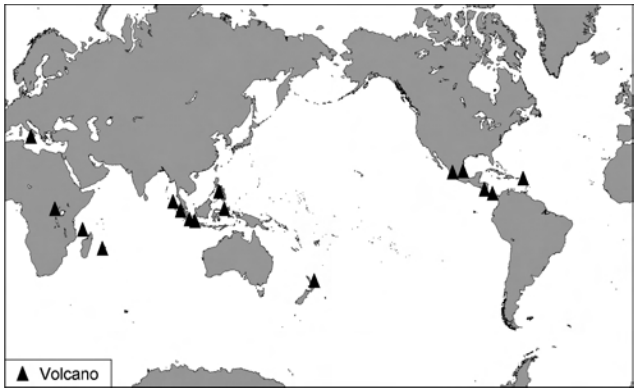
Bulletin of the Global Volcanism Network



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Piton de la Fournaise

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

Five months of slow inflation at Piton de la Fournaise and the eruptive series that occurred between May and July 2003 (*Bulletin* v. 28, nos. 5 and 6) were followed by new activity in August. Ongoing eruptions in June at the Dolomieu crater had ceased by mid-July, but at 1848 on 22 August seismic activity was again detected beneath the crater. Around 2120 that night an eruptive fissure opened in the Bory crater (adjacent to Dolomieu on the W), followed at 2210 by a second fissure at ~ 2,450-2,470 m elevation on the N flank. Both fissures remained active for a short time.

At 2330 a final fissure opened on the N flank ~ 250 m below the second fissure, at 2,200 m elevation. Most of the activity was focused at this third fissure, opening a new crater ~ 50 m E of the 1998 Piton Kapor crater. During this activity on 22 August lava flowed down into la Plaine des Osmondes. The 36 hours following the initial activity were characterized by a substantial increase in tremor intensity and lava emissions, but by 2152 on 27 August the eruption abruptly ceased. A series of long-period events were observed after 27 August through at least 1 September.

Background. The massive Piton de la Fournaise shield volcano on the French island of Réunion in the western Indian Ocean is one of the world's most active volcanoes. Much of its 530,000 year history overlapped with eruptions of the deeply dissected Piton des Neiges shield volcano to the NW. Three calderas formed at about 250,000, 65,000, and less than 5000 years ago by progressive eastward slumping of the volcano. Numerous pyroclastic cones dot the floor of the calderas and their outer flanks. Most historical eruptions have originated from the summit and flanks of Dolomieu, a 400-m-high lava shield that has grown within the youngest caldera, which is 8 km wide and breached to below sea level on the eastern side. More than 150 eruptions, most of which have produced fluid basaltic lava flows, have occurred since the 17th century. Only six eruptions, in 1708, 1774, 1776, 1800, 1977, and 1986, have originated from fissures on the outer flanks of the caldera. The Piton de la Fournaise Volcano Observatory, one of several operated by the Institut de Physique du Globe de Paris, monitors this very active volcano.

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Karthala

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

Since July 2003, Karthala has exhibited significant, but relatively shallow, seismicity. As of 28 August, P. Bachelery of the University of La Réunion reported that an average of 100 seismic events/day were being recorded, some felt by the local population.

The first seismic station was installed at the Karthala Volcanological Observatory in 1988 by the University of La Réunion and the Institut de Physique du Globe de Paris (IPGP). During the summer and fall of 2000 increased seismicity was reported, and an earthquake swarm was recorded in October 2000 (*Bulletin* v. 25, no. 10). In April 1991, a notable increase in the number of seismic events began and, after about three months of seismic activity, there was an eruption in July (*Bulletin* v. 16, nos. 6 and 8).

Background. The southernmost and largest of the two shield volcanoes forming Grand Comore Island, Karthala contains a 3 x 4 km summit caldera generated by repeated collapse. Elongated rift zones extend to the NNW and SE from the summit of the Hawaiian-style shield, which has an asymmetrical profile that is steeper to the south. The lower SE rift zone forms the Massif du Badjini, a peninsula at the SE tip of the island. Historical eruptions have modified the morphology of the compound, irregular summit caldera. More than twenty eruptions have been recorded since the 19th century from both summit craters and flank vents; many lava flows have reached the sea. It has erupted at least 22 times since 1828.

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Nyiragongo

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

Reports from the staff of the Goma Volcano Observatory (GVO) during May to 5 July 2003 noted that the hazard status remained at Yellow ("Vigilance"). Seismicity was characterized by tectonic, long-period, and short-period earthquakes. Deformation across the majority of fractures lacked significant extensional displacements, but the fractures in the S of Shaheru had compressional displacements. In spite of significant crater activity, geochemical and deformation measurements did not suggest any danger to the inhabited zones on the S flank.

During 4-24 May there was ashfall at Kibati (below 2,000 m on the SSE flank, ~8 km from the summit), Rusayo (~8 km from the summit on the SW flank), and Goma (~18 km S). Nightly red glows and degassing were observed each day. Crater observations revealed two pits containing lava fountains, with a NE-SW lengthening of the principal pit. An active lava flow was observed on 7 May inside the crater. During 18-24 May volcanic ash, including Pele's hair, continued to fall in villages around the volcano, including Goma. During 8-28 June the lava lake continued to emit a gas-and-ash plume. The lake was ~ 700 m below the edge of the crater. Collapses in the crater were observed during 13-14 and 18-20 June.

Seismicity. During 4-24 May 2003, seismic activity was dominated by persistent volcanic tremor. During 4-10 May, only two long-period earthquakes and a short-period fracture earthquake were recorded, although during 11-17 May an increased number of long-period earthquakes were distributed on the N flank along the fracture trending from Nyiragongo to Nyamuragira. A small number of short-period earthquakes occurred to the WSW along the Nyiragongo-Sake axis (Sake is ~24 km NW of Goma). During 18-24 May long-period earthquakes continued to appear in the NE-SE direction; some isolated long-period events were observed ENE towards Kibumba.

During 8-21 June persistent tremor continued, and six long-period earthquakes were reported. These tremors suggested intense activity in the crater. Weaker seismicity during the following week, 22-28 June, remained dominated by tremors caused by lava lake activity.

All earthquakes were recorded at the Kibumba, Rusayo, and Bulengo seismic stations and occurred at depths of 0-27 km, with an aseismic zone at 3-7 km.

Deformation and temperature. During 4-10 May 2003, measurements of deformation along the cracks in the S flank indicated neither contraction nor extension when compared with the previous week. During the next two weeks, no deformation occurred along the cracks at numerous other S-flank sites.

Contraction during 8-14 June along the Shaheru fractures (~2 km S of the crater) was 8 mm in Lower Shaheru and 29 mm in Higher Shaheru, suggesting that magma in the fractures S of Nyiragongo had not moved. During 15-21 June, temperature measurements in fractures at Nyiragongo, Shaheru, and Monigi (~1.5 km NE of the Goma airport) varied less than those measured in April-May. Average temperatures were in the range of 14.6-63.1°C.

During 22-28 June deformation measurements of fractures did not reveal any notable variation compared to previous measurements at Monigi, Mugara, and Nyiragongo Cants. Temperatures measured in the Monigi and Lemera fractures did not vary, while those at Mugara showed a slight increase of 3.6°C between 21 May and 28 June.

Crater observations, 22-23 May 2003. Kasereka and Yalire (GVO) remained at the summit of Nyiragongo during 22-23 May. During their SSE-flank ascent, vegetation was covered with slag and ash from Kibati (2,000 m) to the summit (3,470 m). Two types of Pele's hair were observed: those with a length of 20-40 cm were present from Shaheru (2,200 m) to the huts (3,250 m), and those shorter than 15 cm were present from the huts to the summit.

Upon arrival at the summit they observed a gas plume that covered the entire crater. The crater could only be seen for a few seconds at a time. However, the bottom of the crater was entirely occupied by the lava lake, and not by separate lava-filled pits; the crater bottom had an elliptical form elongated in a NE-SW direction. This lava lake was, when calm, characterized by undulatory movements of low amplitude, and, when agitated, projected materials 40-60 m high. A collapse in the crater was not recorded by the seismic network. For three hours that evening there were explosions in the crater, followed by ashfall on the summit.

For one hour on the morning of 23 May there was a total lull, with no growls or explosions, that corresponded to a decline of volcanic tremor recorded at the Bulengo, Kibumba, and Rusayo stations. The atmosphere immediately above the crater then cleared for at least 10 minutes, and photos were taken of the crater floor showing the single lava lake at the bottom of the crater (figure 1). Measurements could not be taken of the depth of the lava lake surface because the atmosphere was clouded by the gas plume.

Figure 1. Photograph of the lava lake (seen through the gas plume) occupying the bottom of the Nyiragongo crater, 23 May 2003. Courtesy of the Goma Volcano Observatory.

Analyses by the GVO showed that the pH of rainwater from the air was 4.13 and its conductivity was 2.08 ms/cm.

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

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Nyamuragira

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

According to reports from the Goma Volcano Observatory, since late October 2002 tectonic and magmatic seismicity at Nyamuragira has continued. Some of this seismicity was thought to be related to the refilling of a magma chamber emptied by a previous eruption. No eyewitness accounts of activity were reported until 26 February 2003, when a seismic crisis occurred. From 30 April into June 2003, local villagers reported rumblings and sounds of explosions coming from the volcano.

Activity during 27 October-14 December 2002. During 27 October-2 November, seismic data were collected at eight operational stations (Katale, Kibumba, Bulengo, Rusayo, Luboga, Goma, Lwiro, and Kunene). During this time volcanic seismicity was masked by aftershocks from a tectonic earthquake on 24 October 2002. Some rare magmatic events had hypocenters 10-25 km deep. During November 2002 epicenters of magmatic seismicity were concentrated in the NE area where the last eruption took place, an observation consistent with refilling of the magma chamber.

During 3-23 November, magmatic seismicity was more prevalent than tectonic seismicity, the latter dominated by aftershocks of the 24 October earthquake. The distribution of the magmatic earthquakes covered a zone 0-22 km deep, with an earthquake-free zone between approximately 3 and 7 km depth. The latter was interpreted as the location of a magma chamber, the same position as the chamber that fed the 27 July 2002 eruption. The tectonic earthquakes had depths of 0-30 km with an aseismic zone between 12 and 17 km. During the week of 24-30 November both tectonic and magmatic earthquakes were more frequent. Magmatic earthquakes increased at Katale to 348 from 239 during the previous week. High-frequency earthquakes in the E disappeared during the period. High-frequency earthquakes appeared in an isolated area in Virunga and densely NW of Lake Kivu in the area of Kalehe, where a landslide in late April 2003 killed ten people.

During 8-14 December the number of long-period earthquakes fell from to 169 at the Katale station from 239 the previous week, though the number of high-frequency earthquakes increased from 92 to 120. This increase was thought to be related to rifting in the area of the Large African Lakes. In general, volcanic tremors remained omnipresent. The epicenters of these long-period earthquakes were mainly concentrated in the NE of the central crater between 0 and 7 km depths. High-frequency earthquakes were concentrated in the aftershock zone of the 24 October 2002 earthquake in the Territory of Kalehe, NW of Idjwi Island.

Activity during February-March 2003. A seismic crisis started the night of 26 February and continued through the next morning. Seismicity increased greatly at the Goma seismic station; it was mainly tremor, but not at the same high levels of July 2002. Seismograms indicated clear increases in the numbers of both long-period and tectonic earthquakes and an increase in tremor amplitude. Visual observations were limited to the E flank, where the eruption of July 2002 started, but clouds obscured the summit crater.

Although seismic activity and warning phone calls occurred at the same time, there was no visible eruptive activity. Some very minor and brief activity (possibly witnessed) might have occurred in the central crater, which was not visible from the Rumangabo site. Seismic activity in late February included fracturing earthquakes, mainly on the N and NE sides of the volcano. Persistent long-period earthquakes were associated with magma movement. Short-period earthquakes associated with fracturing were observed for the first time.

A fresh outbreak of long-period earthquakes was noted in the NE quadrant during the week of 1-8 March, along with the growing presence of short-period events. Many long-period earthquakes occurred during the week of 16-22 March, including frequent fracture-related earthquakes.

Activity during April-June 2003. From 30 March through 27 April long-period earthquakes were concentrated beneath the NE flank, along with some short-period events. Although the number of long-period earthquakes decreased appreciably in late April and early May, similar seismicity continued through 21 June. The long-period events were distributed along a NW-SE trend, corresponding to the fracture zone towards Nyiragongo.

From 30 April until 1 May, it seemed that there was some renewal of activity, but no eruption was detected. Residents of Katale and Tongo, the closest villages to the volcano, reported some rumblings on 30 April between 1730 and 2130, plus clear sounds of individual explosions. The closest seismic station (Katale) recorded at the same time ~ 18 distinct explosion signals, directly followed at 1927 by a tectonic earthquake centered under the volcano. Later, seven type-C events followed until 2232. Another tectonic earthquake occurred at 2338.

Residents of Kunene (~12 km SW), Katale (~10 km NE), and Tongo claimed to have heard explosions and growling noises on 9 May. Local tectonic earthquakes from late May through late June were 0-27 km deep, with an aseismic zone at 3-7 km. Seismicity during 22-28 June was dominated by long-period earthquakes concentrated in the NE, in which there was an apparent increase compared to the previous week.

Background. Africa's most active volcano, Nyamuragira is a massive basaltic shield volcano that rises about 25 km north of Lake Kivu across a broad valley NW of Nyiragongo volcano. Nyamuragira has a volume of 500 cu km, and extensive lava flows from the volcano blanket 1500 sq km of the East African Rift. The broad low-angle shield volcano contrasts dramatically with its steep-sided neighbor Nyiragongo. The 3058-m-high summit of Nyamuragira is truncated by a small 2 x 2.3 km caldera that has walls up to about 100 m high. Historical eruptions have occurred within the summit caldera, frequently modifying the morphology of the caldera floor, as well as from the numerous fissures and cinder cones on the volcano's flanks. A lava lake in the summit crater, active since at least 1921, drained in 1938, at the time of a major flank eruption. Historical lava flows extend down the flanks more than 30 km from the summit, reaching as far as Lake Kivu.

Information Contact: *Goma Volcano Observatory* (see Nyiragongo).

Etna

Sicily, Italy
37.73°N, 15.00°E; summit elev. 3,315 m

Activity at Etna since the end of the last flank eruption on 28 January 2003 (*Bulletin* v. 28, no. 1) was characterized by intense degassing at the Northeast Crater (NEC). In April, ash emission was observed from Bocca Nuova crater (BN), and ash fell for about 1 hour on E-flank villages. On 17 April a helicopter survey, aided by use of a thermal camera, revealed a cinder cone within the S pit of BN with a hot vent at its top. However, no degassing was taking place from this vent, and the pit appeared mostly obstructed by debris from the crater walls. Rare explosions from the vent caused little emission of juvenile material on the crater floor. Another helicopter-borne thermal survey in May showed that the summit craters were mostly obstructed.

Only a hot crack within the S pit of BN was observed during a June field survey. A new vent on the N rim of the Voragine (VOR), detected during a June field survey, was

~ 0.5 m wide, and the temperature measured through a thermal camera was ~ 500°C, much higher than the two vents within the crater. Given the presence of hot features within the summit craters and the obstructions observed inside BN, Southeast Crater (SEC), and VOR, it is possible that renewal of explosive activity at these summit craters could be accompanied by sudden, unpredictable gas explosions.

On the afternoon of 11 August an increase in volcanic tremor at the summit seismic stations lasted about 15 minutes and was followed by about 30 minutes of strong explosion earthquakes recorded at all summit stations of the INGV-CT seismic network. This was the first such event recorded at Etna since the end of the flank eruption. The INGV-CT web camera at Milo (~ 11 km from the summit) showed a puff of red ash from the summit of NEC. Red glows from the same crater were reported that night. A field survey on 14 August did not reveal any explosive activity or sounds of explosions from the crater. There were no explosion earthquakes or increased volcanic tremor between 11 and 16 August.

Periodic measurements of the gas plume from the summit using both COSPEC (SO_2 flux) and FTIR (SO_2/HCl and HCl/HF ratios) showed decreases in all three values since the end of the flank eruption. This suggests a general decreasing trend in gas output from Etna's summit craters.

Background. Mount Etna, towering above Catania, Sicily's second largest city, has one of the world's longest documented records of historical volcanism, dating back to 1500 BC. Historical lava flows of basaltic composition cover much of the surface of this massive stratovolcano, whose edifice is the highest and most voluminous in Italy. The Mongibello stratovolcano, truncated by several small calderas, was constructed during the late Pleistocene and Holocene over an older shield volcano. The most prominent morphological feature of Etna is the Valle del Bove, a 5 x 10 km horseshoe-shaped caldera open to the east. Two styles of eruptive activity typically occur at Etna. Persistent explosive eruptions, sometimes with minor lava emissions, take place from one or more of the three prominent summit craters, the Central Crater, NE Crater, and SE Crater (the latter formed in 1978). Flank vents, typically with higher effusion rates, are less frequently active and originate from fissures that open progressively downward from near the summit (usually accompanied by strombolian eruptions at the upper end). Cinder cones are commonly constructed over the vents of lower-flank lava flows. Lava flows extend to the foot of the volcano on all sides and have reached the sea over a broad area on the SE flank.

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Stromboli

Aeolian Islands, Italy
38.79°N, 15.21°E; summit elev. 926 m

The latest effusive eruption at Stromboli ended between 21 and 22 July (*Bulletin* v. 28, no. 7), when active lava flows on the upper Sciara del Fuoco were no longer visible. Since then explosive Strombolian activity became more common at both summit craters. Four active vents were observed within Crater 1 (the NE crater), and there was one funnel-shaped incandescent depression within Crater 3 (the SW crater). Strombolian activity during the first half of August was very intense at Crater 1, causing a spatter cone to form on the crater floor and incandescent bombs to fall on the outer flanks. Explosive activity at Crater 3 was apparently deeper, and was often accompanied by ash emission.

During the first half of August, thermal images of the apparently inactive lava flow field revealed thermal signatures within cracks on the upper flow field, and within skylights along two lava tubes in the upper Sciara del Fuoco, at ~ 550 m elevation. Temperatures of over 300°C, and incandescence of these hot spots, suggest endogenous growth. Incandescence and thermal signatures at these sites were not observed between 22 and 31 July.

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.

Correction: The previous report about Stromboli (*Bulletin* v. 28, no. 7) included a description of activity at the summit craters in April 2003. The obstructions caused by fallout on 5 April was not a continuing long-term situation, as the text might have implied. The description of explosions on 17 April and 3 May in the rest of that report clearly demonstrated that the blockages no longer existed. We regret any confusion.

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Soufrière Hills

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

Activity at Soufriere Hills has been high over recent months, culminating in the collapse of a major dome and explosive activity during 12-13 July 2003. A summary of reports by the Montserrat Volcano Observatory (MVO) from 27 June to 12 September 2003 is provided below, with sulphur dioxide emissions and activity data (table 1).

Activity was generally at a moderate level in early May, increasing over 7-9 May and remaining high through 23 May. Activity mainly focused towards the NE, with rockfalls and numerous pyroclastic flows along the N side of the

Tar River and in the Tar River Valley. On 12 and 13 May, flows were seen on the N and NW flanks in the area of Farrell's Plain and the upper reaches of Tyre's Ghaut. During 21-23 May there was increased activity on the N flanks, with a number of pyroclastic flows into the top of Farrell's Plain, Tyre's Ghaut, and Tuitt's Ghaut. Pulses of vigorous ash venting were observed at the summit, and intense glow on the summit and NE flanks was seen on the nights of 20 and 21 May. Sulfur emissions varied during May, with a high of 744 metric tons/day (t/d) (8.6 kg/s) on 14 May and a low of 300 t/d (3.4 kg/s) on 18 May. Extreme highs of 850 t/d (9.9 kg/s) and 820 t/d (9.5 kg/s) occurred on 4 and 9 May, respectively.

During the first week of June, activity was variable, generally declining to a moderately low level. Most activity through 6 June was focused on the E and NE flank, producing rockfalls and numerous pyroclastic flows in the Tar River Valley and occasionally in White's Ghaut and Tuitt's Ghaut. Activity during the week ending 13 June decreased to a low level, and remained low through 27 June, increasing over 26-27 June on the N flanks. Hybrid earthquake activity developed into a diffuse swarm on 22-23 June, some events at depths of 3 km below the lava dome. SO_2 emissions were relatively stable in June, varying between 240 t/d (2.8 kg/s) and 540 t/d (6.3 kg/s).

Sulfur emissions varied between 260 t/d (3 kg/s) and 585 t/d (6.8 kg/s) in July, but jumped to 840 t/d (9.7 kg/s) on 2 July. This could be related to increased activity during the first week of July, with pyroclastic flow and rockfall activity focused on the N flanks of the dome. Most flows occurred in Tuitt's Ghaut, with some in Tyre's Ghaut and White's Ghaut. Sporadic flows also occurred on the W side of the dome in the Gages area.

Activity remained high over the week ending 11 July, with a swarm of several thousand small hybrid earthquakes, at a rate of 1-2 per minute, commencing in the early hours of 9 July. While the size of these earthquakes increased slowly, individual events were below the normal recording threshold. The swarm of hybrid earthquakes intensified slightly over the night of 11 July, with events becoming larger and more closely spaced. Glimpses of the N part of the dome complex on 10 and 11 July confirmed that dome growth switched to the N, as was also shown by the northerly focus to the rockfalls and pyroclastic flows. Pyroclastic flows occurred most frequently in White's Ghaut, Tar River Valley, and Tuitt's Ghaut, with several small flows in Tyre's Ghaut earlier in the week.

By the morning of 12 July, events in the earthquake swarm merged into a continuous tremor signal. A period of prolonged and heavy rainfall between 0600 and 0900 caused mudflows in the Belham Valley. Small pyroclastic flows, the first of which were pale and weakly convective, occurred in the Tar River Valley. Flow activity built slowly through the afternoon until it was almost continuous. There were marked increases in the intensity of the activity at 1827 and again at 2007. Some flows traveled more than 2 km over the surface of the sea at the mouth of the Tar River Valley. Pyroclastic flows also reached the sea in White's Ghaut and the Spanish Point area. These flows resulted in the extremely heavy fallout of ash and accretionary lapilli over the island, particularly S of Woodlands.

A number of explosive events took place towards the end of the dome collapse of 12 July, with the largest occurring between 2300 and midnight. Showers of rock fragments fell on the island, with dense rocks up to 60 mm in diameter recorded. The Washington Volcanic Ash Advisory Center (VAAC) provided a column height of around 16 km for this event. The activity persisted at a high level until around 0200 on 13 July. It began subsiding slowly, declining to very low levels by the following morning, when a sudden Vulcanian explosion occurred from the lava dome. Two more explosions occurred in the next two days, producing pumice that reached 15 cm in size at Richmond Hill (~5 km W) and 4 cm in Olveston. Heavy ashfall from the collapse was experienced over all the inhabited parts of Montserrat, with the greatest thickness (over 15 cm) recorded at Vue Pointe Hotel. North of St Peter's the thickness was less than 1 cm.

The bulk of the dome structure was removed in the collapse, and pyroclastic flows impacted the area between Tar River Valley and Spanish Point. The activity destroyed GPS sites at White's Yard and Hermitage, and a camera site at White's Yard. Solar panels were smashed by falling rocks at Spring Estate GPS site and at Garibaldi Hill. After the collapse, sulfur-dioxide emissions jumped to highs between 1,030 t/d (12 kg/s) and 1,720 t/d (20 kg/s), much higher than any other readings over the past several weeks.

Activity was extremely low through 1 August with only a few events triggering the seismic network. The restrictions of the October 2002 exclusion zone were lifted on 1 August. The pattern of

Date (2003)	Rockfall signals	Long-period rockfalls	Long-period earthquakes	Hybrid earthquakes	Volcano-tectonic earthquake
02 May - 09 May	767	88	138	7	2
09 May - 16 May	580	65	55	7	—
16 May - 23 May	774	75	81	8	2
30 May - 06 Jun	445	34	40	5	1
06 Jun - 13 Jun	79	8	16	6	2
13 Jun -20 Jun	48	10	—	55	—
20 Jun - 27 Jun	54	4	2	135	1
27 Jun - 04 Jul	193	61	7	37	—
04 Jul - 11 Jul	156	12	38	9	—
11 Jul - 18 Jul	58	3	24	84	1
18 Jul - 25 Jul	—	6	5	21	—
25 Jul - 01 Aug	34	—	5	30	—
01 Aug - 08 Aug	25	—	5	35	—
08 Aug - 15 Aug	12	—	7	38	2
15 Aug - 22 Aug	5	1	6	39	—
22 Aug - 29 Aug	7	—	2	26	—
29 Aug - 05 Sep	4	—	—	18	—
05 Sep - 12 Sep	2	—	3	27	—

Table 1. Summary of activity at Soufriere Hills, 2 May-12 September 2003. Activity occurred as summarized above, with the addition of three explosion signals during 11-18 August. Courtesy of the Montserrat Volcano Observatory.

earthquakes through the week of 25 July indicated that dome growth in the explosion crater probably restarted, although it was not possible to confirm this visually due to low clouds. Intense activity began at 0608 on 1 August with an episode of powerful ash venting. There were many strong bursts of gas release and jets of ash; the plume rose to over 3.2 km. This activity declined to very low levels about 0730. Another episode of gas venting began at 0834.

Over the next week activity fluctuated, with periods of relative quiet separating episodes of intense degassing and hybrid earthquake activity. At the beginning of the week the volcano was extremely active with intense ash venting from the explosion crater. It was then fairly quiet with occasional rockfalls and hybrid earthquakes. A good view of the new dome was obtained from the air on 5 August, showing a small southerly directed lobe growing extremely slowly, if at all. Earthquake activity increased on the evening of 7 August with eight large hybrid events occurring overnight.

Through 22 August activity was at low levels; the dome remained a small lobe just over 100 m across. Several small slumps from the interior wall of the 12 July collapse scar produced small rockfalls, light ash in the plume, and the formation of some large fumaroles. By 29 August new fumaroles opened SE of the main explosion crater, towards the upper parts of the Tar River Valley. A strong sulphurous smell and blue haze N of the volcano did not reflect increased activity. SO_2 emissions in August were again variable, with a low of 450 t/d (5.4 kg/s) on 6 August and highs approaching 2,500 t/d (29 kg/s) the following week.

Through the latter part of the week ending 5 September, the gas plume was out of reach of the spectrometer network due to winds from Hurricane Fabian. Activity remained low through 12 September, but several episodes of ash venting occurred with a few small earthquakes.

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 east. 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.

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Masaya

Nicaragua
11.95°N, 86.15°W; summit elev. 625 m

During April 2002-May 2003, monthly visits were made to Masaya for observations and temperature measurements. This report summarizes the recorded activity.

Between April and October the volcano continued to emit large amounts of gas. Tremors stayed consistently above 40 RSAM units. Seismicity was low, with fewer than 50 total earthquakes during the observation period; temperatures generally remained constant.

Fumarole temperature measurements in the Santiago crater on 22 April 2002 showed only a slight variation from October 2001. On 9 May, however, temperatures showed an increase of 20°C since April; again on 4 June a 20°C increase from May was observed. Measurements by Jaime Cardenas of the National Park at El Comalito and San Fernando on 10 and 30 April also showed little change from previous measurements. Similarly, on 5 and 21 May and in June measurements at El Comalito and San Fernando showed no significant changes. The temperatures at El Comalito and San Fernando fumaroles remained constant through the rest of the year.

In July 2002 tremor stayed above 40 RSAM units, and the volcano continued to emit great amounts of gas. Seismic stations registered 20 earthquakes. On 7 July several rumblings were reported. During a visit to the volcano emissions of dark-colored gases were seen. Landslides were observed to have extended to the inner crater, which had a diameter of 20 m; the diameter was 10 m when the crater opened on 23 April 2001. Gas emanations were abundant; a plume rising more than 1,000 m was observed. Fumarole temperatures varied between 106 and 89.3°C.

In August 2002 gas emissions continued. Martha Navarro and Virginia Tenorio visited on 15 August and observed and clearly heard gases emanating from two locations in the inner crater. Gas columns mixed with vapor reached heights of up to 700 m. The emission of gases was lower than during the previous month, possibly due to decreased rainfall. The tremor continued to stay above 40 RSAM units, and 11 earthquakes were registered.

Navarro visited the volcano twice in September. Gas columns were low and there was little vapor on 13 September; on 30 September she observed greater gas emissions and within the inner crater she could hear with greater force the sound of gas emissions. Weeds within an area of 600 m had been affected by acid rain. A small collapse along the N and E walls was observed within the crater.

On 3 October park guards reported a small collapse from the W wall. Observations on 7 and 28 October showed more water vapor than in September, as well as greater gas emissions and louder sounds associated with them. Through September and October tremor remained above 40 RSAM units; no earthquakes were registered. On 6, 16, and 18 December fumarole temperature measurements were taken with an infrared camera at Santiago crater; measurements on those dates were 216°C, 230°C, and 205°C respectively.

Through December 2002 and January and February 2003 fumarole temperatures at El Comalito and San Fernando remained constant. The low level of gas and vapor exhalation continued; columns reached as high as 100 m at the mouth of the crater. RSAM stayed constant at 30 units, with frequency between 1.5 and 2 Hz. In both January and February two earthquakes were registered. During 25 and 26 February there was a small earthquake swarm in Masaya caldera, with earthquakes located under the lake. Six earthquakes registered in March, with 3 Hz frequency, and five registered in April, with 2.8 Hz. RSAM stayed at 20 units, with frequencies between 1.5 and 2 Hz, in March and April.

Gustavo Chigna (INSIVUMEH-Guatemala) reported that the sulfur-dioxide measurements obtained using COSPEC on 28 March yielded a flux of 840 t/d. Measurements by Glyn Williams-Jones (University of Hawaii) with a 2FlySPEC (gas measurement spectrometer) on 28 March showed a value of 849 t/d. On 8 and 22 May measurements at El Comalito and San Fernando showed little variation. The temperatures at the six fumaroles at El Comalito ranged between 59.5°C at fumarole 6 and 76.4°C at fumarole 3. At San Fernando temperatures ranged from 56.4°C at fumarole 4 to 63.6°C at fumarole 2. The seismic tremor stayed constant with 20 units RSAM, with frequencies of 1.5-2 Hz. Only one earthquake registered, with 3 Hz frequency. Pedro Pérez measured the fumarole temperatures in the Santiago crater at 175ºC on 15 May.

Gas monitoring. A scientific and technical team from ITER, INETER, and WESTSYSTEMS (Italy) installed a geochemical station, developed by WESTSYSTEMS, for continuous monitoring of diffuse CO_2 and H_2S degassing at El Comalito. The observation site was selected after a 1999 diffuse degassing survey at Masaya. The station has been in operation since 15 March 2002.

Background. Masaya is one of Nicaragua's most unusual and most active volcanoes. It is a broad, 6 x 11 km basaltic caldera with steep-sided walls up to 300 m high. The caldera is filled on its NW end by more than a dozen vents erupted along a circular, 4-km-diameter fracture system. Masaya lies within the massive Pleistocene Las Sierras pyroclastic shield volcano. The twin volcanoes of Nindirí and Masaya, the source of historical eruptions, were constructed at the southern end of the fracture system and contain multiple summit craters. A major basaltic plinian tephra was erupted from Masaya about 6500 years ago. Historical lava flows cover much of the caldera floor and have confined a lake to the far eastern end of the caldera. A lava flow from the 1670 eruption overtopped the north caldera rim. Masaya has been frequently active since the time of the Spanish Conquistadors, when an active lava lake prompted several attempts to extract the volcano's molten "gold."

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Arenal

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

This report concerns Arenal behavior during November 2001 through August 2003, although some reports were absent (specifically, November and December 2001 and January, February, and April 2002). The available reports portrayed an interval with only a few pyroclastic flows and with plumes generally under 500 m. Lava flows continued to travel down Arenal's slopes; in many cases these flows did not follow well-defined channels. Spatter and related deposition from crater C caused a slightly higher summit elevation. During 2002 lavas descended along many routes down the W, NW, N, and NE flanks. Seismicity remained prominent during the interval, with the number of monthly eruption signals in the hundreds (200-800) and monthly tremor duration in the hundreds of hours.

Seismicity registered during March 2000-December 2001 and for the year 2002 appears as figures 2 and 3, where the numbers of eruptions plotted monthly were inferred. The seismic station VACR (table 2) returned to service on 28 March 2000, registering totals for four days at the end of March consisting of 164 eruptions and 45 hours of tremor. Also reported this month, the electronic distance measuring network (sub-radial lines) continued to show a contraction averaging 7-10 ppm per year. Similar conclusions were stated for August 2003, although in that case deflation was only mentioned on Arenal's W flank. In accord with that observation, dry tilt in the radial direction showed a deflation equivalent to 5 μrad per year, a value that has prevailed through mid-2003.

The number of monthly earthquakes generally dropped or held steady during 2002 compared to 2000-2001 (figure 3). Tremor duration, however, did increase through July 2002, approaching 700 hours a month, typically several times larger than seen in the previous two years. Long-period (LP) earthquakes suddenly became prominent in November and December 2002 (roughly 3- to 7-fold more numerous than seen earlier in 2002).

Two prominent PFs occurred during 2000-2001: in August 2000 and March 2001. They did not correlate with short-term increases in precursory seismicity. However, the August 2000 PF took place after clear increases in the number of earthquakes, the duration of tremor (figure 2), and the number of explosions.

One of a series of PFs judged smaller than the one in March occurred on 16 June 2001. They descended the NW flank for an unstated distance in the direction of Balneario de Tabacón (the Tabacón hot springs and resort complex).

Seismic Station Features

Name:	VACR
Location:	10.477°N, 84.684°W
Elevation:	360 m
Distance and azimuth from the active crater:	2.7 km NNE
Instrument:	Ranger SS-short-period (1 Hz)
Gain:	60 decibels (dB)
Amplification:	9,605-times normalized at 1 Hz.

Typical seismic signals recorded at Arenal include those registered in association with explosions and gas eruptions; these signals often correspond to sounds similar to a locomotive or jet engine. Tremors typically correlate to strong degassing and discharge of lava flows. The following types of tremor signal are known to occur: low frequency (typically less than 2.0 Hz), mid-frequency (typically 2.0-3.0 Hz), high frequency (typically above 3.0 Hz), polychromatic (occurring in any frequency range), monochromatic (low-frequency range), and spasmodic (high-frequency range).

Table 2. Background describing the OVSICORI-UNA seismic station at Arenal (station VACR), as well as the typical kinds of seismic and audible acoustical signals and corresponding eruptive conditions. Courtesy of OVSICORI-UNA.

Associated seismic signals persisted for ~ 48 minutes. Although seismicity during June 2001 was comparatively low overall, May 2001 seismicity was moderately high, although not outstanding (figure 2).

During March 2002, Arenal's lava traveled down the N and NE flanks. Eruptive vigor remained low in terms of the number of eruptions and quantity of ejected pyroclastics. On the NE, E, and SE flanks there had been acidic rains and tephra falls. These, in combination with the steep slopes, unconsolidated material, and high rainfall, had caused vegetation to recede. This led to greater erosion, and small cold avalanches swept down the drainages Calle de Arenas, Manolo, Guillermina, and Agua Caliente.

On 18 May 2002 a pyroclastic flow resulted from the structural failure of a lava channel's margin in the region adjacent to the active crater (Crater C). The pyroclastic flow descended to ~ 900 m elevation, traveling roughly NW. Otherwise, the eruptive vigor around this time continued to remain low; a few eruptions produced columns that rose ~ 500 m above Crater C. Some minor changes took place in the lava flow channels during May 2002.

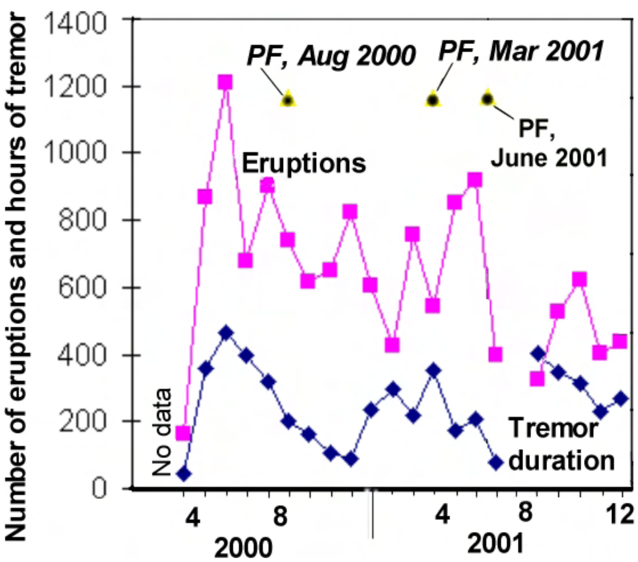

Figure 2. Arenal seismicity registered during March 2000-December 2001 (eruptions inferred). The blank areas before March 2000 and during July 2001 were due to equipment down-times. Known pyroclastic flows are shown, but some may be missing because some monthly reports were not available. Courtesy of OVSICORI-UNA.

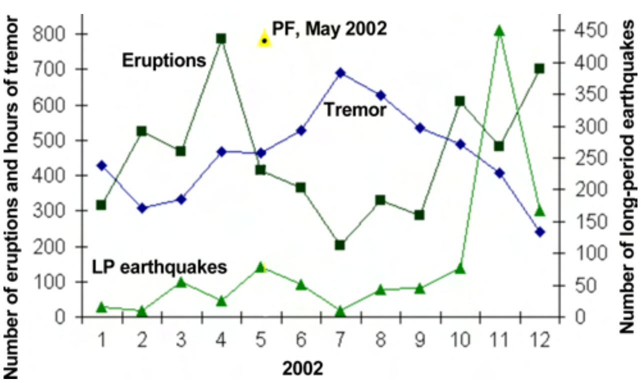

Figure 3. Arenal seismicity registered during 2002 (eruption counts seismically inferred). Note change in scale compared to previous figure. The number of eruptions decreased compared to those registered in the year 2000. On the other hand, long-period (LP) earthquakes grew substantially in number during the last months of 2002; tremor repeatedly reached over 400 hours per month during mid-2002. Courtesy of OVSICORI-UNA.

Although reports for June and July 2002 were absent during the preparation of this report, the August report mentioned sporadic Strombolian eruptions during those months. Lava that began to be emitted in May 2002 traveled NW and stopped during August. After that, a new lava flow began during August, heading NW in its upper reaches. Very close to the crater, it divided into two arms, heading W and NW. The August effusive activity had increased over recent months, yet, overall the eruptive vigor around that time generally remained low with few eruptions bearing ash, and columns failing to rise more than 500 m above crater C's summit.

Low activity again prevailed during September-December 2002, but lava flows continued to emerge. During September lavas were active on Arenal's W flank, and to some extent on its NW, N, and NE flanks. During October, lavas chiefly descended the NW slopes. During November, the NW-flank lava flow that began to be emitted during August 2002 stopped advancing. A new lava flow began to descend the W flank. Flows down the NW-NE flanks were noted in reports for December 2002-August 2003. In addition, during December 2002 and January and August 2003, some lavas appeared active on the SW flank. During January 2003 plumes again rose to under 500 m high, and calm generally prevailed in February through August as well. Two noteworthy events broke the relative calm of 2003; these occurred during February, May, and September.

On 21 February 2003 at about 0825, NE-flank residents witnessed a small pyroclastic flow descending the same flank. Other details were not disclosed in the OVSICORI-UNA reports; nor was the May PF much described. The 5 September 2003 PF will be discussed in a later report.

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

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Popocatépetl

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

Volcanic activity at Popocatépetl during March-July 2003, as reported by the Centro Nacional de Prevención de Desastres (CENAPRED), was similar to that from July 2002 to February 2003 (*Bulletin* v. 27, no. 10 and v. 28, no. 2). Activity was comprised principally of multiple exhala-

Figure 4. Photograph of an eruption at Popocatépetl volcano, 19 July 2003. Courtesy of CENAPRED.

tions (some with significant ash), volcano-tectonic (VT) earthquakes, and explosions. Daily exhalations averaged 10-30 during March, 5-25 during April and May, and _50 during July. VT earthquakes in these months were M 2-3 at depths of 2-5 km located E or SE of the volcano.

On 28 April and 10 May, low-frequency harmonic tremors during the VT events attained moderate, but significant, amplitude levels lasting 13 and 4 hours, respectively. Eruptive activity during June, presumed to be predominantly phreatic, increased and caused ash-bearing exhalations and explosions. Another significant tremor episode was detected on 8 June. Eruptions on 20 and 28 June caused minor ashfall on some towns near the volcano. During July, many exhalations were explosive and carried significant ash. The largest explosive events in July were recorded on 1, 15, 19, and 25. The event of 19 July (figure 4) caused light ashfall as far as the southern metropolitan area of Mexico City. Aerial photography of the crater on 30 April and 19 May indicated no evidence of new lava dome emplacement during the report period.

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Colima

Mexico
19.514°N, 103.62°W; summit elev. 3,850 m
All times are local (= UTC - 6 hours)

In February 2003 lava emission at Colima ceased, ending an earlier eruptive stage (*Bulletin* v. 28, no. 6); after the termination of lava emission a new eruptive stage began. A series of small explosions during March-June was followed by the explosion on 17 July 2003 (*Bulletin* v. 28, no. 7), the first of three large explosions in July and August. The 17 July explosion sent blocks up to 500 m and an ash column higher than 3,000 m. The explosion was accompanied by five pyroclastic flows with runout distances up to 2 km on the W-SW slopes of the volcano (figure 5).

The second large explosion was recorded on 2 August at 1541. The Washington VAAC reported a plume to ~ 7.6 km altitude. The third large explosion occurred on 28 August at 2352 and produced an ash column at least 3 km high with ashfall up to 60 km W-NW of the volcano. The explosion was accompanied by pyroclastic flows out to 2.5 km, covering the majority of the volcano's flanks; the total deposit volume was about 244,000 m^3.

As a result of this explosion sequence, a new crater 200 m across and 30 m deep formed at the summit (figure 6). About 2 x 10^6 m^3 of the material of the former lava dome was ejected as volcanic bombs and projectiles out to distances of ~ 1.0-2.5 km. The seismic energy released during these three large explosions was lower than during the 1999 explosions (*Bulletin* v. 24, no. 1).

Background. The Colima volcanic complex is the most prominent volcanic center of the western Mexican volcanic belt. It consists of two volcanoes, Nevado de Colima (the 4,320 m high point of the complex) on the N and the younger, 3,850-m-high, historically active Volcán de Colima on the S. Volcán de Colima (also known as Volcán Fuego) is a youthful stratovolcano constructed within a 5-

Figure 5. Photo of the WSW flank of Colima showing the paths of pyroclastic flows that followed the 17 July 2003 explosion. Arrows mark five of the pyroclastic-flow deposits. Courtesy of Colima Volcano Observatory.

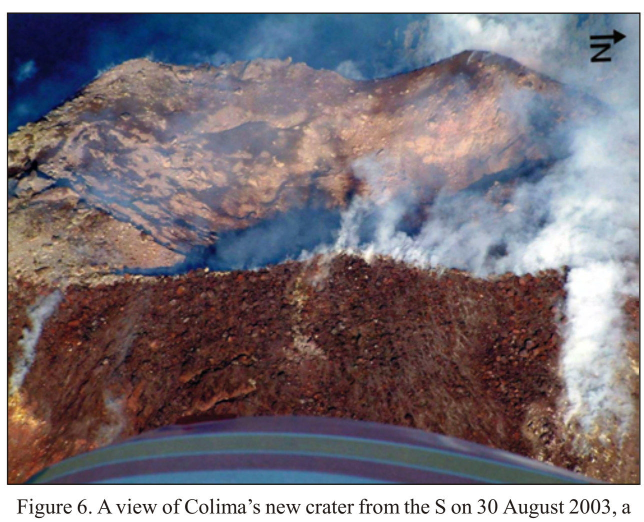

Figure 6. A view of Colima's new crater from the S on 30 August 2003, a result of an explosive sequence that began on 17 July 2003. Courtesy of Colima Volcano Observatory.

km-wide caldera breached to the S, the source of large debris avalanches. 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.

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White Island

Bay of Plenty, New Zealand
37.52°S, 177.78°E; summit elev. 321 m

Following increased SO_2 emissions in December 2002 and mud ejections during February and early March 2003 (*Bulletin* v. 28, no. 2), the active vent at White Island continued to emit a small plume of steam and gases through 4 April, but seismic activity was at a very low level. Seismicity remained low through August 2003.

Scientists visited White Island during the week of 5-11 April for routine monitoring. This fieldwork included sampling high-temperature fumaroles, measuring carbon dioxide output, and geodetic surveying. The crater lake had grown in size and flooded the active vent, greatly reducing the emission of a gas plume from the vent and also reducing the seismicity to very low levels. A minor plume of steam and gases persisted through 20 June, but was not visible the week of 21-27 June; no further mention of a plume was made in reports through August.

Scientists from the Institute of Geological & Nuclear Sciences (IGNS) who visited the island during the week of 28 June-4 July noted striking changes in the crater lake, which had turned a light green color, and was very warm (58°C). The water level had risen several meters, to ~ 30 m below the crater rim, flooding all the active vents and spreading into all the areas of the crater floor. This lake is the largest to form within the 1978/90 Crater Complex. Fumarole temperatures ranged from 101 to 114°C.

By the first week of August the lake seemed to be semi-permanent, reaching a size of ~ 300 m long and somewhat less in width, with an unknown depth. As a result, a Science Alert Bulletin issued by the IGNS on 7 August 2003 noted that the existence of the lake created new hazards. Over the last 10-15 years many small ponds and lakelets have formed in topographic lows or the floors of small sub-craters within the 1978/90 Crater Complex. Their lives have typically been short as they have been filled in by the next eruption, or drained as new vents have formed. The small volumes of these lakes was such that they had no influence on eruptive activity.

However, the current lake volume is large enough that it could influence eruptive activity. Ejection of the lake in an eruption could cause flooding of the shallow stream valleys across the Main Crater floor, maybe as far as the sea. Should there be no significant eruptive activity within the next 18-24 months and the lake continues to fill, it may reach overflow level. In this situation water may overflow into drainage channels on Peg 12 Flat, S of the 1978/90 Crater Complex, and these channels may further erode if water is continuously flowing in them.

As of 29 August seismic and hydrothermal activity remained at the low levels recorded during the past four weeks. The lake level had risen since early July, and the temperature was 53°C, down slightly from 58°C on 2 July. The volcano monitoring team installed temporary benchmarks inside the main crater, so changes in the lake level could be observed from the safety of the crater rim. Although the development of the crater lake has been a concern, there is no significant change in volcanic activity on the island, so the hazard status for White Island remains at Alert Level 1.

Background. Uninhabited 2 x 2.4 km White Island, one of New Zealand's most active volcanoes, is the emergent summit of a 16 x 18 km submarine volcano in the Bay of Plenty about 50 km offshore of North Island. The 321-m-high island consists of two overlapping stratovolcanoes; the summit crater appears to be breached to the SE because the shoreline corresponds to the level of several notches in the SE crater wall. Intermittent moderate phreatomagmatic and strombolian eruptions have occurred at White Island throughout the short historical period beginning in 1826, but its activity also forms a prominent part of Maori legends. Formation of many new vents during the 19th and 20th centuries has produced rapid changes in crater floor topography. Collapse of the crater wall in 1914 produced a debris avalanche that buried buildings and workers at a sulfur-mining project.

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

Tangkubanparahu

western Java, Indonesia
6.77°S, 107.60°E; summit elev. 2,084

In August and September 2002 Tankubanparahu showed its first elevated seismicity since 1992 (*Bulletin* v. 27, no. 9). This activity continued in October of 2002. The volcano is at Alert Level 2.

From September through 6 October, volcanic events dominated seismicity, particularly during the week of 16-22 September, when there were 331 shallow volcanic [B-type] events. Crater fumarole temperatures of 92-95°C were recorded at Domas and Ratu craters; the hotspring temperature at Ciater was 47°C. H_2S concentrations were above detections limits, ranging from 80 to more than 100 ppm at Ratu; more than 80 ppm H_2S was also recorded at Jagal. A "thin white ash plume" was observed to rise 2.5 m, and a whizzing sound could be heard 50 m away. A strong sulfur smell and sulfur sublimation were noted.

Between 7 and 13 October, volcanic events again dominated seismic activity, but numbers were lower than the previous week, with 151 B-type events, down from 199, and four A-type events, down from five. Tectonic activity occurred at the same rate as the previous week, with 21 events. The following week volcanic activity again dropped, with 57 shallow volcanic (B-type) events. However, deep volcanic (A-type) events increased slightly, to 15. Observations during the week included a "white-thin ash plume" to 2 m and medium-strong gas pressure. A strong sulfur smell and yellow sublimation were also noted. The fumarole temperature at Ratu crater was 95°C.

Shallow volcanic earthquakes increased through the week of 21-27 October, with 123 events. Deep volcanic events dropped to 7, and tectonic activity again remained stable, with 19 events. On 25 October Upas crater was measured at 44°C; a "white-thin ash plume" was only noted to rise 0.5-1 m, and the sulfur smell was weak.

Background. Tangkubanparahu is a broad shield-like stratovolcano overlooking Indonesia's former capital city of Bandung that was constructed within the 6 x 8 km Pleistocene Sunda caldera. The volcano's low profile is the subject of legends referring to the mountain of the "upturned boat." The age the caldera-forming eruption exceeds the 40,000 year range of radiocarbon dating (Newhall and Dzurisin 1988). The rim of Sunda caldera forms a prominent ridge on the western side; elsewhere the caldera rim is largely buried by deposits of Tangkubanparahu volcano. The dominantly small phreatic historical eruptions recorded since the 19th century have originated from several nested craters within an elliptical 1 x 1.5 km summit depression.

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Krakatau

Sunda Straits, Indonesia
6.102°S, 105.423°E; summit elev. 813 m

Due to continued foggy weather, no visual observations could be made at Krakatau during July and through 17 August. Throughout this period the volcano remained at Alert Level 2. Seismicity reported by the Volcanological Survey of Indonesia (VSI) between 30 June and 17 August consisted mostly of shallow volcanic events (table 3), although 36 deep volcanic earthquakes were recorded during the week of 30 June-6 July.

Date	Volcanic (deep)	Volcanic (shallow)	Tectonic
30 Jun-06 Jul	36	123	9
07 Jul-13 Jul	5	112	13
14 Jul-20 Jul	4	28	8
21 Jul-27 Jul	8	33	6
28 Jul-03 Aug	7	37	2
04 Aug-10 Aug	6	25	4
11 Aug-17 Aug	2	22	8

Table 3. Seismicity at Krakatau, 30 June-17 August 2003. Courtesy of VSI.

Background. The renowned volcano Krakatau (frequently misstated as Krakatoa) lies in the Sunda Strait between Java and Sumatra. Collapse of the ancestral Krakatau edifice, perhaps in 416 AD, formed a 7-km-wide caldera. Remnants of this ancestral volcano are preserved in Verlaten and Lang Islands; subsequently Rakata, Danan and Perbuwatan volcanoes were formed, coalescing to create the pre-1883 Krakatau Island. Caldera collapse during the catastrophic 1883 eruption destroyed Danan and Perbuwatan volcanoes, and left only a remnant of Rakata volcano. This eruption, the 2nd largest in Indonesia during historical time, caused more than 36,000 fatalities, most as a result of devastating tsunamis that swept the adjacent coastlines of Sumatra and Java. Pyroclastic surges traveled 40 km across the Sunda Strait and reached the Sumatra coast. After a quiescence of less than a half century, the post-collapse cone of Anak Krakatau (Child of Krakatau) was constructed within the 1883 caldera at a point between the former cones of Danan and Perbuwatan. Anak Krakatau has been the site of frequent eruptions since 1927.

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

Tandikat

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

Seismic activity at Tandikat increased significantly over the week of 20-26 January 2003. One felt earthquake (III on the MMI scale) on 20 January was followed by a significant number of deep volcanic earthquakes. The number of both volcanic and tectonic earthquakes resulted in the volcano's hazard status being upgraded to Alert Level 2 on 25 January. Seismic activity decreased over the period 27 January-16 February (table 4), but remained at an elevated level.

Week (2003)	Deep Volcanic	Shallow Volcanic	Emission	Tremors	Tectonic
12 Jan-19 Jan	6	—	—	—	22
20 Jan-26 Jan	149	1	—	2	174
27 Jan-02 Feb	46	—	4	1	54
03 Feb-09 Feb	24	—	3	—	18
10 Feb-16 Feb	19	—	5	—	15

Table 4. Seismicity at Tandikat, 12 January-16 February 2003. Data courtesy of VSI.

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

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

Soputan

North Sulawesi, Indonesia
1.108°N, 124.725°E; summit elev. 1,784 m

On 18 July 2003, large glowing lava avalanches resulted in a pyroclastic surge towards the W and NW. An ash column rose up to 2,000 m above the summit, and the Alert Level was raised to 3. Lava avalanches and ash explosions continued over the next few days, but by 21 July volcanic activity had started to decrease. Night observations showed that areas where glowing lava had illuminated the W slope on 18 and 19 July became dull and gradually disappeared over the three days following the eruption. Volcanic tremor due to fluid movement also ceased as of 22 July. Ash explosions continued sporadically, but were not as thick or as high as during previous observations. On 22 July between 20 of these minor ash explosions were recorded; another 50 ash explosions were reported after that time. No volcanic earthquakes were recorded, although small-amplitude tremor (0.25 mm) was recorded continuously. After 25 July the volcano was lowered to Alert Level 2.

During the week of 28 July-3 August, lava avalanches on the W slope continued, and emissions and avalanche earthquakes dominated seismic records. In addition, a white gas plume rose 50 m.

Background. The small Soputan stratovolcano on the southern rim of the Quaternary Tondano caldera on the northern arm of Sulawesi Island is one of Sulawesi's most active volcanoes. The youthful, largely unvegetated volcano rises to 1784 m and is located SW of Sempu volcano. It was constructed at the southern end of a SSW-NNE trending line of vents. During historical time the locus of eruptions has included both the summit crater and Aeseput, a prominent NE-flank vent that formed in 1906 and was the source of intermittent major lava flows until 1924.

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

Ruang

Sangihe Islands, Indonesia
2.28°N, 125.43°E; summit elev. 725 m

Volcanic activity had decreased by 30 September 2002 after a strong eruption on the 25th (*Bulletin* v. 27, no. 2). After the hazard status was lowered from Alert Level 4 to 3 on 30 September, it was dropped to Level 2 during the week of 7-13 October. However, activity continued to be higher than normal that week, with frequent strong emissions and "thick white ash" rising ~ 100 m above the summit. Emission earthquakes decreased (table 5). High-pressure plumes decreased in frequency from 14 October through 10 November, but "thick white ash" continued to rise from the summit. No ashfall was reported during October or November. Rainfall on 23 October caused a lahar. No volcanic or emission earthquakes were recorded during 4-10 November, and the Alert Level was reduced to level 1.

Week (2002)	Emission earthquakes	Tectonic earthquakes
07 Oct-13 Oct	3	46
14 Oct-20 Oct	6	39
21 Oct-27 Oct	2	85
28 Oct-03 Nov	2	63
04 Nov-10 Nov	—	58

Table 5. Seismicity at Ruang, 7 October-10 November 2002. Courtesy of VSI.

Background. Ruang volcano, not to be confused with the better known Raung volcano on Java, is the southernmost volcano in the Sangihe Island arc, north of Sulawesi Island. The 4 x 5 km island volcano rises to 725 m across a narrow strait SW of the larger Tagulandang Island. The summit of Ruang volcano contains a crater partially filled by a lava dome initially emplaced in 1904. Explosive eruptions recorded since 1808 have often been accompanied by lava dome formation and pyroclastic flows that have damaged inhabited areas.

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

Canlaon

Philippines
10.412°N, 123.132°E; summit elev. 2,435 m

A report on 19 September 2003 from the Philippine Institute of Volcanology and Seismology (PHIVOLCS) summarized activity at Canlaon from 7 March to 23 July 2003. This included the ash ejections of 10 and 11 July (*Bulletin* v. 28, no. 7). There were 46 ash explosions recorded since March, characterized by emission of steam clouds with small amounts of ash rising 100-1,500 m above the active crater. Prevailing winds dispersed the ash mainly SW and SE, which settled predominantly over the mid-upper slopes of the volcano.

Seismic activity remained elevated through this period, with epicenters of some high-frequency events located near the active crater, focal depths ranged from near-surface down to 18 km. From June to July, the numbers of recorded low-frequency volcanic earthquakes and low-frequency short-duration harmonic tremor events increased. This coincided with phreatic episodes between 8 June and 23 July 2003.

On 23 July an ash explosion was observed from Kanlaon Volcano Observatory, 8.5 km ESE of the crater. Ash-laden steam clouds were ejected to heights of ~ 800 m above the active crater. After 23 July only weak steam emission was noted, and seismic activity returned to low levels.

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 south. 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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