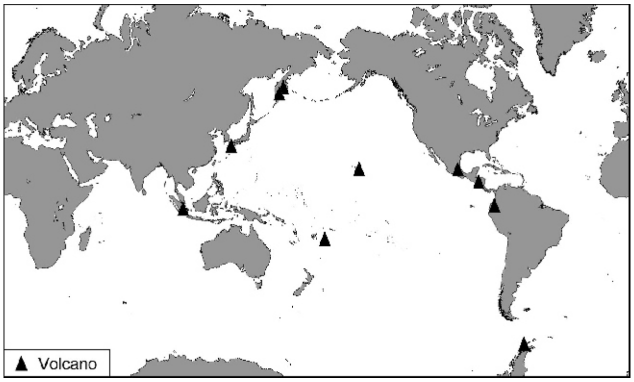
Bulletin of the Global Volcanism Network



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Kliuchevskoi

Kamchatka Peninsula, Russia
56.057°N, 160.638°E; summit elev. 4,835 m
All times are local (= UTC +12 hours)

Significant eruptions resumed in mid-February 2007. Our last report on Kliuchevskoi (*BGVN 32:06)* chronicled activity during April 2005-July 2007. This report covers the period from August 2007 to April 2009.

An eruptive period from February to July 2007 reached peak intensity on 29 June 2007 (*BGVN* 32:06). The ash column was sustained and reached an estimated 8 km high during an 8 hour interval. Plumes reached 2,000 km long. This energetic eruption produced substantial changes to the summit morphology, including removal of the cinder cone on the floor of the summit crater, leaving a deeper crater there. This followed a pattern of earlier substantial morphological change in the summit region during the interval 1968-2007.

Figure 1 shows the pattern of changes during 1968 to mid-2007, but does not show events beyond the time of the 29 June 2007 eruption. Alexey Ozerov (Institute of Volcanology and Seismology, IVS) flew over the volcano during August 2007 and was the first to observe that, following the large eruption, the cinder cone was gone and the crater floor had dropped to an extent that the crater had developed an open capacity of 0.5 km^3. The earlier events shown on figure 1 documents over 600 m of vertical change in the position of the crater floor or the tops of cinder cones on the floor.

Activity during 2008. Preceding the next eruption, increasing seismic activity and thermal alerts were seen during June to October 2008. On 7 August the color code was raised from Green to Yellow due to increased earthquakes and intermittent tremor. A thermal anomaly was registered over the volcano.

Beginning on 8 October observers noted an explosive-effusive summit eruption that included mainly Strombolian activity. On that day the color code was raised to Orange.

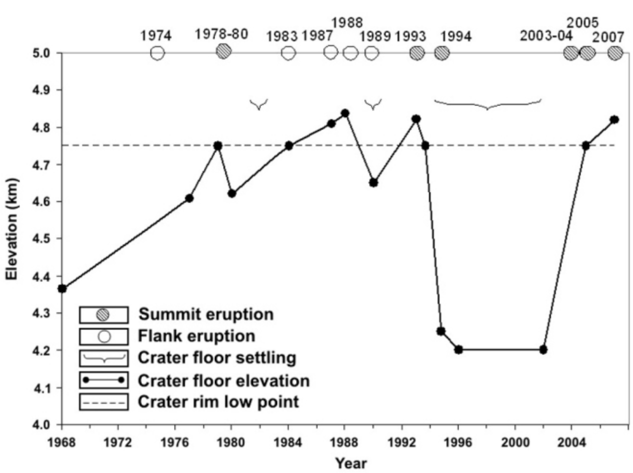

Figure 1. A plot showing the height of the crater floor and intra-crater cones at Kliuchevskoi during 1968-2007. The date of the 29 June 2007 eruption was added by editors, but the extent of post-eruptive topographic changes is not shown. Symbols at the top describe eruption types; crater floor elevation was measured at the dots. After Zharinov and Demyanchuk, 2008.

Figure 2. Strombolian eruption and associated lava flow down the NW flank seen at Kliuchevskoi on 31 October 2008. Photo by Yuri Demyanchuk.

During October-November 2008 analysis of satellite imagery revealed a thermal anomaly in the crater. Lava began filling the crater. Nighttime observers saw the crater rim glowing and lava fountains at least 300 m tall. Extensive lava flows developed by late October (figure 2). From 28 October to 4 November bursting sounds from the volcano were heard in Klyuchi, about 30 km to the NE.

On 21 November 2008, lava flows advanced on the NW slope. They descended to 3 km elevation. Gas-and-steam plumes drifted 80 km NW on 24 November and 20-40 km SE during 25-26 November.

The mostly active period continued from late November 2008 to early January 2009. During 28 November-10 December, Strombolian activity ejected bombs 500 m above the crater and lava effusion on the NW flank continued. Analysis of satellite imagery revealed large daily thermal anomalies in the crater. On 8 December the front of the lava flow made contact with the thick portion of the Erman Glacier, causing phreatic bursts and mudflows (figure 3). A very similar process occurred during the 2007 eruption (*BGVN* 32:06), and the December line of descent was also the same as in 2007. During 8-10 December, ash plumes rose to altitudes of 7.5-8 km, and drifted about 700 km E.

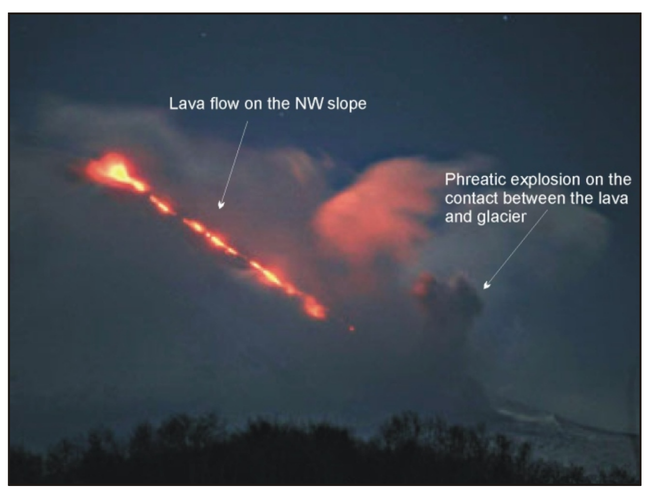

Figure 3. Lava descending Kliuchevskoi's NW slope. Lava from the crater descended over glaciers and where ice was thick in mid-flank areas, phreatic eruptions occurred. Undated photo by Yuri Demyanchuk.

Figure 4. Crossing alpine snow fields at the foot of Kliuchevskoi, a dogsled team pauses as the mountain emits gas and steam plumes on 9 April 2009. Photo by Yuri Demyanchuk.

During the final phase of the eruption (16 January-16 April 2009) the magnitude of volcanic tremor rapidly decreased. The volcano generated ash plumes extending 80-90 km to the NE. Fumarolic activity was seen during last days of April (figure 4).

As noted by Zharinov and Demyanchuk (2008), Shirokov (1985) studied the timing of Kliuchevskoi's volcanic eruptions with respect to lunar cycles. He found that eruptions were associated with a Moon-Earth rotational cycle of 18.6 years duration. According the Zharinov and Demyanchuk (2008), Shirokov (1985) forecast an eruptive interval during May 2006-May 2009.

Reference. Shirokov, V.A., 1985, Some questions method forecast flank eruption at Kliuchevskoi (Kamchatka): Volcanology and Seismology, no. 6, p. 48-58 (in Russian).

Zharinov, N.A., and Demyanchuk, Yu.V., 2008, The summit eruption of Kliuchevskoi volcano in 2007 (Kamchatka): Conference proceedings, dedicated to the day of volcanologists, on 27-29 March, 2008, Petropavlovsk-Kamchatsky: Insitute of Volcanology and Seismology, Far East Division, Russian Academy of Sciences, p. 81-89 (in Russian).

Geologic Summary. Kliuchevskoi is Kamchatka's highest and most active volcano. Since its origin about 6,000 years ago, the beautifully symmetrical, 4,835-m-high basaltic stratovolcano has produced frequent moderate-volume explosive and effusive eruptions without major periods of inactivity. Kliuchevskoi rises above a saddle NE of sharp-peaked Kamen volcano and lies SE of the broad Ushkovsky massif. More than 100 flank eruptions have occurred at Kliuchevskoi during the past roughly 3,000 years, with most lateral craters and cones occurring along radial fissures between the unconfined NE-to-SE flanks of the conical volcano between 500 m and 3600 m elevation. The morphology of its 700-m-wide summit crater has been frequently modified by historical eruptions, which have been recorded since the late-17th century. Historical eruptions have originated primarily from the summit crater, but have also included numerous major explosive and effusive eruptions from flank craters.

Information Contacts: *Kamchatka Volcanic Eruptions Response Team (KVERT)*, Institute of Volcanology and Seismology (IVS), Kamchatka Branch of the Geophysical Service of the Russian Academy of Sciences (KB GS RAS), Far East Division, Russian Academy of Sciences, Piip Ave. 9, Petropavlovsk-Kamchatsky, 683006, Russia (URL: http://www.kscnet.ru/ivs/; http://www.kscnet.ru/ivs/kvert/current/klch/index.html); *Olga Girina* and *Yuri Demyanchuk*, KVERT, Institute of Volcanology and Seismology (IVS); *Alexei Ozerov*, Active Volcanism Laboratory, Institute of Volcanology and Seismology (IVS).

Koryaksky

Kamchatka Peninsula, Russia
53.320°N, 158.688°E; summit elev. 3,456 m
All times are local (= UTC +12 hours)

Koryaksky ended ~ 51 years without fumarolic activity with an eruption late in 2008. Activity that began on about 24 December 2008 continued through 5 March 2009 (*BGVN* 34:01). Fresh ash deposits in early March could be seen on both the summit, E, and SSW slopes of Koryaksky, and on the NNW slope of Avachinsky (figure 5). Between the two volcanoes, the early March ash deposits reached 1-2 mm thick.

Numerous plumes were observed during this reporting interval, 6 March to mid-April 2009 (table 1). A report from 8-14 April noted the presence of two vents on the NW flank. A small SO_2 plume was noted on 20 April. Seismicity often fluctuated, with considerable intervals at background level punctuated by intervals where it was elevated. Occasional tremor was recorded, but it was often weak (low amplitude).

Figure 5. (top) Ash plume from Koryaksky (peak at left) extending to the ESE in an eruption that left deposits of ash on Koryaksky and Avachinsky (peak at right). (bottom) Ash deposits on Koryaksky on the same date. Both photos from the town of Petropavlovsk-Kamchatsky on 7 March 2009 by A. Sokorenko.

KVERT reported that seismic activity at Koryaksky was elevated on 6 and 8 March and at background levels during 7 and 9-13 March. Observers reported that gas plumes containing a small amount of ash rose to an altitude of 4 km and drifted in multiple directions during the week of 11-17 March. The plumes were also seen on satellite imagery.

An eruption on 9 April 2009 followed an increase in the number of local earthquakes and tremor during the previous month (figure 6). The total number of earthquakes during February 2008-December 2008 was 717. That was less than the total of 766 for the first four months in 2009, which were as follows: January, 58; February, 195; March, 239; and April, 274. High level gas-steam and ash emissions occurred during March-April. Some plumes extended more than 200 km (table 1).

On 9 April a photo was taken showing a strong ash plume emerging from fissures in the glacier on Koryaksky's NW flank. On 13 April a flight over the area enabled scientists to measure temperature around two vents (figures 7 and 8). Temperatures of the vent areas reached 400°C. This situation was attributed to glacial instability owing to melting parts of the glacier near the vents.

Geologic Summary. The large symmetrical Koryaksky stratovolcano is the most prominent landmark of the NW-trending Avachinskaya volcano group, which towers above Petropavlovsk-Kamchatsky. Erosion has produced a ribbed surface on the eastern flanks of the 3456-m-high volcano; the youngest lava flows are found on the upper western flank and below SE-flank cinder cones. No strong explosive eruptions have been documented during the Holocene. Extensive Holocene lava fields on the western flank were primarily fed by summit vents; those on the SW flank originated from flank vents. Lahars associated with a period of lava effusion from S- and SW-flank fissure vents about 3,900-3,500 years ago reached Avacha Bay. Only a few moderate explosive eruptions have occurred during historical time. Koryaksky's first historical eruption, in 1895, also produced a lava flow.

Information Contacts: *Kamchatka Volcanic Eruptions Response Team (KVERT)*, Institute of Volcanology and Seismology (IV&S), Far East Division, Russian Academy of Sciences (FED RAS), Piip Ave. 9, Petropavlovsk-Kamchatsky, 683006, Russia (Email: kvert@kscnet.ru, URL: http://www.kscnet.ru/ivs/); Kamchatka Branch of the Geophysical Service, Russian Academy of Sciences (KB GS RAS), Piip Ave. 9, Petropavlovsk-Kamchatsky, 683006, Russia (http://emsd.iks.ru/~ssl/monitoring/main.htm); *Alexander Sokorenko* and *Sergey Ushakov*, IV&S; *Kamchatkan Experimental and Methodical Seismological Department (KEMSD)*, GS RAS, Russia; *Tokyo Volcanic Ash Advisory Center (VAAC)*, Tokyo, Japan (URL: http://ds.data.jma.go.jp/svd/vaac/data/)

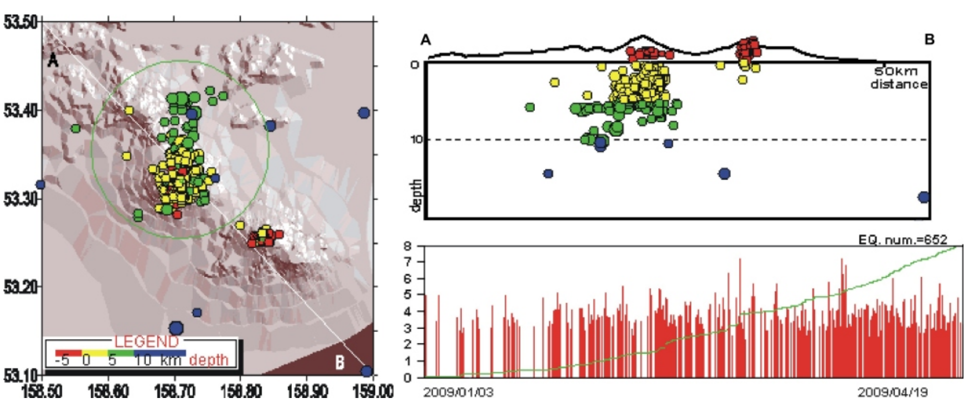

Figure 6. Seismicity of Koryaksky (and Avachinsky, to the SE) recorded during January-April 2009. Map (left) shows location and depths of earthquakes (white line is cross-section AB; 20-km-diameter circle encloses epicenters of earthquakes plotted on histogram. Cross-section shows hypocenters projected onto the vertical plane along AB. Histogram shows daily Koryaksky earthquakes with respect to time; ascending curve is the cumulative number of earthquakes (reaching a total of 652 for the interval). Courtesy of the Kamchatka Branch of the Geophysical Service of the Russian Academy of Sciences (KB GS RAS).

Date (2009)	Observations	Drift direction(s)
08 Mar	Ash reported	—
10 Mar	Ash plume rose to 3.7 km	SE
11-12 and 15 Mar	Ash plumes rose to 3-5.2 km	S, SE, E, and N
18 Mar-24 Mar	Gas plumes containing a small amount of ash rose to 4 km. On satellite imagery plumes drifting up to 140 km away from the volcano. Ash was emitted from the upper fumarolic vent and covered the flanks.	E
25 Mar-31 Mar	Gas plumes containing a small amount of ash to 3-4 km. (On 25th and 26th, gas-and-ash plumes seen on satellite imagery drifting to 225 km SE.)	S, SE, W and NW
01 Apr-07 Apr	Gas plumes containing a small amount of ash rose to 4 km. (During 27-28 and 31 March, and 1-2 April, gas-and-ash plumes were also seen on satellite imagery and drifted 313 km E, in southerly directions.)	E, SE, S, and W
08 Apr-14 Apr	Gas plumes containing a small amount of ash originating from two vents on the NW flank rose to an altitude of 5.4 km. (Plumes were also seen on satellite imagery and drifted 290 km in multiple directions. On 11 April, KVERT staff reported ashfall in Petropavlovsk-Kamchatsky (30 km S). Ash accumulated to 0.1-2.5 cm thickness near the Institute of Volcanology and Seismology (IVS) FED RAS.)	NE, NW, SE, and SW during the reporting period.
15 Apr-21 Apr	Gas-and-ash plumes to 3.7-4.6 km altitude; on satellite imagery (drifting 30-680 km)	Multiple directions, including S, SW, W, NE.
17 Apr-18 Apr	Gas plumes containing a small amount of ash drifted in multiple directions. Gas-and-ash plumes seen on satellite imagery drifted 100 km NE. (On 20 April a sulfur dioxide plume extended about 15 km.)	—

Table 1. A compilation of eruptive plume behavior from Koryaksky based on information from the Yelizovo Airport, KVERT, and KEMSD (the Kamchatkan Experimental and Methodical Seismological Department). The data were initially compiled by the Tokyo VAAC in reports for aviators in an effort to avoid aircraft encounters with volcanic ash. Few of the plumes were considered ash rich, most were considered as gas plumes containing small amounts of ash. Courtesy of the Tokyo VAAC.

Figure 7. A photo taken from Petropavlovsk-Kamchatsky (~ 35 km N of the volcano) illustrating powerful ash-bearing emissions from the NW flank of Koryaksky. Photo taken by Sergei Ushakov 9 April 2009.

Figure 8. A photo showing two vents on the NW flank of Koryaksky. The upper plume is ash rich, the other contains only gas and steam. Photo taken by Alexander Sokorenko on 18 April 2009.

Sakura-jima

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

Our last reports on Sakura-jima (*BGVN* 31:06 and 32:04) discussed an eruption from Showa crater on 4 June 2006, the first eruption outside the summit crater since 1946. It also provided a chronology of plume observations between 7 June 2006 and 20 March 2007.

The current report continues the chronology of plume observations from 20 March 2007 to 24 April 2009 (table 2). Most of the plumes described since 20 March 2007 did not exceed 3 km altitude (figure 9). The tallest plume recorded on the table, an ash plume on 9 April 2009, rose to about 5 km altitude.

On 19 February 2009 JMA lowered the Alert Level from 3 to 2, because after the 1-5 February explosions, no eruptions had occurred either from Showa crater or Minamidake summit crater, seismicity was low, and no crustal deformation was observed (figure 10). As a result of heightened activity, the Alert Level was raised to 3 on 2 March, but dropped to 2 on 24 April 2009 due to low seis-

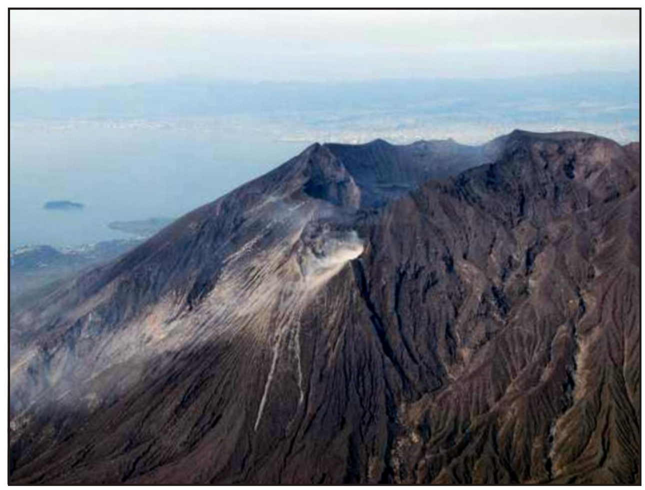

Figure 9. Aerial photograph taken from the W of a plume from Sakura-jima's Showa crater as seen on 10 March 2009. Courtesy of JMA.

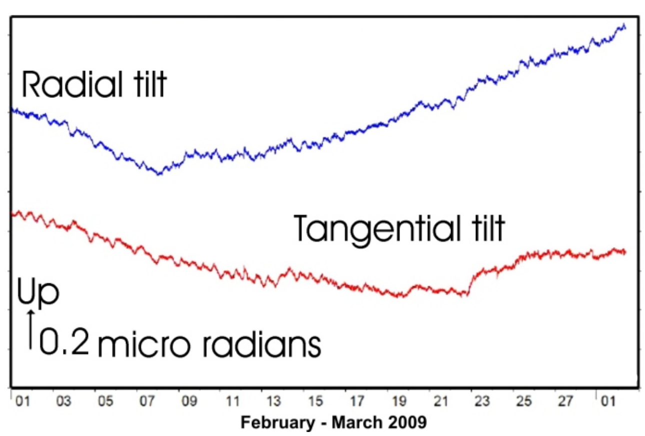

Figure 10. Sakura-jima tilt recorded at Arimura during February 2009. The vertical axis indicates the sense and magnitude of movement. Data from Osumi Kasen Kokudo (Japan's Ministry of Land, Infrastructure, Transport and Tourism). Courtesy of JMA.

Date(s)	Plume altitude/drift	Observations
16 May 2007	1.2-2.7 km/ NW	—
20-22 May 2007	1.2-2.7 km/ up	—
23-24, 26-28 May 2007	1.8-2.1 km/ E, SE, up	—
31 May-01 Jun 2007	2.1-2.4 km/ up	—
04 Jun-05 Jun 2007	2.1-2.4 km/ W, NW, E	Ash not detected by satellite imagery.
08, 10, 11 Jun 2007	2.1 km/ S	Ash not detected by satellite imagery.
16 Jun 2007	—	Explosion. Ash not detected by satellite imagery.
20-21 Jun 2007	2.4 km/N	Ash not detected by satellite imagery.
04 Aug 2007	—	Explosion. Ash not detected by satellite imagery.
29 Oct 2007	3.7 km/E	—
23-24 Dec 2007	2.7 km/S	—
02, 07 Jan 2008	—	Explosions reported.
03 Feb 2008	1.5-2.7 km/ SE	Ash not detected by satellite imagery.
05-06 Feb 2008	1.2-2.1 km/ SE	Ash not detected by satellite imagery.
11-15 Apr 2008	2.1-3.4 km/ various	—
19 Apr 2008	4.6 km/E	Plume contained ash.
20, 23-30 Apr 2008	2.4 km/various	—
06-07 May 2008	2.4-3.4 km/S	—
08 May 2008	4 km/E	—
15-22 May 2008	1.8-3.4 km/various	—
24 May 2008	—	Explosion reported.
30 May-01 Jun 2008	2.1-3 km/various	—
09 Jun 2008	2.1 km/S	—
10-11 Jun 2008	—	Explosions reported.
12-13 Jun 2008	3.4 km/various	Plumes contained ash.
28 Jun 2008	—	Explosion reported.
05 Jul 2008	2.7 km/E	—
10,13 Jul 2008	2.7 km	Plumes contained ash.
25-28 Jul 2008	2.4-4.3 km/various	Plumes contained ash.
10 Aug 2008	>2.7 km/NW	—
23 Aug 2008	—	Explosion reported.
07 Sep 2008	2.1 km/straight up	—
03 Oct 2008	2.7 km	—
09, 15 Jan 2009	2.4, 1.8 km/SE	—
28 Jan -03 Feb 2009	1.8-3.4 km/various	—
01-02 Feb 2009	—	Eight eruptions; bombs up to 800 m from Showa crater. On 2 Feb, JMA Alert level to 3.
04-05 Feb 2009	2.1-2.4 km/SE	Explosions and eruptions.
09-12 Feb 2009	0.6-2.4 km/SE	Ash plumes.
19 Feb 2009	—	JMA lowered Alert Level to 2.
22 Feb 2009	2.7 km/N	Explosion.
28 Feb-04 Mar 2009	1.8-3 km/S	Eruptions or explosions, three Vulcanian explosions from Showa crater ejected bombs up to 1.3 km. Deformation; expansion of edifice (tiltmeter). On 2 Mar, JMA Alert Level to 3.
07-10 Mar 2009	1.8-2.9 km/N, S	Twelve Vulcanian explosions from Showa crater. Ejected bombs up to 1.8 km.
14 Mar 2009	1.5-2.1 km/SE, E	Two Vulcanian explosions ejected bombs up to 800 m.
17 Mar 2009	2.1 km/E	Eruption.
20, 23 Mar 2009	—	Explosions; weak incandescence on 23rd.
26 Mar 2009	—	Eruption.
27-30 Mar 2009	2.1 km/SE	Weak eruptions, strong steam emissions.
05-07 Apr 2009	2.1-3 km/SE, S	Explosions and eruptions.
08 Apr 2009	2.7 km	Eruption.
09 Apr 2009	~ 5 km/SW	Vulcanian explosion, pyroclastic flow to 1 km E, bombs to 1.3 km, heavy ashfall at Kagoshima City.
10 Apr 2009	2.1-2.7 km/W, S	—
24 Apr 2009	—	JMA lowered alert level to 2.

Table 2. Heights and drift of plumes and their character at Sakura-jima from 20 March 2007 to 24 April 2009. Courtesy of Tokyo Volcanic Ash Advisory Center, pilot reports, and the Japan Meteorological Agency (JMA). Times and dates are local.

micity, lack of deformation, and absence of large eruptions. According to JMA, the shape of Showa crater has not changed recently, but the depth of the crater had increased. Photographs taken during an overflight on 10 March 2009 (figures 11 and 12) showed changes in morphology and temperature.

An article in Asahi newspaper contained several photos of the 9 April 2009 ashfall in Kagoshima City, about 10 W of Sakura-jima. This was the heaviest ashfall since October 2002.

During the last two years, the only thermal anomaly recorded by MODIS-MODVOLC for Sakura-jima was on 17 December 2008 (1 pixel).

Two recently published articles (citations below) describe the mechanism of explosive eruptions at Sakura-jima and two other Japanese volcanoes, and color measurements of Sakura-jima's ash deposits.

References: Iguchi, M., Yakiwara, H., Tameguri, T., Hendrasto, M. and Hirabayashi, J. , 2008. Mechanism of explosive eruption revealed by geophysical observations at the Sakurajima, Suwanosejima and Semeru volcanoes: Journal of Volcanology and Geothermal Research, v. 178, no. 1, p. 1-9.

Yamanoi, Y.,Takeuchi Y., Okumura S., Nakashima S., and Yokoyama, T., 2008. Color measurements of volcanic ash deposits from three different styles of summit activity at Sakurajima volcano, Japan: Conduit processes recorded in color of volcanic ash: Journal of Volcanology and Geothermal Research, v. 178, no. 1, p. 81-93.

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.

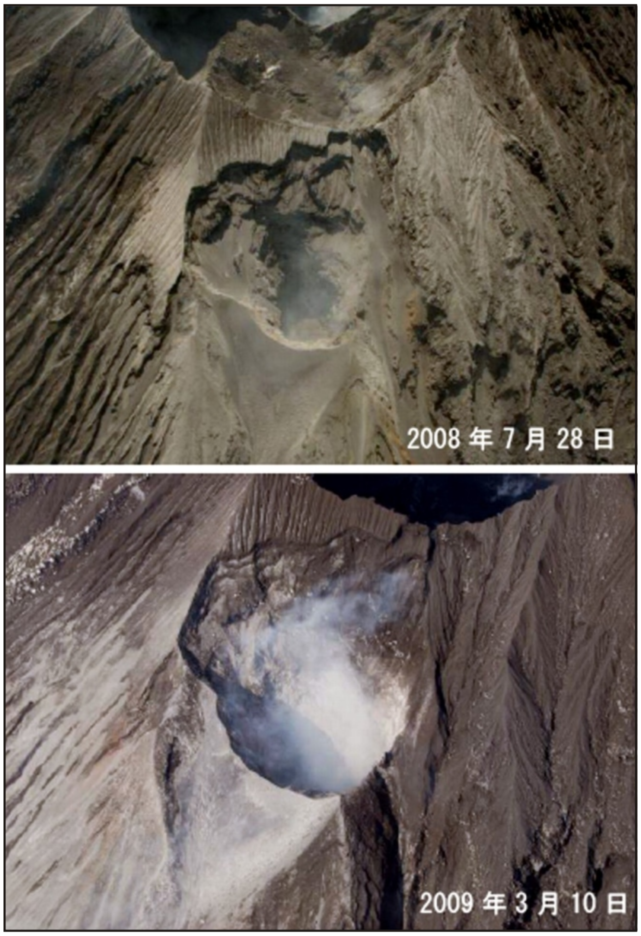

Figure 11. A comparison of the morphology of Sakura-jima's Showa crater: (top) 28 July 2008, (bottom) 10 March 2009. Courtesy of JMA.

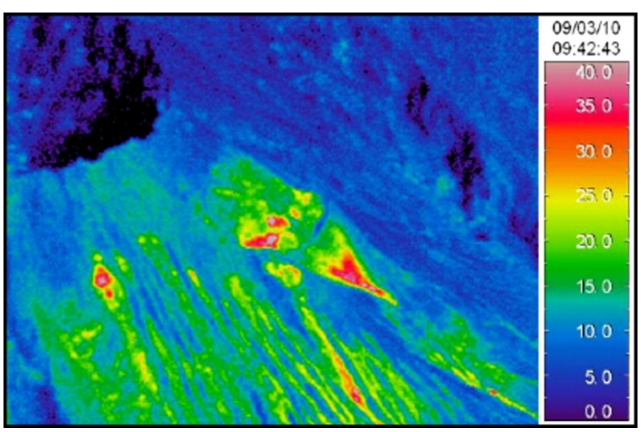

Figure 12. N-looking infrared photo of Sakura-jima's Showa crater on 10 March 2009. Scale at right shows the estimated temperature (°C). Note the high temperature in Showa crater. The crater rim at higher elevation (upper left) is called Minami-dake ("M" on the geologic map in the previous issue). Courtesy of JMA.

Information Contacts: *Japan Meteorological Agency (JMA)*, Otemachi, 1-3-4, Chiyoda-ku Tokyo 100-8122, Japan (URL: http://www.jma.go.jp/jma/indexe.html); *Tokyo Volcanic Ash Advisory Center (VAAC)*, Tokyo, Japan (URL: http://ds.data.jma.go.jp/svd/vaac/data/); *Hawai'i Institute of Geophysics and Planetology (HIGP) Thermal Alerts System*, School of Ocean and Earth Science and Technology (SOEST), Univ. of Hawai'i, 2525 Correa Road, Honolulu, HI 96822, USA (URL: http://hotspot.higp.hawaii.edu/); *Yukio Hayakawa*, Gunma University, Faculty of Education, Aramaki 4-2, Maebashi 371-8510, Japan (Email: hayakawa@edu.gunma-u.ac.jp); *Asahi newspaper* (URL: http://www.asahi.com/national/update/0409/SEB200904090017.html).

Kilauea

Hawaiian Islands, USA
19.421°N, 155.287°W; summit elev. 1,222 m
All times are local (= UTC - 10 hours)

The long-term eruption of Kilauea, continuing since January 1983, is well documented in reports issued by the Hawaiian Volcano Observatory (HVO) and in the literature (eg., Poland and others, 2008), and is thus only episodically covered in our *Bulletin*. This report begins bringing coverage up to date by summarizing activity during the last half of 2007. Events included lava returning to Pu`u `O`o on 2 July, a fissure eruption on 21 July, and the Thanksgiving Eve Breakout (TEB) on 21 November. This report starts with a discussion of the Father's Day Intrusion, or Episode 56, an event heralded by increased summit activity on 17 June 2007 (*BGVN* 32:06).

Father's Day Intrusion (Episode 56) and Pu`u `O`o activity. According to HVO, on Father's Day, 17 June 2007, a swarm of earthquakes and rapid deflation began at 0215 in the upper E rift zone. The earthquakes were centered under Pauahi Crater ~ 1 km SW of the Mauna Ulu shield volcano, and ~ 1.5-3 km deep. Rapid ground tilting was detected at Mauna Ulu. About 70 earthquakes were recorded in the first 2 hours; at least ten of those were M 3 or greater. National Park Service (NPS) crews evacuated visitors and closed the Chain of Craters road and part of the Crater Rim drive.

Fresh cracks about 2 cm wide opened in the Chain of Craters road near the turnoff to Mauna Ulu. Within a few hours, GPS receivers in the area of most intense seismic activity documented an approximate 10 cm of widening across the rift zone, near Makaopuhi crater. The deformation and earthquakes were inferred as associated with magma intrusion that started in the Mauna Ulu area early on 17 June and subsequently moved slowly 6 km E along the East rift zone. HVO observers noted rockfalls from the S wall of Pu`u `O`o cone and collapse of the crater floor around the vents. Some parts of the crater floor subsided up to 80 m within a few days.

On 18 June, the earthquake swarm slowed to ~ 10-15 small earthquakes per hour. Strong tremor beneath the summit was recorded and deflation continued. GPS receivers continued to show extension across the East rift zone, to ~ 100 cm in some areas. Between 18 and 19 June, a new 50-m-long lava flow emerged from a 200-m-long fissure in the forest NE of Kane Nui o Hamo, about 6 km W of Pu`u `O`o. Steam plumes were spotted on the N flank of Kane Nui o Hamo (figure 13).

On 20 June, seismicity and extension decreased on the East rift zone. HVO scientists measured highly elevated sulfur dioxide gas concentrations, greater than 10 parts per million (ppm), in a broad area adjacent to Halema'uma'u crater. Elsewhere typical concentrations were generally negligible except for areas downwind of Halema'uma'u crater, where they reached up to 2.5 ppm in narrow zones.

During 21 June-1 July 2007, no fresh lava was visible on the flow field or at the site of the 18-19 June eruption. The summit area continued to inflate very slowly and seismic tremor values at Pu`u `O`o were below pre-June 17 levels. Ground-based mapping of the new lava flow indicated the eruption occurred from two places along the fissure, separated by ~ 40 m. The intrusion and extension processes had drained a substantial amount of magma from the summit reservoir; Pu`u `O`o's crater collapsed to a level 100 m deeper and the lava tubes drained.

***Lava in Pu`u `O`o Crater (Episode 57).*** On 2 July, HVO scientists saw new lava flows at the bottom of the collapsing Pu`u `O`o crater; incandescence had last been seen there on 18 June. Two vents feeding the lake were identified: the W vent, initially the most active, and the E vent (figure 14). During 3-13 July, a lava lake grew and filled the crater to within 30 m of the rim. On the S wall of West Gap pit, intermittent incandescence and fuming from new vents that opened were observed during 13-14 July. In addition, the level of the lava lake dropped but lava continued to emit from the E vent. On 15 July, the E and W vents erupted small lava flows that drained onto the solidifying lava lake bed. Low lava fountains extruded from West Gap pit. Within a few days, lava filled the pit and overflowed into the main crater.

During 18-21 July, the E vent and dominant W vent in Kilauea's Pu`u `O`o produced lava flows. New vents opened in the Puka Nui pit, in the SSW area of Pu`u `O`o crater, and produced lava flows that ponded there. A low lava fountain occasionally fed the lake from the vicinity of a spatter cone; an unseen source also fed the lake from the NW edge. A vent high on the S crater wall, adjacent to the

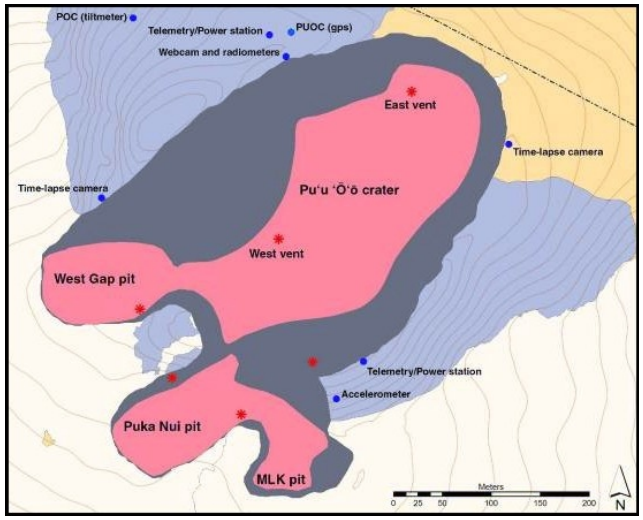

Figure 14. Map of the Pu`u `O`o crater as of 20 July, 2007. The dark gray shaded area represents the composite area of collapse, including the main crater and flank vent pits, following the Father's Day event. The key identifies new lava (episode 57) erupted at Pu`u `O`o shown in light red in colored versions; areas mainly in the center of the crater. Vents active during episode 57 are shown as asterisks. Courtesy of USGS-HVO.

Puka Nui Gap pit, produced spatter and propelled lava bombs 10 m into the air. Meanwhile, the lava lake in the West Gap pit continued to fill, overturn, and occasionally overflow. The spatter cone that built up around the S wall vent in West Gap pit was submerged beneath the lava lake surface on 20 July. Uplift of the crater interior continued. Earthquakes occurred beneath the upper E rift zone, S flank, and Halema'umau crater.

Fissures A-D. Late on 20 July, a tiltmeter recorded a nearly 300 microradian of change as Pu`u `O`o's crater floor started to subside. Early on 21 July, the West Gap lava lake and Puka Nui pit drained. A new eruption initiated along a set of fissures (figure 15) that extended 1.7 km E from a point about 150 m E of the E rim of Pu`u `O`o crater.

Preliminary reports described two 600-800 m long, left-stepping, ENE-trending fissures between Pu`u `O`o and Kupaianaha. The easternmost fissure fed two lava flows, the longer of which reached ~ 2 km SE from the fissure. The lower fissure consisted of three segments, making a total of four. The four fissure segments, A, B, C, and D, defined an approximately 2 km-long line (figure 16).

The westernmost fissure (segment A) was inactive by 21 July and the uppermost segment of the active lower fissure (segment B) was completely sealed by mid-morning on 22 July. The rest of the fissure erupted lava fountains 6-8 m high, constructing several small perched ponds that occasionally overflowed to feed a few longer lava flows. These formed as the edges of pools of lava hardened to create confining walls. These walls enabled the pond's surface to be much higher, in some cases as much as 18 m or

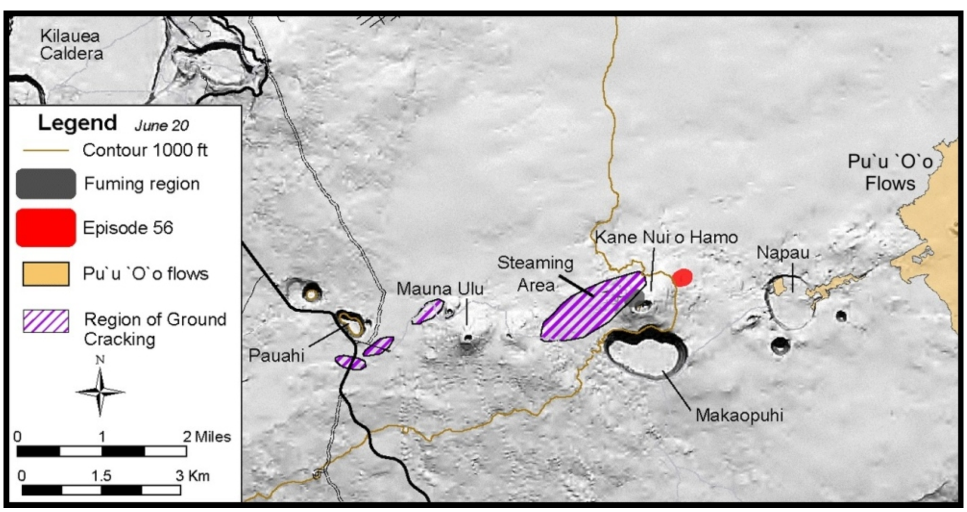

Figure 13. Map of Kilauea's Father's Day Intrusion showing Kilauea caldera and key features and activity near the Makaopuhi crater on 20 June 2007. A small lava flow erupted from a 250-m-long fissure in the forest NE of Kane Nui o Hamo. The lava was cooling and not advancing when observed at 0700 on 19 June. Courtesy of USGS-HVO.

higher than the surrounding land. The ponds were as large as 200 m in diameter.

During 23 July to mid-August, fissure segments C and D fed perched lava ponds created by the NE-advancing `a`a flow. The ponds both grew in thickness and spilled lava over the levees along their edges, or at breaches. By 31 July, segment B had become inactive. By about 12 August, lava ceased extruding at segment C.

During the rest of August through most of November, fissure segment D continued to feed advancing `a`a lava flows that frequently escaped the confines of the levees. Lava flows that branched from the main channel continued to advance, widening and lengthening the flow field. Lava occasionally escaped from lava tubes.

Fissure D and TEB. On 21 November, lava escaped from a perched channel near fissure D. This lava flow became known as the TEB (Thanksgiving Eve Breakout). The bypass of lava from the channel to the surface resulted in an estimated 10 m drop in channel levels. The redirected lava quickly formed two channelized pahoehoe flows; one advanced 300 m N and the second flow advanced 1 km SE.

During 23-27 November, lava built a low shield over the TEB and fed one flow that advanced 2 km. A small lava pond at the top of the TEB shield overflowed and fed lava flows in multiple directions. Clear web-camera views on 9 and 10 December revealed that the TEB shield continued to build vertically and was then an estimated 15 m high. On 16 December, a 4-5-m-high hornito at the summit of the TEB shield was active. On 17 December, fume puffed from the top of the shield about every 15-20 minutes when visible.

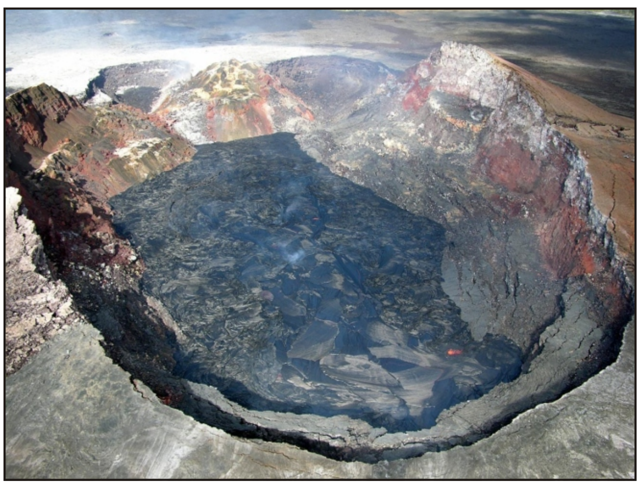

Figure 15. Aerial view at Kilauea showing Pu`u `O`o crater looking WNW on the morning of 13 July 2007. Viewers saw two active vents in the collapsed crater floor. The incandescent E vent is near the lower right part of the crater bottom, and the W vent (less incandescent in this image) is near the middle of the image. Courtesy of USGS-HVO.

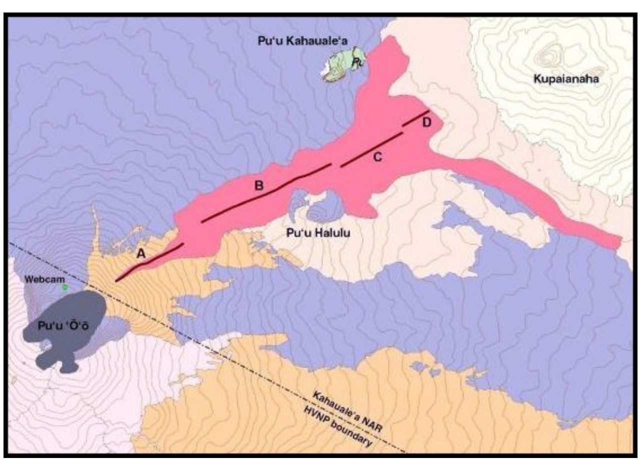

Figure 16. Map showing Kilauea's eruptive fissure segments A, B, C, and D and aerial extent of lava flows from the 21 July eruption (as documented that day). Courtesy of USGS-HVO.

An overflight on 20 December revealed that lava from fissure D built up two more shields SE of the TEB shield. These shields were considered "rootless shields." That term is described by HVO scientists as "...smaller, shield-shaped mounds that form on active lava flows [and] are fed by shallow lava tubes that flow just below the surface."

During 25 December-1 January lava escaped at both the TEB shield and two satellitic shields. Short lava flows travelled SE and N.

Reference: Poland, M., Miklius, A., Orr, T., Sutton, J., Thornber, C., and Wilson, D., 2008, New episodes of volcanism at Kilauea volcano, Hawaii: EOS, Transactions of the Am. Geophys. Union, v. 89, no 5, p. 37-38, 29 January 2008.

Geologic Summary. Kilauea volcano, which overlaps the E flank of the massive Mauna Loa shield volcano, has been Hawaii's most active volcano during historical time. Eruptions of Kilauea are prominent in Polynesian legends; written documentation extending back to only 1820 records frequent summit and flank lava flow eruptions that were interspersed with periods of long-term lava lake activity that lasted until 1924 at Halemaumau crater, within the summit caldera. The 3 x 5 km caldera was formed in several stages about 1,500 years ago and during the 18th century; eruptions have also originated from the lengthy E and SW rift zones, which extend to the sea on both sides of the volcano. About 90% of the surface of the basaltic shield volcano is formed of lava flows less than about 1,100 years old; 70% of the volcano's surface is younger than 600 years. A long-term eruption from the E rift zone that began in 1983 has produced lava flows covering more than 100 sq km, destroying nearly 200 houses and adding new coastline to the island.

Information Contacts: *Hawaiian Volcano Observatory (HVO),* U.S. Geological Survey, PO Box 51, Hawai'i National Park, HI 96718, USA (URL: http://hvo.wr.usgs.gov/; Email:hvo-info@hvomail.wr.usgs.gov).

Dempo

Sumatra, Indonesia
4.03°S, 103.13°E; summit elev. 3,173 m

Our most recent report on Dempo (*BGVN* 34:01) discussed a phreatic eruption on 1 January 2009. This eruption prompted Indonesia's Center of Volcanology and Geological Hazard Mitigation (CVGHM) to raise the alert level from 1 (normal) to 2 (alert) on a scale of 1-4. A few months later, on 23 March 2009, the CVGHM lowered Dempo's Alert Level to 1, based on visual observations of the crater lake during 5-6 January and 2-4 March, and decreased seismicity since the 1 January phreatic eruption.

The name Dempo applies to both the larger complex and to a peak that sits adjacent to a neighboring peak called Marapi. The latter volcano name applies to several different volcanoes in Indonesia and is easily confused with the very prominent volcano Merapi (central Java). The Marapi cone in the Dempo complex contains a ~ 400 m diameter crater lake, the source of both the 2006 and 2009 eruptions.

The remainder of this report discusses the phreatic eruption that occurred in September 2006. This eruption had not been previously discussed in the *Bulletin*, and CVGHM reporting on the subject has recently come to our attention.

Figure 17. Photo of the plume resulting from Dempo's phreatic eruption on 25 September 2006. This is one of a set of multiple photos taken of a rising plume. Photo by Fredy, a local resident. Courtesy of CVGHM.

Figure 18. (top) Pre-eruption and (bottom) post-eruption scenes from the saddle between the cones of Dempo and Marapi looking upslope towards Marapi (which contains the source vent in a steep-sided crater not visible from this perspective). The shots were taken on 7 and 26 September 2009, respectively. Freshly deposited mud and evidence of ejected crater-lake water in the foreground (bottom) represents distal deposits from the 25 September eruption; note peson at right for scale. Large blocks were not from this eruption. Courtesy of the Dempo inspection team, CVGHM.

Figure 19. Pre- and post-eruption photos looking into Marapi crater at Dempo, taken on 7 (top) and 26 (bottom) September 2006. The lake is on the order of 400 m across. The bottom photo portrays the crater's mud-covered walls and sediment-covered lake. Comparison of both photos indicates that after the eruption the lake surface had dropped, consistent with discharge of water and mud. Camera look-direction unstated. Courtesy of the Dempo inspection team, CVGHM.

In the month before this eruption, teams from the CVGHM had visited several times. On 13 August 2006, a team prepared a map of Dempo and reported that the condition of the water in Marapi's crater lake was normal and clear or slightly blue in color, with no bubbling. On 4 September 2006, a team climbed to the peak of Dempo and reported that activity was normal other than some bubbling at the E edge of the crater lake.

2006 phreatic eruption. On 25 September 2006, a phreatic eruption occurred that expelled water from Marapi's crater lake and propelled mud onto the area around the peak up to a radius of 300 m.

On the next day, the inspector for Dempo, Mr. Mulyadi, accompanied by six friends, inspected the volcano and its lake. According to Mulyadi's team, the lake water was bubbling and had changed to a grayish color. Acrid sulfurosu emissions were accompanied by a hissing sound. The NW crater wall was covered by mud from the eruption. Many of the phreatic deposits around the crater lake were only about 0.5 cm thick, although in several other places they were thicker (figures 17-20). A visit on 4 October 2006 found the deposits not yet eroded, owing to a lack of rain since the eruption.

Figure 20. Post-eruption conditions on Dempo's Marapi cone seen from a point a few meters back from the crater rim. Widespread gray-to-brown mud covered the rim and upper crater, creating a desolate scene. The large angular blocks on the rim were placed there in previous events, not the 25 September 2009 eruption. Unstated direction; photographers shadow and gear for scale. Courtesy of the Dempo inspection team, CVGHM.

Geologic Summary. Dempo is a prominent 3,173-m-high stratovolcano that rises above the Pasumah Plain of SE Sumatra. The andesitic Dempo volcanic complex has two main peaks, Gunung Dempo and Gunung Marapi, constructed near the SE rim of a 3 x 5 km caldera breached to the N. The one called Dempo is slightly lower, with an elevation of 3,049 m and lies at the SE end of the summit complex. The taller Marapi cone, with a summit elevation 3,173 m, was constructed within a crater cutting the older Gunung Dempo edifice. Remnants of 7 craters are found at or near the summit of the complex, with volcanism migrating to the WNW with time. The large, 800 x 1100 m wide historically active summit crater cuts the NW side of Gunung Marapi (not to be confused with Marapi volcano 500 km to the NW in Sumatra) and contains a 400-m-wide lake located at the far NW end of the crater complex. Historical eruptions have been restricted to small-to-moderate explosive activity that produced ashfall near the volcano.

Information Contacts: *Center of Volcanology and Geological Hazard Mitigation (CVGHM)*, Jalan Diponegoro 57, Bandung 40122, Indonesia (URL: http://portal.vsi.esdm.go.id/joomla/).

Hunga Tonga-Hunga Ha'apai

Tonga Islands, SW Pacific
20.57°S, 175.38°W; summit elev. 149 m
All times are local (= UTC + 13 hours)

The eruption from Hunga Tonga-Hunga Ha'apai (figure 21) that began from multiple vents at Hunga Ha'apai island on 17 March 2009 ended after five days of activity on 21 March. The eruption destroyed all vegetation on the island, one of two high points on a submarine caldera rim (figure 22). Strong Surtseyan activity was witnessed by passengers on a fishing boat on 18 March (*BGVN* 34:02). Satellite imagery acquired that day (figure 23) revealed a bright eruption plume, an extensive 10-km-radius zone of discolored water around the islands, and pumice rafts that had already drifted 20-25 km towards the NW. By the next day, scientists on the scene observed that the submarine vent offshore to the S (figure 24) had built new land that was connected to Hunga Ha'apai (*BGVN* 34:02).

Based on inspection of an aerial photograph taken on 21 March (figure 25), the island had lengthened by ~ 1 km and the S crater was approximately 350 m in diameter on 21 March, assuming the island was 2 km long as previously described. Calculations using ASTER satellite imagery from 26 March result in similar dimensions for the island and S crater, and showed that the new extension was also about 1 km wide at that time.

Aerial photographs from 21 March showed no activity at the NW vent and a steam plume rising from the S vent. However, airport observers on Tongatapu saw new eruptive activity with ash plumes on the afternoon of 21 March (*BGVN* 34:02). A *Matangi Tonga* news article on 1 April reported the eruption as being on 17-21 March. Although *Radio New Zealand International* reported that residents of

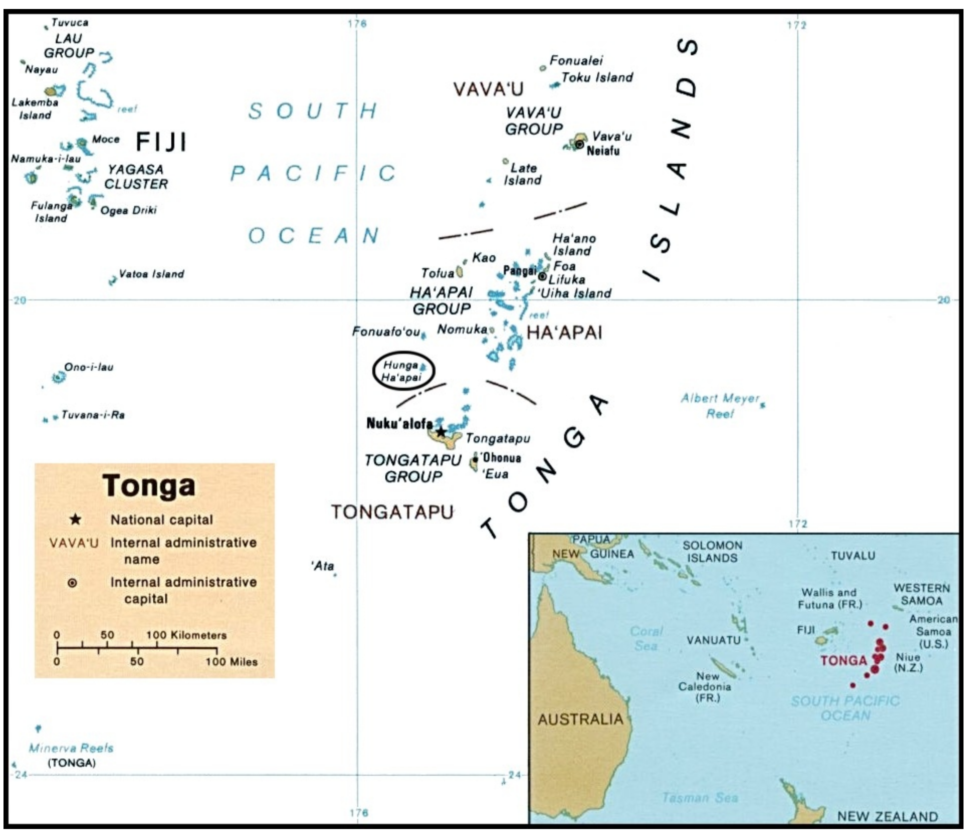

Figure 21. Political map of Tonga, 1989, showing the Vava'u, Ha'apai, and Tongatapu island groups. Hunga Ha'apai is in the oval about 55 km NNW of Tongatapu Island. Map courtesy of the University of Texas Libraries, The University of Texas at Austin.

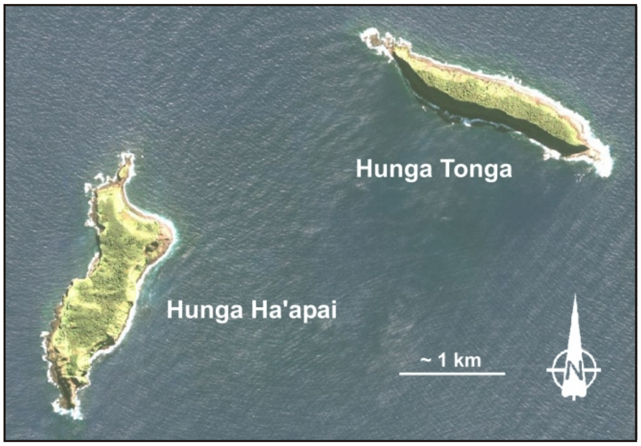

Figure 22. Aerial photo showing the vegetated islands of Hunga Tonga (left) and Hunga Ha'apai (right) before the eruption. Courtesy of Brad Scott, GNS Science.

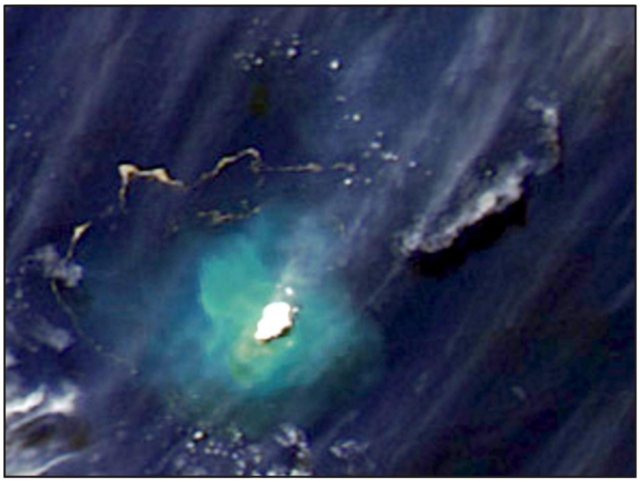

Figure 23. Aqua MODIS satellite image showing the eruption plume drifting NE and pumice rafts from Hunga Ha'apai on 18 March 2009. Hunga Tonga and Hunga Ha'apai are covered by the bright steam plume and surrounded by discolored water caused by suspended sediments reaching a maximum of about 10 km from the island. A detached older plume, possibly ash-bearing, is to the NE. Serpentine-shaped pumice rafts are drifting in the NW sector at a distance of 20-25 km from the island. Contrast has been enhanced. Courtesy of NASA Earth Observatory.

Nuku'alofa saw "glow on the horizon" on 22 March and stated that ash eruptions continued on the 23rd, those observations were not confirmed.

On 27 March a group of four people, organized by Gian Piero Orbassano of the Waterfront Lodge, landed on Hunga Ha'apai using an inflatable dinghy launched from a charter fishing boat. They landed on the newly built southern part of the island and walked to the rim of the crater which they described as filled with orange steaming water. They noted that landing on the "rocky black pumice" shore was difficult in rough seas. Large boulders (sizes not given) on the surface crumbled when touched. The ground was firm to walk on, but the crater rim was "fragile and cracked" (figure 26). Orbassano, in a 5 April news report, stated that people were visiting the island by boat but not landing, viewing the "smoking" vents and yellowish water around the island.

Geologic Summary. The small islands of Hunga Tonga and Hunga Ha'apai cap a large seamount located about 30 km SSE of Falcon Island. The two linear andesitic islands are about 2 km long and represent the western and northern remnants of the rim of a largely submarine caldera lying east and south of the islands. Hunga Tonga and Hunga Ha'apai reach an elevation of only 149 m and 128 m above sea level, respectively, and display inward-facing sea cliffs with lava and tephra layers dipping gently away from the submarine caldera. A rocky shoal 3.2 km SE of Hunga

Figure 24. Aerial photo showing the island of Hunga Ha'apai with a steam plume rising from the vent in the newly created portion of the island. Emissions can also be seen in the vicinity of the small lake (left) marking the location of another vent active during this eruption. Discolored water surrounds the island, but a denser plume of material is originating from the shoreline near the small lake. View is looking SSE on an unknown date, March 2009. Courtesy of AusAID in Tonga.

Figure 25. Aerial photo of the W side of Hunga Ha'apai island showing two steaming lakes in the NW vent area and a steam plume rising from the vent on the new southern part of the island. View is to the S on 21 March 2009. Courtesy of GP Orbassano and the Waterfront Lodge.

Figure 26. Photographs of the southern crater lake on newly formed land at Hunga Ha'apai, 27 March 2009. The steaming lake was colored orange-brown and the rim was unstable, as evidenced by the irregular rim, steep cliffs, and fractures. Courtesy of GP Orbassano and the Waterfront Lodge.

Ha'apai and 3 km south of Hunga Tonga marks the most prominent historically active vent. Several submarine eruptions have occurred at Hunga Tonga-Hunga Ha'apai since the first historical eruption in 1912.

Information Contacts: *Brad Scott*, GNS Science, Wairakei Research Centre, Private Bag 2000, Taupo 3352, New Zealand (URL: http://www.gns.cri.nz/); *NASA Earth Observatory* (URL: http://earthobservatory.nasa.gov/); *GP Orbassano*, Waterfront Lodge, Vuna Road, Ma'ufanga, PO Box 1001, Nuku'alofa, Tonga (URL: http://www.water-front-lodge.com/); *Radio New Zealand International*, PO Box 123, Wellington, New Zealand (URL: http://www.rnzi.com/); *Matongi Tonga Online*, PO Box 958, Nuku'alofa, Tonga (URL: http://www.matangitonga.to/); *Perry-Castañeda Library Map Collection*, University of Texas Libraries, The University of Texas at Austin (URL: http://www.lib.utexas.edu/).

Deception Island

Antarctica
62.97°S, 60.65°W; summit elev. 576 m

Alicia Garcia forwarded to us a report of the geophysical monitoring conducted during December 2008 to February 2009 (the 2008-2009 austral summer). This field work included measurements of seismicity, deformation, and soil temperature. Little if any unrest was detected.

The volcanic alert remained Green during the 2008-2009 campaign. The volcano last erupted in 1970 (and several uncertain eruptions were indicated since then). Seven seismic stations, and a seismic array determined that seismicity was low. During January and February 2009 instruments detected some earthquakes attributed to hydrothermal processes and ice melting. Geodetic leveling surveys were carried out over benchmarks along six lines of an existing network (known as RENID). Only superficial deformation was detected.

The Thermometric Monitoring Network (THONET) was initiated in 2006. It consists of a set of stations monitoring micro-meteorological variables including wind velocity, air temperature and humidity, upward and downward solar and terrestrial radiation, diffuse solar radiation, soil heat flow, soil temperature at several depths and snow depth cover. Not all variables are recorded at all stations or constantly. Measurements indicated that soil thermal behavior was the result of solar and atmospheric forcing.

Ibanez and others (2003) noted both long-period (LP) and volcano-tectonic (VT) earthquakes since 1986, with greatest intensity during 1992 and 1999. This means that in ~ 15 years of seismic monitoring, two intense volcanic crises have been observed. No permanent monitoring stations exist on the island, and seismic measurements are conducted only during 3 months/year (from December to February); thus, similar periods of elevated volcanic seismicity might have occurred more often than detected.

Benitez and others (2007) described a seismic-event classification and monitoring system for Deception. The system, based on hidden Markov modeling (HMM) techniques, enabled monitoring by careful discriminating among different signal types.

As late as 30 April 2009, MODIS/MODVOLC thermal alert satellite measurements showed no anomalies over the island since at least 2000.

References: Benítez, M.C., Ramírez, J., Segura, J.C., Ibáñez, J.M., Almendros, J., García-Yeguas, A., and Cortés, G., 2007, Continuous HMM-Based Seismic-Event Classification at Deception Island, Antarctica, IEEE Transactions on Geoscience and Remote Sensing, v. 45, no. 1, p. 138-146.

Ibáñez, J.M, Almendros, J., Carmona, E., Martínez-Arévalo, C., and Abril, M., 2003, The recent seismo-volcanic activity at Deception Island volcano, Deep Sea Research Part II: Topical Studies in Oceanography, v. 50, no. 10-11, p. 1611-1629.

Geologic Summary. Ring-shaped Deception Island, one of Antarctica's most well known volcanoes, contains a 7-km-wide caldera flooded by the sea. Deception Island is located at the SW end of the Shetland Islands, NE of Graham Land Peninsula, and was constructed along the axis of the Bransfield Rift spreading center. A narrow passageway named Neptunes Bellows provides entrance to a natural harbor that was utilized as an Antarctic whaling station. Numerous vents located along ring fractures circling the low, 14-km-wide island have been active during historical time. Maars line the shores of 190-m-deep Port Foster, the caldera bay. Among the largest of these maars is 1-km-wide Whalers Bay, at the entrance to the harbor. Eruptions from Deception Island during the past 8,700 years have been dated from ash layers in lake sediments on the Antarctic Peninsula and neighboring islands.

Information Contacts: *A. Garcia*, Dept. of Volcanology (MNCN-CSIC), Madrid, Spain (Email: aliciag@mncn.csic.es); *M. Berrocoso*, Cadiz Univ., Spain (Email: manuel.berrocoso@uca.es); *M. Rodríguez-Arias*, Extremadura Univ., Spain (Email: arias@unex.es); *I. Serrano*, Granada Univ., Spain (Email: inma@iag.ugr.es), *MODIS/MODVOLC*. Hawai'i Institute of Geophysics and Planetology (HIGP) Thermal Alerts System, School of Ocean and Earth Science and Technology (SOEST), Univ. of Hawai'i, 2525 Correa Road, Honolulu, HI 96822, USA (URL: http://hotspot.higp.hawaii.edu/).

Reventador

Ecuador
0.077°S, 77.656°W; summit elev. 3,562 m
All times are local (= UTC - 5 hours)

Our previous report covered activity through early August 2008, a period that included extrusions of lava flows (*BGVN* 33:08). This report continues through late April 2009, including a hiatus for much of August into November 2008. In early November observers saw repeated small eruptions emitting plumes with generally minor ash, Strombolian eruptions, and lava flows down two flanks. What follows summarizes reports from the Instituto Geofísico-Escuela Politécnica Nacional (IG).

The last paragraph of the main section of this report discusses an important temporal and spatial correlation made at the volcano on 23 April 2009. The IG correlated satellite thermal data and ground-based observations with high tremor and acoustical noise.

An IG daily report issued 8 August 2008 noted a lack of movement in the lava flows and the emission of gas plumes without ash. That night, glow was observed from the crater. On 18 August, amid rainy conditions, a possible lahar was noted. Except for ongoing seismicity, relative calm prevailed until early November.

The IG noted glow from the crater the night of 7 November, an observation confirmed in satellite thermal data. At 1900 on 8 November high-amplitude seismic signals saturated the seismic stations. Local observers saw an ash-and-steam column that evening to 2 km above the crater. The ash content was moderate. Another IG report noted that in the settlements of Chaco and Quijos residents could hear strong explosions and see gas plumes with low ash content. A pilot report stated the plume blew NW and reached an approximate estimated altitude of 7.6 km.

Special Report 6 (9 November) included a plot of seismicity since 1 February 2007 (figure 27).

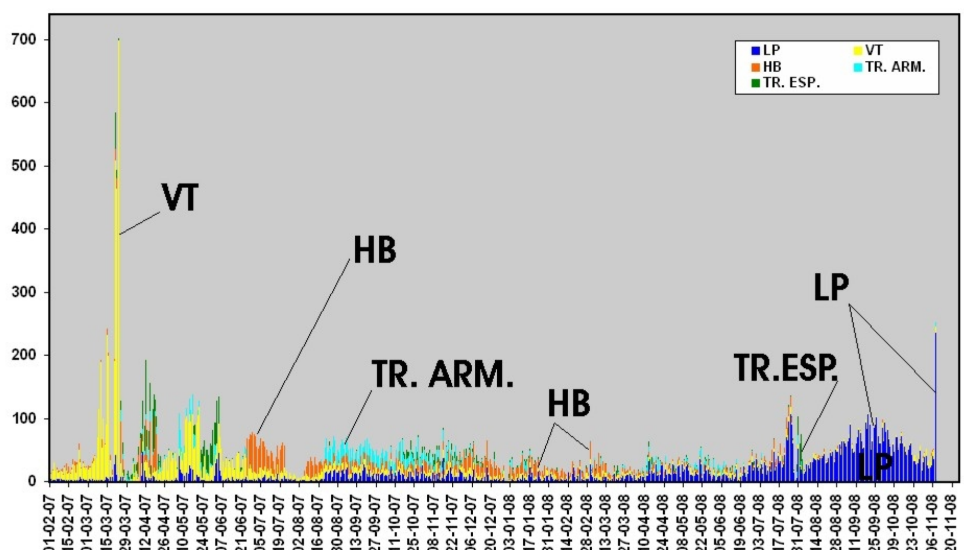

Figure 27. A histogram of daily seismicity for Reventador during 1 February 2007 to 8 or 9 November 2008. The plot includes harmonic tremor (TR. ARM.) and special kinds of tremor (TR. ESP.) in addition to more typically plotted event types (LP earthquakes, VT earthquakes, and hybrid (HB) earthquakes). Courtesy of IG (from their Special Report No. 6, issued 9 November 2008).

Long-period (LP) earthquakes began to dominate in March 2008 and the large spike around 8-9 November 2008 was outstanding compared to the recent pattern. Another larger spike in seismicity had been seen during mid-March 2007, but it was composed of volcano-tectonic (VT) earthquakes.

A follow up report on 11 November stated that Reventador had discharged moderate strombolian explosions on 9-10 November, with ongoing lava flows on the N and S flanks of the central cone. Both the summit eruptions and the flank flows were conspicuous at night.

SO_2 emissions were clear in Aura/OMI imagery of 9 and 10 November (figure 28). About a day later, Reventador calmed considerably (with seismicity dropping strongly after 1000 on 11 November). The escalating activity drove IG to install two more seismometers, two infrasonic sensors, and a monitoring camera.

The IG's Special Reports of 10 and 11 November (Numbers 7 and 8) offered further information. Lava flows had descended to below 2,600 m elevation (the summit is at 3,562 m elevation but the vent elevation was not stated). During the night of 9 November incandescent ejecta rose 100 m above the crater, along with continuous roars and canon-shot noises. Although light ash fell in Cayambe on 9 November, other towns in the region had not been affected. Strombolian emissions had calmed some on the night of 10 November. After 1000 on 11 November, both gas emissions and seismicity calmed.

Seismicity increased starting on 15 December 2008, and remained elevated through 8 January 2009. During 3-8 January there were almost constant gas emissions (with ash contents moderate to low), small-to-moderate explosions, and tremor lasting several hours. The tremor was accompanied by roaring noises and the ejection of blocks that landed near the summit. Explosions and emission tremors were of variable intensity, causing windows in nearby towns to vibrate. Ash rose 2 km above the summit and drifted W, causing ashfall in the towns of El Manzano, Choglontus, Palictahua, and Cahuají.

After 8 January 2009, the IG reported the steady decrease of seismic activity. There were a few explosions and

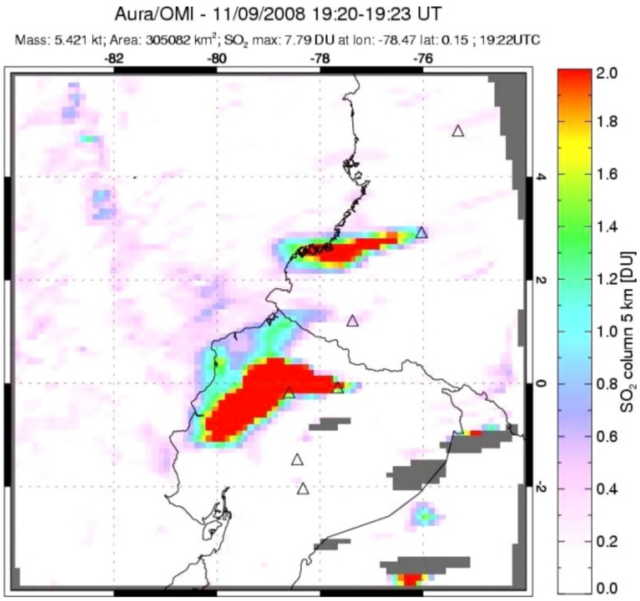

Figure 28. Spectroscopic measurements of SO_2 taken by the Aura/OMI satellite on 9 November 2009 from eruptions at Reventador. The smaller plume to the N is from Galeras. Courtesy of Simon Carn and the OMI Sulfur Dioxide Group.

water vapor emissions with low ash content reaching heights of 1-1.5 km above the crater. These plumes drifted W and SW, with reported minor ashfall in the towns mentioned above. Associated with these emissions, observers heard sporadic roaring noises. Seismic activity continued to decrease during the latter part of January 2009 and into February 2009. Although in mid-February 2009 there was a mild increase in seismicity, overall the level remained low. A single observation revealed the presence of a small column of steam and gas.

During 16-22 February seismic activity remained low, with few seismic events and signals associated with fluid movements at depth. The number of rockfalls was significant, even compared to that seen during cooling of the lava flow from November 2008. During this week there were various episodes of harmonic tremor and explosions. During 23 February-15 March 2009 there was a slight increase in the number of low-intensity seismic events attributed to fluids at depth. There was a later decrease in seismicity

IG's 2009 Special Report Number 1 (26 March) noted a seismic increase on 26 March, which they again attributed to fluids moving within the volcanic edifice. After 1000 on the 26th, instruments detected a seismic swarm consisting of both LP and hybrid earthquakes, intercalated with banded tremor, the later of which had a 4-hour duration. From past experience, the IG inferred these signals could reflect the onset of new lava approaching the surface.

Special Report Number 2 (23 April) noted that later on the 26th the signals dropped off and remained low through at least early 23 April. Despite low seismicity, there were both episodes of banded tremor and intercalated LP earthquakes.

The tremor was of variable amplitudes, including some that saturated local seismic stations, particularly between 0500 and 0700 on 23 April 2009. On that day, a low, gas-rich cloud blew W from Reventador. Several residents living near the volcano also heard loud noises. A satellite-detected thermal hotspot on the volcano beginning at 0300 continued, with high intensity, between 0500 and 0700. The presence of the highest intensity thermal anomalies coincided with the highest tremor amplitudes and audible noises. Multiple MODVOLC thermal alerts were detected on 24-25 April and on 8 and 10 May 2009.

Geologic Summary. Reventador is the most frequently active of a chain of Ecuadorian volcanoes in the Cordillera Real, well E of the principal volcanic axis. The forested, dominantly andesitic Volcán El Reventador stratovolcano rises to 3,562 m above the jungles of the western Amazon basin. A 4-km-wide caldera widely breached to the east was formed by edifice collapse and is partially filled by a young, unvegetated stratovolcano that rises ~ 1,300 m above the caldera floor to a height comparable to the caldera rim. Reventador has been the source of numerous lava flows as well as explosive eruptions that were visible from Quito in historical time. Frequent lahars in this region of heavy rainfall have constructed a debris plain on the eastern floor of the caldera. The largest historical eruption at Reventador took place in 2002, producing a 17-km-high eruption column, pyroclastic flows that traveled up to 8 km, and lava flows from summit and flank vents.

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Masaya

Nicaragua
11.984°N, 86.161°W; summit elev. 635 m
All times are local (= UTC - 6 hours)

Our previous report on Masaya, in April 2006 (*BGVN* 31:04), summarized intermittent ash eruptions and continuing incandescence through March 2005. At that time, the visible SO_2 gas emissions were the lowest seen, a condition attributed to the landslide of 2-3 March 2005 blocking the degassing vent. MODIS/MODVOLC data revealed only one pixel on 24 April 2006.

Activity during 2005-2006. The level of tremor slowly decreased from 20 RSAM units in April 2005 to 10 RSAM units a few months later. A short INETER report noted that there were no micro-earthquakes registered in October 2005. Tremor then stood at 15 RSAM (Real-time Seismic Amplitude Measurement) units, occurring with frequencies of 1.5 Hz. Gas fumes remained steady and strong. No activity was reported from April 2005 until 25-30 April 2006 when there was a small increase in emissions, with columns of gases rising ~ 100 m from the crater; there was also a strong odor of sulfur. During May, increased precipitation resulted in acid rains that burned the vegetation. In June, an observer reported a wall collapse in Santiago crater.

On the evening of 3 August 2006 seismic tremor began to increase, reaching approximately 130 RSAM units. This level was maintained throughout the next day; typically RSAM levels are at about 5 units. INETER volcanologists traveled to the volcano on 4 August and around 1030 observed two small phreatomagmatic explosions from the crater with dark gray ash. From the crater rim incandescence was seen at the bottom of the crater, and jet engine sounds could be heard. Civil Defense also reported that residents of Leon saw ash and gas emissions in the morning. Small amounts of ash fell in Cristo Rey, W of the volcano and in Las Marías to the N. Gas emissions remained strong on 4 August. Small explosions on the morning of 6 August again ejected ash. Activity decreased afterwards, with no further ash emissions and a drop in seismicity to 20 RSAM units. Minor gas emissions continued.

Overall during August 2006 the frequency of tremor shifted slightly from 1.5 to 2.0 Hz, which remained constant through August. Gas emissions increased in August 2006 at a point ~ 800 m from the cone. Gas emissions were released from the old crater as well. Temperatures at the San Fernando and Comalito cones remained unchanged. On 20 August, Martha Navarro (INETER) and Gustavo Chigna (INSIVUMEH, Guatemala), measured SO_2 emissions with a COSPEC near El Crucero, (16 km W of the summit) and noted a level of ~ 900 tons of SO_2 per day.

On 4 September 2006 tremor remained at 15 RSAM units, with frequencies of 1.5 Hz, a level that continued through October. Gas emissions remained constant, steady and strong. INETER reporting on 25 October 2006 discussed a new vent that opened on the floor of Santiago crater with a small lava lake. It displayed intense degassing. Following heavy rains, landslides spilled down the crater walls. Instability was noted at an overlook parking area.

Activity during 2007-2008. The Washington Volcanic Ash Advisory Center (VAAC) provided occasional reports of plumes from 26 April 2007 to 17 December 2008, predominately from GOES-12 satellite observations. Pilots and local residents also contributed observations through the VAAC and INETER.

A steam plume that drifted WSW on 26 April 2007 was visible on satellite imagery and a web camera. Additional plumes on 9 and 12 June, with little or no ash, were noted. No further plumes were reported until 24 December 2007, when a small diffuse plume, possibly containing ash, moved SW; a change in seismicity corresponded to the emission.

Pilots reported an ash plume on 29 April 2008 that was also seen in satellite imagery moving SW at 2.1 km altitude. An explosion on 18 June 2008 registered on the seismometer E of the volcano. The event discharged moderate quantities of gas and volcanic ash, and the resulting cloud was dark in color. Nearby inhabitants felt the explosion.

Satellite imagery during August 2008 revealed plumes described as steam on 12 August and gas on 18 August, both possibly containing ash. Similar plumes on 10 and 12 September drifted ENE. Pilots reported that on 9 October an ash plume rose to an altitude of 4.6 km and drifted NNE. Analysis of satellite imagery through the rest of 2008 showed possible diffuse ash and steam plumes to the SW and S on 4-5 November, a plume with possible ash on 2 December that moved SW, and a gas plume with possible ash to an altitude of 5.3-6.1 km on 17 December.

Geologic Summary. Masaya is one of Nicaragua's most unusual and most active volcanoes. Masaya lies within the massive Pleistocene Las Sierras pyroclastic shield volcano and is a broad, 6 x 11 km basaltic caldera with steep-sided walls up to 300 m high. The caldera is filled on its NW end by more than a dozen vents erupted along a circular, 4-km-diameter fracture system. The twin volcanoes of Nindirí and Masaya, the source of historical eruptions, were constructed at the southern end of the fracture system and contain multiple summit craters, including the currently active Santiago crater. A major basaltic plinian tephra was erupted from Masaya about 6,500 years ago. Historical lava flows cover much of the caldera floor and have confined a lake to the far eastern end of the caldera. A lava flow from the 1670 eruption overtopped the N caldera rim. Masaya has been frequently active since the time of the Spanish Conquistadors, when an active lava lake prompted attempts to extract the volcano's molten "gold." Periods of long-term vigorous gas emission at roughly quarter-century intervals caused health hazards and crop damage.

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Popocatépetl

México
19.023°N, 98.622°W; summit elev. 5,426 m
All times are local (= UTC - 6 hours)

Our most recent report on Popocatépetl (*BGVN* 32:04) described minor explosions, sporadic ash plumes, and lava dome growth during 2006 through April 2007. The current report discusses activity from April 2007 through April 2009, when many small ash plumes were noted.

From April 2007 through April 2009, the Centro Nacional de Prevencion de Desastres (CENAPRED) reported modest activity at Popocatépetl, consisting largely of numerous low intensity earthquakes and tremors (figures 29 and 30), and constant degassing of low intensity steam and gas, often accompanied by ash emissions of variable intensity. Based on information from the Mexico City Meteorological Watch Office (MWO), and the Washington Volcanic Ash Advisory Center (VAAC), there were 17 occasions when ash plumes rose at least 1 km above Popocatépetl's 5.4 km summit (table 3).

According to information provided by the Mexican National University geologist Julie Roberge, the tremors lasted from minutes to hours and varied in frequency and amplitude, but were mostly of low amplitude. The microearthquakes were also of low magnitude (M 2-3) with variable depths; epicenters were typically within 10 km of the crater. Plumes consisting of gas, and gas and ash, and

Figure 29. Popocatépetl upper flanks seen looking SSE in October 2008. During the reporting interval, steam plumes often hung over Popocatépetl's summit. The summit area is steep and glacial covered. The volcano's crater is deep and contains a growing dome of uncertain volume. Photo taken by Julie Roberge, UNAM.

seismicity consisting of earthquakes and tremor varied during 2007 through April 2009 (figure 30).

According to Roberge and others (2009), the deep degassing observed in the ongoing eruption of Popocatépetl may indicate an essentially intrusive event, rather than a convective process. The hypothesis of deep magma degassing beneath Popocatépetl is consistent with observations regarding degassing at the summit that suggest separation of magma and gas at depth beneath the volcano. According to additional information provided us by Roberge, the high gas flux is not associated with processes in the central conduit. The volcano has an elliptical crater (600 m by 800 m). Most of the lava that formed domes was extruded through the crater's major central vent (about 30 m wide). However, several other vents were formed in the crater during the explosive events of 1995. These vents are aligned N-S, and the largest has been the site of long term degassing but only rare extrusion of lava. The smaller secondary vents are ephemeral and their activities depend on the explosive events that reopen them. Often, the most vigorous release of gas occurs from the E vent, and thus much of the degassing seems unrelated to the central vent and conduit from which the lava domes form.

Between April 2007 and April 2009, thermal anomalies at Popocatépetl were detected every month by MODVOLC. The number of thermal anomalies per month ranged from three to seventeen, mostly one pixel, but occasionally two pixels, and once three pixels.

As reported in *BGVN 32:04*, a lava dome irregularly growing since July 2005 covered the floor of the internal crater. People studying the volcano have lacked an image of the dome and crater since 2007, leaving its later status and volume uncertain.

Reference. Roberge, J., Delgado-Granados, H., and Wallace, P. 2009. Mafic magma recharge supplies high CO_2 and SO_2 gas fluxes from Popocatépetl volcano, Mexico: Geology v. 37, no. 2, pp. 107-110.

Geologic Summary. Volcán Popocatépetl, whose name is the Aztec word for smoking mountain, towers to 5,426 m 70 km SE of Mexico City to form North America's 2nd-highest volcano. The glacier-clad stratovolcano contains a steep-walled, 400 x 600 m wide crater. The generally symmetrical volcano is modified by the sharp-peaked Ventorrillo on the NW, a remnant of an earlier volcano. At least three previous major cones were destroyed by gravitational failure during the Pleistocene, producing massive debris-avalanche deposits covering broad areas south of the volcano. The modern volcano was constructed to the south of the late-Pleistocene to Holocene El Fraile cone. Three major plinian eruptions, the most recent of which took

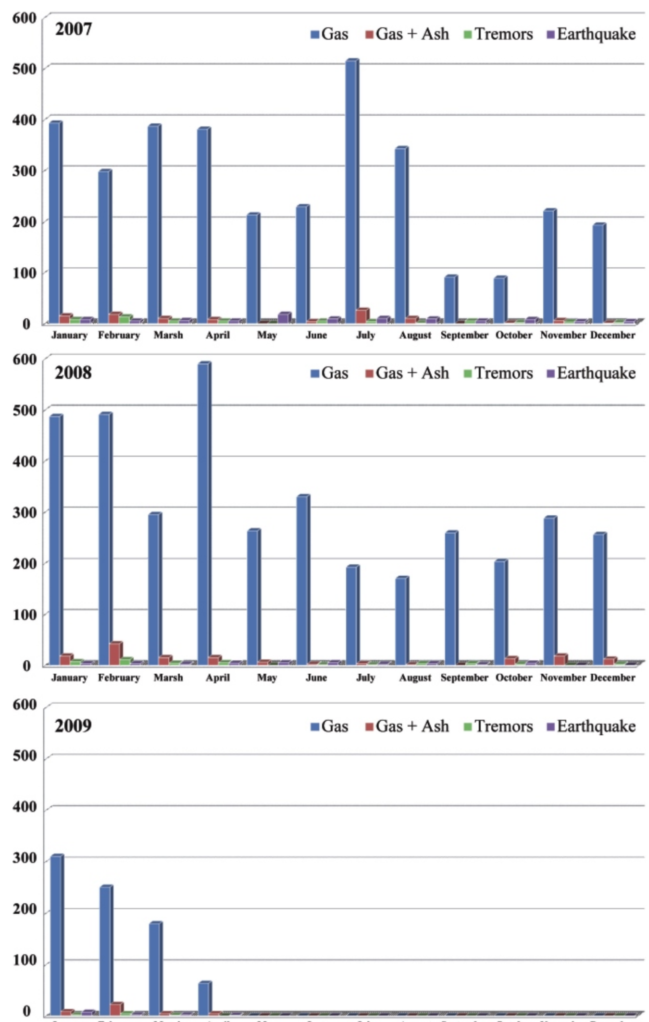

Figure 30. Histogram of selected annual activity at Popocatépetl. The number of earthquakes, tremors, gas, and gas + ash episodes per month between January 2007 and 1 April 2009. The amount of ash in the eruptions was modest, compared to total gas emissions. Courtesy of Julie Roberge.

Date	Plume altitude (km)	Plume direction
01 Apr 2007	7.6	NE
28 Jun 2007	6.4	SSW
28 Jul 2007	7	WSW
01 Dec 2007	7.4-9.1	N, NE
31 Dec 2007	7.4	E, SE
05 Jan 2008	7.3	E, NE
28 Jan 2008	8.6	NW
12 Feb 2008	7	NE
21-22 Feb 2008	7.4	NE
08-09 Mar 2008	6.4	NE
17 Mar 2008	7.4-7.9	NE
17 Nov 2008	6.1	NW, WSW
21 Jan 2009	7	E, NE
22 Jan 2009	7.4	—-
13 Feb 2009	7.2	NE
23 Mar 2009	6.7	SE
01 Apr 2009	6.4	—-

Table 3. Tabulation of ash plumes rising at least 1 km above Popocatépetl's summit between 1 April 2007 and 1 April 2009. Data provided by the Mexico City Meteorological Watch Office (MWO), and the Washington Volcanic Ash Advisory Center (VAAC) and a web camera operated by the Centro Nacional de Prevención de Desastres (CENAPRED).

place about 800 AD, have occurred from Popocatépetl since the mid Holocene, accompanied by pyroclastic flows and voluminous lahars that swept basins below the volcano. Frequent historical eruptions, first recorded in Aztec codices, have occurred since precolumbian time.

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