of A. Peltier, OVPF. b) Spattering cone on 24 July 2006; courtesy of T. Staudacher, OVPF. c) Cone at the main vent on the morning of 25 July 2006; courtesy of A. Peltier, OVPF. d) Erupting cone (date undisclosed); courtesy of Serge Gelabert.