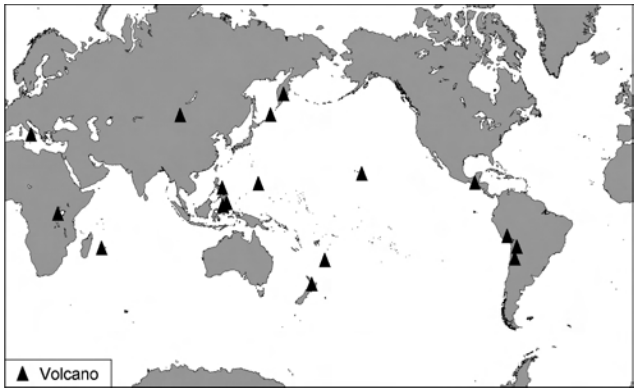
Bulletin of the Global Volcanism Network



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Anatahan

Mariana Islands, central Pacific Ocean
16.35°N, 145.67°E; summit elev. 788 m
All times are local (= UTC + 10 hours)

The explosive eruption that began on 10 May is the first documented eruption from Anatahan in historical time. There were no residents on the island due to their evacuation following a shallow earthquake swarm in 1990 (Moore and others, 1994), and another in 1993 (Sako and others, 1995). Anatahan is a composite volcano that erupts lavas that are primarily dacitic in composition. It has the largest caldera of the volcanoes in the Commonwealth of the Northern Mariana Islands (CNMI). The presence of this caldera indicates that large explosive eruptions are possible.

Strong activity continued over the next few days (*Bulletin* v. 28, no. 4), with high ash plumes seen in satellite imagery. The area within ~ 55 km of the island was also placed off-limits to all boats and aircraft not approved by the CNMI Emergency Management Office (EMO). A smaller but nearly continuous eruption column rose from the E crater of Anatahan for the next several weeks. Activity was continuing in early July, but at low levels.

The EMO invited USGS scientists to provide assistance in tracking the volcano's activity and assessing potential hazards shortly after the eruption began. USGS scientists first arrived in Saipan on 30 May to work directly with EMO officials to install and maintain monitoring equipment and interpret data from overflights and a single seismometer operating on Anatahan. This station became operational on 5 June.

Beginning of the eruption, 10-12 May 2003. On 6 May researchers from Washington University, Scripps Institution of Oceanography, and the EMO aboard the *MV Super Emerald* deployed a seismograph on Anatahan as part of a joint US-Japan Mariana Subduction Imaging Experiment, which is funded by the National Science Foundation. There were no indications of an impending eruption. During the night of 10-11 May the ship was again approaching Anatahan when scientists observed a tremendous lightning display ahead. As morning broke, they saw a pillar of steam and ash billowing to an altitude of 9 km. The ship had to detour around the island to avoid the ashfall.

Initial reports indicated that the eruption began around 2100 on 10 May. Satellite data interpreted by the Washington Volcanic Ash Advisory Center (VAAC) showed that the eruption appeared to have started by 1730. An ash plume was clearly visible in imagery at 2232, resulting in an advisory being issued to the aviation community at 2300 (1300 UTC). Plume heights were reported to be 10-12 km in the early stages of the eruption, with one ash advisory indicating ash to 13.4 km altitude on the 11th. At times multiple clouds were moving in different directions at different altitudes.

On 13 May Joe Kaipat from the CNMI Emergency Management Office (EMO) and seismologist Doug Weins (Washington University) flew to Sarigan (6.5 km W of Anatahan) to retrieve seismic data from a broadband instrument installed on 6 May. Records from the Sarigan station showed increased seismicity commencing at about 1300 on 10 May. The activity remained very strong for about 36 hours before decreasing.

Activity during 13-30 May 2003. A helicopter overflight on 13 May showed that the island was still erupting, but with less intensity than on 11 May. Large volcanic bombs were observed flying high in the air over the crater region, and the whole W side of the island was covered with ash, including the seismograph site. The village appeared to have 15-30 cm of ash (figure 1). Ash advisories for 13-14 May reported that a dense ash cloud was drifting W away from the island, but that it was not continuous and varied in size. Ash plumes through 17 May generally drifted NW or WNW. The eruption clouds through May after the initial activity were generally below ~ 6 km.

On 18 May the EMO group took an overflight accompanied by David Hilton (Scripps Institution of Oceanography) and Tobias Fischer (University of New Mexico). They reported a rising plume comprised of steam and ash. The cloud was much lighter in color, with a reduced ash component compared to the initial phases of the eruption. Bombs, possibly up to several meters in size, were being tossed into the air; most fell back into the E crater. The ash was being blown W, but most of the ashfall was still on the E side of the island. The team landed on the E side of the island and deployed a PS- 2 seismometer that appears to have recorded earthquakes and some tremor. At that site they found ejecta thought to be from the initial stage of the eruption. The ground/vegetation near and under the ejecta was not

Figure 1. The village on Anatahan covered with ash, 13 May 2003. The recently deployed seismograph is barely visible in the clearing to the left. Note the ash on the roofs. Courtesy of Doug Weins.

scorched. Most of the material appeared to be non- juvenile. The largest fragments were up to 50 cm across. The team heard "booms" coming from the crater.

The ongoing explosive activity excavated a deep crater within Anatahan's E crater. Scientists estimated the inner crater was nearly at sea level by about 20 May; before the eruption, the floor of the E crater was 68 m above sea level. On 20 May the EMO group took an overflight and installed a telemetered seismic station. Pressure waves from detonations in the E crater were felt on the E flank. From a helicopter the team also observed rocks several meters across being thrown up above the E crater rim and falling back into the crater. Ash continued to fall on the western two-thirds of the island and out to sea. The ash cloud size and length was variable during 17-23 May; it continued in general to drift WNW from the island, at times spreading over a wide area.

On 23-24 May, typhoon Chan-hom shifted the prevailing east winds to the S, blowing the eruption column toward Saipan and Guam. Light ashfall resulted in flight cancellations and the closure of the Saipan and Guam international airports. Residents of Saipan reported a rotten egg smell associated with the ashfall. The report from Saipan was that 1-2 mm of ash had fallen on the island.

EMO personnel took an overflight on 27 May and reported that ash cloud heights reached 3 km, significantly lower than during the first few days of the eruption. The ash cloud was more opaque and laden with ash; the color was closer to that of 10-11 May than more recent plumes. The streaming ash cloud, still exhibiting variable size and length, drifted NW and NNW through 29 May.

Fieldwork on 21 May 2003. Hilton and Fischer arrived by ship at Anatahan at approximately 0630 on 21 May. The activity level was similar to that on their visit 2 days earlier. The ship sailed through the ashfall out to the SW side of the island, and continued along the W coast. The W coast was draped in ash; vegetation was completely covered giving the island a gray pallor. They landed at 0815 and spent ~ 4 hours ashore. A trench through the recent deposits on the beach area exposed a 25-cm section from the present eruptive phase with three main layers. The lowermost layer consisted of ~ 5 cm of fine-grained ash. Next was a layer ~ 15 cm thick comprised of accretionary lapilli with some fine ash. At the top was a 5-cm-thick layer that was a mixture of coarser grained ash and angular clasts of scoriaceous material. The abandoned village, where a team led by Patrick Shore (Washington University) was working on the seismic station installed on 6 May, was similarly covered in ash with many buildings having collapsed roofs. Two sections also

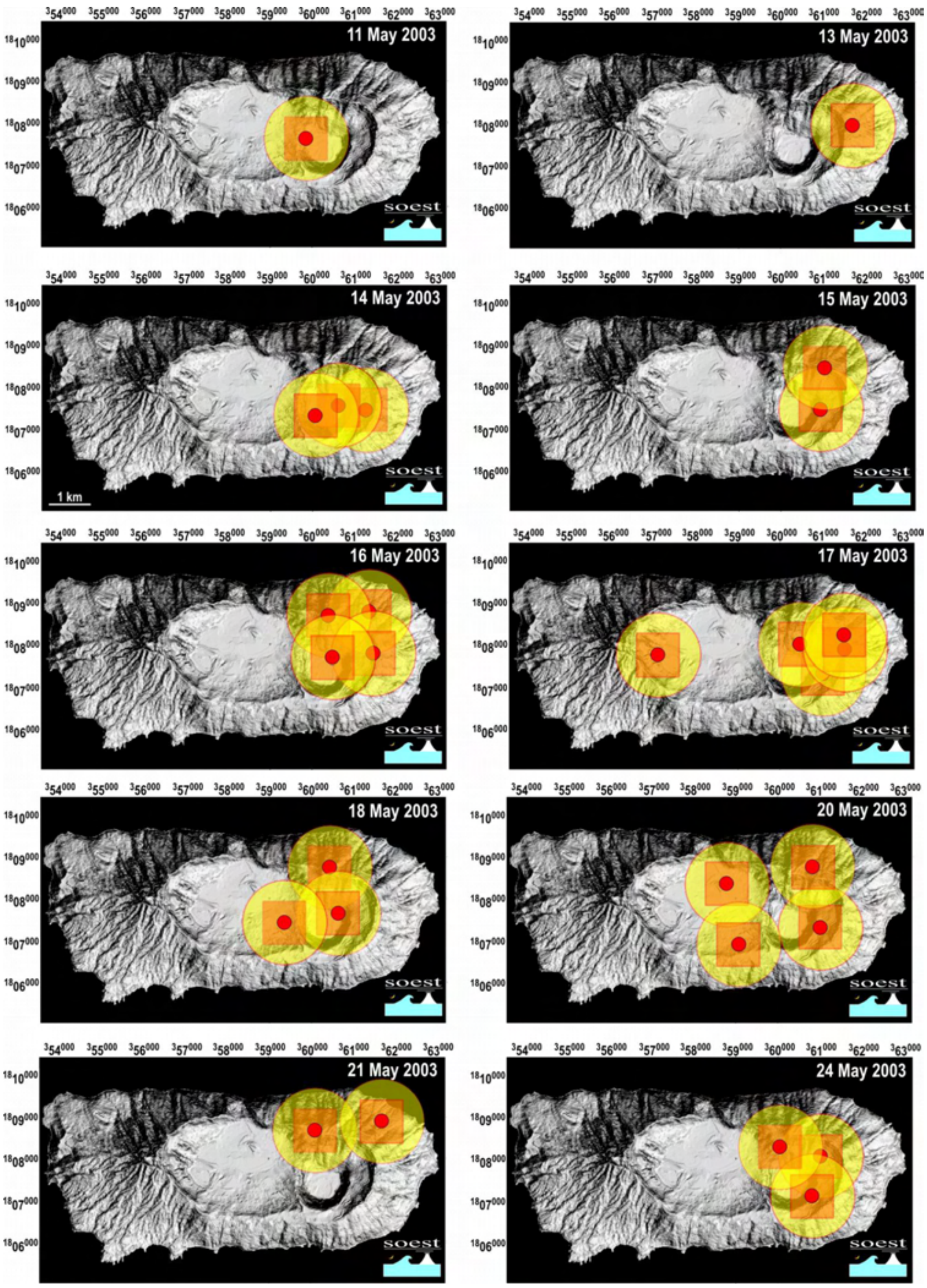

Figure 2. Summary of MODIS thermal alerts detected at Anatahan, 11-28 May 2003. Each dot defines the geodetic location of the pixels flagged by the MODVOLC algorithm (Wright and others, 2002) as containing volcanic hot-spots. However, although the coordinate describes the center point of each pixel, the hot-spots could have been located anywhere in the square boxes (which portray the nominal 1-km pixel size of the MODIS instrument.) The shaded circles denote the absolute limits within which the volcanic hot-spots responsible for the anomalies must have been sited (based on a statistical analysis of long-term hot-spot location stability at other volcanoes). The hot-spot locations are referenced to WGS-84 ellipsoid. Map coordinates are in UTM zone 55 (north). Courtesy of the HIGP MODIS Thermal Alert Team (http://modis.higp.hawaii.edu).

revealed initial ash, covered by accretionary lapilli, then a mixture of ash and scoriaceous material. Pumice was floating in water-collection vessels by the buildings.

From the ship the scientists set up the COSPEC instrument and started a traverse through the plume around 1330. The telescope was oriented vertically and the ship made a N-to-S transect through the volcanic plume at a distance of ~ 1.5 km from shore. Sulfur dioxide (SO_2) in the plume was recorded immediately. The transect took 50 minutes until no SO_2 was being detected. In addition, they sailed through the ash fallout. During the traverse, the volcano erupted every 5 minutes with a deep resonating boom. The width of the volcanic plume was ~ 6 km and its direction was to the SW. From the COSPEC measurements and wind speed data provided by NOAA, the SO_2 flux was estimated to be 3,000-4,500 metric tons/day. As the group sailed away from the island around 1430 there was a very large eruption with a significantly louder "boom" than had been heard previously, followed by a dark billowing ash-laden plume.

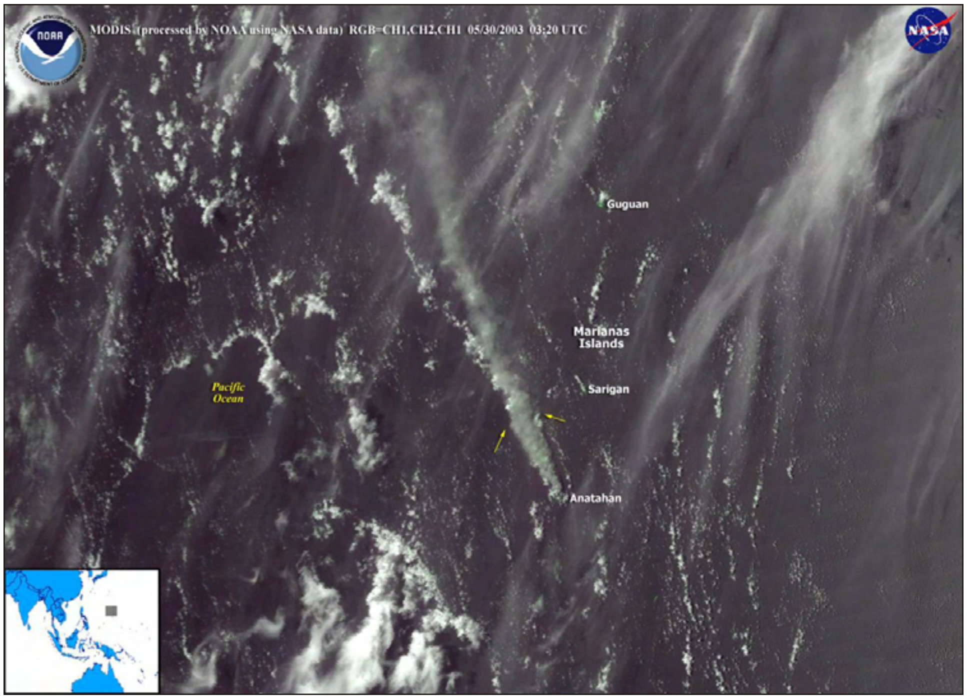

Figure 3. Ash plume from Anatahan (indicated by arrows) visible in MODIS imagery from the Aqua satellite, 0320 UTC on 30 May. Image processed by NOAA with data from NASA. Courtesy of NOAA/NASA.

MODIS thermal observations. Thermal satellite observations of the current eruption of Anatahan provided by the HIGP MODIS Thermal Alert Team (http://modis.higp.hawaii.edu) confirmed that activity was heavily concentrated in the E crater (figure 2). The most recent hot-spot (as of 1700 UTC on 28 May) was observed on 24 May. The large amounts of ash produced during the eruption will have obscured some thermal anomalies from the MODIS sensor. Plumes were clearly visible on MODIS imagery on 14, 21, 22, 25, 26, 28, and 30 May (figure 3). The persistent, long plume from this island volcano was frequently detected in imagery from a wide variety of satellite platforms.

SO_2 data from TOMS. Simon Carn reported that the Earth Probe Total Ozone Mapping Spectrometer (EP TOMS) has observed SO_2 and ash emissions from the ongoing eruption. No emissions were detected in the EP TOMS overpass at 0116 UTC on 10 May, several hours before the reported eruption onset. On May 11 a data gap over the Marianas prevented detection of proximal emissions, though a small ash cloud (no larger than ~ 120 km across) was detected ~ 500 km ESE of Anatahan at 0027 UTC. Washington VAAC estimates suggested a height of 14-15 km for this cloud. A weak SO_2 cloud was also observed, displaced from the ash cloud and centered ~ 560 km SE of Anatahan. This cloud contained an estimated SO_2 mass of ~ 10 kilotons (kt), but it is suspected to be only the distal end of a larger SO_2 plume obscured by the data gap. Diffuse ash was also apparent at least 500 km W of the volcano at 0205 UTC, but no measurable SO_2.

The EP TOMS orbit was better placed on 12 May at 0115 UTC. At this time an ash cloud extending ~ 560 km on its long axis was centered ~ 570 km W of Anatahan. An SO_2 cloud, again displaced from the ash, extended ~ 1,100 km from a point ~ 510 km W of the volcano to a point ~ 700 km SE of it. This cloud contained ~ 110 kt of SO_2. On 13 May a data gap covered the Marianas though ash was detected farther W, with no significant new SO_2 evident. On 14 May a low-level SO_2 plume appeared to be drifting W from Anatahan.

As of May 30 the Earth Probe TOMS instrument continued to detect significant SO_2 emissions from Anatahan. No TOMS data were collected during 15-23 May due to a technical fault on the spacecraft. Thereafter, TOMS detected SO_2 clouds in the region of Anatahan on 24 May (~ 19 kt SO_2), 25 May (~ 23 kt minimum), 26 May (~ 35 kt), 28 May (~ 70 kt), and 30 May (~ 50-100 kt). Data gaps covered the Marianas on other days. Given the persistent ash plume from the volcano reported by the Washington VAAC, these SO_2 clouds are presumed to be the product of continuous emissions and not discrete explosive events.

Observations from 20 May-8 June 2001. Anatahan was visited during 20 May-8 June 2001 as part of fieldwork in the Northern Marianas (Trusdell and others, 2001), including helicopter observations on 4 June. At that time line lengths on the Anatahan EDM network were measured and showed no significant changes. Most line lengths exhibited small contractions when compared to the data from the 1994 survey. Deformation appeared to be slowing down with no significant changes. Temperatures were measured for several boiling pots and springs on the floor of the E crater. The temperature of the ponds as well as fumaroles ranged from a minimum of 96.7°C to a maximum of 100.3°C.

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. The sparseness of vegetation on the most recent lava flows on Anatahan indicate their probable Holocene age.

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Chikurachki

Kuril Islands, Russia
50.325°S, 155.458°E; summit elev. 1,816 m
All times are local (= UTC + 11 hours)

The eruption that began on 18 April 2003 (*Bulletin* v. 28, no. 4) continued throughout May and into early June. According to observers, ash fell on the town of Severo-Kurilsk (~ 60 km from the volcano) on 1 May. Observers from Vasiliev Cape noted weak fumarolic activity on 3 May and satellite data from the USA and Russia that day revealed a gas-and-steam plume more than 150 km long and moving towards the ESE and S. Satellite data continued to show gas-and-steam plumes, possibly containing ash, throughout the remainder of May (table 1). Satellite imaging was obscured by clouds on other days. On 13 May, ash deposits were reported on the ENE and SSE flanks of the volcano and near the summit. At 1800 on 15 May, observers on Paramushir Island reported a strong ashfall at Podgorny settlement.

During the period 1930 to 2310 on 27 May, Leonid Kotenko on Paramushir Island reported that ash explosions attaining heights of 500 m above the crater were observed from Shelekhov Bay. The ash plume at 0900 on 28 May (2200 UTC, 27 May), rose 4,000 m above the crater. On 29 May an ash plume rose ~ 1,200 m above the crater and ash fell on the town of Severo-Kurilsk.

Additional information about the 2002 eruption. Previous KVERT reports indicated that the eruption that began on 25 January 2002 had continued through 16 March (Bulletin v. 27, no. 4), but no further reports were made about that activity. However, later information was received that showed the eruption continuing through at least 22 April. According to satellite data from AVO for 18 March, two consecutive GMS infrared images (1732 and 1832 UTC) showed a narrow, ~ 150-km-long cloud, which extended SE from Paramushir Island. There was no indication of ash based on the split-window technique. On the afternoon of 20 March, a gas-and-steam plume with some ash extended 200 km SE. Paramushir Island was obscured by clouds

Date	Time, UTC	Estimated Length, km	Direction
05 May	—	50	NW
07/08 May	—	150	E/SE
12 May	0019	20	SE
12 May	0449	156	E
13 May	0043	100	E
13 May	0102	70	SE
13 May	0200	50	E
13 May	0423	178	E/SE
13 May	0639	400	E/SE
17 May	—	50	SW
18 May	—	50	NE
21 May	—	10	NW
27 May	0600	100	NE
27 May	2200	100	NE
29 May	AM	15-20	NE

Table 1. Satellite data reports of gas-and-steam and ash plumes emanating from Chikurachki. Courtesy of KVERT.

during the next 2 weeks. On 6 May L. Kotenko (A KVERT contact on the island) reported that hunters had observed fresh ash deposits on the SW flank on 22 April and that ashfall was also noted in Severo-Kurilsk.

Background. Chikurachki, the highest volcano on Paramushir Island in the northern Kurils, is actually a relatively small cone constructed on a high Pleistocene volcanic edifice. Oxidized scoria deposits covering the upper part of the young cone give it a distinctive red color. Lava flows from 1816-m-high Chikurachki reached the sea and form capes on the NW coast; several young lava flows also emerge from beneath the scoria blanket on the eastern flank. The Tatarinov group of six volcanic centers is located immediately to the south of Chikurachki. In contrast to the frequently active Chikurachki, the Tatarinov volcanoes are extensively modified by erosion and have a more complex structure. Tephrochronology gives evidence of only one eruption in historical time from Tatarinov, although its southern cone contains a sulfur-encrusted crater with fumaroles that were active along the margin of a crater lake until 1959.

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Karymsky

Kamchatka Peninsula, Russia
54.05ºN, 159.43ºE; summit elev. 1,536 m
All times are local (=UTC + 11 hours, + 12 hours after 26 October)

According to the Kamchatkan Volcanic Eruptions Response Team (KVERT), the alert level Color Code remained at Yellow (volcano is restless; eruption may occur) from October 2002 to 27 February 2003, when it was dropped to Green (volcano is dormant; normal seismicity and fumarolic activity). The level was raised again to Yellow in March, lowered to Green on 29 March, and raised to Yellow on 18 April, where it remained through May. Seismicity was above background levels until 20 February, after which it fluctuated between at and above background levels until 16 May, when seismicity remained above background levels.

Activity during October 2002. From 4 to 31 October, ~ 200-250 local shallow seismic events occurred per day. The character of the seismicity indicated ash-and-gas explosions to heights of 1,000 m above the volcano (~ 2,500 m altitude) and gas blow-outs. A faint 10-km-long plume extending SSE was visible in an AVHRR satellite image; no ash was detected. Seismicity on 25-26 October indicated possible vigorous gas emissions lasting 5-10 minutes, with the probability of a lava flow. At 1350 on 31 October, pilots reported that an ash plume rose 4 km and extended SE. According to seismic data from the Kamchatka Experimental and Methodical Seismological Department (KEMSD), the character of seismicity after 1400 on 31 October indicated a moving lava flow. At 1314 on 31 October, the MODIS satellite image showed a large bright thermal anomaly at the volcano and a plume ~ 60 km long that extended WSW. At 1100 on 1 November, pilots reported that an ash plume rose 4 km and extended SE.

Activity during November 2002. Local shallow seismic events totaled ~ 200-250 each day. The character of the seismicity indicated ash-and-gas explosions to heights of 1,000-2,000 m above the volcano and vigorous gas emissions lasting 5-10 minutes. At 1605 on 1 November, a 50-km-long plume was observed extending E in satellite imagery; no ash was detected. According to data from KEMSD, at 2357 on 20 November, a seismic event lasting 20 minutes indicated that ash explosions to heights of 1,000 m above the crater and hot avalanches possibly occurred. On 27 November, a > 100-km gas-and-steam plume extending ESE from the crater of the volcano was observed in MODIS satellite imagery. Helicopter observations by KVERT scientists at 1151 on 1 December identified an ash plume to ~ 500 m above the crater extending SE.

Activity during December 2002. Local shallow seismic events totaled ~ 190-230 each day. The character of seismicity indicated that ash-gas explosions to heights of 1,000 m above the volcano (~ 2,500 m altitude) and vigorous gas emissions lasting 5-10 minutes were possibly occurring. The top of the volcano and its SE flank were covered with recent ashfall and debris from continuing Vulcanian / Strombolian eruptions. The old crater was covered by the new cinder-ash cone. On 12 December, two sectors of ash falls extending S and SE from the volcano were noted in a MODIS satellite image.

Activity during January 2003. Local shallow seismic events totaled ~ 110-200 each day. The character of seismicity indicated that ash-gas explosions to heights of 1,000 m above the volcano (~ 2,500 m or 8,200 ft. ASL) and vigorous gas emissions lasting 5-10 minutes were possibly occurring. From 1559 until 1609 on 8 January, a series of shallow events that possibly indicated hot avalanches were registered. On 9 January, a ~ 50-km plume extending ESE from the volcano was noted.

Activity during February 2003. The alert level Color Code remained at Yellow until 27 February, when it was lowered to Green (volcano is dormant; normal seismicity and fumarolic activity). According to satellite data from Russia, a weak thermal anomaly was noted on 3 February. Seismic activity was at background levels on 20-23 February.

Activity during March 2003. The alert level Color Code was raised to Yellow as the activity of the volcano slightly increased. Seismic activity was at background levels on 13-18 March and slightly above background levels on 19 March when seismic data indicated possible hot avalanches. Weak volcanic earthquakes were also registered on this day. According to MODIS-satellite data from Russia and the USA, ash deposits extending more than 30 km SW from the volcano on 17-20 March and gas-steam plumes drifting more than 15 km NW and SW on 18 March and on 20 March, respectively, were noted. Seismic activity dropped to background levels for the week of 20 March. According to satellite data from Russia, a weak thermal anomaly was observed on 25 March, and a gas-and-steam plume extending 10 km ESE was noted on 28 March. According to helicopter observations on 31 March by the Institute of Volcanology (IV), Far East Division, Russian Academy of Sciences, the large old active crater of the volcano and its black ESE flank were noted, but the new cinder-ash cone was not seen. This cone was probably destroyed and its products formed ash-deposits extending > 35 km ESE, which were noted on the 17-18 March MODIS-satellite images.

Activity during April 2003. The alert level Color Code was dropped to Green during the week of 29 March-4 April, when seismic activity was at background levels. Seismicity rose above background levels during the week of 18-24 April, when ~ 40-100 volcanic earthquakes per day were recorded, and the hazard status was raised to Yellow. The character of the seismicity indicated ash-and-gas explosions up to 1,000 m above the crater. According to satellite data from Russia, ash deposits up to 35 km or longer extended in different directions on 19-22 April. According to observers from IV, on 18-24 April occasional ash-gas explosions up to 2,500 m above the crater occurred each day, and on 21 April, an ash-gas plume rose 1,500 m. Seismic activity was above background levels on 24-27 April and at background levels on 27-30 April. During 24-26 April 50-100 volcanic earthquakes per day were registered. The character of the seismicity indicated that three eruption events (possibly ash-and-gas explosions and rock avalanches) occurred on 24 April. According to satellite data from Russia, wide ash deposits longer than 35 km and three narrow ash deposits less than 5 km long extending SE and W and SW from the volcano, respectively, were noted on 25 April and 28-29 April. According to observers from IV FED RAS, on 24 April, an ash-gas plume rose 2,500 m above the crater.

Activity during May 2003. The alert level Color Code remained at Yellow for the month, with intermittent explosive eruptions continuing. Occasional explosions up to 1,500 m above the volcano, producing ash, were considered to be possible, as well as ashfall within a few tens of kilometers. Seismic activity was at background levels during 3-16 May. According to satellite data from Russia, the summit of the volcano was black on 4 May. For the week of 10-16 May, seismic data indicated that 10 ash-and-gas explosions reached heights up to 1,000 m above the crater, and hot avalanches possibly occurred. According to satellite data from the USA and Russia, a weak 1-pixel thermal anomaly on 14 May, and strips of ash deposits extending > 10 km to the S, SSE and SE on 14-15 May were noted. Seismicity was above background levels on 16-30 May.

During 18-21 May, 150-320 local shallow events occurred per day. The character of the seismicity indicated ash-and-gas explosions to heights of 1,000 m above the volcano, gas blow-outs and hot avalanches. According to satellite data from the USA and Russia, a 2-4-pixel thermal anomaly was observed during 18-22 May. Ash deposits on snow E and SE of the volcano were noted on 18 May. Gas-steam plumes extending up to 45 km NE and N of the volcano on 19 and 21 May were noted. For the week of 24-30 May, 280-330 local shallow seismic events occurred per day. The character of the seismicity indicated ash-and-gas explosions to heights of 1,000 m and gas blow-outs. A thermal anomaly continued to be observed. On 25-26 May, gas-and-steam plumes extending 15-115 km SSE from the volcano were noted. Ash deposits on the snow in a different direction from the volcano were noted on 26-27 May.

Background. Karymsky, the most active volcano of the Kamchatka's eastern volcanic zone, is a symmetrical stratovolcano constructed within a 5-km-wide caldera that formed during the early Holocene. The caldera cuts the south side of the Pleistocene Dvor volcano and is located outside the north margin of the large mid-Pleistocene Polovinka caldera, which contains the smaller Akademia Nauk and Odnoboky calderas. Most seismicity preceding Karymsky eruptions has originated beneath Akademia Nauk caldera, which is located immediately south of the Karymsky volcano. The Holocene lava dome Lagerny and the SW edge of the Karymsky caldera is structurally related to Karymsky. The caldera enclosing Karymsky volcano formed about 7,600-7,700 radiocarbon years ago; construction of the Karymsky stratovolcano began about 2,000 years later. The latest eruptive period began about 500 years ago, following a 2,300-year quiescence. Much of the cone is mantled by lava flows less than 200 years old. Historical eruptions have been Vulcanian or Vulcanian-Strombolian with moderate explosive activity and occasional lava flows from the summit crater.

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Har-Togoo

central Mongolia

48.839°N, 101.402°E; summit elevation 1,750 m

In December 2002 information appeared in Mongolian and Russian newspapers and on national TV that a volcano in Central Mongolia, the Har-Togoo volcano, was producing white vapors and constant acoustic noise. Because of the potential hazard posed to two nearby settlements, mainly with regard to potential blocking of rivers, the Director of the Research Center of Astronomy and Geophysics of the Mongolian Academy of Sciences, Dr. Bekhtur, organized a scientific expedition to the volcano on 19-20

March 2003. The scientific team also included M. Ulziibat, seismologist from the same Research Center, M. Ganzorig, the Director of the Institute of Informatics, and A. Ivanov from the Institute of the Earth's Crust, Siberian Branch of the Russian Academy of Sciences.

Geological setting. The Miocene Har-Togoo shield volcano is situated on top of a vast volcanic plateau (figure 4). The 5,000-year-old Khorog (Horog) cone in the Taryatu-Chulutu volcanic field is located 135 km SW and the Quaternary Urun-Dush cone in the Khanuy Gol (Hanuy Gol) volcanic field is 95 km ENE. Pliocene and Quaternary volcanic rocks are also abundant in the vicinity of the Holocene volcanoes (Devyatkin and Smelov, 1979; Logatchev and others, 1982). Analysis of seismic activity recorded by a network of seismic stations across Mongolia shows that earthquakes of magnitude 2-3.5 are scattered around the Har-Togoo volcano at a distance of 10-15 km.

Observations during March 2003. The name of the volcano in the Mongolian language means "black-pot" and through questioning of the local inhabitants, it was learned that there is a local myth that a dragon lived in the volcano. The local inhabitants also mentioned that marmots, previously abundant in the area, began to migrate westwards five years ago; they are now practically absent from the area.

Acoustic noise and venting of colorless warm gas from a small hole near the summit were noticed in October 2002 by local residents. In December 2002, while snow lay on the ground, the hole was clearly visible to local visitors, and a second hole could be seen a few meters away; it is unclear whether or not white vapors were noticed on this occasion. During the inspection in March 2003 a third hole was seen. The second hole is located within a 3 x 3 m outcrop of cinder and pumice (figure 5) whereas the first and the third holes are located within massive basalts. When close to the holes, constant noise resembled a rapid river heard from afar. The second hole was covered with plastic sheeting fixed at the margins, but the plastic was blown off within 2-3 seconds. Gas from the second hole was sampled in a mechanically pumped glass sampler. Analysis by gas chromatography, performed a week later at the Institute of the Earth's Crust, showed that nitrogen and atmospheric air were the major constituents.

Figure 5. Photograph of the second hole sampled at Har-Togoo, with hammer for scale, March 2003. Courtesy of Alexei Ivanov.

The temperature of the gas at the first, second, and third holes was +1.1, +1.4, and +2.7°C, respectively, while air temperature was -4.6 to -4.7°C (measured on 19 March 2003). Repeated measurements of the temperatures on the next day gave values of +1.1, +0.8, and -6.0°C at the first, second, and third holes, respectively. Air temperature was -9.4°C. To avoid bias due to direct heating from sunlight the measurements were performed under shadow. All measurements were done with Chechtemp2 digital thermometer with precision of ±0.1°C and accuracy ±0.3°C.

Inside the mouth of the first hole was 4-10-cm-thick ice with suspended gas bubbles (figure 5). The ice and snow were sampled in plastic bottles, melted, and tested for pH and Eh with digital meters. The pH-meter was calibrated by Horiba Ltd (Kyoto, Japan) standard solutions 4 and 7. Water from melted ice appeared to be slightly acidic (pH 6.52) in comparison to water of melted snow (pH 7.04). Both pH values were within neutral solution values. No prominent difference in Eh (108 and 117 for ice and snow, respectively) was revealed.

Two digital short-period three-component stations were installed on top of Har-Togoo, one 50 m from the degassing holes and one in a remote area on basement rocks, for monitoring during 19-20 March 2003. Every hour 1-3 microseismic events with magnitude < 2 were recorded. All seismic events were virtually identical and resembled A-type volcano-tectonic earthquakes (figure 6). Arrival difference between S and P waves were around 0.06-0.3 seconds for the Har-Togoo station and 0.1-1.5 seconds for the remote station. Assuming that the Har-Togoo station was located in the epicentral zone, the events were located at ~ 1-3 km depth. Seismic episodes similar to volcanic tremors were also recorded (figure 6).

Figure 4. Photograph of the Har-Togoo volcano viewed from west, March 2003. Courtesy of Alexei Ivanov.

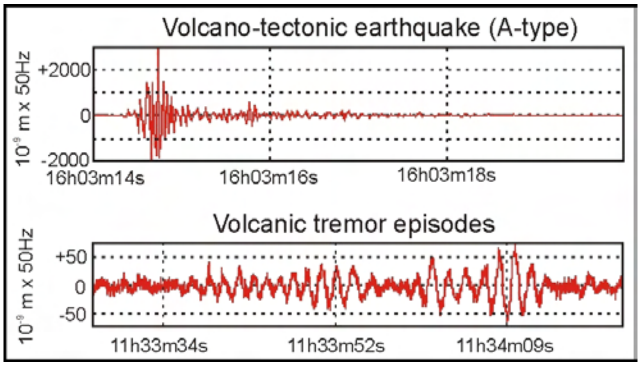

Figure 6. Examples of an A-type volcano-tectonic earthquake and volcanic tremor episodes recorded at the Har-Togoo station on 19 March 2003. Courtesy of Alexei Ivanov.

Conclusions. The abnormal thermal and seismic activities could be the result of either hydrothermal or volcanic processes. This activity could have started in the fall of 2002 when they were directly observed for the first time, or possibly up to five years earlier when marmots started migrating from the area. Further studies are planned to investigate the cause of the fumarolic and seismic activities.

At the end of a second visit in early July, gas venting had stopped, but seismicity was continuing. In August there will be a workshop on Russian-Mongolian cooperation between Institutions of the Russian and Mongolian Academies of Sciences (held in Ulan-Bator, Mongolia), where the work being done on this volcano will be presented.

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Mayon

Luzon, Philippines
13.247°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 small ash and steam explosions from the Mayon volcano on 5 April, 6 May, and 14 May 2003. The alert status for the area around the volcano remained at Alert Level 1 on a scale of 0-5 (indicating an increased likelihood for steam-driven or ash explosions to occur with little or no warning). PHIVOLCS reminded the public to continue avoiding entry into the 6-km-radius Permanent Danger Zone (PDZ), especially in the sectors where life-threatening volcanic flows might be channeled by gullies.

Activity during April 2003. Following a small ash explosion on 17 March 2003 (*Bulletin* v.28, no.3), a brief burst of ash and steam occurred at about 0600 on 5 April. The ash column rose to ~ 1.5 km above the summit crater before being blown SW. The explosion was recorded as a low-frequency volcanic earthquake, signifying a shallow source. Prior to the explosion, the volcano's seismic network had detected three small low-frequency volcanic earthquakes and three low-frequency short-duration harmonic tremors in the past 24 hours. Electronic tiltmeters indicated continuing slight inflation of the edifice. The increases in activity strongly indicated the likelihood of sudden ash explosions. Although no major eruption was expected immediately after the explosion of 5 April, there was growing evidence that magma was ascending the volcano's conduit.

Activity during May 2003. A small explosion from the crater at 0721 on 6 May produced a brownish ash-and-steam column that rose to ~ 450 m above the summit crater and was blown SW. The ash-and-steam column rose slowly with minimal noticeable force and was not detected by the volcano's seismic network, indicating a very shallow source. No significant seismicity occurred prior to the explosion. However, electronic tiltmeters on the N and S flanks continued to show inflation. Likewise, a precise leveling survey on 24 April 2003 showed a general inflation of the N flank. Alert Level 1 remained in effect.

At 1813 on 14 May, a small ash puff was emitted from the summit crater. This very brief explosion caused a small volume of ash and steam to rise less than 100 m above the crater and to later be blown NW. The Mayon Resthouse and Sta Misericordia seismic stations recorded the ash puff as a small-amplitude event. Prior to the ash explosion, one short-duration tremor was recorded. Volcanic gas outputs were notably moderate in volume, and the sulfur dioxide emission rates increased from the previous 1,824 metric tons per day (t/d) to ~ 3,088 t/d. The seismic characteristics associated with the ash and steam emission appeared similar to, though smaller than, previous explosions since 22 October 2002, indicating that this ash puff was very minor. This assessment was also consistent with the smaller volume of ash produced.

Background. Beautifully symmetrical Mayon volcano, which rises to 2,462 m above the Albay Gulf, is the Philippines' most active volcano. The structurally simple volcano has steep upper slopes averaging 35-40° 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 1,200 people and devastated several towns.

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Karangetang [Api Siau]

Siau Island, Indonesia
2.47°N, 125.29°E; summit elev. 1,784 m

During 6 January-4 May 2003 explosions produced ash that fell on various parts of the crater. The S (main) crater emitted "white-gray ash" that reached 150-400 m high. On some nights, a red glow was visible reaching 25-50 m over the crater. The N crater emitted a "white-thin ash" plume that reached 50-300 m high. Fluctuating seismicity was dominated by multiphase earthquakes and emissions (table 2). The Alert Level remained at level 3 (on a scale of 1 to 4) through at least 4 May.

On 11 and 12 January, ash explosions at the S crater were accompanied by glowing material that reached 200 m high and scattered 500 m toward the E and W parts of the crater. An ash column rose up to 500 m above the crater. Two explosions at the S crater on 14 January produced an ash column up to 300 m high; glowing material rose up to 50 m and fell around the crater. Some of the material entered the Beha River, and ash fell into the sea E of the island. Explosions on 29 January and 6 February caused ashfall SW (Beong village) and SSW (Akesembeka village, Tarurane, Tatahadeng, Bebali, and Salili), respectively. A booming noise was heard frequently throughout the report period, and during early February was sometimes accompanied by thick gray emissions up to 350 m above the crater.

Beginning in early March, the booming noise was accompanied by glowing lava avalanches that traveled from the summit towards the Kahetang (1,250 m), Batuawang (750 m), Batang (1,000 m), and Beha (750 m) rivers. On 6 March an explosion from the S crater ejected ash 750 m high that fell in the E part of the crater. The noises and avalanches decreased during mid-to-late March.

An explosion on 15 April was followed by lava avalanches toward the W and S parts of the crater. A loud blasting sound was heard, and a dark-gray ash column reached 1,500 m. Ash fell to the E around Dame and Karalung villages, and over the sea. Lava avalanches from the S crater traveled 1,000 m toward the Batang and Batu rivers. On 20 April another explosion produced a 1,500-m-high ash column, and ash fell E over the sea. This explosion was followed by lava avalanches and a pyroclastic flow toward the Batang river that reached as far as 2,500 m. Lava avalanches extended 1,500 m down the S and W slopes. Blasting noises occurred for about 3 minutes.

On 22 April an explosion ejected ash and glowing material. The ash column reached 1,750 m and ash fell on the W slope, including Lehi, Mini, Kinali, and Hiung villages, while glowing material rose up to 750 m. This explosion was followed by lava avalanches towards the W and S that were accompanied by a pyroclastic flow toward the Batang river that extended 2,250 m. On 24 April, an explosion ejected ash to 750 m and ash fell eastward into the sea. Glowing material from the explosion traveled toward the W slope. During late April, the booming noises were once again accompanied by continuous glowing avalanches. These decreased during the first days of May.

Background. Karangetang (Api Siau) volcano lies at the northern end of the island of Siau, N of Sulawesi. The 1,784-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 Contact: *Volcanological Survey of Indonesia (VSI)*, Jalan Diponegoro No. 57, Bandung 40122, Indonesia (Email: dali@vsi.dpe.go.id; URL: http://www.vsi.dpe.go.id).

Date (2003)	Deep volcanic (A-type)	Shallow volcanic (B-type)	Explosions	Multiphase	Emissions	Tectonic	Avalanches
06 Jan-12 Jan	11	16	2	178	178	28	—
13 Jan-19 Jan	9	16	2	133	42	40	—
20 Jan-26 Jan	12	37	—	189	52	27	—
27 Jan-02 Feb	6	28	1	228	118	22	—
03 Feb-09 Feb	17	84	1	162	306	23	—
10 Feb-16 Feb	9	30	1	85	102	16	—
17 Feb-23 Feb	9	46	—	97	8	32	—
24 Feb-02 Mar	48	68	—	78	17	34	—
03 Mar-09 Mar	19	29	1	48	9	24	398
10 Mar-16 Mar	14	11	—	27	7	30	125
17 Mar-23 Mar	24	145	—	82	4	23	4
24 Mar-30 Mar	21	68	—	35	1	33	2
31 Mar-06 Apr	8	83	—	30	—	36	—
07 Apr-13 Apr	18	143	—	116	6	50	—
14 Apr-20 Apr	12	257	32	226	26	32	7
21 Apr-27 Apr	13	373	2	93	6	17	309
28 Apr-04 May	32	255	—	243	1	21	29

Table 2. Seismicity at Karangetang during 6 January-4 May 2003. Courtesy VSI.

Lokon-Empung

northern Sulawesi, Indonesia
1.36°N, 124.79°E; summit elev. 1,580 m

During 6 January-4 May 2003, higher-than-normal activity was dominated by deep and shallow volcanic earthquakes (table 3), along with gas-and-ash emissions. Several explosions occurred during a period of increased activity in late January-early April. Throughout the report period, a "white-thick ash" emission rose 25-500 m above Tompaluan crater. The Volcanological Survey of Indonesia (VSI) issued a special report during 1-13 February 2003 that described activity in 2002 and early 2003 leading up to the recent increase in activity (table 4).

On 25 January, there was a felt shock (I on the MMI scale). During late January, ash emissions from the crater thickened and emission earthquakes increased. On 3 February the number of deep volcanic earthquakes began to increase at 0600; by 1000, 35 had occurred.

Ash emissions continued to thicken and deep and shallow volcanic earthquakes increased during early February. Emission earthquakes also increased, indicating some low ash explosions. On 8 February at 0443 an explosion ejected ash and glowing material. A booming sound was heard for 30 seconds. A dense ash cloud reached 1,400 m above the crater. Ash fell over the S part of the crater and around Kayau, Tara-tara I and II, and Woloan II and III villages. Ashfall reached thicknesses of 0.5-1 mm. The Alert Level was increased from 2 to 3 (on a scale of 1-4).

Explosions occurred on 10 February at 1405 and 2219. The maximum amplitude of the explosion earthquakes was 50 mm. The height of the ash column could not be observed due to heavy rain. Explosion activity continued on 12 and 16 February. VSI reported that the Alert Level was increased to 4 on 12 February at 0800. From that time through 1100 on 12 February, shallow volcanic earthquakes increased to a total of 164. An explosion followed at 1102, but the ash column could not be observed due to heavy rain. Tremor was recorded beginning on 13 February with amplitudes of 0.5-38 mm.

Date	Deep volcanic	Shallow volcanic	Emission	Tectonic	Explosion
06 Jan-12 Jan 03	1	6	10	13	—
13 Jan-19 Jan 03	1	3	—	20	—
20 Jan-26 Jan 03	8	6	4	23	—
27 Jan-02 Feb 03	6	4	31	11	—
03 Feb-09 Feb 03	239	763	4	9	—
10 Feb-16 Feb 03	32	23	7	14	4
17 Feb-23 Feb 03	239	763	4	9	1
24 Feb-2 Mar 03	97	353	52	19	12
03 Mar-09 Mar 03	—	3	185	6	2
10 Mar-16 Mar 03	—	—	90	14	—
17 Mar-23 Mar 03	2	4	38	17	—
24 Mar-30 Mar 03	49	335	33	7	1
31 Mar-06 Apr 03	7	130	5	18	1
07 Apr-13 Apr 03	4	15	86	17	—
14 Apr-20 Apr 03	44	285	—	17	—
21 Apr-27 Apr 03	46	98	—	14	—
28 Apr-04 May 03	25	71	—	24	—

Table 3. Seismicity at Lokon during 6 January-4 May 2003. Courtesy VSI.

Date	Event
09 Feb 02	An explosion ejected ash to ~ 1,000 m above the crater. Ash fell on Kakaskasen, Telete, and Rurukan villages in the Tondano District in thicknesses of 0.5-2 cm.
10 Apr 02	At 2302 volcanic earthquakes began to increase, reaching a total of 184 events. An explosion at the same time ejected ash to ~ 1,000 m and glowing material to 250 m above the crater. Ash fell on some villages in thicknesses of 1-3 mm.
12 Apr 02	At 1816 an explosion ejected ash to 800 m and glowing material to 150 m. Ash drifted S and fell around Kayawu village.
23 Dec 02	At 0532 an explosion at Tompaluan crater produced an 800-m-high ash column. Ash drifted S and fell around the edifice. Before the explosion, an increase in seismicity (130 volcanic earthquakes in less than 12 hours) was noted.
03 Feb 03	Volcanic earthquakes began to increase, with a total of 255 events occurring through 7 February.
08 Feb 03	Tremor was followed by an explosion at 0443 that ejected ash to 1,400 m above the crater. The ash drifted S and was accompanied by glowing material. Ash fell around Taratara, Waloan, and Kayawu villages, at thicknesses of 0.5-1 cm.
10 Feb 03	After two days repose, at 2219 an explosion occurred. The height of the ash column could not be observed due to heavy rain near the summit. The explosion was preceded by a booming sound. Based on seismograph recordings, the explosion was of medium-high intensity. Explosion earthquakes stopped at 2335. A phreatic eruption at 1406 lasted for 8 minutes.
12 Feb 03	A significant increase in volcanic earthquakes, mainly during 0100-1000. An explosion at 1408 was followed by a larger explosion at 1102 (based on seismic data; visual observation obscured by thick fog). At 1133 the explosion diminished. At 1225 continuous tremor began with amplitudes of 13-55 mm that continued until 0046 on 13 February.

Table 4. Summary of a special report of activity at Lokon during 2002-2003. Courtesy VSI.

VSI reported that during 18-20 February, there were 16 explosions and a "white-gray ash" column rose 500 m. An explosion on 22 February was preceded by a swarm of 224 shallow volcanic earthquakes. On 21 February, 29 deep volcanic earthquakes occurred. Within two days, the number of volcanic earthquakes decreased gradually and ended with a large explosion on 23 February at 1034. The explosion was accompanied by thundering and a booming sound, and a "thick-gray ash" column reached 2,500 m above the crater. Ash drifted toward the SE. Tremor (with an amplitude of 1-20 mm) began soon after the explosion. Lokon was at Alert Level 3 during 17-23 February.

During 24 February-2 March, 12 explosions occurred and a "white-gray ash" column rose 300 m. An explosion on 2 March at 2129 was accompanied by glowing material that fell within the crater. A dark gray ash column rose 1,500 m above the crater and ash fell toward the Tondano area (~ 14.5 km from the crater) with a thickness of ~ 1 mm. Tremor (with amplitudes of 0.5-25 mm) began soon after the explosion. The explosion had been preceded by a swarm of 204 shallow volcanic earthquakes. A total of 77 deep volcanic earthquakes occurred during 26 February-1 March 2003. Following the 2 March explosion, there were 2 medium-intensity explosions that produced a ~ 600-m-high "white-gray ash" column.

Ash explosions and emission earthquakes ended on 14 March. On 24 March, the Alert Level was lowered to 2. Normal activity continued, comprised mainly of "white-thick ash" emissions from Tompaluan crater that reached up to 300 m. Tremor continued with amplitudes of 0.5-12 mm.

On 27 March at 0156, an explosion produced a 1,500-m-high ash column that was accompanied by glowing material. Booming and blasting sounds were heard. Ash drifted S and some fell around the edifice, while glowing material reached 400 m high before falling around the crater. Activity was low after the explosion. Tremor continued with amplitudes of 0.5-24 mm.

Following another explosion on 1 April, activity at Lokon decreased. A "white-thick ash" plume continued to rise 100-450 m above the crater. Seismicity was dominated by tremor with amplitudes of 0.5-25 mm. Shallow volcanic earthquakes increased on 15 April to 106 events. Through 20 April, the daily number of shallow volcanic earthquakes fluctuated between 23 and 56 events, but there were no explosions. Activity remained low, but above normal, through at least 4 May.

Background. The twin volcanoes Lokon and Empung, rising about 800 m above the plain of Tondano, are among the most active volcanoes of Sulawesi. Lokon, the higher of the two peaks (whose summits are only 2.2 km apart), has a flat, craterless top. The morphologically younger Empung volcano has a 400-m-wide, 150-m-deep crater that erupted last in the 18th century, but all subsequent eruptions have originated from Tompaluan, a 150 x 250 m wide double crater situated in the saddle between the two peaks. Historical eruptions have primarily produced small-to-moderate ash plumes that have occasionally damaged croplands and houses, but lava-dome growth and pyroclastic flows have also occurred.

Information Contact: *Volcanological Survey of Indonesia (VSI)*, Jalan Diponegoro No. 57, Bandung 40122, Indonesia (Email: dali@vsi.dpe.go.id; URL: http://www.vsi.dpe.go.id).

Ruapehu

New Zealand
39.28°S, 175.57°E; summit elev. 2,797 m

Since the middle of March 2003 the temperature of Ruapehu's summit Crater Lake had been slowly rising. The lake temperature rose from 30°C on 5 March (*Bulletin* v. 28, no. 2) to a high of 41.6°C on 15 May (table 5). Similar values were recorded in January 2003 when the lake temperature reached 42°C. This is the fourth time that the temperature of the Crater Lake has risen above 35°C since the start of 2001, and the temperature has been above 30°C since December 2002. It is not unusual for the temperature to cycle over periods of 6-9 months; minor hydrothermal activity can occur in the lake during temperature peaks. Lake temperatures dropped steadily from 41ºC after mid-May. However, during the late morning of 26 May a steam plume was observed rising 200-300 m above Crater Lake. No seismicity accompanied this plume, suggesting that it was generated by atmospheric conditions alone (a warm lake and a cold, windless, morning). Steam plumes were also observed on 28 March and 21 April.

Date (2003)	Crater Lake Temperature
05 Mar	30°C
28 Mar	35°C
11 Apr	38°C
29 Apr	39.4°C
15 May	41.6°C
26 May	Slightly over 40°C
29 May	36°C
01 Jun	33°C

Table 5. Lake water temperatures measured at Ruapehu's Crater Lake, 5 March-1 June 2003. Courtesy of IGNS.

Weak intermittent seismic tremor was recorded through early April, then remained at a constant moderate level during 12-17 April. The following week, 18-24 April, there was an increase in tremor accompanied by discrete volcanic earthquakes. By 2 May volcanic tremor levels had declined, but volcanic earthquakes continued to occur. Levels of volcanic tremor fluctuated during the week of 3-9 May, with several periods of enhanced tremor and small volcanic earthquakes. Tremor had declined by 16 May, and seismicity remained very low through the 30th. The level of volcanic tremor began to increase slightly in early June, but the lake temperature was still declining during the week of 7-13 June. Very low levels of activity continued through the 20th. There were no significant changes observed in the lake water chemistry. The hazard status remained unchanged at Alert Level 1.

Background. Ruapehu, one of New Zealand's most active volcanoes, is a complex stratovolcano constructed during at least 4 cone-building episodes. The 110 cu km volcanic massif is elongated in a NNE-SSW direction and is surrounded by a 100 km^3 ring plain of volcaniclastic debris, including the Murimoto debris-avalanche deposit on the NW flank. A series of subplinian eruptions took place at Ruapehu between about 22,600 and 10,000 years ago, but pyroclastic flows have been infrequent at Ruapehu. A single historically active vent, Crater Lake, is located in the broad summit region, but at least five other vents on the summit and flank have been active during the Holocene. Frequent mild-to-moderate explosive eruptions have occurred in historical time from the Crater Lake vent, and tephra characteristics suggest that the crater lake may have formed as early as 3000 years ago. Lahars produced by phreatic eruptions from the summit crater lake are a hazard to a ski area on the upper flanks and to lower river valleys.

Information Contact: *Institute of Geological & Nuclear Sciences (IGNS)*, Private Bag 2000, Wairakei, New Zealand (URL: http://www.gns.cri.nz/).

Monowai Seamount

Kermadec Islands, New Zealand
25.887°S, 177.188°W; summit elev. -100 m

Monowai is a frequently active submarine volcano, with a volcanic swarm recorded in November 2002 (*Bulletin* v. 28, no. 2) and another during April-May 2003. A major part of its volcanic activity is detected by hydro-acoustic waves (also called T-waves) generated during the eruptions, through the Réseau Sismique Polynésien (RSP), the French Polynesian seismic network (table 6).

A strong volcanic swarm located on the Monowai seamount was recorded during April-May 2003 (figure 7). This volcanic swarm was very well located around Monowai, using the inversion of the arrival times of T-waves recorded by the network. As an example of the precision of location, with the contribution of some IRIS stations like RAR (Cook Island) to enlarge the array dimension, the ellipse of error can typically be 13 km on the major axis and 2 km on the minor axis, with a Root Mean Squared (RMS) of 0.25 s.

This volcanic swarm was composed of three episodes lasting 4-5 days each. It started suddenly on 10 April 2003 with a rate of 100 events per day (about one signal every 10 minutes) and reached a maximum intensity later that day. The average rate over the first four days was 75 events per day (300 signals between 10 and 14 April), but the number of events detected is thought to be underestimated by a factor of at least 3 to 5 because only the main packets of recorded T-waves were picked. Volcanic activity started again during 19 April, with 120 events recorded in the next five days. The last episode occurred between 3 and 6 May, with ~ 100 volcanic signals recorded. The swarm ended as suddenly as it started.

Background. Monowai seamount, also known as Orion seamount, rises to within 100 m of the sea surface about halfway between the Kermadec and Tonga island groups. The volcano lies at the southern end of the Tonga Ridge and is slightly offset from the Kermadec volcanoes. Small parasitic cones occur on the north and west flanks of the submarine volcano, which rises from a depth of about 1500 m and was named for one of the New Zealand Navy bathymetric survey ships that documented its morphology. Numerous eruptions have been detected from submarine acoustic signals since it was first recognized as a volcano in 1977. A shoal that had been reported in 1944 may have been a pumice raft or water disturbance due to degassing. Surface observations have included water discoloration, vigorous gas bubbling, and areas of upwelling water, sometimes accompanied by rumbling noises.

Information Contacts: *Dominique Reymond* and *Olivier Hyvernaud*, Laboratoire de Geophysique, CEA/DASE/LDG Tahiti, PO Box 640, Papeete, French Polynesia (Email: reymond.d@labogeo.pf, hyvernaud@labogeo.pf).

Station code	Latitude	Longitude
PAE	17.6619°S	149.5800°W
PPT	17.5682°S	149.5761°W
PPN	17.5308°S	149.4322°W
TIA	17.5578°S	149.3458°W
TVO	17.7825°S	149.2517°W
MEH	17.8753°S	148.0661°W
PMOR	15.0017°S	147.8942°W
VAH	15.2364°S	147.6272°W
TBI	23.3489°S	149.4608°W
RKT	23.1197°S	134.9733°W

Table 6. Seismic station codes and coordinates of instruments in the French Polynesian seismic network. Courtesy of RSP.

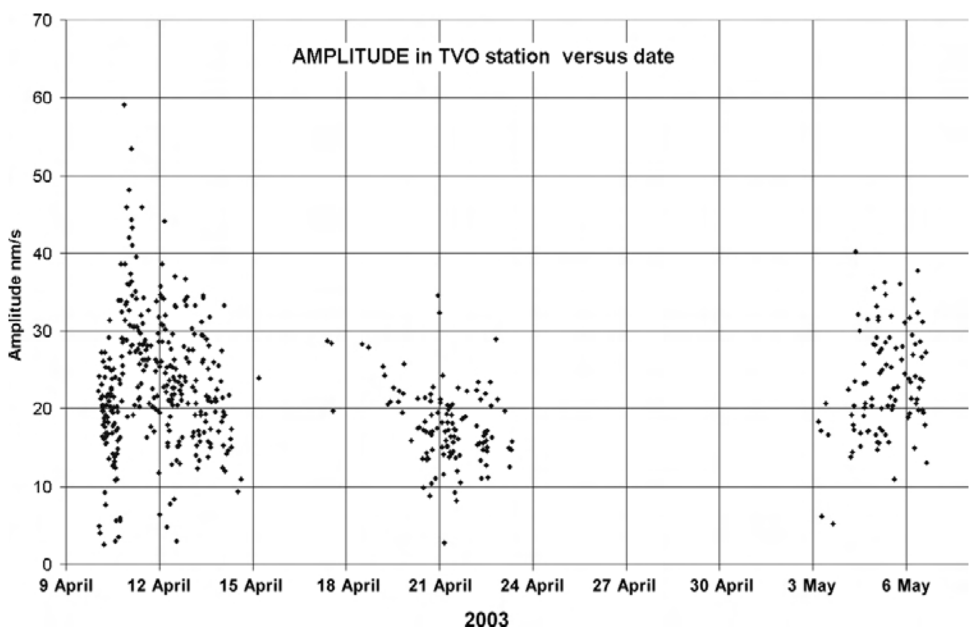

Figure 7. T-wave amplitude versus time for the TVO seismic station, showing the three distinct and well separated episodes of the Monowai Seamount swarm. Courtesy of RSP.

Piton de la Fournaise

Réunion Island, Indian Ocean
21.229°S, 55.713°E; summit elev. 2631 m
All times are local (= UTC + 4 hours)

Eruptions are common at Piton de la Fournaise, with the most recent activity occurring in January 2002 (*Bulletin* v. 26, no. 12) and November-December 2002 (*Bulletin* v. 27, no. 11). At the end of the November 2002 eruption, seimicity beneath Dolomieu crater increased from 28 November to 23 December. On 22 December there were 5,700 seismic events recorded. At 1002 on 23 December a magnitude 3 event occurred and seismicity stopped. The next day a new crater was observed in the SW part of the larger Dolomieu crater.

Since March 2003, the extensometer network and GPS measurements had indicated inflation of Piton de la Fournaise. A new eruption began on 30 May within Dolomieu crater. The eruption proceeded in multiple phases through at least 24 June; activity through 6 June is reported below.

Seismicity increased slightly on 28 May. At 1137 on the morning of 30 May a seismic crisis began that lasted 17 minutes with a total of 34 events. Tremor appeared at 1155 beneath Dolomieu crater, and an eruption started within the pit crater formed on 23 December 2002. Lava fountaining was observed until 1400, after which most surface activity stopped. A lava flow ~ 400 m long and 250 m wide extended into the W part of Dolomieu. The total volume of lava emitted during the 30 May activity was estimated to be 0.2-0.3 x 10^6 m^3. Seismicity beneath the crater continued, with intermittent weak tremor being registered through 3 June. No deflation was detected, and there was strong degassing in the collapse area.

Figure 9. Photograph of the W part of Dolomieu crater at Piton de la Fournaise at 0850 on 6 June 2003 showing the active vent and most of the recent lava-flow field. View is towards the SW. Courtesy of OVPF.

On 4 June at 1155 the eruption started again from the same site, enlarging the lava flow in the W part of Dolomieu crater. Lava fountains reached 15 m in height. Steady lava emission continued into 6 June (figures 8 and 9). Volcanic tremor remained stable until the morning of 6 June, when a decreasing tendency was noted. After a short phreatic eruption, the second phase of this eruption stopped on the evening of 6 June. The lava-flow field had grown to ~ 600 x 400 m in size by that time (figure 10).

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.

Figure 8. Photograph of the SW part of Dolomieu crater at Piton de la Fournaise at 0812 on 6 June 2003 showing the active vent and part of the recent lava-flow field. View is towards the W. Courtesy of OVPF.

Information Contacts: *Observatoire volcanologique du Piton de la Fournaise (OVPF)*, Institut de Physique du Globe de

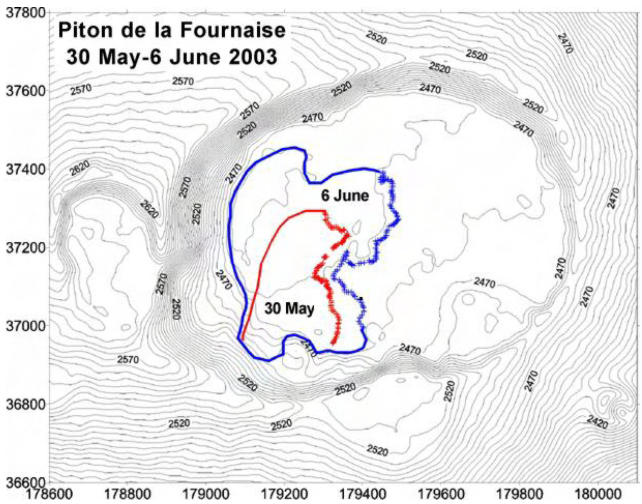

Figure 10. Topographic map of Dolomieu crater at Piton de la Fournaise showing the extent of the lava-flow field on 30 May and 6 June 2003. Elevations are in meters, and the Gauss-Laborde Piton des Neiges system is used for the map coordinates. Courtesy of OVPF.

Paris, 14 RN3, le 27Km, 97418 La Plaine des Cafres, La Réunion, France (Email: Thomas.Staudacher@univ-reunion.fr).

Stromboli

Aeolian Islands, Italy
38.79°N, 15.21°E; summit elev. 926 m
All times are local (= UTC + 1 hour late September-late March; + 2 hours late March-late September)

The latest eruptive episode from Stromboli began on 28 December 2002 (Bulletin v. 28, no. 1) and included a significant explosion on 5 April (Bulletin v. 28, no. 4). This report includes field observations provided by the Istituto Nazionale di Geofisica e Vulcanologia (INGV) through mid-June 2003. Thermal alerts based on infrared satellite imagery over the course of this eruption have been compiled and summarized by scientists at The Open University.

Activity during 17 April-16 June 2003. Effusion of lava from vents located at ~ 600 m elevation, on the upper eastern corner of the Sciara del Fuoco, continued until 16 June with a generally decreasing effusion rate. This caused a significant increase in the thickness of the lava field formed since 15 February to over 50 m. Since the 5 April eruption, the summit craters of the volcano have been blocked by fallout material obstructing the conduit. Small, occasional, short-lived explosions of hot juvenile material were observed on 17 April during a helicopter survey with a hand-held thermal camera, and on 3 May from the SAR fixed camera located at 400 m elevation on the E rim of the Sciara del Fuoco.

The effusion rate from the 600-m-elevation vents on the Sciara del Fuoco showed a significant decline between 1 and 4 May, when inflation of the upper lava flow field was detected through daily helicopter-borne thermal surveys. Inflation stopped on 6 May, when two new vents opened on the inflated crust of the flow field, causing drainage and spreading new lava flows along the Sciara del Fuoco. Between the end of May and early June, gas-rich magma was extruded from the 600 m vents on the upper Sciara del Fuoco. Spattering built up two hornitos, which in a few days reached an estimated height of over 6 m. This activity was accompanied by lava flow effusion along the upper Sciara del Fuoco, with lava descending to 150 m elevation.

On 1 June, Strombolian activity resumed at Crater 1 (NE crater). It was revealed first through helicopter-borne thermal surveys, and then by direct observations from the eastern Sciara del Fuoco rim. Most of the ejecta fell within the crater, and from the lower slopes of the volcano only pulsating dark ash emissions were observed. Strombolian activity stopped around 6 June, and occasional lava flows occurred at the hornitos at 600 m elevation on 11 June. The summit craters showed discontinuous ash emission until mid-June, and the SAR fixed camera at 400 m elevation showed a Strombolian explosion with abundant ash emission on the night of 15 June.

MODIS Thermal Alerts. MODIS thermal alerts for Stromboli covering the period from the start of MODIS data acquisition over Europe in May 2000 until the present were compiled using data available at http://modis.higp.hawaii.edu/.

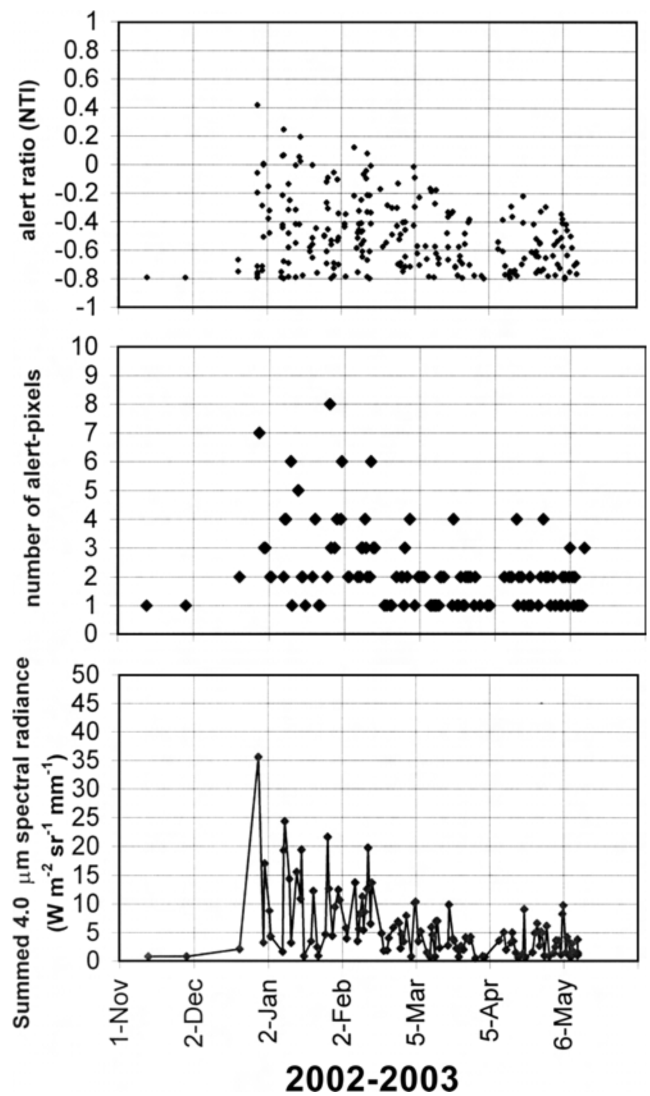

Figure 11. Alert-ratio, number of alert pixels, and summed 4 mm (MODIS band 21) spectral radiance for MODIS thermal alerts on Stromboli between 1 November 2002 and 13 May 2003. MODIS data courtesy of the HIGP MODIS Thermal Alert Team.

With the exception of single-pixel alerts on 8 July and 19 September 2000 (with alert ratios of -0.798 and -0.794, both barely above the -0.800 automatic detection threshold of the thermal alerts algorithm), activity at Stromboli remained below the automatic detection threshold until November 2002 (figure 11). In that month there were two single-pixel alerts, barely above detection threshold (-0.790 on 12 November and -0.792 on 28 November). Thermal infrared radiance was higher than ever before at the time of the MODIS overpass on 20 December 2002, when there was a two-pixel alert, with alert ratios of -0.667 and -0.749.

These five dates were the only MODIS thermal alerts prior to the start of effusive activity on 28 December 2002 (*Bulletin* v. 27, no. 12 and v. 28, no. 1). The source of the radiance to trigger these alerts was evidently incandescence at one or more of the active vents. In the case of a volcano such as Stromboli, prior to December 2002, isolated thermal alerts are more likely to represent the chance coincidence of a short-lived peak of incandescence with the time of MODIS overpass, rather than a sustained emission of infrared radiation. However the November-December 2002 thermal alerts can with hindsight be seen to have been indicators of enhanced activity in the lead-up to the 28 December effusive eruption.

On 28 December 2002 MODIS recorded its highest ever alert ratio at Stromboli (+0.419) and highest summed radiance at 4.0 µm (MODIS band 21) in a seven-pixel alert, corresponding to the daily MODIS overpass at 2115 UTC. This is a record of radiance from 300-m-wide lava flows from the NE crater (*Bulletin* v. 27, no. 12). Subsequent to that date, thermal alerts have occurred persistently at Stromboli, and evidently reflect ongoing lava effusion. The general trend of the highest alert ratio on each date, the number of alert pixels, and the summed 4.0 µm radiance for all alert pixels on each date shows an exponential decline.

There are no thermal alerts for 3-7 April 2003 inclusive, which could be because of cloud cover. There is thus no direct record of the explosion on the morning of 5 April that completely covered the upper 200 m of the volcano with bombs. However, the mild intensification of subsequent thermal-alerts indicates slight re-invigoration of the ongoing lava effusion.

Background. Spectacular incandescent nighttime explosions at Stromboli volcano have long attracted visitors to the "Lighthouse of the Mediterranean." Stromboli, the NE-most of the Aeolian Islands, has lent its name to the frequent mild explosive activity that has characterized its eruptions throughout much of historical time. The small, 926-m-high island of Stromboli is the emergent summit of a volcano that grew in two main eruptive cycles, the last of which formed the western portion of the island. The Neostromboli eruptive period from about 13,000 to 5000 years ago was followed by formation of the modern Stromboli edifice. The active summit vents are located at the head of the Sciara del Fuoco, a prominent horseshoe-shaped scarp formed about 5000 years ago as a result of the most recent of a series of slope failures that extend to below sea level. The modern volcano has been constructed within this scarp, which funnels pyroclastic ejecta and lava flows to the NW. Essentially continuous mild strombolian explosions, sometimes accompanied by lava flows, have been recorded at Stromboli for more than a millennium.

Information Contacts: *Sonia Calvari*, Istituto Nazionale di Geofisica e Vulcanologia, Piazza Roma 2, 95123 Catania, Italy (URL: http://www.ct.ingv.it/, Email: calvari@ct.ingv.it); *David A Rothery* and *Diego Coppola*, Department of Earth Sciences, The Open University, Milton Keynes, MK7 6AA, United Kingdom (Email: d.a.rothery@open.ac.uk, diego.coppola@unito.it). MODIS data courtesy of the HIGP MODIS Thermal Alert Team.

Nyiragongo

central Africa
1.52°S, 29.25°E; summit elev. 3,469 m
All times are local (= UTC + 2 hours)

Nyiragongo, located along the East African Rift (figure 12), ceased generating flank lava flows following its January 2002 eruption, but remained active inside its summit crater where it hosts a restless lava lake. Observations made by staff from the Goma Volcano Observatory (GVO) in August 2002 included the opening of a new sinkhole, and measurements of CO_2 and O_2 gas concentrations at three fumarolic areas (locally termed mazukus). For context, handbook values for CO_2 concentrations and their resulting

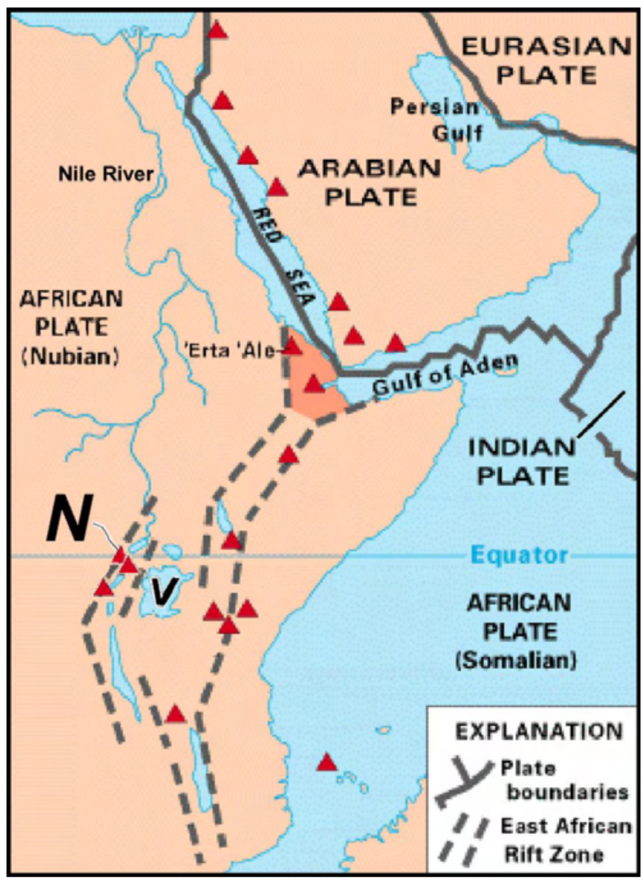

Figure 12. Schematic map illustrating the trend of the East African rift. The rift's overall shape is curved, concave towards the E, and it contains a central segment composed of two branches passing on the E and W sides of Lake Victoria (**V**). The overlapping triangles labeled ***N*** at the N end of the rift's Western segment identify the approximate location of Nyamuragira and Nyiragongo volcanoes N of Lake Kivu. The latter volcano sits to the E and closer Lake Kivu. This figure is based on one in an online book by W.J. Klius and R.I. Tilling of the US Geological Survey. A smaller scale map showing some often mentioned local features appeared in *Bulletin* v. 26, no. 3 (Nyamuragira report).

symptoms in humans are discussed. The GVO has also brought to light reports from local residents of abnormally rapid ripening of picked bananas (and in some cases yams) prior to the January 2002 eruption.

This report also discusses GVO and resident volcanologist summit crater visits during late November 2002-early May 2003. In all cases the lava lake within the summit crater remained dynamic, with one or more windows on the crater floor exposing agitated molten lava. During this interval, degassing continued and tephra fell on the upper flanks. A summary of some ancillary observations such as seismicity measured on the GVO network is also provided.

A later section discusses ash plumes as described in aviation reports. Ash clouds extended as visible swaths on satellite imagery for up to ~ 100 km from the volcano. These reports include some as recent as 15 May 2003. The final section discusses MODIS thermal imagery during late 2002 through early 2003. The 2003 MODIS data reflect the lava lake seen deep within the summit crater. Finally, satellite data show atmospheric SO_2 burdens for the Nyiragongo-Nyamuragira region during 13 December 2002 to 15 June 2003.

GVO's August 2002 field observations. On 12 August 2002 GVO was called to Bugarura village upslope from Munigi on the S flank. A new sinkhole had developed that morning, leaving a steaming opening ~ 3-4 m in diameter. Scientists could not see the opening's bottom through the steam, but they timed falling stones and estimated the sinkhole's depth at ~ 15 m. The odorless gas being emitted led them to believe that the steam chiefly represented vaporized groundwater.

GVO staff and collaborators hoped to advance gas monitoring efforts by measuring CO_2 and other escaping gases at multiple sites in the region. They continued to make spot-checks with hand-held devices, but also sought a more-nearly continuous record from dedicated monitoring instruments. Although noxious gases are a familiar problem in volcanic areas, some of the gas concentrations in the rift are surprisingly high for areas adjacent human habitation. The Swahili word mazuku allegedly connotes places associated with "evil winds," and the term is currently used to describe fumarolic areas, which have also been described as dry gas vents.

Possible precursors to January 2002 eruption. In the weeks before the 17 January 2002 eruption, there were widespread reports of picked crops ripening at unusually rapid rates. From the settlements of Rusayo (8 km SW of the summit) and Katale (~ 18 km NNE of the summit and ~ 10 km NE of Nyamuragira's summit) people reported in early January that the normal 5-day ripening processes of bananas placed in the ground decreased to only 2 days. From Rusayo, people also reported that sweet potatoes, which are normally sun-dried on the ground surface, dried even without sun. GVO observers saw this first-hand and, as a result sought funds to hire porters and observe Nyiragongo directly, but the eruption began before the expedition started.

Although radiant or conductive heat may have been a factor (since heat speeds up the ripening process), heat's transport to broad areas on the surface by conduction through rocks would be comparatively slow. Heat at depth may have more rapidly reached the surface in the form of heated, liberated gases (such as steam). Discussions with gas chemist Vern Brown and a scan of the literature also revealed that the release of certain gases could conceivably have played another role as well. Both acetylene (C_2H_2, a colorless, flammable gas with an odor similar to garlic and slightly less dense than air) and C_2H_4 (ethylene, a colorless, faintly odorous gas less dense than air) speed up the ripening process in many agricultural products (including bananas and yams). Ethylene can cause banana peels to shift from green to yellow at low (ppm) concentrations. These gases occur naturally and may form or escape in association with heating organic material. In contrast, CO_2 generally slows the ripening process. For the interval prior to the January 2002 eruption, observers lack documentation of increases in degassing or heating.

Seismicity and crater visits, November 2002-May 2003. Multiple GVO crater visits were documented: 23-25 November 2002; 9-10 and 21-22 January 2003; 4-5 and 25-26 February 2003; 18-19 March 2003; 22-24 April 2003; 6 May 2003. GVO also sent out occasional updates discussing seismicity and other observations.

During 23-25 November 2002, GVO team members Kasereka Mahinda, Ciraba Mateso, Arnaud Lemarchand, and Jacques Durieux watched the active lava lake on the crater floor. The lake was then located within the southern crater in the 16 November collapsed area. Two broad openings lay at the bottom of this new depression; both permitted viewers to see the lava lake's surface. A third, smaller opening ejected only high-temperature gases. The great quantity of gas occupying the bottom of the crater thwarted efforts to carry out a precise laser-based measurement of the depth to the lava-lake surface. The visual estimate for this depth from the summit was ~ 700 m.

The lava lake was very active, as it was before 1977. The lava surface was disturbed by the rise of abundant large gas bubbles. Breaking bubbles threw molten fragments onto the margins of the two openings. Consistent with the bubbles and constant degassing, a gas plume was visible at night from Goma. Occasionally, light dustings of tephra and Pele's hair came from the crater and fell on the surrounding areas. Although the current lake was impressive, the observers pointed out that the crater has contained a dynamic lava lake for nearly 50 years. The earlier lake's surface was much larger and stood nearly 500 m higher.

Jean-Christophe Komorowski accompanied GVO staff on a climb up Nyiragongo on 9-10 January 2003. While on the upper slopes, the climbers heard a few detonations associated with more energetic gas plumes. From the rim they saw a deep pit in the SW part of the inner crater. There were two vents on the crater floor separated by a thin rocky ridge. The SW vent (vent A) was characterized by a high-pressure fluctuating gas jet that gave off very loud roaring noises, along with flames of incandescent and combusting gases. Condensing steam clouds here were dense, rendering visual observations difficult. The other active vent (vent B) was just to the NE and consisted of an area of stable incandescence at least 100 m in diameter with an active lava fountain. Projections of lava spatter there took place every 30-60 seconds and typically reached 40-60 m in height.

The large area of incandescence indicated that a small lava lake must have been present deep in the pit, although the observers never saw the moving lava surface. Peak high-pressure degassing in vent A did not necessarily correlate with peak lava fountaining activity at vent B. Observations were conducted for several hours at night and during the day. Laser binocular measurements established the crater floor's depth at ~ 800 m. Very light ash consisting of Pele's hair and tears, and millimeter-sized vitric scoria fragments fell continuously on the rim. Conditions were made difficult at times when the SO_2-rich gas plume blew towards the W.

Acid rain that flushed the volcano's SO_2 gas plume, sampled at elevation 2,600 m, had a pH of 2.26. In contrast, rain collected in Kibati (below 2,000 m on the SSE flank) on 6 January had a pH of 6.15. Damage to about two-thirds of the vegetation by acid plume condensates was evident above 2,900 m on the SW and S flanks.

Compared to the last visit by GVO staff, 30-31 December 2002, degassing had increased significantly. However the level of the lava in the crater and/or lake had not risen and might have dropped lower in the conduit. The gas-plume height, measured regularly by the GVO, reached 4,500-5,000 m altitude. At times, although the very loud roaring sound remained unchanged, the entire crater became gas-filled to an extent that incandescence was entirely blocked, even from the vantage of surrounding villages. Information brought regularly to the attention of the GVO by the populations of Kibati, Mudja, Mutaho, and Rusayo villages attested to their exposure to the gas and ash plumes from Nyiragongo. Through at least early May 2003 the volcano's hazard status remained at yellow ("vigilance," the second lowest level on a 4-step scale).

Another climb enabled observers to peer into the crater during 21-22 January 2003 (figure 13). Compared to the 9-10 January observations, only one opening remained active inside the crater. The former vent A probably disappeared following a collapse. The active opening had about the same diameter and its lava fountain attained similar heights compared to earlier vent B observations. The level of the lava had not changed in the crater, remaining deep in the volcanic conduit. Degassing had increased significantly. Periodically more vigorous lava fountains sent smaller fragments to higher elevation that cooled to black scoria fragments. A small scoria cone had started to build around the active vent. Recent small lake overflows formed thin lobate lava sheets around the vent. The ascent velocity of individual gas plumes within the crater varied between 7 and 12 m/s.

A series of incandescent pits extended to the SE of the active pit along a line that corresponds to a major pre-existing fault-fracture system trending N25°W. This system transected the crater from NW to SE and linked with the upper Shaheru fracture and 1977 vent network that reactivated in 2002. A hot fracture zone trended N10°E-N20°E in the NE part of the crater wall. This zone had extended into the active deep crater forming a conspicuous, elongate, vertical-walled canyon. Observers frequently heard and saw rockfalls, and noted that those events often generated plumes that spread and deposited ash over local vegetation. Intra-crater ash reached 5 mm in thickness. The gas plume remained rich in SO_2. Rain water collected at the top of Nyiragongo had a pH of 2.84.

The late-January plume height estimated during favorable atmospheric conditions by GVO members varied from 4,500 to 5,500 m altitude. Often, the prevailing wind carried ash, cinder, and Pele's hair S towards Kibati, Rusayo, Mudja, and Mutaho villages.

A 13 February GVO report said that for four consecutive days, Pele's hair fell in Goma, 17 km SSW. Although cloudy and foggy due to the start of the rainy season, Nyiragongo's plume reached at least 5 km above the crater. Between Goma and the Nyiragongo stood heavy gray-to-black ash-rich clouds. The fall of Pele's hair was due to lava fountains inside the crater.

The same report noted that seismicity was probably lower than the previous week and consisted of low tremor, few long-period earthquakes, and almost no tectonic earthquakes. Very small-amplitude seismic noise (small earthquakes) occurred, presumably due to collapses and perhaps intra-crater explosions.

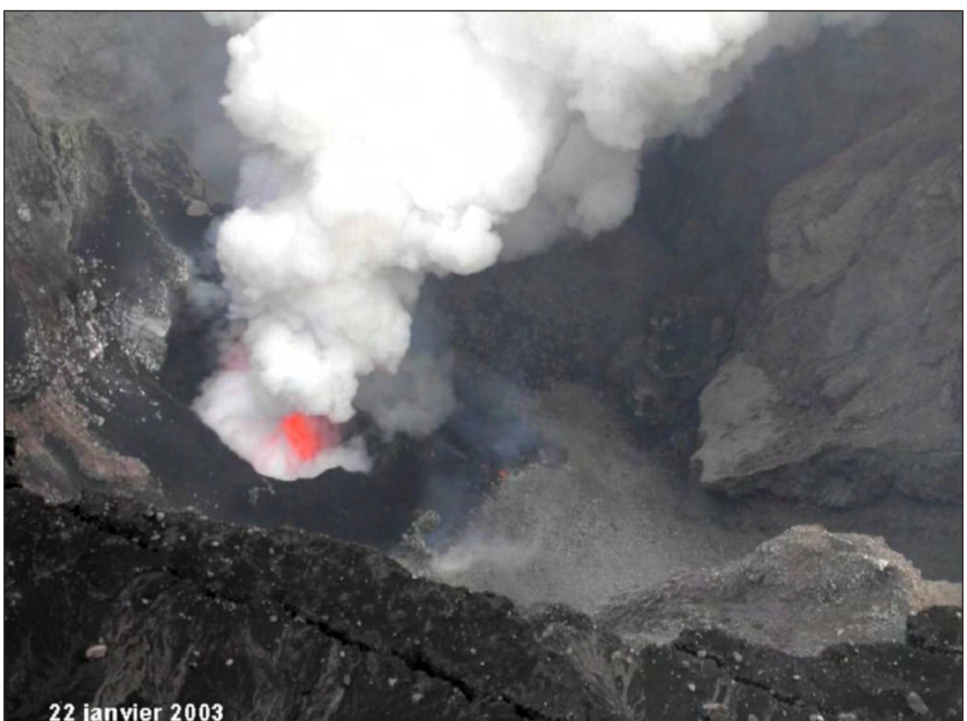

Figure 13. A photo of Nyiragongo's crater and the one opening in the lava lake visible on 22 January 2003. Copyrighted photo used with permission of GVO.

GVO went on to say that one side effect of the ash falls was that villages around Goma had serious water shortages, since they rely on collecting rainfall. All UN agencies and NGOs were informed and asked to start potable water distribution around Goma. A few more physical problems might arise because of the Pele's hair, including stress on people's eyes and breathing. Crops around the volcano in some cases have been burned by acid rains and ash, while cattle might also suffer from ingestion of ash-polluted grass.

The 25-26 February ascent revealed more robust activity than observers had seen on their 4-5 February visit. By the latter date, all vegetation had died near the main crater. Approaching the rim in the upper 220 m of the ascent, tephra falls had accumulated to form deposits several centimeters thick; those, along with acidic plumes, had killed plants. The flora and fauna at lower elevations were still surviving, although they showed signs of serious stress. Loud sounds were audible several kilometers from the central crater. Intra-crater activity seemed intense, but thick fumes in the crater area thwarted day-time visibility. On 25 February views from the W rim revealed that a spatter cone had begun to grow on the crater floor. Lava fountaining occurred all night; discharging lava probably rose more than 100 m high, but it was difficult to assess the maximum rise height. Lava fountains chiefly came out at one spot, although a second, much smaller point of emission gave off mainly flames and sometimes scoria. Pele's hair fell all night long.

An update disseminated on 27 February 2003 noted that compared to previous weeks, during 21-27 February Nyiragongo's activity had decreased, although seismicity measured on the S flanks continued to contain low-amplitude tremor. S-flank seismicity also contained comparatively few long-period (LP) earthquakes. The update also said that local winds had begun to blow predominantly from the ENE, thus sweeping plumes and associated tephra falls clear of Goma. A 22 February visit to the SW-flank settlement of Rusayo revealed conspicuous tephra deposits on roofs and trapped in the crevices of banana trees.

During a visit to Nyiragongo on 18-19 March, GVO scientists observed a thick plume engulfing the crater. Two possible emission points were noted; one was related to powerful lava and ash emissions, and the other was related to a much weaker white-pink plume. An inner active cone was visible in the crater and was at least 200 m in diameter. Lava fountains rose to maximum heights of 150-200 m and as low as 50 m. Scoria ejection made observations difficult at times. Several permanent fumaroles, also observed during the previous visit, were seen in the crater.

Dario Tedesco noted that the cone morphology seemed slightly different from the trip 3 weeks earlier. He observed that on the N side of the crater a new platform had been formed, probably due to the continuous accumulation of ejecta, scoria, and ash. The team saw a huge lava fountain of at least 150-200 m in height. In contrast, when viewed in late February, fountains seemed to remain below ~ 100 m in height. The lava fountains generated abundant falling ash of millimeter size at the observation point, a process that lasted all night long.

Stronger and higher lava fountains, reaching almost 300 m high, were witnessed at 0230 on 19 March. The eruptive vigor as well as the intensity of the falling tephra declined at 0530. The last witnessed activity was of 50-m-high fountains. A second pit was noted on the E side of the crater that had been hidden during the night by the very thick plume.

For many days prior to visits on 22-24 April the seismic stations considered most representative of the Nyiragongo activity only registered very weak and steady continuous tremor. Although other types of seismicity were absent in the, A-type and C-type earthquakes occurred near the volcano. Despite the comparative seismic quiet, a prominent gas plume rose from the volcano. When weather conditions permitted, the plume top was measured at 5-6 km altitude.

The 22-24 April field excursion noted five distinct vents on the crater floor, almost continuous emissions of tephra, an agitated molten-lake surface that included emerging gas, and lava splashing 50-60 m high. Occasional waves of lava rolled across portions of the crater floor and walls. Excursion members also witnessed crater-wall collapses taking place along the NW and S fracture zones.

Widely felt earthquakes also continued in the region, presumably related to extension along the massive East African rift system. For example, three C-type events occurred on 23 April below Nyiragongo at a depth of ~ 15 km. During the whole day of 24 April, sustained tremor plus C-type events registered. On 25 April a few seismic events occurred amid sustained tremor. A main volcano-tectonic shock had been recorded and later a series of A-type events in the Nyiragongo field, between the S flank and Lake Kivu. Increasing tremor followed. For the rest of the week, the seismic network recorded a concentration of volcanic events to the NW and the S of the volcano, along the preferential fracture axis.

On 2-3 May unusually dense ash plumes were visible from Goma. Continuous ashfall occurred in many villages close to the volcano, and permanent tremor and long-period earthquakes were recorded. SO_2 emission rates were relatively high during 1-6 May, with the largest emission on 3 May (~ 50,000 tons, see TOMS data below). UN peace keepers provided a 3 May helicopter flight that gave volcanologists clear views of the crater. The lava lake's molten surface appeared slightly larger than during a visit to the crater rim on 22-24 April. At that time a significant plume containing gas and ash rose high above the volcano.

On 6 May GVO climbers entered the village of Kibati, the usual departure point for the ascent, ~ 8 km from the crater rim. Kibati residents told how ash falls and acid rains had negatively affected local crops. For example, bean leaves had been burnt in many places. Along the ascent, at 2,260 m elevation, Pele's hair was found, including some intact individual strands 30 cm long. At 2,700 m elevation, thin ash grains completely covered the vegetation. At 3,200 m elevation on the S flank (~ 270 m below the summit), all vegetation had died.

Atmospheric conditions initially allowed quite clear views from the crater rim. The lava lake underwent violent outbursts from bursting of gas bubbles estimated at up to 40 m wide. The resulting projections of spatters and surges splashed on the walls of the pit. The lake had regained its former dimensions (~ 60 m across). The wider lake, recently seen from helicopter, had shrunken, leaving a solid platform on its side. Pressure of the escaping gases seemed very high and yielded a continuous roaring. GVO climbers again witnessed intermittent pale yellow-green flames hurling from the vents up to 50 m high.

At 0644 on 6 May a seismic shock was felt by the team on top of the volcano. It was recorded by the whole network as a low-amplitude long-period earthquake. Then, fog and gases halted further sightings into the crater. The fog lifted around 0100 on 7 May; at this time viewers saw a small narrow lava flow in the southern inner wall adjacent the active pit's margin ~ 200 m above the crater floor. The lava escaped out of what looked like a tunnel or tube. Although the lava descended at a steep angle and appeared to escape from the tube at a constant rate, its rate of advance remained slow. The lava front had not made it to the crater center. Below the tube, however, intricate individual lava flows had formed a long delta.

Aviation reports. A Volcanic Ash Advisory (VAA) for Nyiragongo was issued by the Toulouse Volcanic Ash Advisory Center (VAAC) on 6 March 2003. That advisory stated, "A cloud probably containing ash can be seen on [visible wavelength] METEOSAT imagery extending 100 NM [(nautical miles, 185 km)] westward from the volcano." Several hours later the ash cloud was no longer visible. Advisories were also issue on 9, 12, 14, and 15 May 2003. The one for 9 May noted, "Renewed activity since early May. Ash plume witnessed during a helicopter flight around early May up to 5-6 km above sea level. Many ash falls and acid rains all around the volcano." No cloud was observable due to convective weather clouds. The reports on 14 and 15 May stated, "According to Goma observatory [GVO], a plume of steam and ash is often emitted since early May. It may rise 1,500-2,500 m above the volcano's summit. No new message from Goma observatory since early May." Meteorological satellite (METEOSAT) imagery was unable to detect an ash cloud on 14 May due to weather clouds around the volcano.

MODIS satellite data. During early 2002 to early 2003 Nyiragongo was monitored on a daily basis with thermal satellite imagery (1-km pixel size). Investigators Matt Patrick, Luke Flynn, Harold Garbeil, Andy Harris, Eric Pilger, Glyn Williams-Jones, and Rob Wright used NASA's Moderate Resolution Imaging Spectroradiometer (MODIS) instrument and processed these data using the automated MODIS thermal alert system at the University of Hawaii, Manoa.

Prior to the January 2002 eruption, Nyiragongo activity appeared insignificant; anomalies were absent from the start of the MODIS-based alert system in April 2000, and through all of 2001. Anomalous pixels remained absent during 24 February-12 June 2002. The absence of anomalies could be explained either by a lack of exposure of the lava lake or by cloud cover obscuring the heat source from the satellite's view.

Nyiragongo's major effusive eruption in mid-January 2002 caused strong initial thermal anomalies (figure 14). Lava flows extending down the S flank to Lake Kivu resulted in anomalies as large as 45 pixels. Afterwards, the anomalies diminished quickly. Small intermittent anomalies (1-3 pixels) occurred near the summit for the remainder of 2002 and into early 2003, consistent with the kind of lava-lake activity described above.

Atmospheric SO_2. The Earth Probe Total Ozone Mapping Spectrometer (EP TOMS) SO_2 data presented in figure 15 are preliminary. The bars indicated as "TOMS SO_2" plotted on the lower axis of the chart represent EP TOMS

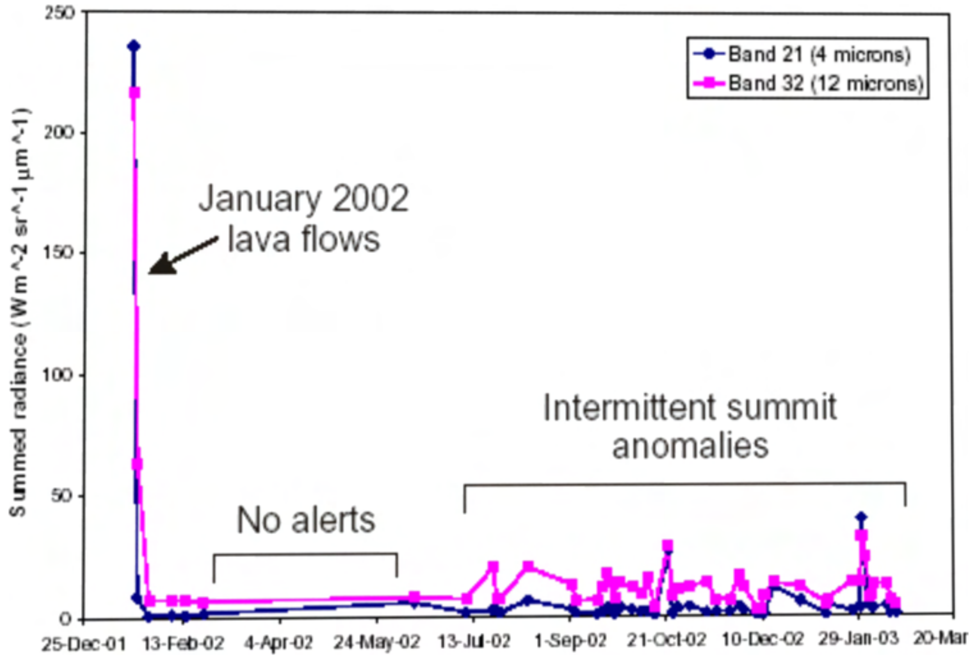

Figure 14. A plot illustrating MODIS data for Nyiragongo with the sum for short-wave (4 micron, band 21) radiance as well as the sum for long-wave (12 micron, band 32) radiance for all anomalous pixels in each image. The x-axis (time axis) starts before the eruption in December 2001 and ends in early 2003. Courtesy of Hawaii Institute of Geophysics and Planetology, University of Hawaii, Manoa.

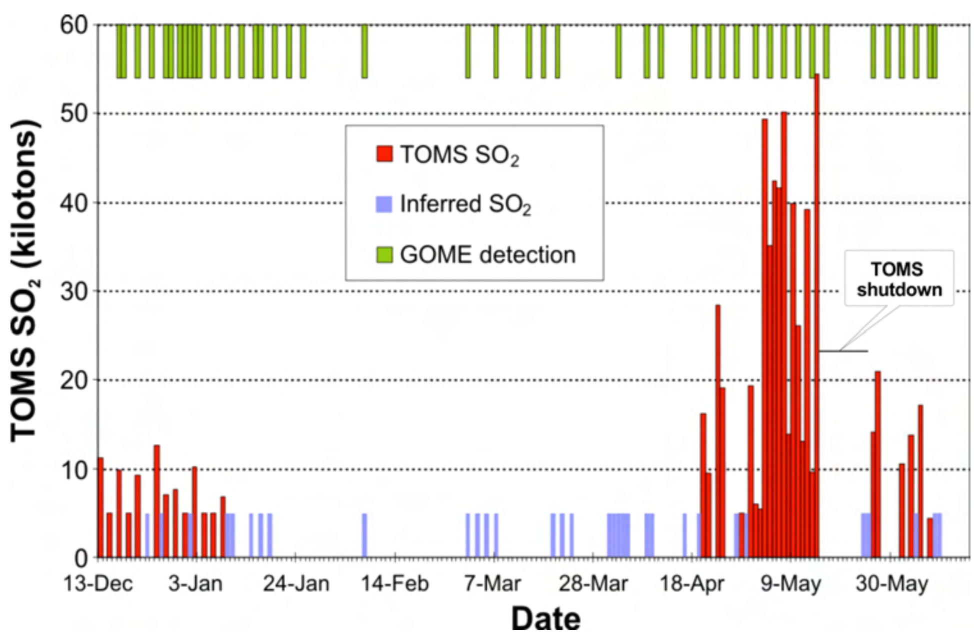

Figure 15. Preliminary atmospheric SO_2 data taken from satellite measurements of the Nyiragongo-Nyamuragira region during 13 December 2002 to 15 June 2003. The data along the lower axis are from the EP TOMS instrument; the data on the upper axis are from the GOME instrument on the European satellite ERS-2. Only the data described as "TOMS SO_2" are quantitative (see text). Blank spaces for certain days and time intervals on the chart imply that either a data gap occurred over the region, or that no SO_2 was detected. One of these blank intervals in the EP TOMS data took place during 15-23 May 2003, in this case due to the one instrument shutdown during the data-collection period. Courtesy of Simon Carn.

measurements on days when the signal was large enough to allow retrieval of the SO_2 mass. The height of these bars corresponds with the y-axis scale. Note that these values represent the SO_2 mass in a satellite 'snapshot' of the volcanic cloud taken around local noon, and not an SO_2 flux. The bars indicated as "Inferred SO_2" on the lower axis denote days on which the presence of SO_2 could be inferred from EP TOMS data, but the signal was too weak to allow retrieval of an atmospheric SO_2 mass. Hence these bars are non-quantitative, but they indicate that non-trivial SO_2 emissions probably occurred.

More, non-quantitative data appear as bars indicated as "GOME detection" along the upper axis of figure 15; in this case, showing dates when another instrument detected SO_2 emissions in the region. These emission dates denote SO_2 detection over central Africa by the European GOME (Global Ozone Monitoring Experiment) instrument aboard the ERS-2 satellite. GOME measurements are based on scans by a visible- and ultraviolet-wavelength spectrometer. GOME has inferior spatial and temporal resolution to EP TOMS, but is more sensitive to atmospheric SO_2.

TOMS SO_2 mass retrievals are dependent on the altitude of the volcanic plume and are also affected by meteorological cloud cover, and therefore may be adjusted as more information becomes available. The largest of these preliminary estimates during this interval was in excess of 50 kilotons (kt) SO_2. These peaks in the first half of May 2003 were truncated by an instrument shutdown during 15-23 May. Given the crater and plume observations by GVO, and other data discussed above, the vast majority of the SO_2 shown on figure 15 was probably emitted by Nyiragongo.

CO_2 gas concentrations at three mazukus on the flanks of Nyiragongo in vicinity of Lac Vert at the ground surface measured up to ~ 40% by volume, but concentrations of the heavier-than-air gas dropped quickly with height above the ground surface. Spot measurements were made with a Geotechnical Instruments multi-gas landfill analyzer. Field notes reported CH_4 concentrations consistently at zero and O_2 concentrations at only one site where it was 22 vol. % at the ground surface and 16-17 vol. % nearby. The 15 August 2002 field excursion was led by GVO scientists Mathieu Yalire, Ciraba Mateso, and Kasereka Mahinda, with Chris Newhall present.

Effects of carbon dioxide. People in the region apparently understand the hazard of escaping CO_2 gas, and in the past several years CO_2 gas exposure has not led to reported human fatalities. CO_2 gas, which is more dense than air at equivalent temperature and pressure, can be lethal to humans at 9-12 vol. % concentrations in as little as 5 minutes. The US standards for indoor air quality suggest that long-term human exposures remain below 0.1-0.2 vol. %, and that short-term (10- to 15-minute) exposures remain below 3 vol. %. The odor of CO_2 is too weak to warn of dangerous concentrations. Table 7 lists some symptoms associated with the inhalation of air containing progressively higher levels of CO_2.

Volume % CO_2	Physical Symptoms
2%	50% increase in breathing rate
3%	10-minute exposure limit; 100% increase in breathing rate
5%	300% increase in breathing rate, headache and sweating may begin after about an hour.
8%	Short-term exposure limit
8-10%	Headache after 10 or 15 minutes. Dizziness, buzzing in the ears, blood-pressure increase, high pulse rate, excitation, and nausea.
10-18%	After a few minutes, cramps similar to epileptic fits, loss of consciousness, and a sharp drop in blood pressure. The victims recover very quickly in fresh air.
18-20%	Symptoms similar to those of a stroke

Table 7. The AGA Gas Handbook included these CO_2 gas concentrations (in volume percent) and accompanying symptoms for adults in good health (after Ahlberg, 1985).

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.

Reference: Ahlberg, K., 1985, AGA Gas Handbook: Properties & Uses of Industrial Gases, AB, Lidingo/Sweden, ISBN 91-970061-1-4 (out of print).

Information Contacts: *Celestin Kasereka Mahinda, Kavotha Kalendi Sadaka, Jean-Pierre Bajope, Ciraba Mateso*,and *Mathieu Yalire*, Goma Volcano Observatory (GVO), Departement de Geophysique, Centre de Recherche en Sciences Naturelles, Lwiro, D.S. Bukavu, D.R. Congo; *Dario Tedesco, Jacques Durieux, Jean-Christophe Komorowski, Jack Lockwood, Chris Newhall, Paolo Papale, Arnaud LeMarchand,* and *Orlando Vaselli*, UN-OCHA resident volcanologists, c/o UN Office for the Coordination of Humanitarian Affairs, United Nations Geneva , Palais des Nations,1211 Geneva 10, Switzerland (URL: http://www.unog.ch); *Tolouse Volcanic Ash Advisory Center (VAAC)*, Toulouse, Météo-France, 42 Avenue G. Coriolis, 31057 Toulouse Cedex, France (Email: vaac@meteo.fr; URL: http://www.meteo.fr/aeroweb/info/vaac/homepage/eindex.html); *Matt Patrick, Luke Flynn, Harold Garbeil, Andy Harris, Eric Pilger, Glyn Williams-Jones,* and *Rob Wright*, Hawaii Institute of Geophysics and Planetology, University of Hawaii, Manoa (URL: http://modis.higp.hawaii.edu/); *Vern Brown* , President, ENMET Corporation, P.O. Box 979, Ann Arbor, Michigan 48106-0979 (Email: info@enmet.com; URL: http://www.enmet.com/); *Simon A. Carn*, TOMS Volcanic Emissions Group, Joint Center for Earth Systems Technology (NASA/UMBC), University of Maryland Baltimore County, 1000 Hilltop Circle, Baltimore, MD 21250 USA (Email: scarn@umbc.edu; URL: http://skye.gsfc.nasa.gov/).

Robledo

Argentina
26.77°S, 67.72°W; summit elev. 4,400 m

A satellite-based interferometric synthetic aperture radar (InSAR) survey of the remote central Andes volcanic arc (Pritchard and Simons, 2002) revealed deformation in the Robledo caldera between May 1992 and October 2000 (figure 16). Subsidence was detected, with a maximum deformation rate in the radar line-of-sight of 2-2.5 cm/year. The subsidence rate seemed to be decreasing with time. The inferred source depth was 4.5-6 km below sea level. Additional details about the study and analysis are available in Pritchard and Simons (2002).

Background. The small Robledo caldera is located 80 km SW of the much larger Cerro Galán caldera in NW Argentina. The Holocene Cerro Blanco lava dome is located on the southern rim of the Robledo caldera. Well-preserved pyroclastic-flow deposits from Cerro Blanco are exposed on the floor of the caldera (de Silva and Francis, 1991) and represent its most recent activity.

References: de Silva, S.L., and Francis, P.W., 1991, Volcanoes of the Central Andes: Springer-Verlag, Berlin, 216 p.

Pritchard, M., and Simons, M., 2002, A satellite geodetic survey of large-scale deformation of volcanic centres in the Central Andes: Nature, v. 418, p. 167-170.

Information Contacts: *Matthew Pritchard* and *Mark Simons*, Division of Geological and Planetary Sciences, California Institute of Technology, Pasadena, CA 91125,

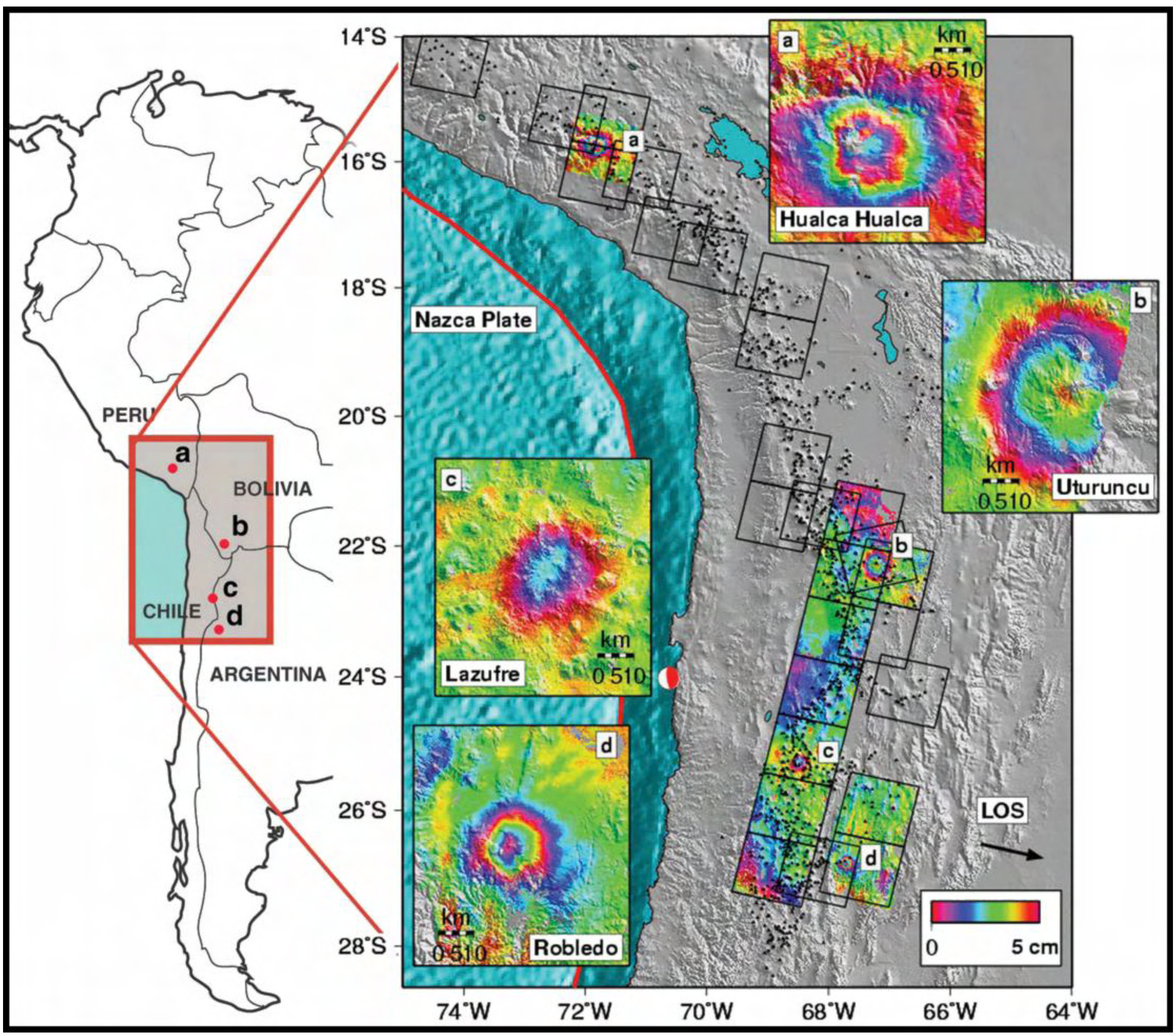

Figure 16. Shaded relief topographic map of the central Andes with insets showing areas of deformation detected by Pritchard and Simons (2002). Interferograms (draped over shaded relief) indicate active deformation; each color cycle corresponds to 5 cm of deformation in the radar line-of-sight (LOS). The LOS direction from ground to spacecraft (black arrow) is inclined 23° from the vertical. Black squares indicate radar frames, and black triangles show potential volcanic edifices. Courtesy of Matthew Pritchard.

USA (Email: matt@gps.caltech.edu, URL: http://www.gps.caltech.edu/).

Uturuncu

Bolivia
22.27°S, 67.22°W; summit elev. 6,008 m

A large-scale concentric pattern of deformation was detected between May 1996 and December 2000 centered on Uturuncu volcano, Bolivia (figure 17), based on satellite geodetic surveys (Pritchard and Simons, 2002). The observed deformation is primarily surface uplift with a maximum rate at the uplift center of 1-2 cm/year in the radar line-of-sight direction (figure 16). A reconnaissance investigation by a team composed of scientists from Bolivia, Chile, the USA, and the UK, took place during 1-6 April 2003 to identify any other signs of volcanic unrest and assess past volcanic behavior.

A single-component vertical one-second seismometer was placed at five locations for periods of up to 14 hours. Data were recorded at a rate of 100 samples per second on a laptop computer. Persistent low-level seismicity was observed mainly from one source location on the NW flank, close to the center of deformation observed by satellite surveys. Two other sources within the volcanic edifice could not be located with the available data. The rate of volcanic earthquakes was up to 15 per hour, and the magnitudes were in the 0.5-1.5 range based on coda length. The sources were considered to be within 3-4 km of the surface (much shallower than the deformation source); more accurate information will be available when the data are analyzed further.

The summit region of Uturuncu has two active fumarole fields with substantial sulfur production and areas of clay-silica hydrothermal alteration. Maximum temperatures in four fumaroles were measured at 79-80°C. A hot spring on the NW flanks had a temperature of 20°C.

Uturuncu is a stratovolcano composed of hypersthene andesites, hypersthene-biotite dacites, and biotite-hornblende dacites. Almost all the exposed products are extensive coulée-type lavas and domes; no pyroclastic deposits were observed. Flow features are well-preserved on the youngest lavas. A wide variety of xenoliths were found in most lavas, including mafic magmatic inclusions, cumulates, microcrystalline igneous inclusions, and hornfels of possible basement rocks including sandstones and calcareous rock types.

Lavas around the summit area appear to be the most recent products, but have been affected by glaciation; there is however no present-day ice. There is thus no evidence yet for Holocene activity. The recent unrest manifested by substantial ground deformation and reconnaissance seismicity indicate, however, that a magmatic system is still present and therefore further monitoring is warranted.

Reference: Pritchard, M., and Simons, M., 2002, A satellite geodetic survey of large-scale deformation of volcanic centres in the Central Andes: Nature, v. 418, p. 167-170.

Information Contacts: *Mayel Sunagua* and *Ruben Muranca*, Geological Survey of Bolivia, SERGEOMIN, Casilla 2729, La Paz, Bolivia (Email: mayelsuco@hotmail.com); *Jorge Clavero*, Geological Survey of Chile, Servicio Nacional de Geología y Minería (SERGEOMIN), Avenida Santa María 0104, Casilla 10465, Santiago, Chile (Email: jclavero@sernageomin.cl); *Steve McNutt*, Alaska Volcano Observatory and Geophysical Institute, University of Alaska Fairbanks, 903 Koyukuk Drive, P.O. Box 757320, Fairbanks, AK 99775-7320 (Email: steve@gieis.alaska.edu, URL: http://www.avo.alaska.edu/); *Matthew Pritchard*, Division of Geological and Planetary Sciences, California Institute of Technology, Pasadena, CA 91125, USA (Email: matt@gps.caltech.edu, URL: http://www.gps.caltech.edu/); *C. Annen*, *M. Humphreys*, *A. le Friant*, and *R.S.J. Sparks*, Department of Earth Sciences, University of Bristol, Bristol BS8 1RJ, UK (Email: Steve.Sparks@bris.ac.uk).

Figure 17. Photograph of Uturuncu viewed from the south, April 2003. Courtesy of Steve Sparks.

Sabancaya

Perú
15.78°S, 71.85°W
summit elev. 5,967 m

A satellite-based interferometric synthetic aperture radar (InSAR) survey of the remote central Andes volcanic arc (Pritchard and

Simons, 2002) revealed deformation in the Sabancaya area during June 1992-mid 1997. Inflation was detected ~ 2.5 km E of the Hualca Hualca cone and 7 km N of Sabancaya (figure 16), with the maximum deformation rate in the radar line-of-sight being ~ 2 cm/year. While not temporally well-constrained, this inflation seems to have stopped in 1997, perhaps related to the large eruption of Sabancaya in May 1997 (*Bulletin* v. 22, no. 7). No deformation was observed between mid 1997-December 2001. The inferred source depth was 11-13 km below sea level. Additional details about the study and analysis are available in Pritchard and Simons (2002).

Background. Sabancaya, located on the saddle between 6288-m-high Ampato and 6025-m-high Hualca Hualca volcanoes, is the youngest of these Holocene volcanic centers. Sabancaya is the only one to have erupted in historical time. The 5967-m-high Sabancaya, meaning "tongue of fire" in the Quechua Indian language, first appeared in records in 1595, suggesting activity prior to that date. Holocene activity has consisted of plinian eruptions followed by emission of voluminous trachytic and dacitic lava flows, which form an extensive 15-km-wide apron around the volcano. Records of historical eruptions of Sabancaya date back to 1750.

Reference: Pritchard, M., and Simons, M., 2002, A satellite geodetic survey of large-scale deformation of volcanic centres in the Central Andes: Nature, v. 418, p. 167-170.

Information Contacts: *Matthew Pritchard* and *Mark Simons*, Division of Geological and Planetary Sciences, California Institute of Technology, Pasadena, CA 91125, USA (Email: matt@gps.caltech.edu, URL: http://www.gps.Caltech.edu/).

Santa María

Guatemala
14.756°N, 91.552°W; summit elev. 3,772 m

At Santiaguito, the active lava-flow front continued to generate ash plumes through early 2002 (*Bulletin* v. 27, no. 5). INSIVUMEH reported that during January-October 2002, activity at Santiaguito included lahars, explosions, growth of the lava dome, and collapses from the Caliente dome. The main lahar during that period occurred on 8 January 2002. Farmers in the Monte Claro area heard rockfalls on the W flank. Field inspections near the San Isidro ravine showed an abundance of material deposited by mudflows and other volcanic debris, mainly fine ash. These deposits formed ash knolls called "hummocks." The San Isidro ravine begins at the Nimá II river, now covered by the SW lava flow, which created a dam ~ 200-300 m high. A rupture of the dam in the high part of the Brujo dome contributed fine material and blocks to the high-velocity lahar, which traveled ~ 4 km until it was stopped by old landslide deposits.

At the height of the Property Florida, there are old lahar deposits, possibly from the eruptions of Santa Maria in 1902 and/or Santiaguito in 1929, with blocks of 1, 2, 3, and 5 m in diameter. With the arrival of the rainy season, San Isidro, which became a new channel for lahars from May to October, had at least six "strong" lahars. The active lava flow from July 1999 had stopped its advance in the channel of the Nimá II river as of April 2002.

Since renewal of activity in April and May 2002, a new lava flow had been advancing on top of the high part of the existing lava flow, in front of the Santiaguito viewpoint. This constant movement was filling up the ravine that divided the lava flow from the El Faro farm. The new lava flow quickly built a small lobe reaching ~ 300 m high. It advanced in a fan shape toward the S and W flanks, with continuous collapses from the front.

A volcanic ash advisory issued on 16 August was based on a report from INSIVUMEH about a dome collapse with some near-summit ash. However, no ash was evident in GOES-8 satellite imagery. After 29 August there were frequent collapses from the crater rim of the Caliente cone, generating pyroclastic flows that extended to the base of the domes. The greatest collapse occurred on 3 October, accompanied by a strong explosion and several pyroclastic flows that descended all flanks of the volcano at high speeds, covering the volcano completely in a few minutes and producing abundant ashfall on the SW flank. During October there were continued collapses of the crater rim.

In the early hours of 17 October the inhabitants of the El Faro and La Florida farms, and areas such as Palmar Nuevo and part of San Felipe Retalhuleu, heard a strong explosion. At OVSAN (Vulcanológico Observatory of Santiaguito Volcano), this activity was felt, and a collapse of the dome from the edge of the crater was seen. After 19 October moderate and strong explosions occurred at a rate of 3-5 per hour, some accompanied by rumblings. There was also an increase in the number of phreatomagmatic ash explosions that sent abundant gray ash 800-1,200 m high, dispersed mainly on the SW flank. In November observers reported constant collapses of the SE and E lava flows. On the morning of 11 November there was a series of collapses from the S lava flow, and heavy ashfall on the seismic station housing.

Background. Symmetrical, forest-covered Santa María volcano is one of the most prominent of a chain of large stratovolcanoes that rises dramatically above the Pacific coastal plain of Guatemala. The 3772-m-high stratovolcano has a sharp-topped, conical profile that is cut on the SW flank by a large, 1.5-km-wide crater. The oval-shaped crater extends from just below the summit of Volcán Santa María to the lower flank and was formed during a catastrophic eruption in 1902. The renowned plinian eruption of 1902 that devastated much of SW Guatemala followed a long repose period after construction of the large basaltic-andesite stratovolcano. The massive dacitic Santiaguito lava-dome complex has been growing at the base of the 1902 crater since 1922. Compound dome growth at Santiaguito has occurred episodically from four westward-younging vents, accompanied by almost continuous minor explosions and periodic lava extrusion, larger explosions, pyroclastic flows, and lahars.

Information Contacts: *Otoniel Matias* and *Gustavo Chigna*, Unit of Volcanology, Geologic Department of Investigation and Services, Instituto Nacional de Sismologia, Vulcanologia, Meteorologia e Hidrologia (INSIVUMEH), 7a Av. 14-57, Zona 13, Guatemala City, Guatemala; *Washington VAAC*, Satellite Analysis Branch (SAB), NOAA/NESDIS E/SP23, NOAA Science Center Room 401, 5200 Auth Road, Camp Springs, MD 20746, USA (URL: http://www.ssd.noaa.gov/).

Kilauea

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

From December 2002 through June 2003, lava from Kilauea continued to flow down the S flanks and into the ocean at several points. Seismicity generally continued at normal (background) levels. The Mother's Day flow, which began erupting 12 May 2002, continued through June 2003 (figure 18).

Lava flows. During December 2002, lava continued to flow into the sea at entry points from two lava deltas. Moderate-to-large littoral explosions tossed spatter onto the front of the West Highcastle delta. Surface lava flows were visible on the coastal flat. On 15 December, shortly after 0700, the Wilipe'a lava delta partially collapsed, losing about 1/3 of its area. The tip of the delta retreated shoreward about 260 m and most of the collapse was in the central part of the delta. Around 15 and 16 December a substantial collapse occurred at the West Highcastle delta. On 28 December moderate collapses occurred at the Wilipe'a lava delta, apparently in the area of the 15 December collapse. Surface lava flows were visible on the coastal flat and upslope on Pulama pali.

During January and February 2003, lava continued to flow into the sea at the West Highcastle entry. Surface lava flows were visible on the coastal flat and upslope of it on Paliuli. Most of the surface lava flows on the coastal flat crusted over, so that less incandescence was visible than previously. Relatively large surface lava flows were visible starting on 21 January around 2035. Around 28 January a large lava breakout occurred from the West Highcastle lava tube about 170 m inland from the old sea cliff. As of 2 February the area of the new breakout was about 6.15 hectares (6.15×10^4 m^2), and surface flows and lava in lava tubes traveled down the Pulama pali fault scarp. The Chain of Craters road was closed due to a wildfire that was started by lava flows. Surface lava flows continued to travel through vegetation, igniting fires and causing methane explosions. Rangers' office huts, restrooms, and signs were moved out of the path of the lava flow, which reached the Chain of Craters Road on 19 February at 1005. Beginning 15 February and going into March, lava flowed into the sea at the Kohala entry. Fresh lava oozed out of the cooling Kohala lava flow, both within the body of the flow and along its E margin.

During 26 February to 3 March lava continued to enter the sea at the West Highcastle entry, but the lava-flow rate was reduced to a small trickle at the Kohala entry. Small surface flows occurred along the W edge of the Kohala lava flow and surface lava flows were visible above the Pulama pali fault scarp. Tongues of lava were visible traveling down Pulama pali, part of the activity that began on 12 May 2002 (named the Mother's Day flow).

Through April 2003, Kilauea continued to erupt, sending lava down its SE flank either traveling over the land surface or through tubes. Lava entered the sea at the West Highcastle entry; activity there was sometimes weak, though one or more glowing areas were typically seen. On 16 April a large tract of land not over-run by surrounding lava (a kipuka or ahu in the local parlance) remained within the Kohola lava flow, still ~ 30 cm above the top of inflated lavas that surround it. On the eastern margin of the swath of lava flows going down the steep slopes of Pulama pali, one partly crusted-over lava stream was highly visible. The crater of Pu'u 'O'o was dark and obscured by fumes, but eruptive activity at Pu'u 'O'o continued unabated. The flows on Pulama pali were frequently visible at night as streams of incandescence from the top of the pali down to the coastal flats. Late in April, the E arm of the Mother's Day flow split in two with the W segment being more active. A new ocean entry near Lae'apuki only lasted a day before the flow stagnated. Scattered surface breakouts were seen throughout the inflating Kohola flow, especially on its W side. As of 24 April, lava entered the ocean at two points along the West Highcastle delta.

In early May, lava flows continued to descend the S flanks and pour into the sea. On 12 May lava began to enter the sea again at the West Highcastle lava delta. Surface lava flows were visible on the coastal flat and the Pulama Pali fault scarp. During June, lava continued to flow down Kilauea's SE flank, with surface lava flows occasionally visible on the coastal flat and upslope at Pulama pali, and Paliuli. Small amounts of lava continued to flow into the sea at Highcastle beach.

Geophysical activity. During December 2002 and January 2003, seismicity was generally at normal levels. The swarm of long-period earthquakes and tremor beneath Kilauea's caldera, occasionally seismically active since June 2002, continued to show some short bursts of tremor inter-

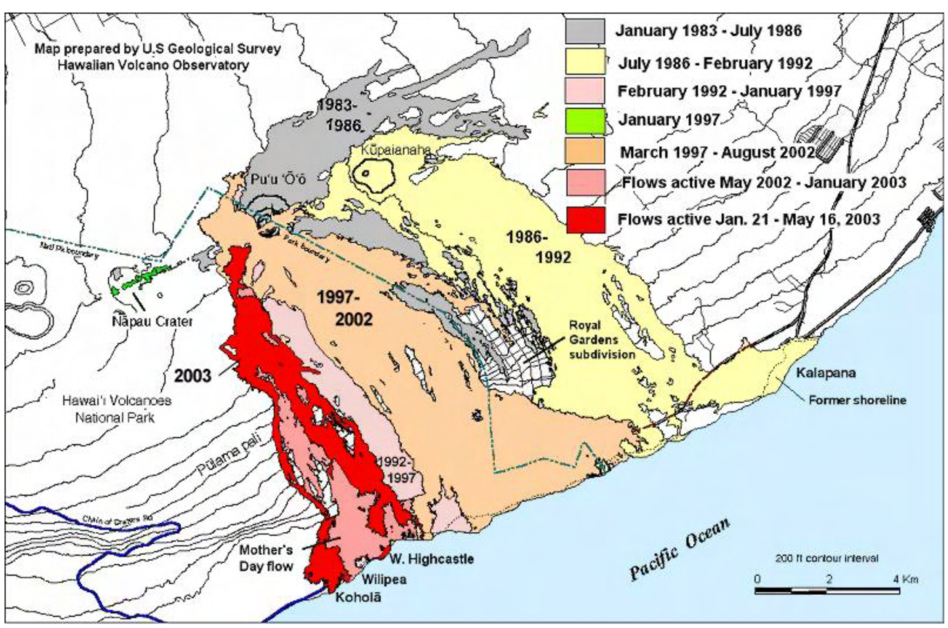

Figure 18. Map of lava flows erupted during 1983 through 16 May 2003 from Pu'u 'O'o and Kupaianaha. The most recently active flows are on the SW side of the flow-field. Courtesy of HVO.

spersed with small earthquakes. Small inflation and deflation events occurred at Pu'u' O'o and Uwekahuna tilt meters. The Pu'u 'O'o tiltmeter showed deflation for about one week from 10 to 17 December. During 27-28 December, slight deflation occurred at the Uwekahuna and Pu'u 'O'o tiltmeters.

Kilauea's summit began to deflate on 20 January 2003 at 1710, and Pu'u 'O'o began to deflate a few tens of minutes later. Both areas deflated well into the next day. On the 21st at 1610 rapid, brief inflation began at the summit. The inflation and preceding deflation were centered near the NE corner of Halemaumau Crater, the normal center of small deformation events. Seismicity increased with the deformation events, returning to normal levels afterwards. By 22 January seismicity had returned to its normal level, with the long-lasting swarm of long-period earthquakes and tremor at Kilauea's summit continuing at weak-to-moderate levels.

During February and March, seismicity was at background levels. The long-lasting swarm of long-period earthquakes and tremor at Kilauea's summit continued at low-to-moderate levels. On 9 and 10 February, short periods of deflation and inflation occurred at the Uwekahuna and Pu'u 'O'o tiltmeters. Moderate tremor was recorded by the nearest seismometer to Pu'u 'O'o until the seismometer broke on 5 March. Moderate deflation occurred on 8 March, first at the Uwekahuna tiltmeter and then at the Pu'u 'O'o tiltmeter. According to a news report, a member of a tour group suffered burns on 10 March when he fell on hot lava while hiking near Chain of Craters road.

For about a week in early April, volcanic tremor at Pu'u 'O'o was relatively high and small deformation changes occurred, mostly at Pu'u 'O'o. During 16-17 April, the Uwekahuna tiltmeter at Kilauea's summit recorded three small inflations, the last apparently right at its crest. Pu'u 'O'o has generally followed suit, though in this case showing only two of the inflations very well. These tilts are not major but continue to illustrate the clear connection between Kilauea's summit, where most tilt events start, and Pu'u 'O'o, 20 km away, where the tilt events follow a few minutes later. Seismicity during the week was at low to normal levels. Instruments continued to register the summit swarm of long-period earthquakes and tremor, which began last June. Volcanic tremor at Pu'u 'O'o remained elevated, as has been the norm for more than a week.

During 30 April to 6 May, distances measured across Kilauea caldera between two points ~ 10 km apart, remained stable as they have since early 2003. There had been consistent progressive lengthening of this distance during late 2001 through mid-2002, and some minor fluctuations after that. In general, tilt during late April through 2 May changed little at Uwekahuna station (W side of the caldera), and showed a progressive decline at Pu'u 'O'o station (E of the caldera). In the first few days of May slight inflationary tilt appeared at both stations.

Seismicity at Kilauea's summit was at moderate-to-high levels from about 1 June through 14 June, with many small, low-frequency earthquakes occurring at shallow depths beneath the summit caldera. The tiny earthquakes occurred at the notably high rate of 2-4 per minute. Little or no volcanic tremor accompanied the swarm, however. Volcanic tremor at Pu'u 'O'o remained moderate to high, as is the norm. A quasi-cyclic inflation and deflation occurred at Kilauea's summit and at Pu'u 'O'o during the week of 6-13 June, but did not culminate in significant overall tilt.

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 East 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 longterm eruption from the East rift zone that began in 1983 has produced lava flows covering more than 100 sq km, destroying nearly 200 houses and adding new coastline to the island.

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