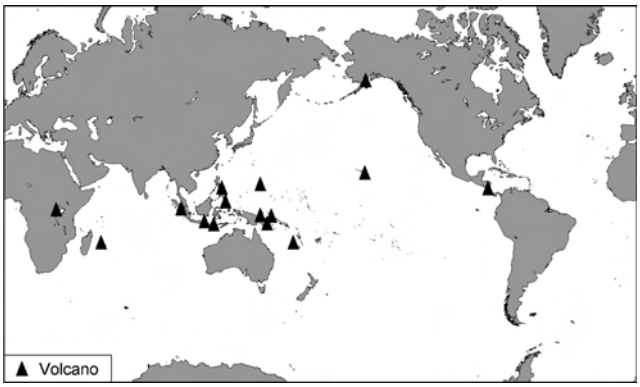
Bulletin of the Global Volcanism Network



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Kilauea

Hawaii, USA
19.425°N, 155.292°W; summit elev. 1,222 m
All times are local (= UTC - 10 hours)

During 2003, lava from Kilauea continued to flow down the S flanks and into the ocean at several points. The Mother's Day flow, which began erupting from Pu`u `O`o on 12 May 2003, remained active. Seismicity generally persisted at normal (background) levels. A recent report from the U.S. Geological Survey, edited by Heliker, Swanson, and Takahashi (2003) described the nearly uninterupted Pu`u `O`o-Kupaianaha eruption that started 3 January 1983 and continues today.

Lava flows. Lava entered the sea mainly at the Highcastle ocean entry during 11-17 June and surface lava flows were visible on the coastal flat and Pulama pali during June and July 2003. However, no lava flowed into the sea during the later half of July and into early August.

Deflation that began on 8 August amounted to ~ 1.8 µrad at the Uwekahuna (UWEV) tiltmeter and ~ 4 µrad at the Pu`u `O`o tiltmeter, both located near the Kilauea summit (figure 1). The deflation was accompanied by a drop in the level of lava in a lava tube, as seen by field workers at midday. Inflation began later that day at 1928, and in ~ 3.5 hours ~ 3.5 µrad of inflation was recorded at Uwekahuna and ~ 6 µrad at Pu`u `O`o.

A lava breakout occurred on 9 August between 0200 and 0300, ~ 1.3 km SE of the center of the Pu`u `O`o cone. A very large sheet flow emerged from the up-tube side of a rootless shield formed on 21 January. Observers saw a lava stream up to 40 m wide. By 0600 the flow covered ~ 5.2 hectares (0.052 km^2).

Later in August and into September, surface lava flows were visible on Kilauea's coastal flat, in some areas flowing to within 500 m of the sea. On 2 October lava began to flow westward after filling West Gap Pit on the W flank of Pu`u `O`o cone. Fairly vigorous spattering was visible in the pit, but decreased to only sporadic bursts later in the day. The flow appeared to have stopped by 4 October when no glow was observed coming from the pit.

Lava flows have erupted from 1983 through 10 October 2003 from Pu`u `O`o and Kupaianaha. The area of recent lava flows on the W side of the flow-field has been designated the Mother's Day flow, which began erupting on 12 May 2002 and continues to the present (figure 2). Through Sep-

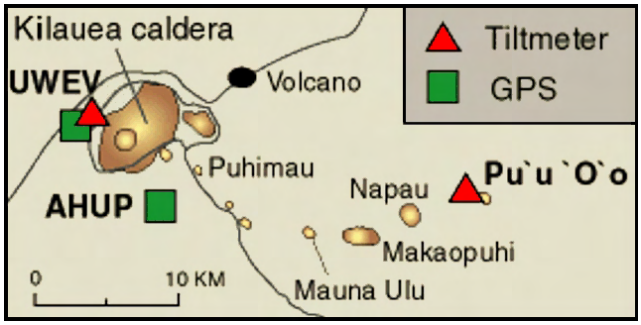

Figure 1. Map of selected deformation stations at Kilauea, 2003. Courtesy of HVO.

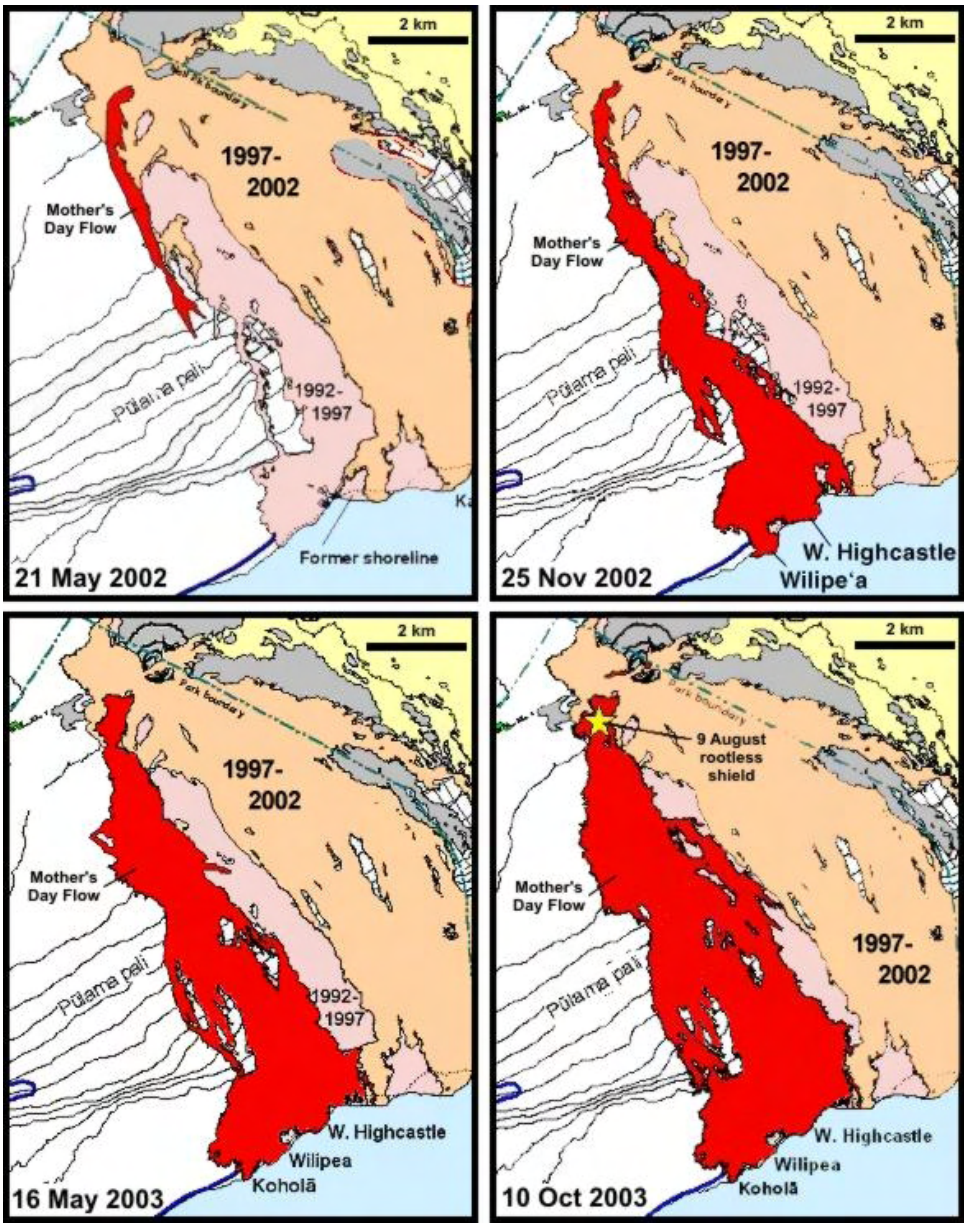

Figure 2. Map sequence showing Mother's Day lava flows that began on 12 May 2002 (darkest shade) from the Pu`u `O`o cone at Kilauea as of 21 May 2002, 25 November 2002, 16 May 2003, and 10 October 2003. Modified from original maps created by the USGS Hawaiian Volcano Observatory.

tember and into early October, lava was moving along the E and W sides of the Mother's Day flow. The E-side lava (mentioned previously as the 9 August breakout) came from the 9 August rootless shield, itself fed by the main Mother's Day tube from Pu`u `O`o. The W-side lava, known as the Kohola arm of the Mother's Day flow, branched off the tube system below the rootless shield. In early October, the E-side flow stopped moving, the W-side flow died back to a trickle, and the rootless shield gained prominence. By 16 October, however, the shield had partly collapsed, leaving several drained perched ponds. Upstream from the shield, many hornitos and small flows formed over the Mother's Day tube.

Geophysical activity. During the second half of June and into August 2003, seismicity at the summit was at moderate-to-high levels, with many small, low-frequency earthquakes occurring at shallow depths beneath the summit caldera at a rate of about 1-2 per minute. Little or no volcanic tremor accompanied the swarm at the caldera, however. Volcanic tremor at Pu`u `O`o remained at moderate-to-high levels, as is the norm. A quasi-cyclic tilt pattern ended at Kilauea's summit and Pu`u `O`o on 13 June after lasting about a week. Small periods of inflation and deflation occurred during July and into August.

During the deflation on 8 August, there was an increase in small, low-frequency earthquakes and changes in their frequency content. Some larger events occurred at depths of a few kilometers, as during the previous several weeks. A magnitude 5.0 earthquake 10 km beneath Kilauea's central S flank on 26 August at 2024 was the largest since 2 April 2000, which occurred in almost exactly the same spot. No significant damage was done, no cracks or rockfalls were seen, and there was no change in the eruption. Generally, following that event and into September, summit seismicity continued at moderate levels with 1-2 small low-frequency earthquakes per minute occurring at shallow depths beneath the summit caldera. There were some larger events at depths of a few kilometers.

At about 1500 on 20 September 2003, first Uwekahuna and then Pu'u O'o started to deflate. Pu'u O'o lost ~ 1.5 µrad during the deflation, and Uwekahuna lost ~ 0.9 µrad. The deflation ended with a sharp inflation in the early morning on 21 September, which lasted until early on 22 September, when the tilt flattened.

Background. Kilauea volcano, which overlaps the east 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 1500 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 Kilauea is formed of lava flows less than about 1100 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 km^2, destroying nearly 200 houses and adding new coastline to the island.

Reference: Heliker, C., Swanson, D.A., and Takahashi, T.J. (eds), 2003, The Pu`u `O`o-Kupaianaha eruption of Kilauea Volcano, Hawaii: The first 20 years: U.S. Geological Survey Professional Paper 1676, Denver, CO.

Information Contact: *Hawaiian Volcano Observatory (HVO)*, U.S. Geological Survey, Hawaii Volcanoes National Park, P.O. Box 51, Hilo, HI 96718, USA (URL: http://hvo.wr.usgs.gov; Email: hvo-info@hvo-mail.wr.usgs.gov).

Katmai

Alaska Peninsula, USA
58.280°N, 154.963°W; summit elev. 2,047 m

According to the National Weather Service, strong winds in the Katmai area on 21 September 2003 picked up old, loose volcanic ash and carried it E. Reports of minor ashfall were reported from Kodiak Island, ~ 100 km from Katmai. This phenomenon was not the result of volcanic activity and no eruption occurred.

Andrea Steffke of the Geophysical Institute, University of Alaska Fairbanks, reported a relatively large ash cloud observed in satellite images coming from the Katmai area on 21 September 2003. The cloud was first seen in satellite imagery (AVHRR, GOES, and MODIS) extending ~ 69 km to the SE. The maximum temperature difference observed was -1.46°C. Dave Schneider of the Alaska Volcano Observatory reported on 22 September 2003 that at its greatest extent the cloud was detectable for ~ 400 km. It was initially observed by an overflying (high-altitude) jet, and subsequently identified in split-window images from AVHRR, MODIS, and GOES satellites. Additional pilot reports placed the cloud top at ~ 2.1 km altitude.

The Katmai Group of volcanoes are seismically monitored by AVO, so it was possible to quickly confirm that an eruption had not taken place. SIGMETS were issued by the Alaska Aviation Weather Unit (AAWU) for this event and an AVO Information Release was distributed that indicated that this cloud of re-suspended ash was potentially hazardous to aircraft. This event is unusual in its intensity and extent of transport. The Katmai region is characterized by frequent high winds that can be strong enough to re-suspend large (several centimeters in size) pumice fragments, yet these events typically don't produce large, extensive airborne ash clouds.

Background. Prior to 1912, Mount Katmai was a compound stratovolcano with four NE-SW-trending summits, most of which were truncated by caldera collapse in that year. Most of the two overlapping pre-1912 Katmai volcanoes are Pleistocene in age, but Holocene lava flows from a flank vent descend the SE flank of the SW stratovolcano into the Katmai River canyon. Katmai was initially considered to be the source of the Valley of Ten Thousand Smokes ash flow in 1912. However, the 3 x 4 km wide caldera of 1912 is now known to have formed as a result of the voluminous eruption at nearby Novarupta volcano. The steep-walled young Katmai caldera has a jagged rim that rises 500-1000 m above the caldera floor and contains a 250-m-deep, still-rising lake. Lake waters have covered a small post-collapse lava dome (Horseshoe Island) that was seen on the caldera floor at the time of the initial ascent to the caldera rim in 1916. Post-1912 glaciers have formed on a bench within Katmai caldera.

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).

Anatahan

Mariana Islands, central Pacific Ocean
16.35°N, 145.67°E; summit elev. 788 m

The first recorded historical eruption at Anatahan, which began on 10 May 2003, continued through that month with nearly continuous ash plumes (*Bulletin* v. 28, nos. 4-5). Two strong explosions on 14 June removed much of a small lava dome that had been extruded in the crater; dark ash plumes were last reported on 16 June, after which time seismicity decreased significantly (*Bulletin* v. 28, no. 6). Only steaming without ash emissions was reported by scientists doing fieldwork immediately afterwards (*Bulletin* v. 28, no. 7) and on overflights in July. Volcanic tremor and other seismicity reported by the Commonwealth of the Northern Mariana Islands (CNMI) Emergency Management Office (EMO) persisted into early August at a relatively low level. This report covers observed activity from 4 August to 5 October 2003.

Seismicity was low throughout the report period and no apparent eruption signals or potential precursory events occurred. Tremor and seismic energy release were at low levels. During 2-6 August, small long-period (LP) events occurred regularly. At the end of that interval, the number of small LP events increased to several hundred in 24 hours, compared to a couple dozen per day earlier in the swarm, but the overall energy release increase was not significant. No LP events were reported again until mid-September. On 5 September, tremor and seismic energy release were reported to be at their lowest levels since early July.

Overflights of the volcano were made by USGS and EMO personnel on 30 August and 8, 9, and 11 September. Observations on these days revealed no ash emissions, and the feeble plume was dominated by steam and lesser amounts of volcanic gases, mainly SO_2. Sporadic emissions sometimes rose above the crater rim. The E crater floor was covered by dirty, sediment-laden, steaming water, and an active geothermal system had mud pots, mini-geysers, and steam jets. Steaming water and sulfurous gases were emitted from the crater walls and floor. Observations during an 18 September overflight were similar to those earlier in the month, although the crater floor appeared to be covered by muddy water instead of a shallow lake. A distinct odor of SO_2 and blue fume were noted during a helicopter inspection of the E crater lake on 27 September. On 29 September, geysering was seen and the odor of H_2S was present in addition to SO_2.

By 12 September USGS and EMO had reestablished the original, pre-eruption Anatahan seismic station (ANAT) on the SW caldera rim. On 15 September, several, small-amplitude, LP events lasting up to 15 seconds were visible on the ANAT records with dominant frequencies of 4-5 Hz. Some of the larger events had a short burst of 6-7 Hz energy about 2.5 seconds after the onset. The largest events were barely above background at the E Anatahan station (ANA2) and may have been occurring undetected for the past several weeks. The LP events at the ANAT station continued over the next two days at a rate of several per hour.

Background. The elongated, 9-km-long island of Anatahan in the central Mariana Islands consists of two coalescing volcanoes with a 2.3 x 5 km, E-W-trending summit depression formed by overlapping summit calderas. The larger western caldera is 2.3 x 3 km wide and extends eastward from the summit of the western volcano, the island's 788 m high point. Ponded lava flows overlain by pyroclastic deposits fill the caldera floor, whose SW side is cut by a fresh-looking smaller crater. The summit of the lower eastern cone is cut by a 2-km-wide caldera with a steep-walled inner crater whose floor is only 68 m above sea level.

Information Contacts: *Juan Takai Camacho* and *Ramon Chong*, Commonwealth of the Northern Mariana Islands Emergency Management Office, P.O. Box 10007, Saipan, MP 96950 USA (URL: http://www.cnmiemo.org/, Email: juantcamacho@hotmail.com and rcchongemo@hotmail.com); *Frank Trusdell*, Hawaiian Volcano Observatory, P.O. Box 51, Hawaii National Park, HI 96718-0051 USA (URL: http://hvo.wr.usgs.gov/cnmi/, Email: trusdell@usgs.gov).

Mayon

Phillippines
3.257°N, 123.685°E; summit elev. 2,462 m
All times are local (= UTC + 8 hours)

The Philippine Institute of Volcanology and Seismology (PHIVOLCS) reported on 18 September 2003 that earthquake activity at Mayon had been within background levels (< 5 events/day) since 14 August with no volcanic earthquakes over the previous five days and moderate volcanic gas outputs. However, the sulfur dioxide (SO_2) flux at 1,237 metric tons per day (t/d) was above baseline levels, having increased from 829 t/d since 5 September. In view of increased SO_2 gas emissions, and recent significant earthquake occurrences, PHIVOLCS set the hazard status at Alert Level 1 (on a scale of 0-5).

For the period 29 September-5 October, 16 low-frequency volcanic earthquakes (19.0 mm amplitude), five high-frequency volcanic earthquakes (26.0 mm amplitude), and four high-frequency short-duration volcanic earthquakes (2.5 mm amplitude) were recorded, accompanied by weak to moderate steaming and no visible crater glow. During 6-12 October, 29 low-frequency volcanic earthquakes (14.0 mm amplitude), four high-frequency volcanic earthquakes (6.2 mm amplitude), and two high-frequency short duration volcanic earthquakes (2.0 mm amplitude) were recorded, with moderate steaming and faint crater glow.

PHIVOLCS reported on 9 October that a faint glow had been seen by telescope at the inner E portion of the summit crater between 2330 on 8 October and 0048 on 9 October,

and again between 1630 and 1650 on 9 October. Low-frequency volcanic earthquakes occurred four and six times, respectively, during 8 and 9 October. Steam emission remained moderate, with visible plumes barely rising above the crater rim. Mayon's SO_2 flux on 9 October rose to 2,386 t/d from 1,616 t/d on 1 October.

On 11 October PHIVOLCS noted persistent and significant incandescence inside the summit crater, apparently from lava in the E portion of the volcano's conduit. Seismicity over the previous 24 hours was relatively low (three low-frequency volcanic earthquakes). The Alert Level was raised to 2, signifying instability that may lead to ash explosions or a magmatic eruption.

Background. Beautifully symmetrical Mayon volcano, which rises to 2462 m above the Albay Gulf, is the Philippines' most active volcano. The structurally simple volcano has steep upper slopes averaging 35-40 degrees that are capped by a small summit crater. The historical eruptions of this basaltic-andesitic volcano date back to 1616 and range from Strombolian to basaltic Plinian. Eruptions occur predominately from the central conduit and have also produced lava flows that travel far down the flanks. Pyroclastic flows and mudflows have commonly swept down many of the approximately 40 ravines that radiate from the summit and have often devastated populated lowland areas. Mayon's most violent eruption, in 1814, killed more than 1200 people and devastated several towns.

Information Contact: *Philippine Institute of Volcanology and Seismology (PHIVOLCS)*, Department of Science and Technology, PHIVOLCS Building, C.P. Garcia Avenue, University of the Philippines Campus, Diliman, Quezon City, Philippines (URL: http://www.phivolcs.dost.gov.ph/).

Karangetang

Sangihe Islands, Indonesia
2.78°N, 125.48°E; summit elev. 1,784 m

Ash explosions have been frequent at Karangetang during 2003 (*Bulletin* v. 28, nos. 5 and 7). A red glow at night and lava avalanches were reported during 9-15 June (*Bulletin* v. 28, no. 7). Although detailed observations were not provided by the Volcanological Survey of Indonesia (VSI) for the next two weeks, the hazard status remained at Alert Level 2 (on a scale of 1-4).

VSI weekly reports from 30 June through 3 August indicated that white gas plumes from the S crater typically rose 350-500 m above the crater rim, night glow often extended 25 m above the crater, and white gas plumes from the N crater rose as high as 350 m. Seismic data showed that lava avalanches and shallow volcanic earthquakes in early July were significantly reduced compared to the first half of June (table 1).

During 18-20 July there were ash-producing explosions and lava avalanches. On 21-22 July an ash explosion produced a 150-m-high ash column and a glowing lava avalanche flowed 350 m toward the Beha river. During the week of 28 July-3 August another glowing lava avalanche flowed 1,500 m toward the Beha river and 350 m toward the Batang river. On 29 July volcanic tremor was recorded with a maximum amplitude of 0.5-2 mm.

Karangetang was not included in August reports, but the report for 1-28 September noted white gas emissions from the S crater rising 150-350 m and red glow at night reaching 25 m over the crater, with the N crater exhibiting white gas emissions to 50-150 m above the crater. There were no lava avalanches during this period. The Alert Level remained at 2.

Background. Karangetang (Api Siau) volcano lies at the northern end of the island of Siau, north of Sulawesi. The 1784-m-high stratovolcano contains five summit craters along a N-S line. Karangetang is one of Indonesia's most active volcanoes, with more than 40 eruptions recorded since 1675 and many additional small eruptions that were not documented in the historical record (Catalog of Active Volcanoes of the World). Twentieth-century eruptions have included frequent explosive activity sometimes accompanied by pyroclastic flows and lahars. Lava dome growth has occurred in the summit craters; collapse of lava flow fronts has also produced pyroclastic flows.

Information Contacts: *Dali Ahmad*, *Hetty Triastuty*, and *Nia Haerani*, Volcanological Survey of Indonesia (VSI), Jalan Diponegoro No. 57, Bandung 40122, Indonesia (Email: dali@vsi.esdm.go.id; URL: http://www.vsi.esdm.go.id/).

Date (2003)	Deep Volcanic	Shallow Volcanic	Explosion	Multiphase	Emission	Avalanches	Tectonic
02 Jun-08 Jun	11	348	—	233	46	110	26
09 Jun-15 Jun	32	438	1	228	21	447	20
30 Jun-06 Jul	15	93	—	446	11	32	11
07 Jul-13 Jul	15	93	—	534	22	35	7
14 Jul-20 Jul	21	174	31	672	38	45	22
21 Jul-27 Jul	17	112	9	94	131	66	25
28 Jul-03 Aug	10	8	—	312	174	94	10
01 Sep-07 Sep	8	44	1	80	341	1	20
08 Sep-14 Sep	5	14	0	50	266	5	23
15 Sep-21 Sep	6	90	0	3	16	0	74
22 Sep-28 Sep	9	60	0	75	130	0	37

Table 1. Seismicity at Karangetang during 2 June-28 September 2003. VSI did not issue reports for Karangetang during weeks not included in the table; a dash indicates no data reported. Courtesy of VSI.

Dukono

Halmahera, Indonesia
1.68°N, 127.88°E; summit elev. 1,185 m

Volcanological Survey of Indonesia (VSI) reports for June and July 2003 noted volcanic activity and ash emissions from Dukono. VSI reported an ash explosion commencing on 7 June, with ashfall in the Galela area (~ 7 km from the summit) on 9 June (*Bulletin* v. 28, no. 6). Explosive events had decreased by 9 June, but as of 10 June the plume was still visible on satellite imagery. No additional activity was reported through the end of June.

Ash explosions were again reported by VSI during 9-23 July, with a maximum plume height of 1,000 m in clear weather on 22 July (*Bulletin* v. 28, no. 6). No Dukono activity was reported in the report for 21-27 July. Ash explosions were reported again during 28 July-3 August, with a white-gray column, under weak pressure, rising 15-75 m. Some explosions produced dark-gray ash columns reaching 95-450 m high. On 27 and 28 July some blasting sounds were heard in the Galela area and continuous blasting sounds were heard on 25, 26, and 29 July. Minor ash fell around the crater, and ash drifted E, SE, and NE.

Ash explosions continued during 18-31 August, producing a gray ash plume 75 m high and an ash column that rose 200-250 m accompanied by booming sounds. VSI reported that ash explosions during the 1-28 September period produced a gray ash plume 50-200 m high. When there was no explosive activity, white-gray ash emissions were observed rising 50 m from the crater. The hazard status has remained at Alert Level 2 (on a scale of 1-4) since early June.

Background. Reports from this remote volcano in northernmost Halmahera are rare, but Dukono has been one of Indonesia's most active volcanoes. More or less continuous explosive eruptions, sometimes accompanied by lava flows, occurred since 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: *Dali Ahmad* and *Nia Haerani*, Volcanological Survey of Indonesia (VSI) (see Karengetang).

Gamalama

Halmahera, Indonesia
0.80°N, 127.325°E; summit elev. 1,715 m

An eruptive event on 31 July 2003 at Gamalama produced ashfall and pyroclastic flows (*Bulletin* v. 28, no. 7). The Volcanological Survey of Indonesia (VSI) report for the week of 28 July-3 August noted that the hazard status was downgraded to Alert Level 3 on 2 August. A white gas plume was reported as rising 10-50 m above the summit and the seismograph record was dominated by emission events.

Date (2003)	Deep Volcanic	Shallow Volcanic	Emission	Tectonic
01-07 Sep	1	7	35	64
08-14 Sep	3	1	16	59
15-21 Sep	0	1	12	57
22-28 Sep	0	3	21	49

Table 2. Seismicity at Gamalama during 1-28 September 2003. Courtesy of VSI.

Volcanic activity was low during 18-31 August, with white gas emissions and several small ash explosions. White-gray ash plumes emitted from the crater reached 100 m high. Night glow was seen just above the crater rim. Recorded emission and tectonic earthquakes averaged four events per day. Reduced activity continued during 1-28 September 2003, again with white gas emission and small ash explosions that occurred several times. Seismicity was dominated by tectonic and emission events (table 2). The hazard status since 18 August has been at Alert Level 2 (on a scale of 1-4).

Background. Gamalama (Peak of Ternate) is a near-conical stratovolcano that comprises the entire island of Ternate off the western coast of Halmahera and is one of Indonesia's most active volcanoes. The island of Ternate was a major regional center in the Portuguese and Dutch spice trade for several centuries, which contributed to the thorough documentation of Gamalama's historical activity. Three cones, progressively younger to the N, form the summit of Gamalama, which reaches 1715 m. Several maars and vents define a rift zone, parallel to the Halmahera island arc, that cuts the volcano. Eruptions, recorded frequently since the 16th century, typically originated from the summit craters, although flank eruptions have occurred in 1763, 1770, 1775, and 1962-63.

Information Contact: *Dali Ahmad*, Volcanological Survey of Indonesia (VSI) (see Karengetang).

Tongkoko

Sulawesi, Indonesia
1.52°N, 125.20°E; summit elev. 1,149 m

The Volcanological Survey of Indonesia (VSI) reported deep volcanic and A-type earthquakes at Tongkoko (also known as Tangkoko) over the period 7 October-24 November 2002 and more deep-volcanic events during 23 December 2002-19 January 2003 (table 3). The earthquakes, which began in May 2002, were recorded following relocation of an observatory post to Wainenet village in the Bitung area. The temperature at Batu Angus hot spring on 10 October 2002 was 70-73°C. While no visible activity has been observed, the hazard status was raised to Alert Level 2 (on a scale of 1-4) on 24 October 2002 as a result of the increased seismicity. The last recorded activity at Tongkoko consisted of flank lava flows and lava dome extrusion in 1880.

Background. The NE-most volcano on the island of Sulawesi, Tongkoko has a summit that is elongated in a

Date (2002-03)	Deep Volcanic	A-type	Tectonic
07 Oct-13 Oct	4	—	—
14 Oct-20 Oct	—	12	23
21 Oct-27 Oct	—	9	34
28 Oct-03 Nov	—	17	19
04 Nov-10 Nov	—	9	38
11 Nov-18 Nov	—	2	37
19 Nov-24 Nov	—	2	25
23 Dec-29 Dec	5	—	16
06 Jan-12 Jan	11	—	21
13 Jan-19 Jan	5	—	28

Table 3. Earthquakes recorded at Tongkoko, 7 October 2002-19 January 2003. In addition, one shallow volcanic event was recorded during 13-19 January 2003, and single B-type earthquakes each occurred during 21-27 October and 4-10 November 2002. Courtesy of VSI.

NW-SE direction with a large deep crater that in 1801 contained a cone surrounded by lake water. The slightly higher Dua Saudara stratovolcano is located only 3 km to the SW of Tongkoko, and along with Tongkoko, forms the most prominent features of Gunung Dua Saudara National Park, a noted wildlife preserve. Eruptions occurred from the summit crater of Tongkoko in the 17th century and in 1801. The prominent, flat-topped lava dome Batu Angus formed on the E flank of Tongkoko in 1801, and, along with an adjacent E-flank vent, has been the source of all subsequent eruptions.

Information Contact: *Dali Ahmad*, *Hetty Triastuty*, *Nia Haerani*, and *Suswati*, Volcanological Survey of Indonesia (VSI) (see Karengetang).

Tandikat

Sumatra, Indonesia
0.433°S, 100.317°E; summit elev. 2,438 m

Volcanic seismicity at Tandikat increased significantly following a felt event (MM III) on 20 January 2002 (table 4). Deep-volcanic earthquakes totaled 149 during the week of 20-26 January, a period when 174 tectonic events were also recorded. Both types of earthquakes decreased significantly the next week, and gradually declined further over the following two weeks. The weekly report for 27 January-2 February noted that visual observations were not possible due to thick fog. The hazard status was set at Alert Level 2 (on a scale of 1-4) on 25 January 2002 and remained at that level through 16 February.

Background. Tandikat and its twin volcano to the NNE, Singgalang, lie across the Bukittinggi plain from Marapi volcano. Volcanic activity has migrated to the SSW from Singgalang and only Tandikat has had historical activity. The summit of Tandikat has a partially eroded 1.2-km-wide crater containing a large central cone capped by a 360-m-wide crater with a small crater lake. The only three reported historical eruptions, in the late 19th and early 20th centuries, produced only mild explosive activity.

Information Contact: *Dali Ahmad*, Volcanological Survey of Indonesia (VSI) (see Karengetang).

Date (2002)	Shallow Volcanic	Deep Volcanic	Emission	Tremor	Tectonic
13 Jan-19 Jan	—	6	—	—	22
20 Jan-26 Jan	1	149	—	2	174
27 Jan-02 Feb	—	46	4	1	54
03 Feb-09 Feb	—	24	3	—	18
10 Feb-16 Feb	—	19	5	—	15

Table 4. Seismicity recorded at Tandikat, 13 January-16 February 2002. Courtesy of VSI.

Dieng

Java, Indonesia
7.20°S, 109.92°E; summit elev. 2565 m

The Volcanological Survey of Indonesia (VSI) activity report for the week of 4-10 August 2003 noted, for the Sileri crater in the Dieng volcano complex, one shallow volcanic earthquake, a white gas plume rising 25-60 m, and water temperature of 83°C. The hazard status was set at Alert Level 2 (on a scale of 1-4).

Background. The Dieng plateau in the highlands of central Java is renowned both for the variety of its volcanic scenery and as a sacred area housing Java's oldest Hindu temples, dating back to the 9th century AD. The Dieng volcanic complex consists of two or more stratovolcanoes and more than 20 small craters and cones of Pleistocene-to-Holocene age over a 6 x 14 km area. Prahu stratovolcano was truncated by a large Pleistocene caldera, which was subsequently filled by a series of dissected to youthful cones, lava domes, and craters, many containing lakes. Lava flows cover much of the plateau, but have not occurred in historical time, when activity has been restricted to minor phreatic eruptions. Toxic volcanic gas emission has caused fatalities and is a hazard at several craters. The abundant thermal features that dot the plateau and high heat flow make Dieng a major geothermal prospect.

Information Contact: *Dali Ahmad* and *Nia Haerani*, Volcanological Survey of Indonesia (VSI) (see Karengetang).

Semeru

Java, Indonesia
8.108°S, 112.92°E; summit elev. 3,676 m

Volcanic activity at Semeru between 30 June and 28 September remained at high levels. Except for the middle two weeks of July, ash explosions were reported several times every week, producing white-gray plumes that rose 400-500 m above the summit. Recorded seismic data (table 5) reflected this continued activity, with between 447 and 804 explosion events weekly (~ 88 per day on average over this 90-day period). Avalanche events, tremor, tectonic, deep-volcanic, shallow-volcanic, and flood-related seismicity were also recorded. A pilot report from Qantas noted a plume to twice the height of the volcano (~ 7.2 km

Date (2003)	Explosion	Avalanche	Tremor	Other	Tectonic
30 Jun-06 Jul	611	7	6	—	7
07 Jul-13 Jul	615	10	18	2 deep	9
14 Jul-20 Jul	579	19	1	—	8
21 Jul-27 Jul	529	11	7	—	10
28 Jul-03 Aug	447	21	5	—	6
04 Aug-10 Aug	499	20	10	1 shallow	5
11 Aug-17 Aug	550	8	16	—	6
18 Aug-24 Aug	516	13	2	1 shallow	10
25 Aug-31 Aug	804	11	1	—	7
01 Sep-07 Sep	735	12	0	0	6
08 Sep-14 Sep	699	30	1	1 flood	5
15 Sep-21 Sep	731	11	5	0	8
22 Sep-28 Sep	636	20	9	0	4

Table 5. Seismicity at Semeru, 30 June-28 September 2003. Courtesy of VSI.

altitude) on 9 September that was drifting S. The hazard status remained at Alert Level 2 throughout the report period.

Background. Semeru, the highest volcano on Java, and one of its most active, lies at the southern end of a volcanic massif extending north to the Tengger caldera. The steep-sided volcano, also referred to as Mahameru (Great Mountain), rises abruptly to 3,676 m above coastal plains to the S. Gunung Semeru was constructed S of the overlapping Ajek-ajek and Jambangan calderas. A line of lake-filled maars was constructed along a N-S trend cutting through the summit, and cinder cones and lava domes occupy the eastern and NE flanks. Summit topography is complicated by the shifting of craters from NW to SE. Frequent 19th and 20th century eruptions were dominated by small-to-moderate explosions from the summit crater, with occasional lava flows and larger explosive eruptions accompanied by pyroclastic flows that have reached the lower flanks of the volcano. Semeru has been in almost continuous eruption since 1967.

Information Contacts: *Dali Ahmad* and *Nia Haerani*, Volcanological Survey of Indonesia (VSI)Volcanological Survey of Indonesia (VSI) (see Karengetang); *Darwin Volcanic Ash Advisory Centre (VAAC)*, Bureau of Meteorology, Northern Territory Regional Office, PO Box 40050, Casuarina, NT 0811, Australia (URL: http://www.bom.gov.au/info/vaac/).

Manam

Papua New Guinea
4.10°S, 145.061°E; summit elev. 1,807 m

Recent activity at Manam has consisted of white vapor emissions from both the Main and Southern craters, and low seismicity (*Bulletin* v. 28, no. 3). The Rabaul Volcanological Observatory reported that the two vents in the Main crater gently released weak, thin white vapor during 7-12 May, with occasional white-gray emissions on 11 May. Fine ashfall resulting from occasional emissions of thin white gray ash plumes from Main crater was reported on the NW side of the island on 17-19 and 23 May. No audible noise or glow was reported. Southern crater continued to gently release small amounts of thin white vapor. The volcano was quiet over the period 25-30 June, with both craters gently releasing occasional thin white vapor emissions and low seismicity.

Background. The 10-km-wide island of Manam, lying 13 km off the N coast of Papua New Guinea, is one of the country's most active volcanoes. Four large radial valleys extend from the unvegetated summit of the conical 1,807-m-high 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 present; both are active, although most historical eruptions have originated from the southern crater, concentrating eruptive products during the past century into the 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.

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Pago

New Britain, Papua New Guinea
5.58°S, 150.52°E; summit elev. 742 m

The eruption at Pago that began in August 2002 continued during early 2003 with lava effusion through at least 28 February and vapor emissions (*Bulletin* v. 28, no. 3). The Rabaul Volcanological Observatory (RVO) reports that activity at Pago continued, but remained low, from 14 April through 9 October 2003.

The line of vents on the NW slope of Pago continued to release small amounts of thin white vapor over the whole of the period. Occasional weak audible booming noises were heard (eg. on 20 April) and roaring noises were heard on 24 April, 6 May, and 22 May. Very small traces of blue vapor were seen coming from the lower vents on 8 May.

An aerial inspection on 22 May showed that lava effusion from the NW vent had ceased since the February inspection; there were no indications of fresh lava near the vent, no movement of the N and S lobes, and no change in the height of lava against the caldera wall. It also revealed a new fumarolic area to the E.

Monitoring instruments were restored on 19 May. Leveling measurements showed a few centimeters of inflation compared to December 2002. This was considered by RVO to be very significant when compared to previous measurements, but may have been due to nearby roadwork.

Less than 20 volcano-tectonic earthquakes per day were recorded during 25-30 June. A local tectonic earthquake on

9 August seemed to lead to an increase in energy release and event numbers at one seismic station, but it may have been an instrumentation problem. An airborne spectrophotometer revealed only trace amounts of SO_2 in early August. Between two and seven volcano-tectonic earthquakes per day were reported in the 26 September-9 October period.

Background. Pago is a young post-caldera cone that was constructed within the 5.5 x 7.5 km Witori caldera. Extensive pyroclastic-flow deposits are associated with formation of the caldera about 3300 years ago. The gently sloping outer flanks of Witori volcano consist primarily of dacitic pyroclastic-flow and airfall deposits produced during a series of five major explosive eruptions from about 5600 to 1200 years ago. The Buru caldera, which may have formed around the same time, cuts the SW flank of Witori volcano. The post-caldera cone of Witori, Mount Pago, may have formed less than 350 years ago. Pago has grown to a height above that of the Witori caldera rim. A series of ten dacitic lava flows from Pago covers much of the caldera floor. The youngest of these was erupted during 2002-2003 from vents extending from the summit nearly to the NW caldera wall.

Information Contact: *Ima Itikarai*, Rabaul Volcanological Observatory (see Manam).

Ulawun

New Britain, Papua New Guinea
5.05°S, 151.33°W; summit elev. 2,334 m

Variable amounts of emergent vapor and minor debris flows at Ulawun were reported during January-March 2003 (*Bulletin* v. 28, no. 03). Rabaul Volcanological Observatory (RVO) reports, covering much of the period 14 April-5 October 2003, indicated the volcano remained quiet over this time, without emissions from the N-valley vent.

The main summit crater continued to release weak to moderate volumes of white (occasionally white-gray) vapor during 14-29 April, 7-27 May, and 11-18 June. Seismicity was low except for an episode of volcanic tremor between 15 and 19 April. Gas effervescence was reported close offshore of Ulamona Jetty in the second half of April. A slight increase in seismicity was noted between 18 and 23 May.

The period 25 June-22 July was quiet, with no audible noise or night-time glow, and weak to moderate volumes of vapor from the main summit crater. The Volcanic Ash Advisory Center in Darwin reported these plumes as being visible on weather satellite imagery. The plumes appeared white-gray on occasions and were unusually strong bluish white gray over the last three days of the period. Volcanic seismicity was low, with several strongly felt tectonic earthquakes on the night of 3-4 July. A large regional earthquake centered 45 km N of Rabaul affected the area on 16 July, leading to a large tiltmeter offset, which slowly recovered over the following days.

Reports for the period 12 September-5 October indicated that the main summit continued to release weak to moderate volumes of white vapor, with occasional white-gray emissions. Seismicity was low with no significant ground movements.

Background. The symmetrical basaltic-to-andesitic Ulawun stratovolcano is the highest volcano of the Bismarck arc, and one of Papua New Guinea's most frequently active. Ulawun volcano, also known as the North Son, rises above the north coast of the island of New Britain across a low saddle NE of Bamus volcano, the South Son. The upper 1000 m of the 2334-m-high Ulawun volcano is unvegetated. A prominent E-W-trending escarpment on the south may be the result of large-scale slumping. Satellitic cones occupy the NW and eastern flanks. A steep-walled valley cuts the NW side of Ulawun volcano, and a flank lava-flow complex lies to the south of this valley. Historical eruptions date back to the beginning of the 18th century. Twentieth-century eruptions were mildly explosive until 1967, but after 1970 several larger eruptions produced lava flows and basaltic pyroclastic flows, greatly modifying the summit crater.

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Rabaul

New Britain, Papua New Guinea
4.271°S, 152.203°E; summit elev. 688 m

Reports from the Rabaul Volcanological Observatory (RVO) over the period 20 March-9 October show that ash eruptions from the Tavurvur cone at Rabaul are continuing. Activity has been nearly continuous since the major September 1994 eruption (*Bulletin* v. 19, no. 8).

Eruptions during 20 March-6 April were characterized by discrete, slow, convoluted ash plumes occurring at long irregular intervals rising slowly to several hundred meters over the summit. The ash plumes were mainly light to pale gray, blowing to the SE. Seismicity was generally low, with low- to intermediate-frequency events of 1-5 minute duration associated with the ash emissions, and greater energy expended over the first 10 seconds of the more forceful eruptions. Ground deformation fluctuated without showing any real trends.

Short forceful and slow sub-continuous discrete ash emissions were reported for 7-29 April. Light to pale gray ash-laden plumes rose as high as 1,500 m over the summit, blowing NW and SE on variable winds, with ash accumulation in Rabaul Town to the NW. Seismicity was generally low and reflected the eruptive activity. Most activity involved low-frequency, low-amplitude short- to long-duration sub-continuous volcanic tremors. Some high-frequency earthquakes were recorded NE of Rabaul Town. Deformation measurements showed minor inflation.

Steady ash eruptions continued during 7-12 May. While the ash content in individual plumes was fairly low, the accumulation of ash on the ground became quite significant within 5 km of the volcano. Seismicity was generally low (low-frequency earthquakes with durations of several minutes), reflecting summit activity. This increased to moderate seismicity over 10-12 May. Short-term ground-deformation measurements were ambiguous; long-term trends showed minor inflation.

There was a noticeable decline in ash eruptions and seismicity during 19-30 June, from one every few minutes

to less than one per hour and then complete cessation on 29 June. Very occasional low roaring noises were heard early in the period. Tavurvur released only variable amounts of thin white vapor through 9 August. It began to erupt again on 10 August, with slow convoluted emissions of mainly white to pale-gray ash at irregular intervals blowing to the NW, including over the Rabaul Town area. Discrete moderate to large explosions began to occur on 25 August (1-3 per day). Occasional low rumbling noises were heard. Seismic activity was low and there were no significant ground movements.

From 29 August to 11 September the level of eruptive activity was low to moderate, characterized by convoluted ash clouds at short irregular intervals. Moderate explosions (3-6 per day) produced thick columns of pale gray to dark ash clouds rising 2-4 km above the summit. The prevailing SE winds resulted in ashfall to the NW, including in the Rabaul Town area. Seismic activity was low, with some high-frequency earthquakes NE of Rabaul Caldera and no significant ground-deformation movements.

The level of eruptive activity was generally low during 12-25 September (figure 3), with light to pale gray ash clouds rising 500-1,500 m above the summit and light downwind ashfall in the early part of the reporting period. Over 22-25 September the ash cloud emissions became light gray, with high water vapor content. Low to moderate rumbling noises were heard, but seismic activity was low and ground deformation movements were not significant.

Eruptive activity continued at a low level from 26 September to 9 October, with light to pale gray emissions (containing some ash but mostly water vapor) rising 500-1,500 m. The emissions occurred at long, irregular intervals, and many were accompanied by low roaring and rumbling noises. Very fine ash was blown mainly to the N and NW. Seismic activity was low, with no high-frequency earthquakes inside the caldera or NE of the caldera. Ground-deformation measurements showed a long-term inflationary trend between May and September, but the magnitude of change was small.

Background. The low-lying Rabaul caldera on the tip of the Gazelle Peninsula at NE end of New Britain forms a broad sheltered harbor utilized by what was the island's largest city prior to a major eruption in 1994. The outer flanks of the 688-m-high asymmetrical pyroclastic shield volcano are formed by thick pyroclastic-flow deposits. The 8 x 14 km caldera is widely breached on the east, where its floor is flooded by Blanche Bay. Two major Holocene caldera-forming eruptions at Rabaul took place about 7100 and 1400 years ago. Three small stratovolcanoes lie outside the northern and NE caldera rims. Post-caldera eruptions built basaltic-to-dacitic pyroclastic cones on the caldera floor near the NE and western caldera walls. Several of these, including Vulcan cone, which was formed during a large eruption in 1878, have produced major explosive activity during historical time. A powerful explosive eruption in 1994 occurred simultaneously from Vulcan and Tavurvur volcanoes and forced the temporary abandonment of Rabaul city.

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Figure 3. Photograph showing a plume from the Tavurvur cone at Rabaul (left background) taken from the Rabaul Volcanological Observatory, with Rabaul Town and Harbor in the foreground, 17 September 2003. Courtesy of William Kiene, UCLA.

Lamington

Papua New Guinea
8.95°S, 148.15°E; summit elev. 1,680 m

The Rabaul Volcanological Observatory reported that Lamington remained quiet over the period 25 June-9 October 2003. Vapor emissions were difficult to observe because of the distance to the observation point, but on a few clear days very small volumes of thin white vapor were seen in the summit area. The report also noted that high-frequency volcano-tectonic-like earthquakes began in early July at a rate of up to five events per day and continued into early October. This is the first time since the seismic station was re-established in 1997 that these types of earthquakes have been recorded in significant numbers over a short period of time.

Background. Lamington is an andesitic stratovolcano with a 1.3-km-wide breached summit crater containing a lava dome. Prior to its renowned devastating eruption in 1951, the forested peak had not been recognized as a volcano. Mount Lamington rises to 1680 m above the coastal plain north of the Owen Stanley Range. A summit complex of lava domes and crater remnants rises above a low-angle base of volcaniclastic deposits that are dissected by radial valleys. A prominent broad "avalanche valley" extends northward from the breached crater. Mount Lamington sprang suddenly to life in 1951, producing a powerful explosive eruption during which devastating pyroclastic flows and surges swept all sides of the volcano, killing nearly 3000 persons. The eruption concluded with growth of a 560-m-high lava dome in the summit crater.

Information Contact: *Ima Itikarai*, Rabaul Volcanological Observatory (see Manam).

Ambrym

Ambrym Island, Vanuatu
16.25°S, 168.12°E; summit elev. 1,334 m
All times are local (= UTC + 11 hours)

John Seach previously reported his observations of the Ambrym caldera made during a visit in December 2002 (*Bulletin* v. 27, no.12). This report contains his observations of the caldera during a 7-11 September 2003 visit and flyovers on 6 and 13 September. The level of activity during September 2003, with visible lava in six vents, was higher than that during his previous visit.

Observations of Benbow. During the 6 September flyover, two white plumes were rising 200 m above the crater rim and drifting NW. On the evening of 7 September, orange glows were seen from the caldera edge (3 km SE). A strong glow originated N of the crater and the central crater pit produced a less intense fluctuating glow. During the 13 September flyover, both pits continued to emit white and light-brown plumes to 200 m above the rim.

Observations of Mbogon Niri Mbwelesu. Large white vapor emissions from the collapse pit formed mushroom-shaped clouds on 6 September that drifted W and attained a height of 300 m. A visit to the S rim on 7 September showed a weak orange glow and copious gas emissions. On 8 September, observations from the N rim showed the pit full of swirling brown and white vapor. The NW wall was stained with yellow and red deposits, and pungent sulfurous gases were being emitted. Loud, rhythmic degassing sounds were heard every few seconds. The bottom of the pit was visible on 10 September, allowing views of two glowing red holes 150 m below the rim separated by a small wall a few meters wide. The two vents degassed simultaneously, but the E vent emitted larger amounts of brown ash.

Observations of Niri Mbwelesu. During the 6 September overflight, the pit of Niri Mbwelesu crater was filled with white vapor. The crater was climbed on 8 September and observations from the S rim showed the crater still filled with vapor; no sounds were heard. During that evening, an orange glow was observed. Excellent visibility on 10 September enabled sighting of a 10-m-diameter, crusted lava pond. Red lava was visible through surface cracks, and lava spatter rose 10 m above them at infrequent intervals.

Loud cannon-like explosions about every 20 minutes shook the ground and were accompanied by the sounds of cracking rock. During the evening, glowing projectiles were ejected into the air, although none fell outside the crater. Loud, roaring degassing noises like a jet engine at take-off were also heard. The roar would gain intensity over 30 seconds, cease for 15 seconds and then re-start. During periods of intense roaring, red lava was observed through cracks in the crusted surface.

Both types of intense degassing were accompanied by gentle emissions of brown vapor. A pit, 6 m in diameter, located N of the crusted pond in the crater wall, emitted brown ash. Fumaroles were high on the N inner crater wall. Brown ash was emitted from the S crater floor.

Observations of Mbwelesu. Mbwelesu crater was observed for 3 hours during mid-day on 8 September from a position on the SW rim. At times, the crater was filled with vapor, but observation of the lake surface was only possible about 60% of the time. The lava lake showed remarkable similarities in location, size, and dynamics compared to December 2002. The 50-m-diameter lava lake was contained inside a circular funnel-shaped pit 100-120 m in diameter. Violent agitation of the surface occurred most of the time. Lava splashed onto the pit walls and drained back vertically 25 m into the pit.

Large 10-m-diameter gas bubbles burst in the SE half of the lava lake with up to eight bubbles visible at the same time. Jets of lava were ejected every few seconds, created by wave intersections from the bursting bubbles. During periods of low activity, lasting tens of seconds, lava drained back into the middle of the pit. Surface crusting occurred after as little as one minute during quiet periods. Subsequently, the crust was broken up by a resumption of degassing from the SW side of the pit. On several occasions, up to 80% of the lava lake surface was covered by darker crust.

Acid rain was experienced on the edge of the crater and observers felt minor burning on the face. White, light-brown, and blue-tinged vapors smelling of sulfur were emitted from the crater.

Mbwelesu was scaled again on 10 September and observations of the lava lake (figure 4) were made over eight hours. The crater was clear, enabling detailed observations. At times 80% of the lake surface was deformed by bubbling. The SE portion of the pit contained the most degassing. Violent explosions regularly sprayed orange lava mixed with black crust in all directions. At one point the whole lake surface rotated clockwise and lava drained back into the middle of the pit. This whirlpool was followed by an avalanche on the W side of the pit that threw black material into the lake. A second pit with a diameter of 75 m NE of the lava lake was separated by an unstable 10-m-wide wall from which numerous avalanches occurred during the day; red lava spatter was ejected once.

An afternoon flyover on 13 September enabled excellent views of the active lava lake. The smaller pit NE of the lava lake contained a small lava pond with a diameter of ~ 8-10 m.

Observations of Marum. Two areas of fumarolic activity were seen at the edge of the 1953 crater (between Marum and Mbwelesu). Brown ash was being emitted from the ground at these locations.

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Figure 4. Lava lake inside Mbwelesu crater at Ambrym on 10 September 2003. Surface crusting and degassing are clear, note new crater at top of photo. Courtesy of John Seach.

Momotombo

Nicaragua
12.422°N, 86.540°W; summit elev. 1,297 m

Instituto Nicaraguense de Estudios Territoriales (INETER) reports from March 2002 through September 2003 indicate that seismicity has generally been low. Occasional visits to the summit of Momotombo (figure 5) are made to sample gases and take temperature measurements.

The first visit during this time period was on 13 April 2002. Temperature measurements in the crater fumaroles showed little variation from previous measurements, except for fumarole 14, which showed an increase from 434 to 583°C. There were no visits in May; seismic monitoring recorded only one earthquake.

Seismicity increased during the early part of June, with a seismic cluster from 1 to 11 June SW of Momotombo consisting of more than 120 earthquakes. Thirty of these earthquakes occurred on 9 June. An event on 8 June was felt at the geothermal plant W of the volcano. The majority of these events were volcano-tectonic earthquakes with frequencies between 15 and 20 Hz. The unusual tornillos (screw-type events) have continued to occur at Momotombo, usually lasting 2-5 seconds with a dominant frequency of 5 Hz.

Only 16 earthquakes were recorded in July, four of them on 12 July; none were located. Tornillos continued with a frequency of 7.5 Hz in both July and August. Seismicity increased in August with a small seismic cluster and 176 registered earthquakes, mainly volcano-tectonic. The majority of the activity took place on 1 and 2 August, including one event felt by staff at the geothermal plant. Seismicity dropped dramatically in September, October, and November, with 7 and 12 volcano-tectonic events in September and October, respectively, and none in November. Visits were made on 19, 20, 21, and 22 November for gas sampling and temperature measurements. Temperatures were measured in 12 fumaroles and around the seismic stations at the base of the volcano. The highest temperatures were found at fumaroles 3, 4, 5, 8, and 9, with the maximum temperature of 768°C at fumarole 9. Temperatures at the three fumaroles around the seismic station were 89.9°C, 99.1°C, and 90.2°C.

Seismicity increased again in December 2002 and January 2003. A seismic cluster of 88 events was recorded during 24-25 December. Locations determined for 18 of the eventsput them all very close to the volcano. In January 55 tectonic earthquakes were registered. After January, seismicity dropped considerably. No earthquakes were registered in February, and only one was recorded in March.

Site visits in February included walking around the crater; no morphological changes were observed. The visit also included gas sampling and temperature measurements. Fumaroles 8 and 9 measured 759°C and 762°C, respectively; more monitoring on 8 and 27 March showed that temperatures were staying relatively constant. No visits were made in April, May, or June, but seismic monitoring continued. Although only one volcano-tectonic earthquake registered in April, tornillos continued, with frequencies above 12 Hz. There were 35 volcano-tectonic events in May, including a three-hour-long cluster on 30 May. Six seismic events registered in June.

Figure 5. Photograph of Momotombo (unknown date) showing the E flank and the 1905 lava flows. Note that a small steam plume is rising from the crater fumaroles. Lake Managua is in the background. Courtesy of INETER.

A visit was made to the volcano on 12 July 2003; temperatures were similar to the previous months, ranging from 243°C at fumarole 13 to 737°C at fumarole 9. Two earthquakes registered in August; seismicity stayed low through September.

Background. Momotombo is a young, 1297-m-high stratovolcano that rises prominently above the NW shore of Lake Managua, forming one of Nicaragua's most familiar landmarks. Momotombo began growing about 4500 years ago at the SE end of the Marrabios Range and consists of a somma from an older edifice that is surmounted by a symmetrical younger cone with a 150 x 250 m wide summit crater. Young lava flows from Momotombo have flowed down the NW flank into the 4-km-wide

Monte Galán caldera. The youthful cone of Momotombito forms a 391-m-high island offshore in Lake Managua. Momotombo has a long record of strombolian eruptions, punctuated by occasional larger explosive activity. The latest eruption, in 1905, produced a lava flow that traveled from the summit to the lower NE base. A small black plume was seen above the crater after an April 10, 1996 earthquake, but later observations noted no significant changes in the crater. A major geothermal field is located on the S flank of the volcano.

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Concepcíon

Nicaragua
11.538°N, 85.622°W; summit elev. 1,700 m

Reports from March 2002 through September 2003 were provided by Instituto Nicaraguense de Estudios Territoriales (INETER). Activity has been generally constant from 2001 through 2003, with tremor and very low magnitude earthquakes, usually detected by the station on the N side of the volcano (CONN). Throughout the summary period, there were occasionally technical difficulties at the Mombacho station, so no activity was registered on those days. Periods of noticeably high seismicity occurred between June and October 2002, in April 2003, and during June-August 2003 (table 6).

Seismicity between April 2002 and February 2003. In April 2002 there were 1,433 microearthquakes detected, a significant increase over the total of 33 recorded during February-March; the majority of the seismicity was recorded on 5, 9, and 10 April. The majority of activity was classified as long-period (LP) events with frequencies between 1 and 4 Hz; some events related to rock fracturing had frequencies between 8 and 10 Hz. Activity in May was similar, with low-magnitude earthquakes and tremor. However, due to problems with CONN, only 346 earthquakes were detected. On the day of the highest activity, 19 May, 76 microearthquakes were recorded. One earthquake, only recorded at CONN, occurred on 28 May with an S-P time difference of 0.8 seconds, suggesting the hypocenter was at ~ 6.4 km depth.

June-August activity was consistent with previous months. June recorded 865 microearthquakes, while July recorded 1,229 events, mostly early in the month. CONN registered 1,219 earthquakes in August. Seismicity was heaviest on 29 and 30 August, with 116 and 139 earthquakes, respectively. The earthquakes were classified as mainly LP. On 4 August an earthquake of M 2.7 occurred ~ 15 km S of the volcano at a depth of 12.5 km. On 14 August another seismic station (URBN) was installed around Concepcion, this one in the community of Urbaite, on the S flank.

In September activity levels were again generally stable. Reception problems continued but by 2 September the signal was reestablished. There were 1,250 earthquakes recorded, the majority at the end of the month, with highs of 149 on 26 September and 152 on 27 September. In October, technical problems prevented recordings until after 21 October. However, in those ten days 1,031 microearthquakes registered, with 161 and 172 on 28 and 31 October, respectively. Both CONN and URBN detected lahars on the N flank on 28 and 31 October, during a time of moderate rainfall. Activity declined in November, although 784 earthquakes were still recorded. Activity was highest on 1 and 2 November, with 115 and 129 earthquakes respectively.

Month	Number of earthquakes	Notes
Feb 2002	24	
Mar 2002	9	
Apr 2002	1,433	Most activity on 5, 9, and 10 April.
May 2002	346	Total of 76 earthquakes on 19 May; technical problems may have lowered number.
Jun 2002	865	
Jul 2002	1,229	
Aug 2002	1,219	Most activity on 29 and 30 August.
Sep 2002	1,250	Most activity on 26-27 September; no records 1-2 September.
Oct 2002	1,031	Ten days worth of records; most activity on 28 and 31 October.
Nov 2002	784	Most activity on 1 and 2 November.
Dec 2002	389	
Jan 2003	179	Missing four days of recordings.
Feb 2003	108	
Mar 2003	700	Higher amplitude events recorded between 2 and 18 March.
Apr 2003	1,400	Majority recorded after 11 April.
May 2003	476	
Jun 2003	1,298	
Jul 2003	> 1,100	Missing three days of recordings.
Aug 2003	1,586	
Sep 2003	828	Most activity on 12-13 September.

Table 6. Monthly count of earthquakes registered at Concepcion, February 2002-September 2003. Courtesy of INETER.

Activity declined further in December, with 389 microearthquakes, although no recordings were obtained on five days due to technical problems. Similar to the past several months, activity was classified as generally LP or degassing events. Only 179 microearthquakes were recorded in January (data was not received on four days). In February, only 108 microearthquakes were detected. All events ranged between 1.5 and 3.5 Hz frequency and were classified as LP or degassing events.

Seismicity between March and June 2003. Beginning in March 2003 and continuing through April and May, activity increased to unusual levels. Between 2 and 18 March CONN registered a series of 31 earthquakes with considerable amplitude; they were not felt by residents in the area. Because the stations at Urbaite (URBN) and Maderas (MADN) were not working, only CONN recorded the activity. However, the difference in arrival times between the S and P waves indicated a depth of 15-16 km. The seismic signals began at low frequencies, followed by an increase in the spectral frequency content.

On 19 March the volcano entered a new period of increased activity. By the end of March more than 700 events were registered by the seismic station. Although during the first week of April very few earthquakes were recorded, by

11 April the station began to register a series of earthquakes of considerable amplitude, similar to the series in March. More than 1,400 events were recorded, mainly LP events. Only 476 events were recorded in May, also mainly LP events. A total of 1,298 events were recorded in June.

Seismicity between July and September 2003. Unusual seismic activity, including harmonic tremor that began at the end of June, continued in July. Starting 1 July, CONN began to register a series of LP events accompanied by low-frequency harmonic tremor and a saturated seismic signal like the one that occurred in March. Harmonic tremor occurred throughout July, with episodes of 7 minutes on 2 July, 45 minutes on 4 July, and about 60 minutes on 13 July. Long-period earthquakes and harmonic tremor increased between 23 July and the end of the month.

A total of 43 earthquakes with saturated amplitudes were registered only by CONN in July, but it was not possible to determine locations or magnitudes. The time difference in the S-P arrivals implied hypocenters 15-16 km beneath the volcano. They lasted a little over a minute and had a combination of high and low frequencies. The earthquakes with saturated signals had frequencies of 2-4 Hz; some were accompanied by a low-energy high-frequency signal. The majority of these events (7) occurred on 15 and 16 July, and had ceased by 23 July. Taking the spectral content into account, these appear to be LP events; however, it is not very common for LP events to begin with low frequencies followed by high. No data were recorded on 18, 21, and 22 July due to technical problems at Mombacho, but a total of more than 1,100 earthquakes were recorded by seismic stations.

With 1,586 earthquakes registered, seismicity was unusually high in August. Harmonic tremor also increased. Starting 1 August, CONN began to register a series of LP earthquakes accompanied by low-frequency harmonic tremor and earthquakes with saturated signals, as in previous months. Frequency ranged from 1 to 2.5 Hz, with occasionally higher values. On 16 August tremors were registered that lasted for four minutes; on 22 August, after two days with no tremor and few earthquakes, there was more unusual activity consisting of seven hours of intermittent tremor episodes.

Seismicity continued in September with 828 total events, the majority on 12 and 13 September. Seismic tremor was present throughout September, with frequency levels similar to those of the previous months.

Background. Volcán Concepción is one of Nicaragua's highest and most active volcanoes. The symmetrical stratovolcano forms the NW half of the dumbbell-shaped island of Ometepe in Lake Nicaragua and is connected to neighboring Madera volcano by a narrow isthmus. A steep-walled summit crater is 250 m deep and has a higher western rim. N-S-trending fractures on the flanks of the volcano have produced chains of spatter cones, cinder cones, lava domes, and maars located on the NW, NE, SE, and southern sides extending in some cases down to Lake Nicaragua. Concepción was constructed above a basement of lake sediments, and the modern cone grew above a largely buried caldera, a small remnant of which forms a break in slope about halfway up the north flank. Frequent explosive eruptions during the past half century have increased the height of the summit significantly above that shown on current topographic maps and have kept the upper part of the volcano unvegetated.

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Arenal

Costa Rica
10.463°N, 84.703°W; summit elev. 1,657 m
All times are local (= UTC - 6 hours)

On 5 September the Observatorio Vulcanologico y Sismologico de Costa Rica (OVSICORI-UNA) reported that a new sequence of pyroclastic flows started at 1055 that day (figure 6). At least eight signals related to the collapses were recorded within the next two hours by seismographs at the observatory. Material shed from high-elevation accumulations of lava generated the pyroclastic flows, which descended the N and NE flanks down to 800 m elevation; accompanying ash drifted W and NW. No injuries or deaths occurred, and the main effects were limited to within the National Park boundaries. Patches of vegetation at the flow terminations caught on fire. Similar flows have occurred in recent years (e.g. May 1998, August 2000, and

Figure 6. Photograph of a pyroclastic flow descending the NE flank of Arenal, 5 September 2003. Courtesy of OVSICORI-UNA.

March 2001) affecting the summit and upper areas of the active cone C. No explosive eruptions or extraordinary seismic activity were associated with these latest pyroclastic flows.

Unreported observations from 2002. At the time of the last summary report about Arenal (*Bulletin* v. 28, no. 8), information from January, February, and April 2002 was not available; those OVSICORI-UNA reports have since been located. Both seismic and volcanic activity were low during those months, without significant pyroclastic flows or energetic eruptions. Pyroclastic flows from other months that had been described in that and other reports all originated from failures along the margins of lava flows, rather than stemming from explosive eruptive processes.

Background. Arenal is the youngest stratovolcano in Costa Rica and one of its most active. The 1657-m-high andesitic volcano towers above the eastern shores of Lake Arenal, which has been enlarged by a hydroelectric project. The earliest known eruptions of Arenal took place about 7000 years ago. Growth of Arenal has been characterized by periodic major explosive eruptions at several-hundred-year intervals and periods of lava effusion that armor the cone. Arenal's most recent eruptive period began with a major explosive eruption in 1968. Continuous explosive activity accompanied by slow lava effusion and the occasional emission of pyroclastic flows has occurred since then from vents at the summit and on the upper western flank.

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Poás

Costa Rica
10.20°N, 84.233°W; summit elev. 2,708 m

This report concerns Poás during the interval September 2001 through December 2002. It draws on both a set of extensive half-year reports from UCR-ICE (Mora, 2001a, b; 2002) and monthly OVSICORI-UNA reports (available on the web, and sometimes prepared with co-authors Orlando Vaselli and Franco Tassi). OVSICORI-UNA reports were absent for November and December 2001.

Poás was non-eruptive during the reporting interval. The volcano was last reported on in *Bulletin* (v. 26, no. 11); the key focus of activity remains the main crater and its fumaroles, and its low-pH, variably colored lake. That lake is sometimes called Laguna Caliente or el Poás, but more frequently in past issues of the *Bulletin* simply described with terms like the active lake, lake in the active crater, hot lake, etc. During the reporting interval the active lake repeatedly changed pH, color, and temperature. As in the past, Laguna Caliente contained some thermally active zones, sometimes displaying up-welling water, bubbles, and zones of native sulfur. Lake Botos lies in a crater S of the active one. It remained inactive.

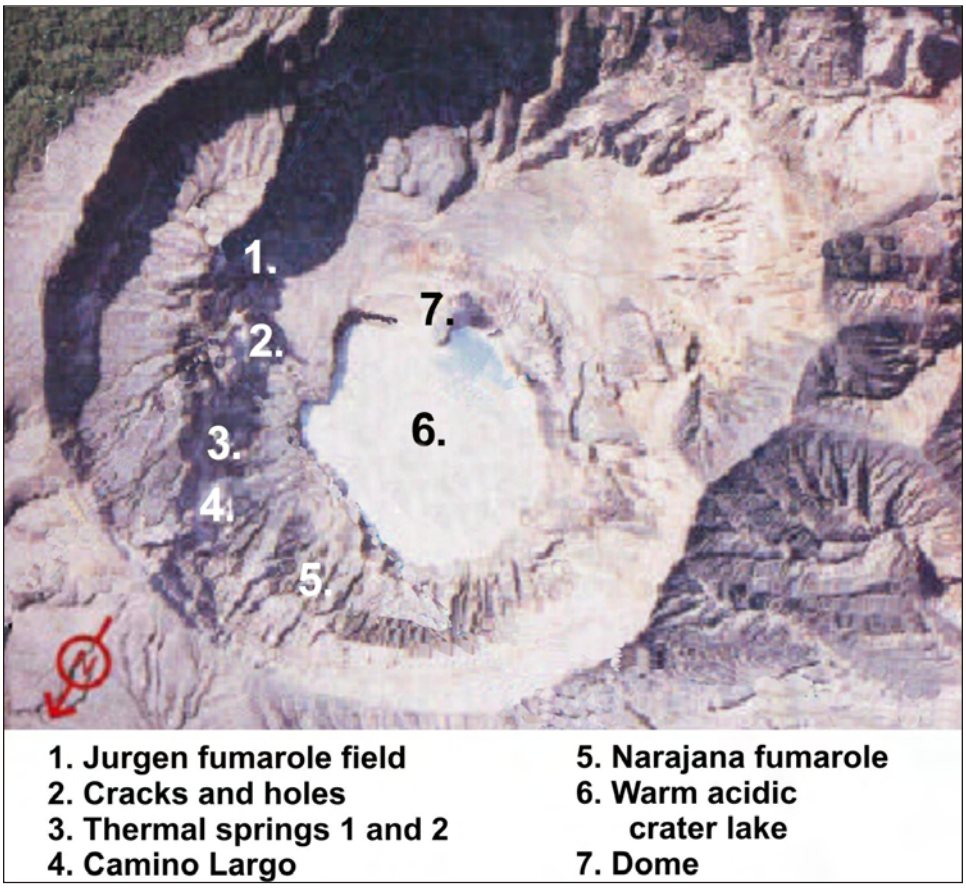

Figure 7. A vertical or sub-vertical aerial photo taken of the summit at Poás, with N toward the bottom left. Numbers on the photo refer to locations named on the key. As an approximate scale, the lake is ~ 200-300 m in diameter. This was taken from figures in Mora (2001a and b, and 2002) that had several other photos around the margin. Construction lines originally across this photo have been removed here, with some resulting loss and local misrepresentation of what must have been present on the original photo. Courtesy of UCR-ICE (after Mora 2001b and 2002).

The origin and terminology for the main crater's dome or pyroclastic cone remains controversial; both terms are used in this report, congruent with those favored by the authors of summarized reports and included photos. Whatever its name or origin, this feature supports especially active fumaroles, and is frequently masked by steam.

Observers at the crater noted acoustical noise from vigorous degassing. Again, as typical, monthly reports consistently mentioned variable secondary fumarolic activity and occasional mass-wasting along the crater walls. Seismicity, including tremor, continued and is mentioned below, but it will be discussed more comprehensively in a later report.

UCR-ICE observations. Mora (2001b and 2002) included an

overview photo of Poás (figure 7). Those reports also included numerous other photos of fumaroles and mass wasting, most of which are not shown here. Some pronounced arcuate cracks associated with mass wasting along the NE side of the lake were thought possibly related to changes in lake level and pore pressure (figure 8). A shot of the steaming dome appears as figure 9.

Mora (2001a, b and 2002) collected and presented considerable data on Laguna Caliente, and we include several available plots. Lake temperature and pH during 2001-2 appears as figure 10; precipitation and lake level for most of 2002, as figure 11.

Mora (2002) reported March-December 2002 precipitation ranging from 33 to 607 mm per month (figure 11). The lake's variable surface heights during March-December 2002 deviated from an established (arbitrary) datum (zero point), from which heights ranged from ~ 400 mm below the datum to ~ 100 mm above it. During this interval the lake's high stand occurred in December; it then covered the border of the lowest N terrace. The lowest stand for the interval occurred during May. During this time interval the

Figure 8. Laguna Caliente, the hot lake at Poás (lower right) lies within a crater bounded by unstable cliffs. This photo shows part of the lake's NE margin. The person in this scene stands on a substantial though eroding terrace and inspects arcuate cracks (circumferential faults) in unstable material along the crater rim. Some of these cracks reached 40 cm wide. Landslide deposits from failures along this and other cliff faces were mentioned frequently in reports. Courtesy of UCR-ICE (from Mora 2001a).

Figure 9. The N face of the dome (or pyroclastic cone) at Poás rises from the lake and supports strong fumaroles. This photo was taken looking S. Scientists partially visible atop the dome were walking to fumaroles where they measured gas temperatures and pH. Courtesy of UCR-ICE (from Mora, 2001).

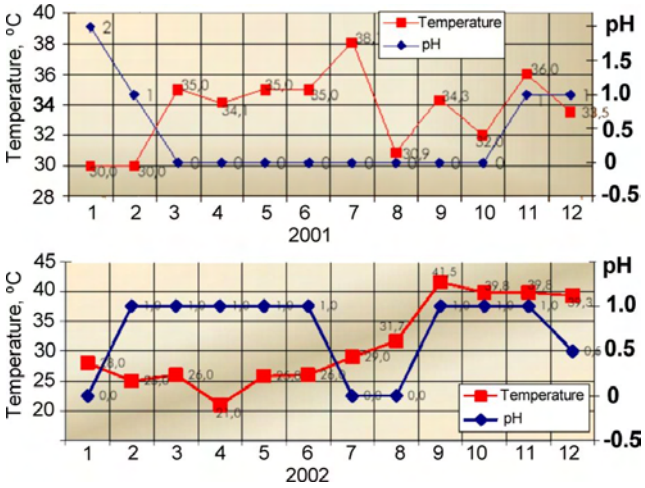

Figure 10. For Laguna Caliente at Poás, plots showing temperature and pH versus month during (top) 2001 and (bottom) 2002. The various scales are unequal. The two-year peak temperature measured 41.5°C in September 2002. The lowest pH measured ~ 0 during March-October 2001 and during January, July, and August 2002. (After Mora, 2001b and 2002).

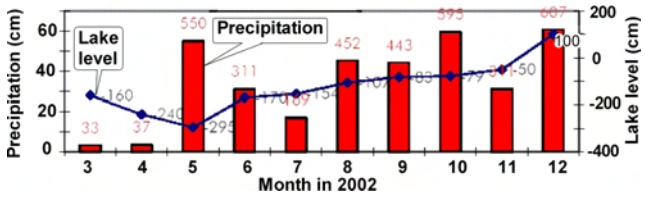

Figure 11. For Laguna Caliente at Poás, a plot showing precipitation and lake-surface level versus month during March-December 2002. The location where the precipitation measurements were taken was unstated. Values shown on the plot are in millimeters (After Mora, 2002).

variables of precipitation and lake height appeared to lack consistent correlation.

OVSICORI-UNA observations. During late 2001 and through 2002, low-frequency earthquakes continued to dominate the record, with OVSICORI-UNA reporting ~ 500 events per day on 8 September, but more typically 100-300 events per day. In addition during this interval instruments typically recorded several hours of tremor per month. During some months of the reporting interval, medium- and high-frequency earthquakes continued to occur in conjunction with new fumaroles appearing in the active crater.

The OVSICORI-UNA report discussing September 2002 noted that tremor rose slightly, prevailing for ~ 5 hours on each of several days. Long-period earthquakes numbered more than 100 per day, and typically 300-450 per day. Medium-frequency earthquakes occurred much less often, their numbers approaching ~ 20 per day on several days, and more typically fewer than 10 per day.

During the last half of 2002 the lake's water temperature rose above 30°C, attaining 39°C during September-December 2002. Lowered air temperatures in late 2002, particularly in November 2002, led to condensate forming over the lake's surface and rising to accumulate in larger, optically dense clouds (figure 12).

References: Mora, R., 2002, Informe anual de la actividad de la Cordillera Volcánica Central, 2002, Costa Rica (proofed and revised by Alvarado, G., Fernández, M.,

Figure 12. Conspicuous condensate hung over the active crater lake at Poás during late 2002. The condensate stemmed from warm lake temperatures (~ 39°C) combined with cooler ambient air temperatures. At the time of this photo (November 2002) the lake was light green in color. Courtesy of OVSICORI-UNA.

Month	Lake-water color	Fumarolic activity and OVSICORI-UNA's comments.
Sep 2001	Turquoise, with central lake convection cells of coffee color	Highest recorded temperatures, 92-110°C.
Oct 2001	Turquoise	Loud noises at pyroclastic cone, where escaping gases continued to be most plentiful and vigorous; these had measured temperatures of 91°C at an accessible spot. Highest recorded temperatures, 92-110°C.
Nov 2001	n.a.	
Dec 2001	n.a.	
Jan 2002	Dark green	Pyroclastic cone vapor emissions rose to 200 m. Maximum fumarole temperatures measured 85-91°C.
Feb 2002	Blue	Cone vapor emissions rose to 200 m; maximum fumarole temperatures measured 90-100°C.
Mar 2002	Clear blue	Cone's vapor emissions rose to 300 m; maximum temperatures reached 93-98°C.
Apr 2002	Celeste (a grayish blue to pale purplish blue)	300 m; 93-99°C.
May 2002	Turquoise	Noisy, audible from northern crater margin; 97-107°C; new fumaroles appeared.
Jun 2002	Turquoise-green to celeste	Prominent cracks crossing lake terrace; new fumaroles appeared but had low gas flux rates.
Jul 2002	Turquoise to celeste	300-400 m high; 119°C; sulfur deposition.
Aug 2002	Turquoise to celeste	300 m high; new bubbling noticed at lake's center and S margin; maximum reported temperature, 119°C.
Sep 2002	Turquoise to celeste	119°C.
Oct 2002	Turquoise to celeste	Noisy; 400 m high; sulfur deposition; low gas fluxes; maximum temperature, 130°C.
Nov 2002	Turquoise to celeste	A comparatively warm lake surface and cooler air temperatures led to conspicuous clouds forming over the lake surface. A maximum temperature was seen at a N terrace fumarole (122°C).
Dec 2002	Turquoise	Max temp 119°C.

Table 7. For the active crater at Poás, a summary on lake-water color and visible and thermal observations during the interval September 2001 through December 2002. The fumarolic activity typically refers to outgassing at the pyroclastic cone (dome). Missing data is indicated by n.a. (not available). The source reports excluded the exact dates and details describing the collection of these observations. Courtesy of OVSICORI-UNA.

Mora, M., Paniagua S., and Ramírez, C.): Universidad de Costa Rica, Red Sismológica Nacional, UCR-ICE, Sección de Sismología, Vulcanologíay Exploración Geofísica (published June 2003 as mini-CD Rom with PDF files).

Mora, R., 2001a, Informe semestral de la actividad de la Cordillera Volcánica Central, Enero-Junio 2001, Costa Rica: Universidad de Costa Rica, Red Sismológica Nacional, UCR-ICE, Sección de Sismología, Vulcanologíay Exploración Geofísica (published November 2001 as mini-CD Rom with PDF files).

Mora, R., 2001b, Informe semestral de la actividad de la Cordillera Volcánica Central, Julio-Diciembre 2001, Costa Rica (proofed and revised by Alvarado, G., Fernández, M., Montero, W., and Ramírez, C.): Universidad de Costa Rica, Red Sismológica Nacional, UCR-ICE, Sección de Sismología, Vulcanologíay Exploración Geofísica (published 6 May 2001 as mini-CD Rom with PDF files).

Background. The broad, well-vegetated edifice of Poás, one of the most active volcanoes of Costa Rica, contains three craters along a N-S line. The frequently visited multi-hued summit crater lakes of the volcano, which is one of Costa Rica's most prominent natural landmarks, are easily accessible by vehicle from the nearby capital city of San José. A N-S-trending fissure cutting the 2,708-m-high complex stratovolcano extends to the lower northern flank, where it has produced the Congo stratovolcano and several lake-filled maars. The southernmost of the two summit crater lakes, Botos, is cold and clear and last erupted about 7,500 years ago. The more prominent geothermally heated northern lake is one of the world's most acidic natural lakes, with a pH of near zero. It has been the site of frequent phreatic and phreato-magmatic eruptions since the first historical eruption was reported in 1828. Poás eruptions often include geyser-like ejection of crater lake water.

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Barva

Costa Rica
10.135°N, 84.10°W; summit elev. 2906 m

Geologist Raul Mora, along with Carlos Ramirez and Maritta Alvarado, visited Barva volcano during December 2002 and investigated the Barva and Copey crater lakes. Located in a small crater, the Barva crater lake (figure 13) was very clear; at 5 m from the shore the water had a temperature of 11-12°C with a pH of 4-5. Water in the Copey lake was amber colored and very cloudy, with a temperature at 0.5 m depth of 12.2°C and a pH of 5. Near-surface black lapilli deposits were found that were more than a meter thick near the Barva lake, but became more irregular in thickness around the Copey lake.

Background. The central and least known of three massive volcanoes towering over the capital city of San José, Volcán Barva (Barba) is a complex volcano with multiple summit and flank vents. Its three principal summits visible from the Central Valley give it the common local name of Las Tres Marías. The voluminous Tiribí Tuff, exposed in the Central Valley of Costa Rica, was erupted about 330,000 years ago from the Barva summit caldera. Four pyroclastic cones are constructed within the 2 x 3 km caldera at the central and NW part of the summit. The SW peak contains four cones, one of which has a crater lake.

Figure 13. Photograph of the Barva crater lake, December 2002. The lake has an area of 9,000 m^2 and a depth of ~ 7.7 m. Courtesy of Raul Mora.

Satellitic cones are found on the northern and southern flanks. Lava flows blanket the south side of Barva volcano. The Los Angeles flow, one the most recent, descends nearly to the city of Heredia. A large plinian eruption occurred at Barva during the early Holocene. Eruptions were reported in 1760 or 1766, 1776? (also a mudflow), and 1867, but later visits to the summit did not provide evidence of eruptions during historical time.

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Nyamuragira

DR Congo, central Africa
1.408°S, 29.20°E; summit elev. 3,058 m

The last eruption at Nyamuragira occurred during 25 July-27 September 2002 (*Bulletin* v. 27, nos. 7 and 10, and v. 28, no. 1). Tectonic and magmatic seismicity continued through June 2003, but there has been no confirmed eruptive activity. This report covers activity from early July to the beginning of August 2003. Seismicity generally consisted of long-period (LP) earthquakes on the NE side of the volcano. In addition, earthquake swarms were occasionally observed.

Between 6 and 12 July, seismicity was dominated by LP earthquakes NE of the volcano and SE along the fracture zone between Nyamuragira and Nyiragongo. Two large swarms occurred on 7 and 8 July, with 161 LP earthquakes and 10 short-period earthquakes. The earthquakes at Nyamuragira have been deep, between 15 and 20 km.

During 13-19 July 2003, LP earthquakes NE of the volcano again dominated seismicity. Compared to the previous week, activity was low, with no swarms and only one high-frequency earthquake. The following week, between 20 and 26 July, LP earthquakes continued in the NE and to a lesser extent along the SE fracture zone. Between 19 and 21 July new sequences of earthquakes occurred, with LP events followed by short-period earthquakes, coupled with high-amplitude tremor episodes.

Between 27 July and 2 August, LP earthquakes continued to dominate seismicity NE of the volcano as well as along the SE fracture zone. Seismicity increased from the previous week, with sequences of LP earthquakes coupled with volcanic tremor episodes between 28 and 31 July. Average seismicity doubled to 200 earthquakes with hypocenters between 3 and 20 km deep.

Background. Africa's most active volcano, Nyamuragira is a massive basaltic shield volcano that rises about 25 km north of Lake Kivu across a broad valley NW of Nyiragongo volcano. Nyamuragira has a volume of 500 cu km, and extensive lava flows from the volcano blanket 1500 sq km of the East African Rift. The broad low-angle shield volcano contrasts dramatically with its steep-sided neighbor Nyiragongo. The 3058-m-high summit of Nyamuragira is truncated by a small 2 x 2.3 km caldera that has walls up to about 100 m high. Historical eruptions have occurred within the summit caldera, frequently modifying

the morphology of the caldera floor, as well as from the numerous fissures and cinder cones on the volcano's flanks. A lava lake in the summit crater, active since at least 1921, drained in 1938, at the time of a major flank eruption. Historical lava flows extend down the flanks more than 30 km from the summit, reaching as far as Lake Kivu.

Information Contact: *Goma Volcano Observatory*, Departement de Geophysique, Centre de Recherche en Sciences Naturelles, Lwiro, D.S. Bukavu, DR Congo (Email: ocha.volcan@wfp.org).

Nyiragongo

DR Congo, central Africa
1.52°S, 29.25°E; summit elev. 3,470 m

New reports of activity at Nyiragongo include observations from visits on 12-13 July and 14-15 August 2003. Seismicity was low during the report period, but tremor related to the lava lake continued to characterize volcanic activity. Staff at the Goma observatory have kept the hazard status for Nyiragongo at Yellow (Vigilance).

During 6-12 July two long-period earthquakes were detected. Four tectonic earthquakes registered to the S and beneath Lake Kivu; none of these were felt by area residents. Fracture measurements at Monigi, Mugara, and the Nyiragongo hut did not show any significant change from previous measurements, but at Lemera fracture spacing increased from 7.537 to 7.550 m, and there was an extension of 8 mm at Shaheru. Also during the visit, Pele's hair as long as 10-15 cm was observed between Shaheru and the crater; gas plumes were noted in the S, SW, and W, along with large scoriae. Crater observations indicated the possible formation of a third platform at 650 m depth. Two small vents formed NE of the main lava lake and there was significant degassing along the S base of the internal wall.

Between 13 and 19 July, seismic activity remained low, with four long-period earthquakes beneath the NE flank. No earthquakes were felt and only seven tectonic earthquakes were recorded to the S and beneath Lake Kivu. Volcanic tremor persisted, indicating activity in the lava lake. Fracture spacing measurements were taken at Shaheru and the Nyiragongo hut, but without noticeable changes (14.778 m at Shaheru 1, 29.602 m at Shaheru 2, and 0.942 m at Nyiragongo hut). Observations of fumarole openings had been reported by residents in the Mutwanga district. Also on 18 July investigations at Kiziba revealed a recent tongue of lava infiltrating older lava layers, found in a hole dug as a septic tank.

Volcanic tremors continued between 20 July and 2 August; no earthquakes were reported. Fracture measurements at Busholoza and Kabutembo did not indicate significant changes; temperature and deformation measurements at the top of Nyiragongo, the Nyiragongo hut, Shaheru, Mugara, and Monigi also did not reveal any notable changes. However, local CH_4 (methane) was present at concentrations of 35.5%.

Between 1 and 3 August the lava lake appeared very active, with lava fountains up to 10 m high, projecting large but light scoriae into the atmosphere. Pele's hair was observed at Shaheru (2,200 m elevation) and heat radiating from the lake could be felt at the observation camp on the edge of the crater. Because of the considerable projection of volcanic products, pilots were advised to avoid the area.

Following a magnitude 5.2 earthquake in the Virunga region on 5 August, scientists from the Goma observatory visited Nyiragongo on 14-15 August. Measurements included deformation and gas geochemistry in fractures, and the lava lake was monitored. No significant deformation was observed at cracks on the S side of Nyiragongo. Gas measurements at Shaheru showed that local CO_2 concentrations had increased by 1.7%, while methane there had doubled. At the top of Nyiragongo, however, measurements on 15 August were half those on 14 August. Late on 14 August a "swirl" of air caused gas to fill the crater, and ~ 2 hours later scientists as well as residents west of Virunga felt an earthquake. Another earthquake was felt in Kibati and at the crater on 15 August.

The lava lake appeared calm on 14 August, and two small vents were visible; only one was visible the next day. The lava lake was measured to be 260 m in diameter, nearly the same as on 2 August. Also during the visit scientists installed a scorimeter: Two hours worth of scoria, weighing 236.2 g per square meter, were sampled.

Background. One of Africa's most notable volcanoes, Nyiragongo contained a lava lake in its deep summit crater that was active for half a century before draining catastrophically through its outer flanks in 1977. In contrast to the low profile of its neighboring shield volcano, Nyamuragira, 3470-m-high Nyiragongo displays the steep slopes of a stratovolcano. Benches in the steep-walled, 1.2-km-wide summit crater mark levels of former lava lakes, which have been observed since the late-19th century. Two older stratovolcanoes, Baruta and Shaheru, are partially overlapped by Nyiragongo on the north and south. About 100 parasitic cones are located primarily along radial fissures south of Shaheru, east of the summit, and along a NE-SW zone extending as far as Lake Kivu. Many cones are buried by voluminous lava flows that extend long distances down the flanks of the volcano. The extremely fluid 1977 lava flows caused many fatalities, as did lava flows that inundated portions of the major city of Goma in January 2002.

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Piton de la Fournaise

Réunion Island, Indian Ocean
21.23°S, 55.71°E; summit elev. 2,631 m
All times are local (= UTC + 4 hours)

A seismic crisis started at 2225 on 30 September 2003 beneath the SW corner of Dolomieu crater ~ 2 km below the summit. At 2330 eruption tremor appeared and was localized beneath the SSW flank of Piton de la Fournaise. A straight 400-m-long fissure opened at 2,350 m elevation. The eruption tremor reached a maximum at 0100 on 1 October and declined after 0200, disappearing completely at 1300.

Since March 2003, the extensometer network and GPS measurements had indicated inflation of Piton de la

Fournaise. A new eruption that began on 30 May within Dolomieu crater proceeded in multiple phases through 7 July, followed by new activity through 27 August (*Bulletin* v. 28, nos. 5, 6, and 8).

Background. The massive Piton de la Fournaise 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 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. The Piton de la Fournaise Volcano Observatory, one of several operated by the Institut de Physique du Globe de Paris, monitors this very active volcano.

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