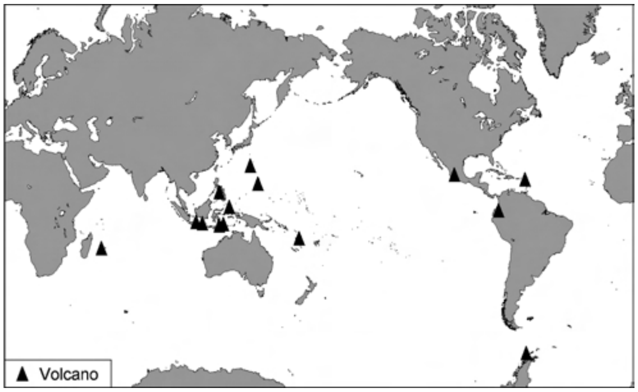
# Bulletin of the Global Volcanism Network

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# Piton de la Fournaise

Réunion Island, Indian Ocean
21.229°S, 55.713°E; summit elev. 2,631 m
All times are local (= UTC + 4 hours)

Reports from the Observatoire Volcanologique du Piton de la Fournaise (OVPF) indicated ongoing eruptive activity from late May to 6 June 2003 (*Bulletin* v. 28, no. 5). The activity was characterized by sporadic seismicity, degassing from fissures, and lava flows. Inflation of Piton de la Fournaise was observed beginning in March 2003, without later indications of deflation as of July 2003. Eruptive activity within Dolomieu crater continued until 7 July.

Eruptive tremor had completely disappeared by 8 June, and on the 10th that phase of the eruption was considered to be finished. About thirty small earthquakes were observed, caused by minor collapses. The extensometric network continued to show an opening of cracks at Magne and Chateau-Fort. On 10 June, 71 earthquakes were observed, the strongest of which had magnitudes of 1.4-2.0. The earthquakes were located ~ 400 m under Dolomieu in the SW part near the site of the 30 May-4 June eruption. Extensometers continued to indicate swelling of the volcano, but no summit inflation was observed during the eruption.

On 13 June at 0308 new eruption tremor appeared - within Dolomieu crater. A helicopter overflight confirmed that the eruption continued from the same site as the first two eruptive phases. Such a scenario was expected because the extensometer network showed continuous opening of the monitored fissures. Seismicity on 12 June had decreased compared to the previous two days, with a lack of very low amplitude earthquakes. That day eruptive tremor began without being preceded by even a small earthquake.

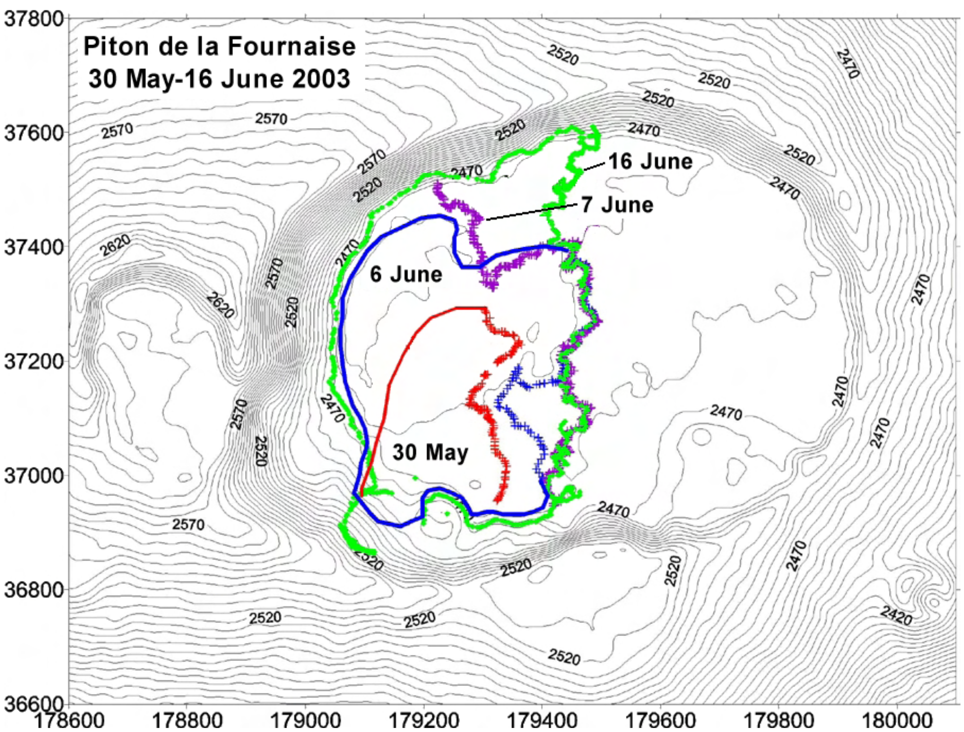


Figure 1. Topographic map of Dolomieu crater at Piton de la Fournaise showing the extent of the newly erupted lava-flow field on 30 May, 6 June, 7 June, and 16 June 2003. Elevations are in meters, and the Gauss-Laborde Piton des Neiges system is used for the map coordinates. Courtesy of OVPF.

During the morning of 14 June eruption tremor was stable and practically constant; other seismic events did not register. On 15 June at 0600, the tremor entirely disappeared. Crater observations showed that lava flows had extended to the N wall of Dolomieu crater, covering almost half of the crater floor as of 16 June (figure 1). After a cessation of several days, the eruption began again on 21 June at about 2330. After a progressive increase of tremor in the hours that followed, the situation stabilized, and the tremor then strongly decreased.

On 24 June the eruption was still in progress. The tremor increased strongly in the night and reached the maximum level of the preceding eruptive phases. Observations on 26 June showed two small openings in front of the principal cone. The first showed degassing, and the second, which was almost closed, emitted sporadic weak projections. Within 100 m of the cone an emission of a very fluid and degassed lava had produced significant flows. On 27 June the tremor had strongly diminished.

After 0630 on 28 June highly variable tremor related to "gas pistons," or regular degassing, was observed on a scale not previously seen at Piton de la Fournaise. Some lava flows in Dolomieu remained active. A small cone opposite the Piton kaf degassed strongly in time with the other gas explosions.

On 1and 2 July, no change in eruptive activity was observed. The tremor varied with a time interval of 12-13 minutes between total stop and maximum tremor amplitude. The eruption continued on 3 July, but on 4 July the tremor had diminished, and the tremor variations observed in past days were less pronounced. No lava projections were seen in the crater during this phase, and volcanic earthquakes were not detected until one occurred on 3 July. The eruption ended on 7 July.

***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.

***Information Contacts:*** *Observatoire Volcanologique du Piton de la Fournaise (OVPF)*, Institut de Physique du Globe de Paris, 14 RN3, le 27Km, 97418 La Plaine des Cafres, La Réunion, France (URL: http://volcano.ipgp.jussieu.fr:8080/reunion/stationreu2.html; Email: Thomas.Staudacher@univ-reunion.fr).

## Deception Island

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

While fieldwork was conducted during 1 December 2002-18 April 2003, Spanish and Argentine scientists measured Deceptions Island's seismicity, thermal activity, and gas emissions. Gravimetric field surveys, geodetic measurements, and geological studies were also carried out.

***Monitoring during 2002-2003.*** During the 2002-2003 Antarctic summer the scientists installed two dense seismic antennas in trigger mode and four continuous-recording short-period stations (figure 2). Each of the antennae were composed of eight short-period seismometers with apertures of ~ 250 m. One was located at the Argentinean Base and the other in Pendulum Cove. Three vertical-component seismometers were located on the N side of Fumarole Bay, at the beach between Murature Point and Cross Hill, and near 70'Craters. Finally, a three-component seismic station was installed near the Spanish Station.

The recorded seismicity included volcano-tectonic earthquakes (VT), long-period events (LP), and a few episodes of volcanic tremor. More than 56 VT and 700 LP events were recorded, 54 of them with hybrid character; 55 recorded tremor episodes had durations ranging from less than one hour to eight hours. The recording period could be divided into two different phases on the basis of the degree of activity. The first, from 22 December until the beginning of March, was characterized by a relatively high level of activity with frequent VT earthquakes, LP events, and volcanic tremors. The second phase, from the beginning of March until 4 April, was characterized by a similar rate of VT earthquakes but fewer LP events and tremor. This observation supported the idea that LP seismicity might be related to seasonal thaw water. Most earthquakes were centered on the island, in accord with their VT designation. Compared to previous surveys, the 2002-2003 level of seismicity was considered to be moderate.

Temperatures of fumaroles and hot soils remained stable at 99-101°C in Fumarole Bay, 95°C in Caliente Hill, 65°C in Whalers Bay, 41°C in Telefon Bay, and 72°C in Pendulum Cove (figure 2). Fumarolic activity was also monitored, with radon measurements being made for the first time. Standard wet-analysis techniques revealed that the composition of gas obtained from the vents at Fumarole Bay was similar to that of recent years, namely $H_2O_{(v)}$ (70-95%), $CO_2$ (7-29%), $H_2S$ (0.12-0.39%), and $SO_2$ (0.01-0.07%). Elemental sulfur was seen around the vent outlets, and pyrite with lapilli coatings were found at a few centimeters depth.

***Background.*** Ring-shaped Deception Island, one of Antarctica's most well known volcanoes, contains a 7-km-wide caldera flooded by the sea. Deception Island is located at the SW end of the Shetland Islands, NE of Graham Land Peninsula, and was constructed along the axis of the Bransfield Rift spreading center. A narrow passageway named Neptunes Bellows provides entrance to a natural harbor that was utilized as an Antarctic whaling station. Numerous vents located along ring fractures circling the low, 14-km-wide island have been active during historical time. Maars line the shores of 190-m-deep Port Foster, the caldera bay. Among the largest of these maars is 1-km-wide Whalers Bay, at the entrance to the harbor. Eruptions from Deception Island during the past 8700 years have been dated from ash layers in lake sediments on the Antarctic Peninsula and neighboring islands.

***Information Contacts:*** *A.T. Caselli*, *M.R. Agusto*, and *L. Ferreyra*, Universidad de Buenos Aires-Instituto Antártico Argentino, Ciudad Universitaria, Pab.2, (1428) Buenos Aires, Argentina (Email: acaselli@gl.fcen.uba.ar); *Jesús Ibáñez*, *Daria Zandomeneghi*, *Daniel Stich*, *Francisco Carrión*, and *Javier Almendros*, Instituto Andaluz de Geofísica, Universidad de Granada, 18071-Granada, Spain (Email: ibanez@iag.ugr.es).

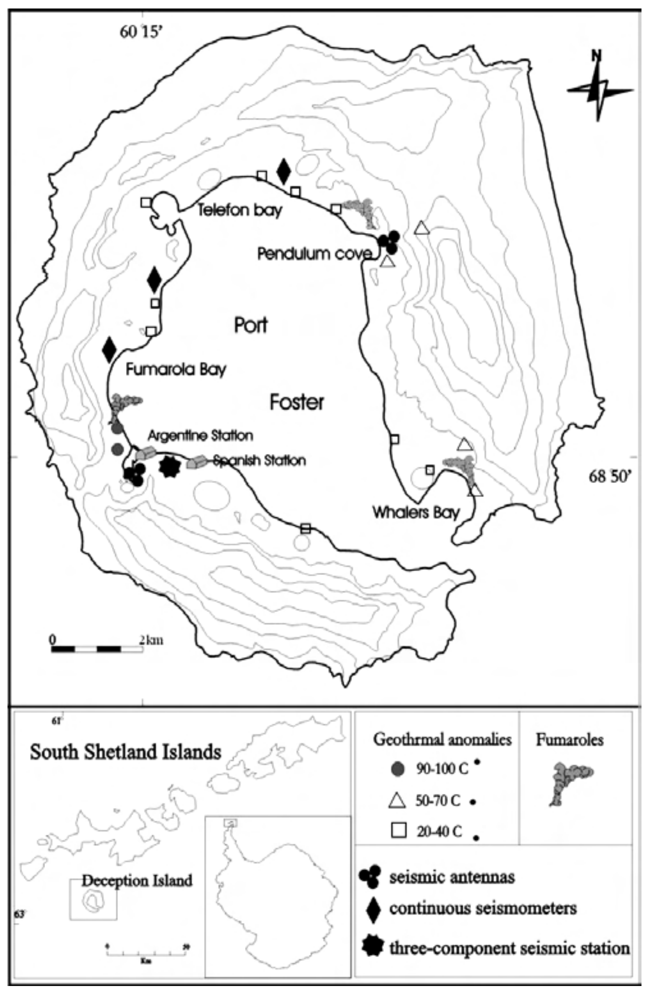


Figure 2. Map of Deception Island indicating seismic stations, antennas, fumaroles, and geothermal anomalies measured during 1 December 2002-18 April 2003. Courtesy of A. T. Caselli.

# Reventador

Ecuador
0.078ºS, 77.656ºW, summit elev. 3,562 m

After a 26-year repose without signs of unusual activity, Reventador burst unexpectedly into a VEI 4 eruption on 3 November 2002 (*Bulletin* v. 27, no. 11). A preliminary evaluation indicated that this was one of Ecuador's most powerful eruptions of the past 100 years. The following report provides an update on activity since March 2003 (*Bulletin* v. 28, no. 2) through mid-July 2003. Available seismic records are incomplete for this period (table 1). However, by late April all types of recorded seismic events had declined to very low levels.

Heavy rains in March 2003 mixed with ash on Reventador's flanks, causing mudflows and lahars that disrupted traffic along routes crossing rivers draining the volcano (figure 3). A gas column reached 300-500 m above the summit early in the month. Low-level seismicity was characterized by bands of harmonic tremor and a few isolated earthquakes; long-period (LP) seismic events were possibly associated with gas discharges. The seismic station in Copete registered high-frequency signals associated with lahars; however, only a few lahars were observed. Activity during the last week of March was characterized by persistent low-energy emissions of white steam and yellowish gases. Seismicity was also low during this time. The reference seismic station was moved nearer to the volcano, allowing detection of smaller magnitude earthquakes.

When the weather permitted in April and May 2003, observers saw continuous low-level emissions of white steam and yellow gases rising several hundreds of meters above the volcano's cone. This was corroborated by the seismicity recorded at station LAVA2 (inside the caldera near the lava front). Rains have been frequent, generally of short duration, and accompanied by some lahars. Low-frequency tremor on 12 April was recorded at LAVA2 (0.9 Hz) and CONE (1.3 Hz), in the caldera NE of the cone near the head of the Rio Reventador. During April, rivers swelled with water and mud that blocked river crossings. Seismicity was characterized by a fairly constant number of long-period (LP)/hybrid and volcano-tectonic (VT) events, with a slight diminution in the number of LPs (table 1). Lahars on 18-19 April produced significant flooding in Rio Reventador and Rio Marker. Seismic activity stayed at very low levels.

| Date (2003) | Long-period / Hybrid | Volcano-tectonic |
|---|---|---|
| 08-14 Mar | 120 avg. daily | 15 avg. daily |
| 24-31 Mar | 50-60 daily | 20-30 daily |
| 01-06 Apr | 42-98 daily<br>26-65 daily | 5-13 daily |
| 07-12 Apr | 63.5 avg. Daily<br>30 avg. daily | 2.33 avg. daily |
| 13 Apr | 58 | 6 |
| 14 Apr | 29 | 3 |
| 15 Apr | 35 | 8 |
| 16 Apr | 37 | 6 |
| 17 Apr | 31 | 8 |
| 18 Apr | 22 | 8 |
| 19 Apr | 20 | 6 |
| 28 Apr-02 May | 0 daily | 0 daily |
| 03 May | 1 | 1 |
| 04 May | 0 | 0 |
| 30 Jun-06 Jul | 1 | 4 |
| 07-13 Jul | 2 | 2 |

Table 1. Summary of seismic activity at Reventador, 8 March-13 July 2003. Note that data are incomplete. Courtesy of the Instituto Geofisico.

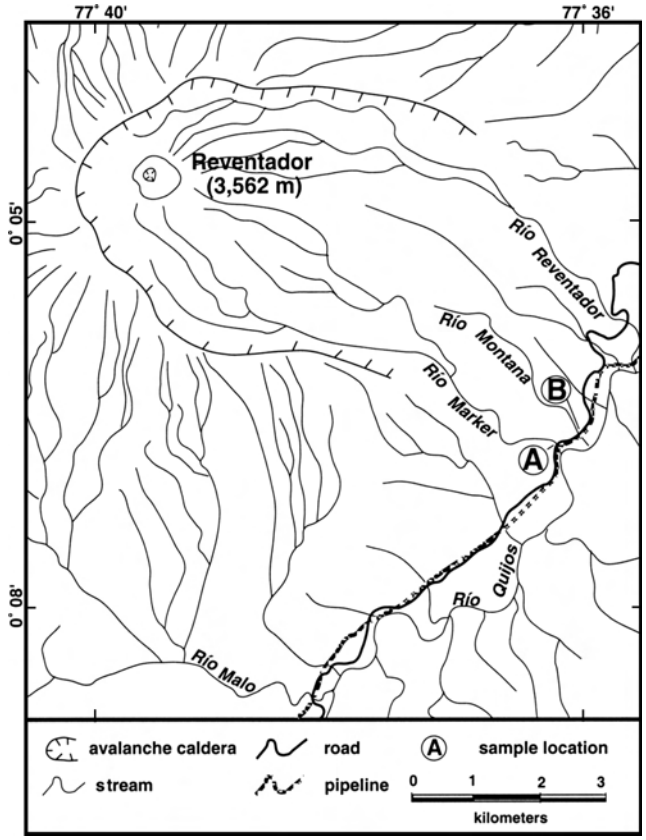


Figure 3. Map showing drainages from Reventador and the location of roads and pipelines SE of the volcano. Courtesy of the Instituto Geofisico.

On 1 May strong rains in the area of the volcano generated mud flows or lahars that destroyed the highway in the Rio Reventador sector. Heavy rainfall of up to 200 mm in less than 24 hours on 6 May led to the remobilization of ash from the November 2002 eruption. Lahars traveled down the SE flank via the Rio Marker and Rio Reventador gorges. Seismic signals indicated that lahars occurred in seven main pulses, with the longest pulse lasting ~ 2 hours. Lahars crushed a portion of the petroleum pipeline on the SE flank and dragged it 22 m. Lahars also destroyed a bridge and blocked a highway. On 8 May, satellite images showed a plume that extended ~ 50 km NW.

During much of June and July 2003, the volcano was not visible due to cloudiness. Seismic activity during June was characterized by bands of continuous tremor, some related to increased volume of the rivers and/or mud flows. On 19 June, a steam plume reached a height of ~ 300 m. Seismic tremor was associated with flowing gas and observed emissions. Small seismic events (magnitudes less than 3.4) occurred on 23 and 25 June. During 30 June-1 July a gas column was observed that rose ~ 200 m and drifted W. Seismicity was at low levels in early July, but continuous tremor occurred associated with degassing.

***Background.*** Reventador is the most frequently active of a chain of Ecuadorian volcanoes in the Cordillera Real, well E of the principal volcanic axis. The forested stratovolcano rises to 3562 m above the remote jungles of the western Amazon basin. A 4-km-wide caldera widely breached to the E was formed by edifice collapse and is partially filled by a young, unvegetated stratovolcano that rises about 1300 m above the caldera floor to a height above the caldera rim. Reventador has been the source of numerous lava flows as well as explosive eruptions that were visible from Quito in historical time. Frequent lahars in this region of heavy rainfall have constructed a debris plain on the eastern floor of the caldera. The largest historical eruption at Reventador took place in 2002, producing a 17-km-high eruption column, pyroclastic flows that traveled up to 8 km, and lava flows from summit and flank vents.

***Information Contact:*** *Geophysical Institute*, National Polytechnical School, Campamento, San Rafael, Ecuador (URL: http://www.igepn.edu.ec).

| Date (2003) | Rockfall signals | Hybrid events | Long-period (LP) events | Long-period rockfalls | Volcano-tectonic (VT) events |
|---|---|---|---|---|---|
| 02 May-09 May | 767 | 7 | 138 | 88 | 2 |
| 09 May-16 May | 580 | 7 | 65 | 55 | — |
| 16 May-23 May | 774 | 8 | 81 | 75 | 2 |
| 23 May-30 May | 404 | 1 | 41 | 45 | — |
| 30 May-06 Jun | 445 | 5 | 40 | 34 | 1 |
| 06 Jun-13 Jun | 79 | 6 | 16 | 8 | 2 |
| 13 Jun-20 Jun | 48 | 55 | — | 10 | — |
| 20 Jun-27 Jun | 54 | 135 | 2 | 4 | 1 |
| 27 Jun-04 Jul | 193 | 37 | 7 | 61 | — |

Table 2. Summary of weekly seismicity at Soufrière Hills during 2 May-4 July 2003. Courtesy MVO.

## Soufrière Hills

Montserrat, West Indies
16.72°N, 62.18°W; summit elev. 915 m
All times are local (= UTC - 4 hours)

Seismic activity at Soufrière Hills during May-June 2003 was moderate to high, especially during May, and dominated by rockfalls. Most activity was focused on the N and NE flanks of the dome, with rockfalls and pyroclastic flows entering the Tar River Valley and occasionally White's Ghaut. During most of June activity remained, but was at substantially decreased levels. Brief views of the summit in June revealed that the extrusive lobe on the E side persisted.

The Washington VAAC issued daily notices to the aviation community regarding ash clouds that rose to low levels above the summit. Seismicity during the report period was dominated by rockfalls (table 2), particularly during May. Average daily $SO_2$ emission rates varied throughout the report period (table 3) from 240 to 860 metric tons/day.

Throughout the report period, authorities prohibited access to all areas S of the Belham Valley, to Waterworks, Happy Hill, Lower Friths, Old Towne, and to Bramble airport and beyond. A maritime exclusion zone around the S part of the island extended 3.7 km beyond the coastline from Trant's Bay in the E to Lime Kiln Bay on the W coast.

***Activity during May 2003.*** Most of the activity in May was focused on the NE flank of the dome, producing rockfalls and pyroclastic flows in the Tar River Valley and occasionally in White's Ghaut. Brief views of the summit dome on 12 May indicated that the direction of growth had switched towards the NE. On 12-13 May several pyroclastic flows were observed on the N and NW flanks of the dome in the area of Farrell's Plain and in the upper reaches of Tyre's Ghaut. During 16-23 May, rockfalls and pyroclastic flows continued along the N side of the Tar River Valley and White's Ghaut with a number of pyroclastic flows reaching the tops of Farrell's Plain, Tyre's Ghaut, and Tuitt's Ghaut. Pulses of vigorous ash-venting were observed on the summit during clear periods, and intense glow was seen on the summit and NE flanks during the nights of 20-21 May. Clear views of the summit region during an observation flight on 29 May showed that the NE lobe, which had developed over the previous few weeks, was broken up and the summit was irregular and blocky. Lava-dome growth was more centralized, building vertically and accumulating debris in the summit region.

***Activity during June 2003.*** The dome's E and NE flanks continued producing rockfalls and pyroclastic flows into the Tar River Valley, and occasionally White's Ghaut or Tuitt's Ghaut. On the morning of 3 June, a period of increased activity on the NW flank of the dome produced many rockfalls; three pyroclastic flows entered Tyre's Ghaut. Clear views of the summit on 5 June revealed that the active lobe had a well-developed whale-back shape inclined gently upwards towards the E from the summit center. Activity decreased to low levels during the week of 6-13 June and remained low until the last week of the month. Brief views of the summit revealed that the well-developed extrusion lobe on the E side persisted. The focus of activity continued to be on the E and NE flanks of the dome, producing sporadic rockfalls and a few pyroclastic flows in the Tar River Valley, White's Ghaut, and Tuitt's Ghaut. Hybrid earthquakes developed into a diffuse swarm on 22-23 June, with some of the larger events at depths of

| Date (2003) | $SO_2$ emission (tons/day) |
|---|---|
| 02 May-09 May | 440-850 |
| 09 May-16 May | 484-820 |
| 16 May-23 May | 300-730 |
| 23 May-30 May | 480-860 |
| 30 May-06 Jun | 390-560 |
| 05 Jun | Fourier transform infrared spectrometer measurements show HCl:$SO_2$ mass ratio = 2.80 in the plume. |
| 06 Jun-13 Jun | 350-520 |
| 13 Jun-20 Jun | 295-457 |
| 20 Jun-27 Jun | 215-505 |
| 27 Jun-04 Jul | 240-840 |

Table 3. Range of average daily $SO_2$ emission rates measured at Soufrière Hills during 2 May-4 July 2003. Courtesy MVO.

~ 3 km beneath the lava dome. During the last week of June pyroclastic flow and rockfall activity was focused on the N flank with most flows entering Tuitt's Ghaut, and to a lesser extent, Tyre's and White's ghauts. Sporadic flows also occurred in the Gages area on the W side of the dome.

***Background.*** The complex andesitic Soufrière Hills volcano occupies the southern half of the island of Montserrat. The summit area consists primarily of a series of lava domes emplaced along an ESE-trending zone. Prior to 1995, the youngest dome was Castle Peak, which was located in English's Crater, a 1-km-wide crater breached widely to the E. Block-and-ash flow and surge deposits associated with dome growth predominate in flank deposits. Non-eruptive seismic swarms occurred at 30-year intervals in the 20th century, but with the exception of a 17th-century eruption, no historical eruptions were recorded on Montserrat until 1995. Long-term small-to-moderate ash eruptions beginning in that year were accompanied by lava-dome growth and pyroclastic flows that forced evacuation of the southern half of the island and ultimately destroyed the capital city of Plymouth, causing major social and economic disruption to the island.

***Information Contacts:*** *Montserrat Volcano Observatory (MVO),* Mongo Hill, Montserrat, West Indies (URL: http://www. mvo.ms/); *Washington Volcanic Ash Advisory Center (VAAC),* Satellite Analysis Branch (SAB), NOAA/NESDIS E/SP23, NOAA Science Center Room 401, 5200 Auth Rd., Camp Springs, MD 20746 USA (URL: http://www.ssd.noaa.gov/).

## Colima

western Mexico
19.514°N, 103.62°W
summit elev. 3,850 m

Effusive activity that began at Colima on 14 February 2002 (*Bulletin* v. 27, nos. 5 and 11) had stopped by the end of February 2003. Eight lava flows were emitted during this eruption (figure 4). The total volume of effusive material was calculated to be ~ 8.3 x $10^6$ $m^3$. That number includes the lava dome (2 x $10^6$ $m^3$) and lava flows (4.3 x $10^6$ $m^3$), in addition to pyroclastic-flow and rockfalls deposits (2 x $10^6$ $m^3$). A plot showing the daily number of rockfalls reflects the level of activity over the course of the eruption (figure 5).

Weak gas explosions occurred in March 2003. As of April there were still observations of night glow at the summit, degassing, and 10-20 daily seismic events. However, no deformation had been noted.

***Corrections.*** Two typographical errors were made in the June 2002 Colima report (*Bulletin* v. 27, no. 6). In table 12 the final date of 26 November 2002 should be 2001. The reference in table 14 for 1998-2001 analyses should be to Mora et al. 2002.

***Background.*** The Colima volcanic complex is the most prominent volcanic center of the western Mexican Volcanic Belt. It consists of two southward-younging volcanoes, Nevado de Colima (the 4320 m high point of the complex) on the N and the 3850-m-high historically active Volcán de Colima at the S. A group of cinder cones of probable late-Pleistocene age is located on the floor of the Colima graben west and E of the Colima complex. Volcán de Colima (also known as Volcán Fuego) is a youthful stratovolcano constructed within a 5-km-wide caldera, breached to the S, that has been the source of large debris avalanches. Major slope failures have occurred repetitively from both the Nevado and Colima cones, and have produced a thick apron of debris-avalanche deposits on three sides of the complex. Frequent historical eruptions date back to the 16th century. Occasional major explosive eruptions (most recently in 1913) have destroyed the summit and left a deep, steep-sided crater that was slowly refilled and then overtopped by lava dome growth.

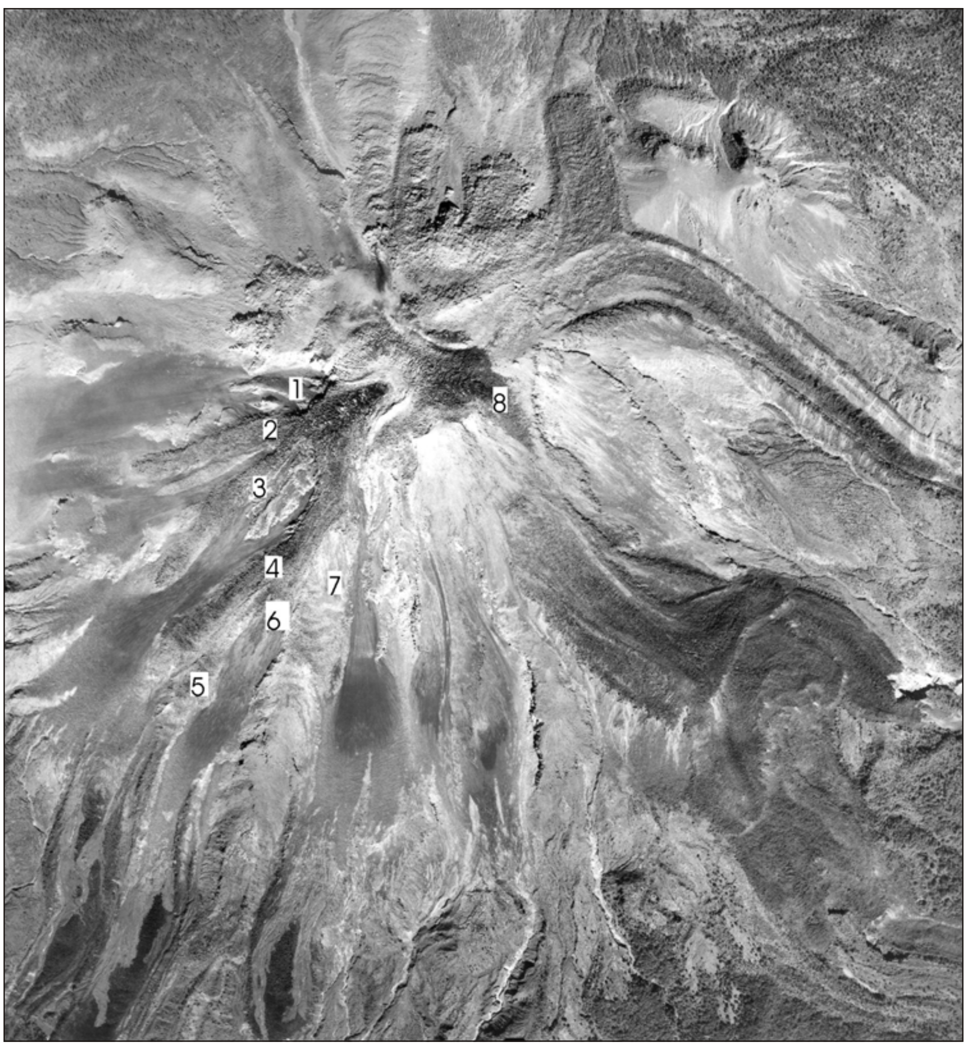


Figure 4. Aerial photo of Colima taken from an airplane on 23 January 2003. Numbers mark the eight new lava flows emplaced during the February 2002-February 2003 eruption. Courtesy of Instituto Nacional de Estadística Geografía e Informática (INEGI).

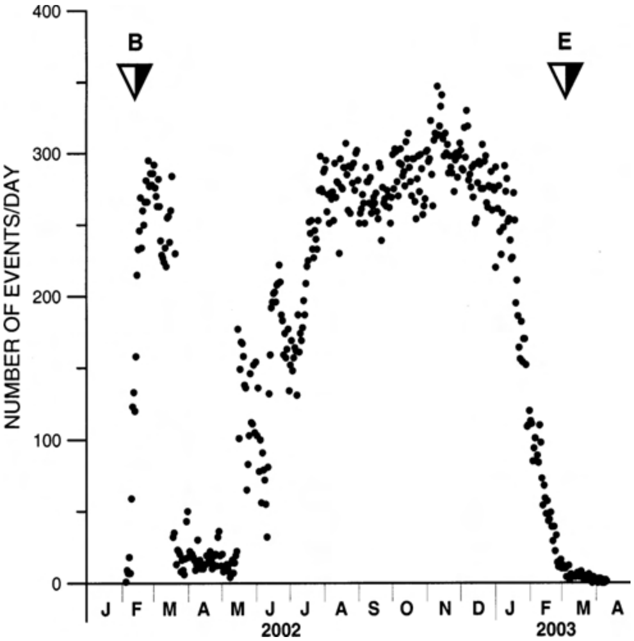


Figure 5. Daily variations in the number of rockfalls during the 2002-2003 effusive eruption at Colima volcano. The beginning (B) and the end (E) of effusive activity are shown by arrows. Courtesy of Observatorio Vulcanológico de la Universidad de Colima.

***Information Contact:*** *Observatorio Vulcanológico de la Universidad de Colima*, Colima, Col., 28045, México (Email: vzobin@cgic.ucol.mx).

## Lopevi

Central Islands, Vanuatu
16.507°S, 168.346°E; summit elev. 1,413 m
All times are local (= UTC + 11 hours)

On 8-9 June 2003, a volcanic ash advisory was issued for Lopevi. The Port Vila tower in Vanuatu reported that at 0055 on 8 June, an ash cloud with a thick plume rose to above 12 km altitude and drifted SE. The plume was not visible on satellite images. Later reports from pilots at 2311 indicated that the activity had subsided, with no further signs of an ash cloud. At 0330 on 9 June, the Port Vila tower reported another thick black ash cloud rising to 2.7 km, with a diameter of ~ 18 km, drifting SE. Observations of volcanic activity were not possible after that time.

The eruption continued through at least 14 June. An airport in Vanuatu reported to the Wellington VAAC that a thick plume rose to ~ 7.5 km altitude on 11 June. The plume drifted SE and was ~ 9 km in diameter. They reported that on 13 June a ~ 9-km-diameter plume rose to ~ 2.5 km altitude. Also, on 14 June an ash cloud was at a height of ~ 2.5 km altitude and a thin lava flow was visible on the volcano's W flank.

A news article from the Australian Broadcasting Corporation stated that the eruption was causing acid rain to fall on island villages in Vanuatu that are close to the volcano. Local disaster management personnel warned residents of the islands of Paama, Epi, and villages in SE Ambrym to secure their rain-based water supplies.

***Background.*** The small 7-km-wide conical island of Lopevi is one of Vanuatu's most active volcanoes. A small summit crater containing a cinder cone is breached to the NW and tops an older cone that is rimmed by the remnant of a larger crater. The basaltic-to-andesitic volcano has been active during historical time at both summit and flank vents, primarily along a NW-SE-trending fissure that cuts across the island, producing moderate explosive eruptions and lava flows that reached the coast. Historical eruptions at the 1413-m-high volcano date back to the mid-19th century. The island was evacuated following eruptions in 1939 and 1960. The latter eruption, from a NW-flank fissure vent, produced a pyroclastic flow that swept to the sea and a lava flow that formed a new peninsula on the western coast.

***Information Contact:*** *Wellington Volcanic Ash Advisory Center (VAAC)*, MetService, PO Box 722, Wellington, New Zealand (URL: http://www.ssd.noaa.gov/VAAC/OTH/NZ/messages.html); *Australian Broadcasting Company*, ABC Ultimo Centre, 700 Harris Street, GPO Box 9994, Sydney, NSW 2001, Australia (URL: http://www.abc.net.au/).

## Iliwerung

Lesser Sunda Islands, Indonesia
8.54°S, 123.59°E; summit elev. 1,018 m

During 17-26 October 2001 the Volcanological Survey of Indonesia reported an increase in felt earthquakes. A total of 2-11 events occurred per day, with Mercalli magnitudes of I-II. The earthquakes S and P wave arrival times differed by between 1 and 35 seconds. Visual and instrumental monitoring revealed a lack of significant changes. The Alert Level was increased from 1 to 2 (on a scale of 1-4). No further reports were issued through at least May 2003. The last reported activity was a submarine eruption from the Hobal vent on the SE flank of the volcano occurred in September 1993 (*Bulletin* v. 18, nos. 8 and 10).

***Background.*** Constructed on the southern rim of the Lerek caldera, Iliwerung forms a prominent S-facing peninsula on Lomblen Island. Craters and lava domes have formed along N-S and NW-SE lines on the complex volcano; during historical time vents from the summit to the submarine SE flank have been active. The Iliwerung summit lava dome was formed during an eruption in 1870. In 1948 Iligripe lava dome grew on the eastern flank at 120 m altitude. Beginning in 1973-74, when three ephemeral islands were formed, submarine eruptions began on the lower SE flank at a vent named Hobal; several other eruptions took place from this vent before the end of the century.

***Information Contact:*** *Dali Ahmad*, 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).

## Lewotobi

Lesser Sunda Islands, Indonesia
8.53°S, 122.78°E; summit elev. 1,703 m
All times are local (= UTC + 8 hours)

An explosion on 12 October 2002 at Lewotobi Lakilaki, one of the twin stratovolcanoes that comprise Lewotobi, produced an ash column that rose ~ 500 m above the vol-

| Date (2003) | Volcanic | Tectonic | Ash Emissions | Tremor | Plume Height(s) |
|---|---|---|---|---|---|
| 20 May | 2 | 1 | — | — | 25 m |
| 21 May | 0 | 0 | — | — | — |
| 22 May | 4 | 1 | — | — | 25 m |
| 23 May | 9 | 5 | — | — | 25 m |
| 24 May | 6 | 3 | — | — | 25 m |
| 25 May | 5 | 1 | — | — | 25 m |
| 26 May | 0 | 0 | — | — | 25 m |
| 27 May | 2 | 6 | — | — | 25 m |
| 28 May | 0 | 2 | — | — | — |
| 29 May | 2 | 0 | — | — | — |
| 30 May | 6 | 3 | — | — | 200 m |
| 31 May | 6 | 0 | — | — | — |
| 01 Jun | 3 | 1 | — | — | — |
| 02-08 Jun | 13 | 12 | 29 | 20 | 300 m |
| 09-15 Jun | 24 | 9 | 40 | 33 | 75 m |

Table 4. Seismicity and height of the gas plume at Lewotobi during 20 May-15 June 2003. Courtesy VSI.

cano (*Bulletin* v. 27, no. 11). Through at least 24 November, a "thin white low-pressure ash plume" rose 150-250 m above the summit.

No further reports were issued until May 2003, when the Volcanological Survey of Indonesia reported an explosion at 1650 on 30 May 2003. The resulting ash column reached 200 m above the summit and caused ashfall at the observatory, ~ 5 km from the crater. Visual and seismic data showed no significant increases during the week prior to the explosion (table 4). On 1 June, two explosion earthquakes and two tremor earthquakes were recorded. The hazard status was set at Alert Level 2 (on a scale of 1-4).

Activity during the week of 2-8 June 2003 was marked by explosions and ash emissions. Ash plumes reached a maximum height of 300 m above the summit. Seven explosions were recorded accompanied by a blasting sound on 3, 5, and 6 June. Ash fell at Bawalatang, Duang, and Boru villages. Shallow volcanic earthquakes were recorded, but were fewer in number compared to the previous week; there was no record of deep volcanic earthquakes, although tectonic earthquakes were recorded.

During the week of 9-15 June, activity was marked by ash emissions, with an ash plume reaching a maximum height of 75 m above the summit. Tremor events were also observed, with the tremor showing an amplitude of 0.5-7 mm. There were no deep volcanic earthquakes recorded, although the numbers of shallow volcanic earthquakes, tremor and ash emissions increased.

***Background.*** The Lewotobi "husband and wife" twin volcano (also known as Lewetobi) in eastern Flores Island is composed of the Lewotobi Lakilaki and Lewotobi Perempuan stratovolcanoes. Their summits are less than 2 km apart along a NW-SE line. The conical 1,584-m-high Lewotobi Lakilaki has been frequently active during the 19th and 20th centuries, while the taller and broader 1,703-m-high Lewotobi Perempuan has erupted only twice in historical time. Small lava domes have grown during the 20th century in the crescentic summit craters of both volcanoes, which are open to the N. A prominent flank cone, Iliwokar, occurs on the E flank of Lewotobi Perampuan.

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# Kelut

Java, Indonesia
7.93°S, 112.31°E
summit elev. 1,731 m

During 6 March-9 April 2001 at Kelut, the temperature of the crater lake decreased from 50 to 48°C. Tectonic earthquakes were recorded during mid-March 2001, with two occurring per week during 12-23 March. Visual and instrumental observations showed no significant changes. Kelut remained at Alert Level 2 (on a scale of 1-4). No further reports were issued through at least May 2003.

***Background.*** The relatively inconspicuous, 1,731-m-high Kelut stratovolcano contains a summit crater lake that has been the source of some of Indonesia's most deadly eruptions. A cluster of summit lava domes cut by numerous craters has given the summit a very irregular profile. Satellitic cones and lava domes are also located low on the eastern, western, and SSW flanks. Eruptive activity has in general migrated in a clockwise direction around the summit vent complex. More than 30 eruptions have been recorded from Gunung Kelut since 1000 AD. The ejection of water from the crater lake during Kelut's typically short, but violent eruptions has created pyroclastic flows and lahars that have caused widespread fatalities and destruction. After more than 5,000 persons were killed during an eruption in 1919, an ambitious engineering project sought to drain the crater lake. This initial effort lowered the lake by more than 50 m, but the 1951 eruption deepened the crater by 70 m, leaving 50 million cubic meters of water after repair of the damaged drainage tunnels. After more than 200 deaths in the 1966 eruption, a new deeper tunnel was constructed, and the lake's volume before the 1990 eruption was only about 1 million cubic meters.

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

# Dieng Volcanic Complex

Java, Indonesia
7.2°S, 109.9°E; summit elev. 2,565 m

Seismicity and plume frequency increased at Dieng beginning in April 2002 (*Bulletin* vol. 27, no. 5). During 27 May-7 July 2002, the Volcanological Survey of Indonesia (VSI) reported higher-than-normal activity. Deep and shallow earthquakes were recorded, along with tectonic events (table 5). During 27 May-9 June, VSI reported a white plume from Sileri crater up to 50 m high. Observations in mid-June revealed a mud ejection from Sikidang crater. Dieng remained at Alert Level 2 (on a scale of 1-4). No further reports were issued through at least May 2003.

| Date (2002) | Deep volcanic | Shallow volcanic | Distant tectonic |
|---|---|---|---|
| 27 May-02 Jun | 1 | 25 | 1 |
| 03 Jun-09 Jun | 1 | 38 | 1 |
| 10 Jun-16 Jun | 13 | 14 | 1 |
| 17 Jun-23 Jun | — | 18 | 3 |
| 24 Jun-30 Jun | — | 7 | 2 |
| 01 Jul-07 Jul | — | 3 | — |

Table 5. Earthquakes recorded at Dieng during 27 May-7 July 2002. Courtesy VSI.

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

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

## Dukono

Halmahera, Indonesia
1.70°N, 127.87°E; summit elev. 1,185 m
All times are local (= UTC + 9 hours)

According to the Volcanological Survey of Indonesia (VSI), Dukono erupted at 0105 on 22 February 2003. A gray-black ash cloud rose to 500 m and drifted E and then S. During 1200-1355 fiery flashes were observed for ~ 30 minutes, and on 28 February activity returned to normal.

The Darwin VAAC reported that an ash plume was visible on NOAA and GOES 9 imagery beginning on 8 June at 1625. The ash plume reached ~ 4.5 km altitude and drifted NE. On 9 June ashfall reached the Galela area, as far as 7 km from the summit. Explosive activity decreased, but a blasting sound was still frequent. The Alert Level was set at 2 (on a scale of 1-4). As of 10 June the plume was visible on satellite imagery extending ~ 75 km N.

During 3-8 July activity preceded by gas emissions from the crater was observed and a gas plume rose 25-75 m. Ash explosions during 9-14 July produced ash columns 800-900 m high, accompanied by a continuous strong blasting sound. Ash fell around the Mamuya and Galela areas. A white-gray ash plume emitted during the week of 15-23 July rose 375 m. On 22 July, an ash explosion from the crater in clear, calm conditions, formed an ash column that reached a maximum height of 1,000 m.

***Background.*** Reports from this remote volcano in northernmost Halmahera are rare, but Dukono is currently one of Indonesia's most active volcanoes. More or less continuous explosive eruptions, sometimes accompanied by lava flows, have occurred since 1933. During a major eruption in 1550, a lava flow filled in the strait between Halmahera and the N-flank cone of Gunung Mamuya. Dukono is a complex volcano presenting a broad, low profile with multiple summit peaks and overlapping craters. Malupang Wariang, 1 km SW of Dukono's summit crater complex, contains a 700 x 570 m crater that has also been active during historical time.

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

## Canlaon

Negros Islands, Philippines
10.412°N, 123.132°E; summit elev. 2,435 m
All times are local (= UTC + 8 hours)

Following an ash emission from Canlaon on 17 March 2003 (*Bulletin* v. 28, no. 3), the Philippine Institute of Volcanology and Seismology (PHIVOLCS) raised the hazard status to Alert Level 1 (on a scale of 0-5), which signified possible ash explosions in the coming days or weeks. There was another ash emission on 23 May.

Beginning on 1 June, the seismic network detected an average of five low-frequency volcanic earthquakes per day. Moderate steaming was noted, which is unusual for Canlaon because steam is typically wispy or nonexistent during normal and quiet conditions.

Brief bursts of ash and steam reaching 100 m above the active crater were observed on 1, 3, 4, 5, 6, 7, and 8 June. An ash emission during 0645-0700 on 8 June deposited traces of ash at Canlaon City proper and in the barangays of Masulog and Linutangan. Eight low-frequency volcanic earthquakes and four low-frequency short-duration harmonic tremors were recorded in the 24-hour period prior to the event. In addition, PHIVOLCS seismographs in Cabagnaan (6 km SW of the active crater) and Canlaon City (8.7 km SE) detected episodes of low-frequency tremor.

Small ash ejections continued after 8 June. Ash-and-steam columns rose to 1,000 m before drifting SSE and SE. Ash explosions on 13 June between 0647 and 0756 were recorded at Cabagnaan as low-frequency short-duration harmonic tremors. The explosions produced voluminous dirty-white steam which rose to ~ 500 m and drifted SSE and ESE. Six low-frequency volcanic earthquakes and three low-frequency short-duration harmonic tremors were detected the 24 hours prior to the event.

Two small steam-driven explosions occurred during 0820-0835 and 1020-1030 on 17 June. The ejected ash-and-steam columns rose to ~400 m above the summit crater and drifted NNE. In the 24-hour period prior to the explosions, the volcano's seismic network detected eight low-frequency volcanic earthquakes, two high-frequency volcanic earthquakes, and one low-frequency short-duration harmonic tremor.

A mild ash ejection at 1422 on 18 June was recorded as a low-frequency volcanic earthquake. A grayish ash-and-steam cloud rose ~ 400 m above the summit crater before drifting SE. Only two low-frequency volcanic earthquakes and one short-duration harmonic tremor preceded the explosion. Mild ash explosions occurred during 0701-0707, 0743-0750, and 1420-1430. These explosions produced voluminous ash-and-steam clouds that rose 400 m above the summit crater before drifting NW. The events were reflected in seismic records as low-frequency volcanic earthquakes. In the 24-hour period prior to the events, two low-frequency earthquakes, one high-frequency volcanic earthquake, and one short-duration harmonic tremor were recorded by the seismic network.

The volcano continued to manifest moderate steaming and ash emission activity with an ash column rising ~ 900 m above the summit crater at 0515 on 4 July. In the 24-hour period prior to the event the seismic network recorded five low-frequency volcanic earthquakes and two low-frequency short-duration harmonic tremors.

The hazard status during June and July remained at Alert Level 1, and PHIVOLCS reminded the public to avoid entering the 4-km-radius Permanent Danger Zone. The absence of longer duration harmonic tremor suggested to PHIVOLCS that there was no magma movement or intrusion, indicating that the explosions were possibly a result of reactivation of a shallow hydrothermal system.

***Background.*** Canlaon volcano (also spelled Kanlaon), the most active of the central Philippines, forms the highest point on the island of Negros. The massive 2435-m-high stratovolcano is dotted with fissure-controlled pyroclastic cones and craters, many of which are filled by lakes. The summit of Canlaon contains a broad northern crater with a crater lake and a smaller, but higher, historically active crater to the S. The largest debris avalanche known in the Philippines traveled 33 km to the SW from Canlaon. Historical eruptions, recorded since 1866, have typically consisted of phreatic explosions of small-to-moderate size that produce minor ashfalls near the volcano.

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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 first historical eruption of the small volcanic island Anatahan began at about 1700 on 10 May 2003 (*Bulletin* v. 28, No. 4). The island is in the Commonwealth of the Northern Mariana Islands (CNMI) and has been uninhabited since it was evacuated on 29 May 1993 as the result of an earthquake swarm (*Bulletin* v. 18, nos. 5 and 8). Shortly after the eruption began, the Emergency Management Office (EMO) of CNMI invited U.S. Geological Survey (USGS) scientists to provide assistance in tracking the volcano's activity and assessing potential hazards. This report discusses a seismically detected phreatic stage during 10-20 May followed by a new lava discharge on 4 June. After mid-July seismicity and volcanism declined.

Records from a broadband seismograph installed by Washington University 6.5 km W of the Anatahan crater on 6 May 2003 were retrieved on 20 May. F.A. Trusdell and R. White (USGS) reviewed the records and plotted estimate of the numbers of volcano-tectonic (VT) events and their maximum magnitudes, and an estimate of the background and/or tremor level for 9-11 May 2003 (figure 6). No VT events or tremor appeared during 6-9 May. Unrecorded precursory activity may have occurred prior to the seismograph installation. Trusdell and White described their findings as follows in their report of 5 June 2003.

"Beginning on May 10, the number of hourly events increases from 0-1 the first couple of hours to 20-33 by [1400 and 1500 hours local time]—then surges to more than 100 events/hr beginning at [1600]. These events are all VTs, with impulsive P and S phases that decay rapidly. The largest events didn't exceed about M 2 on May 10. The spectra are broadband with dominant frequencies between 8 and 10 Hz, the higher frequencies probably attenuated by the 6.5 km travel path—{the distance between the crater and the Washington University seismograph}. Note that late on the 10th, the number of events begins to decrease rapidly and about this same time, the amplitude of the largest events increases rapidly. The largest VT of all (through the last record available, of May 20) had a magnitude of about M 3.1 and occurred a little after noon on the 11th. After that event, both the numbers and amplitudes of the VTs dropped off rapidly (and remained very low through the last record available, on May 20.

"The background noise level remained very low until [1700] on May 10, when the level increased by 2.5x and by [1800] the tremor level was ~ 6x above the background level. We infer that the rising tremor level corresponds to the approximate onset of gas and ash emission into the atmosphere. The VAAC (Wash D.C) —{volcanic ash advisory center}—estimates that the ash first appeared about [1730]. The tremor level increased further and peaked on May 11.

"Notes on May 11-20: The tremor level remained very high for a couple of days before decreasing by about half (10 arbitrary units on the figure) by May 20. By about May 15, unambiguous LP's—{long periods}—begin to appear. By May 19 and 20, there appear brief moments (several seconds) when the tremor level drops to near background immediately prior to the largest LP's which often contain

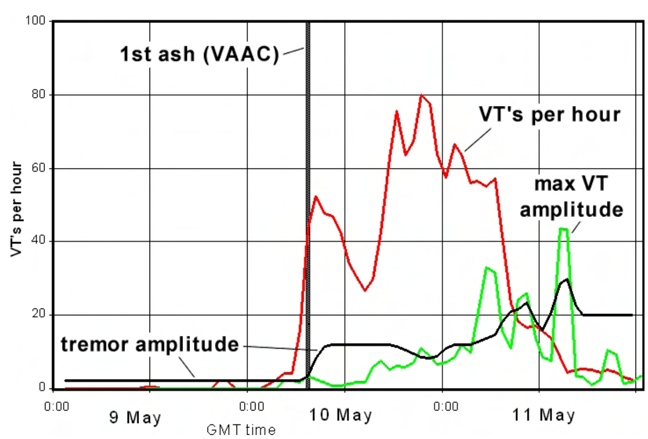


Figure 6. Plot of several seismic parameters at Anatahan, 9-11 May 2003. Estimates of numbers of VT events/hour (left-side scale) and their maximum magnitudes (arbitrary scale), and the tremor magnitudes (arbitrary scale). Courtesy of F.A. Trusdell, USGS.

air phases. Even the largest LP's are not particularly large, maybe M 2-2.5. All of this activity from May 10-20 is compatible with an aggressive phreatic stage."

The spiny surface of a lava flow was first observed in the inner crater on 4 June. The flow appeared to form a mound-shaped lava dome, but its volume is unknown. Scientists also noted the presence of new fault scarps and slump features within the E crater, as well as additional faulting to its W. Such features commonly develop around active vents due to the rise and subsequent eruption of magma. On 5 June the EMO seismic station was repaired and ash samples were collected from the site. Through 12 June, the seismic records showed only continuous ground shaking (tremor) to varying degrees. The most intense periods of tremor lasted 3-10 hours and occurred about every 24-36 hours. On 12 June, three LP earthquakes were recorded, the largest about M 2. Other earthquakes followed on the late afternoon and early evening of 13 June.

Two strong explosions on 14 June removed much of the small new dome in the inner crater. Just before noon on that day, earthquakes began to occur every 1-2 minutes. For the next two days, several episodes of intense tremor and earthquakes lasting ~ 1.5 hours occurred about every 12 hours. These episodes of increased seismic activity accompanied strong ash emissions from the E crater, with eruption columns higher than 2 km. Quiet intervals in which the eruption column consisted of little ash were accompanied by continuous low tremor. At 1613 on 16 June observers noticed that the light-colored, steam-dominated, eruption cloud got darker and rose very quickly (20-40 seconds) to ~ 2.5 km altitude (figure 7). At this time, the seismic amplitude went from "small" to "large" (a 5-10x increase). Since 16 June seismic activity has consisted only of low-level tremor, and even that low level was gradually shrinking.


Figure 7. Ash cloud rising from Anatahan on 16 June 2003. Courtesy USGS Hawaiian Volcano Observatory.

As of 9 July the eruption continued to wane, as shown by decreasing amplitudes of volcanic tremor. Observations from a helicopter on that day revealed only white steam low in the E crater and a minor amount of light brown fume without ash emission.

***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 indicates that the flows are of Holocene age.

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## Unknown Source

Volcano Islands, Japan

Robert Dziak and Christopher Fox at the National Oceanic and Atmospheric Administration's Pacific Marine Environmental Laboratory (NOAA PMEL), reported that a continuous series of low-frequency, long-duration signals were recorded beginning on 18 April 1998, and then during the next 3.3 years by omnidirectional hydrophones deployed throughout the Pacific basin (see *Bulletin* v. 24, nos. 11 and 12, and v. 25, no. 5). These hydroacoustic signals were detected 21 different times from April 1998 through December 1999. After a 6-month hiatus, the signals were detected 26 more times from June 2000 through August 2001 (figure 8). The authors concluded that the signals came from a source in the Volcano Islands.

Dziak and Fox (2002) reported that "The character of the acoustic signals recorded from the Volcano Islands resembles tremor recorded during episodes of magmatic activity at subaerial volcanoes, suggesting that a significant magmatic, and potentially eruptive, process took place in the Volcano Islands between April 1998 and August 2001 and may occur again. To the authors' knowledge, the character of the Volcano Islands harmonic tremor with a 10-Hz fundamental and multiple overtones has not been previously recorded from a submarine volcano. Additionally, detection of harmonic tremor at teleseismic distances (> 30º) is a rare occurrence for either a subaerial or submarine volcano."

Matt Fowler (Oregon State University) provided the following information on harmonic tremors from S of Japan from October 2000 to September 2002; all the tremor signals are from the same general area (figure 8) and have roughly the same frequency-time characteristics. Data through August 2001 were also reported by Dziak and Fox (2002). Possible tremors were detected on 18 and 28-31 October, 5, 9, 13, and 19 November 2000. Definite tremors were identified on 17, 22, and 30 December 2000, 13 January 2001, and 15-20 February 2001. During 21-23 February 2001 the tremors became well defined. Over the next few months tremors were only detected during 18-22 March, on 17, 21, and 24 April, and on 16 and 21 June. After another quiet interval, tremor signals were again recorded on 12, 14, 19, 22, and 30 July, and 8-10, 20, and 29 August 2001; tremors on 20 August were "excessively loud." No tremors were detected again until 26 February 2002, followed by a quiet interval until 16-19 and 31 March. Activity increased again during April-May 2002 with tremors recorded on 1, 2, 18, 20, 22, and 23 April, and 2-3, 13-16, and 21 May; "exceptionally loud" tremors occurred on 2-3 May. Additional tremors were detected on 9 June, 6-13 August, 15 August ("exceptionally loud"), and 19 September 2002.

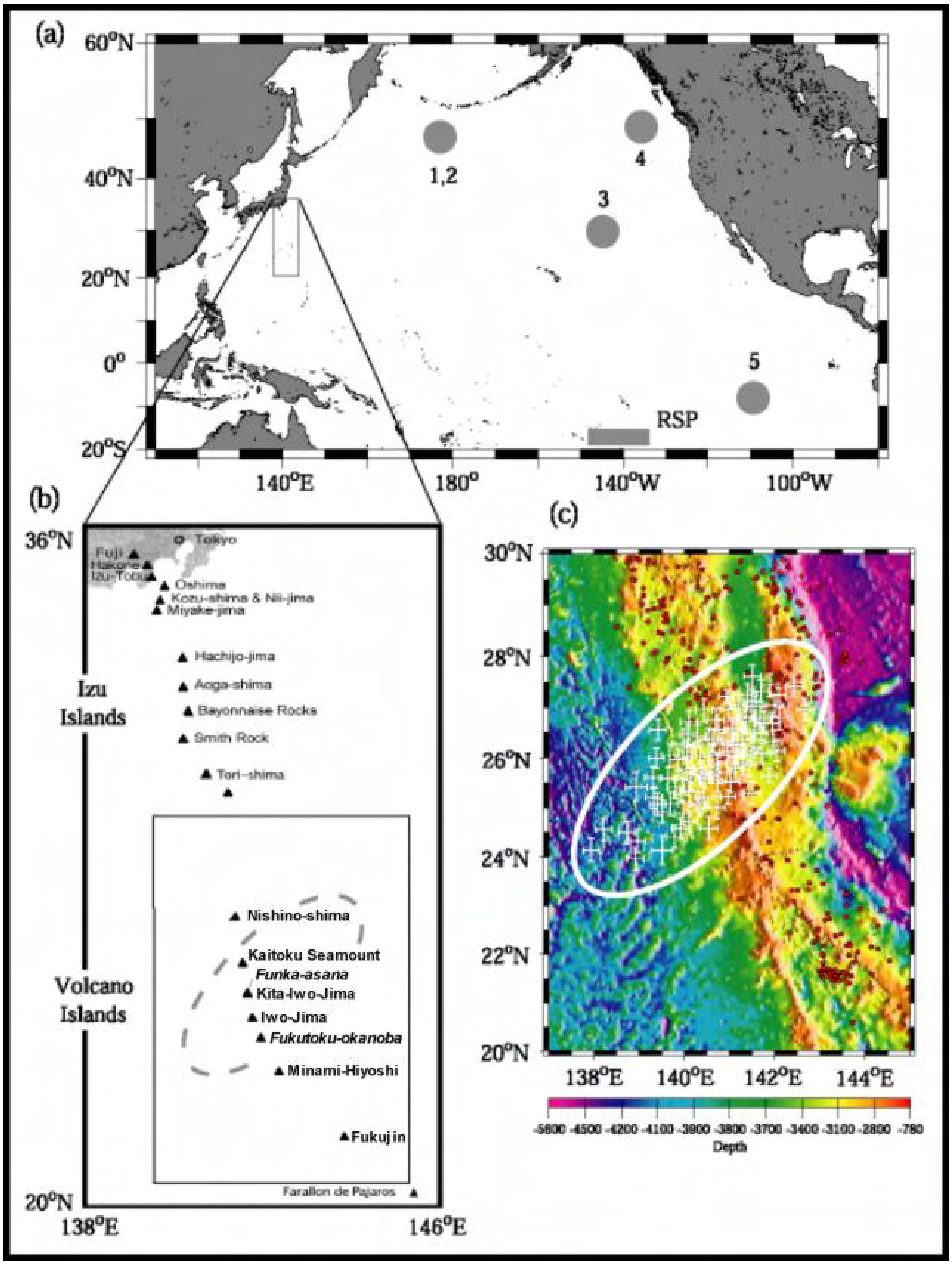


Figure 8. Maps showing location of hydrophones and islands of the Izu-Bonin and Volcano Islands groups in the western Pacific S of Japan, and source area of hydroacoustic signals during April 1998-August 2001 from Dziak and Fox (2002). (a) Approximate locations (shaded dots) of SOSUS and NOAA eastern equatorial hydrophones arrays; shaded bar shows the location of the French Polynesian Seismic Network (RSP). (b) Location of the major volcanoes in the Izu and Volcano Islands groups. (c) Location of the tremor waveforms (crossed error bars) estimated using 16 individual hydrophone stations positioned off the W coast of the United States, Hawaii, western Aleutians, and along the East Pacific Rise near the equator. The location error bars indicate the 68% confidence interval. See Dziak and Fox (2002) for additional details. Courtesy of Robert Dziak.

***Reference:*** Dziak, R.P., and Fox, C.G., 2002, Evidence of harmonic tremor from a submarine volcano detected across the Pacific Ocean basin: Journal of Geophysical Research, v. 107, no. B5, p. ESE 1-1 - 1-12.

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