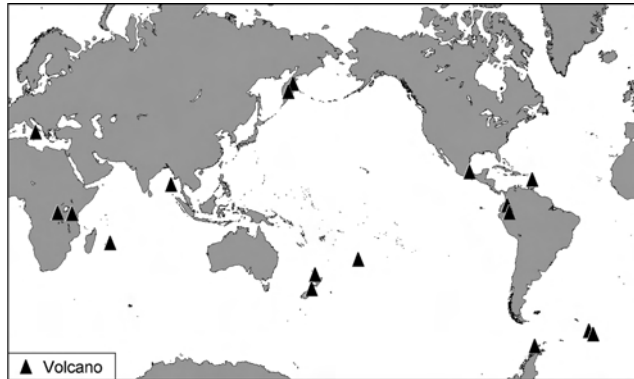


Bulletin of the Global Volcanism Network

Volume 28, Number 2, February 2003



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Montagu Island (South Sandwich Islands) <i>Satellite data provide first evidence of Holocene eruptive activity</i> . . .	2
Michael (South Sandwich Islands) <i>Lava lake detected in satellite imagery during 1995-2002</i>	4
Deception Island (Antarctica) <i>Fumarole temperatures stable during 2000-2002; sulfur dioxide detected</i> . . .	5
Reventador (Ecuador) <i>Ashfall in January, mudflows in February-March; additional data from November</i> . .	6
Galeras (Colombia) <i>Phreatic explosion in June 2002; increased long-period seismicity in late 2002</i>	9
Soufriere Hills (Montserrat) <i>Continued dome growth, rockfalls, and pyroclastic flows</i>	9
Popocatepetl (Mexico) <i>Cycles of dome growth and destruction; continuing explosive activity</i>	12
Shiveluch (Kamchatka Peninsula) <i>Continued lava dome growth, short-lived explosions, and seismicity</i> . . .	13
Kliuchevskoi (Kamchatka Peninsula) <i>Seismicity above background levels; explosion and thermal anomaly</i> .	15
Monowai Seamount (Kermadec Islands) <i>Volcanic earthquake swarm during 1-24 November eruption</i> . . .	15
White Island (New Zealand) <i>Increased SO₂ emissions since December, mud ejections in February</i>	17
Ruapehu (New Zealand) <i>Volcanic tremor episodes and Crater Lake temperature variations</i>	17
Barren Island (Indian Ocean) <i>Fumarolic activity noted during fieldwork in February</i>	18
Piton de la Fournaise (Réunion) <i>Infrared data from November-December 2002 eruption</i>	20
Ol Doinyo Lengai (Tanzania) <i>Continuing lava flows and vent activity in late December 2002</i>	21
Nyiragongo (DR Congo) <i>Aftershocks, lava lake, SO₂ fumes, acidic rains, and highly fluorinated water</i> . . .	22
Etna (Italy) <i>Petrographic and geochemical comparison of 2001 and 2002 lavas</i>	25

Editors: Edward Venzke, Jennifer Fela, Rick Wunderman, and Gari Mayberry

Volunteer Staff: Jacquelyn Gluck, David Charvonia, Robert Andrews, and Ashley McCleaf

Global Volcanism Program • National Museum of Natural History, Room E-421 • Washington, DC 20560-0119 • USA
Telephone: (202) 357-1511 • Fax: (202) 357-2476 • Email: gvn@volcano.si.edu • URL: <http://www.volcano.si.edu/>

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Montagu Island

South Sandwich Islands
58.42°S, 26.33°W; summit elev. 1,370 m

Although previous eruptions have been recorded elsewhere in the South Sandwich Islands (Coombs and Landis, 1966), ongoing volcanic activity has only recently been detected and studied. These islands (figure 1) are all volcanic in origin, but sufficiently distant from population centers and shipping lanes that eruptions, if and when they do occur, currently go unnoticed. Visual observations of the islands probably do not occur on more than a few days each year (LeMasurier and Thomson, 1990). Satellite data have recently provided observations of volcanic activity in the group, and offer the only practical means to regularly characterize activity in these islands. These observations are especially significant because there has previously been no evidence of Holocene activity on Montagu Island (LeMasurier and Thomson, 1990).

Using Advanced Very High Resolution Radiometer (AVHRR) data, Lachlan-Cope and others (2001) observed apparent plumes and unreported single anomalous pixels intermittently on images of Montagu Island during March 1995 to February 1998. However, field investigations in January 1997 revealed that Montagu Island, as viewed from Saunders Island, was apparently inactive, with the summit region entirely covered in snow and ice. Hand-held photographs of the island obtained in September 1992 also showed the summit to be wholly inactive.

Significant volcanic activity may have begun on Montagu Island in late 2001 based upon analysis of thermal sat-

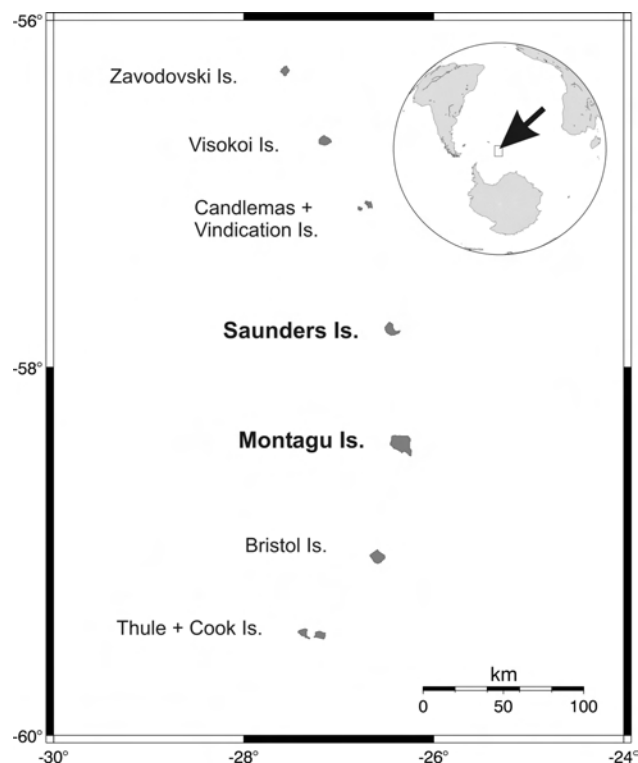


Figure 1. The South Sandwich Island archipelago, located in the Scotia Sea. The South Sandwich Trench lies approximately 100 km E, paralleling the trend of the islands, where the South American Plate subducts westward beneath the Scotia Plate. Courtesy Hawaii Institute of Geophysics and Planetology and British Antarctic Survey.

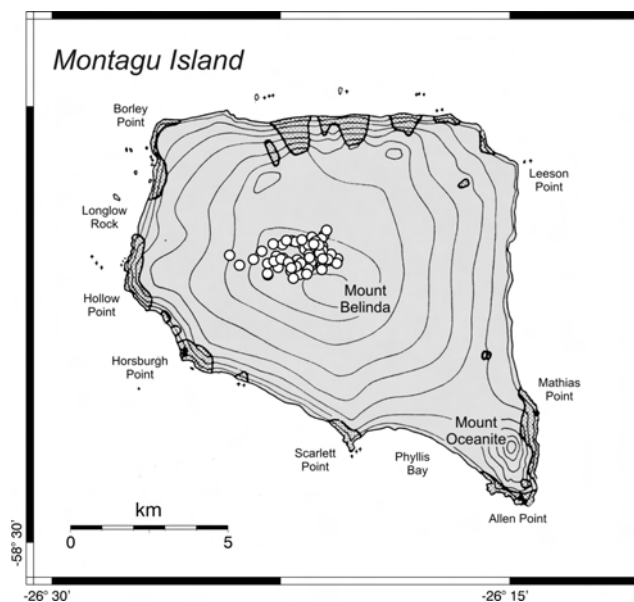


Figure 2. Map of Montagu Island with circles showing the location of all anomalous MODIS pixels detected since October 2001. Stippled areas show rock outcrop, the remainder is snow or ice covered. Relief is shown by form lines that should not be interpreted as fixed-interval contours. Map adapted from Holdgate and Baker (1979); courtesy Hawaii Institute of Geophysics and Planetology and British Antarctic Survey.

ellite imagery (1 km pixel size) from NASA's Moderate Resolution Imaging Spectroradiometer (MODIS) instrument. Using the automated MODIS Thermal Alert system (Wright and others, 2002), image pixels containing volcanic activity were detected and analyzed to characterize the eruption. From its location, the erupting center may be associated with a small hill on the NW edge of the ice-filled summit caldera, ~ 6 km from Mount Belinda (figure 2).

The first thermal alert on Montagu occurred on 20 October 2001 with a single anomalous pixel on the N side of the island. Subsequent anomalies generally involved 1-2 pixels, with the exception of several images in August and September 2002 that peaked at four pixels in size (figures 3 and 4). Visual inspection of the images revealed that the anomalies were all located between the summit of Mount Belinda and the N shore, changing in position either due to satellite viewing geometry or actual migration of hot material. We can generally discount other possible explanations for the anomalies, the most likely being solar reflectance influencing the short-wave bands, due to the presence of clear anomalies in nighttime imagery and the concomitance of apparent low-level ash plumes in several of the images. The persistence of the anomaly, and the lack of large ash plumes, suggests that activity here may involve a lava lake.

Background. The largest of the Sandwich Islands, Montagu consists of one or more stratovolcanoes with parasitic cones and or domes. The roughly rectangular-shaped island rises about 3,000 m from the sea floor and is roughly 15 x 20 km wide with a prominent peninsula at its SE tip. Around 90% of the island is ice-covered; glaciers extend to the sea over much of the island, forming vertical ice cliffs. Mount Belinda, rising to 1,370 m, is the high point of the island and lies at the southern end of a 6-km-wide ice-filled summit caldera. Mount Oceanite, an isolated 900-m-high peak, lies at the SE tip of the island and was the source of lava flows exposed at Mathias Point and Allen Point. There

was no record of Holocene or historical eruptive activity at Montagu until MODIS satellite data beginning in late 2001 revealed thermal anomalies consistent with lava lake activity that has been persistent since late 2001. Apparent plumes and single anomalous pixels were observed intermittently on AVHRR images during the period April 1995 to February 1998, possibly indicating earlier unconfirmed more sporadic volcanic activity.

References: Coombs, D.S., and Landis, C.A., 1966, Pumice from the South Sandwich eruption of March 1962 reaches New Zealand: *Nature*, v. 209, p. 289-290.

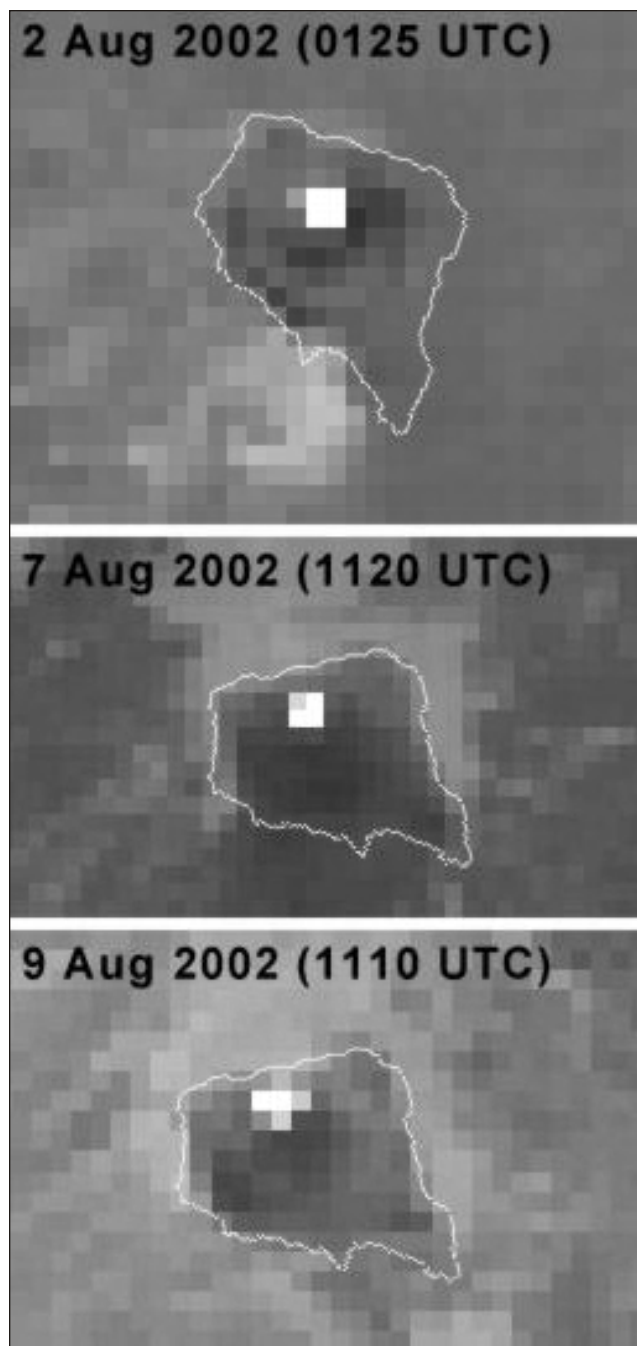


Figure 3. Selected MODIS images showing thermal anomalies on Montagu Island. Band 20 ($3.7 \mu\text{m}$) is shown here. The thermal anomalies appear to be located between the summit of Mount Belinda and the N shore. Images are not georeferenced for purposes of radiance integrity, therefore coastlines are approximate. Courtesy Hawaii Institute of Geophysics and Planetology and British Antarctic Survey.

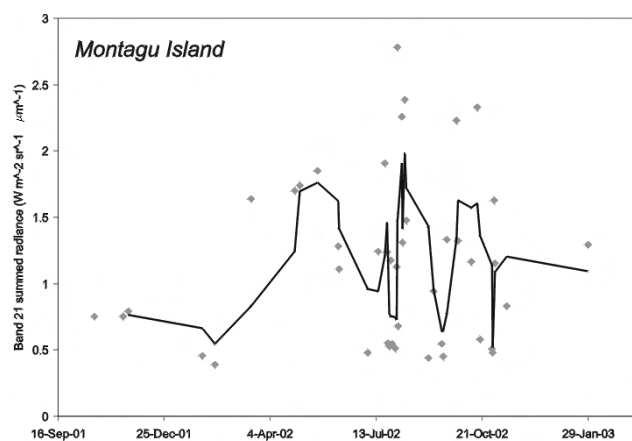


Figure 4. Summed radiance of anomalous pixels in each image. Band 21 ($3.9 \mu\text{m}$) was used for these plots. Points show the result for each image, and the line is a three point running mean of values. Courtesy Hawaii Institute of Geophysics and Planetology and British Antarctic Survey.

Holdgate, M.W., and Baker, P.E., 1979, The South Sandwich Islands, I, General description: British Antarctic Survey Science Report, v. 91, 76 p.

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LeMasurier, W.E., and Thomson, J.W. (eds), 1990, *Volcanoes of the Antarctic Plate and Southern Oceans*: American Geophysical Union, Washington, D.C., AGU Monograph, Antarctic Research Series, v. 48.

Wright, R., Flynn, L.P., Garbeil, H., Harris, A.J.L., and Pilger, E., 2002, Automated volcanic eruption detection using MODIS: *Remote Sensing of Environment*, v. 82, p. 135-155.

Information Contacts: Matt Patrick, Luke Flynn, Harold Garbeil, Andy Harris, Eric Pilger, Glyn Williams-Jones, and Rob Wright, HIGP Thermal Alerts Team, Hawaii Institute of Geophysics and Planetology (HIGP) / School of Ocean and Earth Science and Technology (SOEST), University of Hawai'i, 2525 Correa Road, Honolulu, HI 96822, USA (URL: <http://hotspot.higp.hawaii.edu/>, Email: patrick@higp.hawaii.edu); John Smellie, British Antarctic Survey, Natural Environment Research Council, High Cross, Madingley Road, Cambridge CB3 0ET, United Kingdom (URL: <http://www.antarctica.ac.uk/>, Email: jls@pcmail.nerc-bas.ac.uk).

Michael

South Sandwich Islands
57.78°S, 26.45°W; summit elev. 990 m

Although previous eruptions have been recorded in the South Sandwich Islands (Coombs and Landis, 1966), ongoing volcanic activity has only recently been detected and studied. These islands (figure 1) are all volcanic in origin, but sufficiently distant from population centers and shipping lanes that eruptions, if and when they do occur, currently go unnoticed. Visual observations of the islands probably do not occur on more than a few days each year (LeMasurier and Thomson, 1990). Satellite data have re-

cently provided observations of volcanic activity in the group, and offer the only practical means to regularly characterize activity in these islands.

Using Advanced Very High Resolution Radiometer (AVHRR) data, Lachlan-Cope and others (2001) discovered and analyzed an active lava lake on the summit of Saunders Island (figure 5) that was continuously present for intervals of several months between March 1995 and February 1998; plumes originating from the island were observed on 77 images during April 1995–February 1998. J.L. Smellie noted that during helicopter overflights on 23 January 1997 (Lachlan-Cope and others, 2001) “dense and abundant white steam was emitted from the crater in large conspicuous puffs at intervals of a few seconds alternating with episodes of less voluminous, more transparent vapour.” Smellie also observed that the plume commonly extended ~8–10 km downwind.

The MODIS Thermal Alert system also detected repeated thermal anomalies throughout 2000–2002 in the summit area (figure 6), indicating that activity at the lava lake has continued. Anomalous pixels (1 km pixel size) were detected intermittently and were all 1–2 pixels in size, consistent with the relatively small confines of the crater. The timing of anomalous images in this study likely has more to do with the viewing limitations imposed by weather (persistent cloud cover masks any emitted surface radiance in the majority of images) than it has to do with fluctuations in activity levels, so this plot of radiance (figure 7) should not be used as a proxy for lava lake vigor.

Background. The young constructional Mount Michael stratovolcano dominates glacier-covered Saunders Island. Symmetrical 990-m-high Mount Michael has a 700-m-wide summit crater and a remnant of a somma rim to the SE. Tephra layers visible in ice cliffs surrounding the island are evidence of recent eruptions. Ash clouds were reported from the summit crater in 1819, and an effusive eruption was inferred to have occurred from a north-flank fissure around the end of the 19th century and beginning of the 20th century. A low ice-free lava platform, Blackstone Plain, is located on the north coast, surrounding a group of

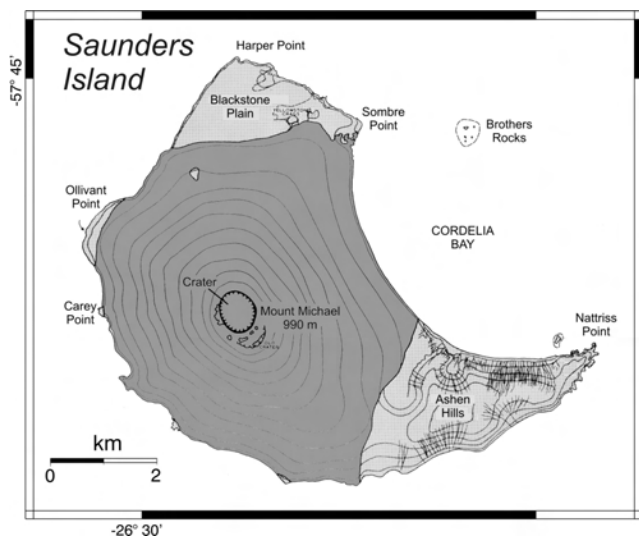


Figure 5. Map of Saunders Island, adapted from Holdgate and Baker (1979). Lighter shaded stippled areas show rock outcrop, the remainder is snow or ice covered. Relief is shown by form lines that should not be interpreted as fixed-interval contours. Courtesy Hawaii Institute of Geophysics and Planetology and British Antarctic Survey.

former sea stacks. A cluster of parasitic cones on the SE flank, the Ashen Hills, appear to have been modified since 1820 (LeMasurier and Thomson 1990). Vapor emission is frequently reported from the summit crater. Recent AVHRR and MODIS satellite imagery has revealed evidence for lava lake activity in the summit crater of Mount Michael.

References: Coombs, D.S., and Landis, C.A., 1966, Pumice from the South Sandwich eruption of March 1962 reaches New Zealand: *Nature*, v. 209, p. 289–290.

Holdgate, M.W., and Baker, P.E., 1979, The South Sandwich Islands, I, General description: British Antarctic Survey Science Report, v. 91, 76 p.

Lachlan-Cope, T., Smellie, J.L., and Ladkin, R., 2001, Discovery of a recurrent lava lake on Saunders Island (South Sandwich Islands) using AVHRR imagery: *Journal of Volcanology and Geothermal Research*, v. 112, p. 105–116.

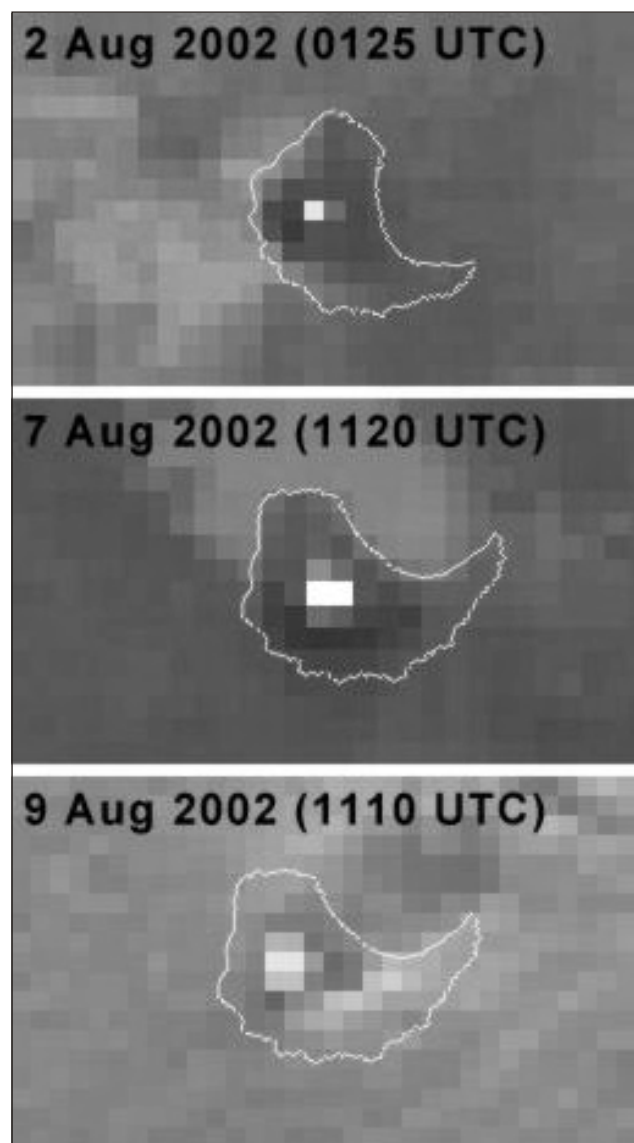


Figure 6. Selected MODIS images showing thermal anomalies on Saunders Island. Band 20 (3.7 μm) is shown here. Anomalous pixels on Saunders Island correspond to the lava lake in the summit crater of Mt. Michael volcano (figure 5). Images are not georeferenced for purposes of radiance integrity, therefore coastlines are approximate. Courtesy Hawaii Institute of Geophysics and Planetology and British Antarctic Survey.

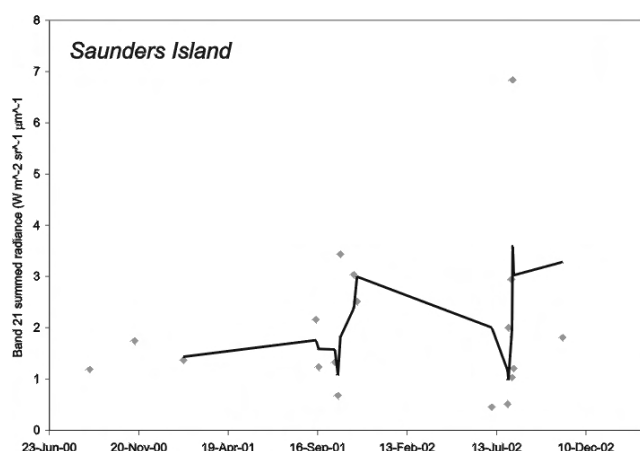


Figure 7. Summed radiance of anomalous pixels in each image. Band 21 (3.9 μm) was used for these plots. Points show the result for each image, and the line is a three point running mean of values. Courtesy Hawaii Institute of Geophysics and Planetology and British Antarctic Survey.

LeMasurier, W.E., and Thomson, J.W. (eds), 1990, *Volcanoes of the Antarctic Plate and Southern Oceans*: American Geophysical Union, Washington, D.C., AGU Monograph, Antarctic Research Series, v. 48.

Wright, R., Flynn, L.P., Garbeil, H., Harris, A.J.L., and Pilger, E., 2002, Automated volcanic eruption detection using MODIS: *Remote Sensing of Environment*, v. 82, p. 135-155.

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Deception Island

Antarctica

62.97°S, 60.65°W; summit elev. 576 m

The Deception Volcano Observatory has monitored the volcano every austral summer since 1993. Investigations of fumarole geochemistry, thermal anomalies, and volcanic activity were made during the summer survey of 2000 and 2002 by the Argentina Research Group. Compared to measurements made during the latest surveys, temperatures of fumaroles and hot soils remained stable at 99-101°C in Fumarole Bay, 97°C on Caliente Hill, 65°C in Whalers Bay, 41°C in Telefon Bay, and 70°C in Pendulum Cove (figure 8).

Following a possible magma intrusion during the summer of 1999 (*Bulletin* v. 24, no. 5), the composition of gases from fumarolic vents at Fumarole Bay changed compared to previous surveys. The chemical composition of the fumarolic gases was mainly H₂O (70-95 vol. %), CO₂ (5-30%), H₂S (0.1-0.3%), and SO₂ (0.01-0.08%). For the

first time, SO₂ was detected. Elemental sulfur and iron sulfide coatings on lapilli were found around the vent outlets and at a few centimeters of depth, respectively. Elemental sulfur and iron sulfide occurrences were intermittent during the 2000 and 2002 summer surveys.

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. dos Santos Afonso, and M. Agosto, Universidad de Buenos Aires, Instituto Antártico Argentino, Ciudad Universitaria, Pabellón 2, C1428EHA Buenos Aires, Argentina (Email: acaselli@gl.fcen.uba.ar).

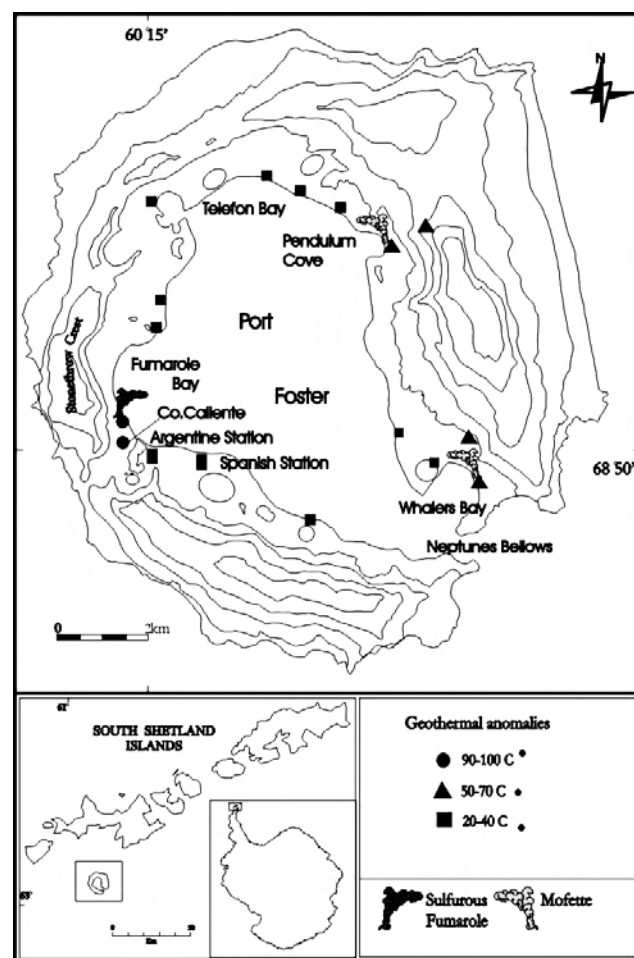


Figure 8. Map of Deception Island showing the area of geothermal anomalies during austral summer 2002. Courtesy of A.T.Caselli, M. dos Santos Afonso, and M. Agosto.

Reventador

Ecuador

0.078°S, 77.656°W; summit elev. 3,562 m

All times are local (= UTC - 5 hours)

On 3 November 2002, an unexpected eruption occurred at Reventador (*Bulletin* v. 27, no. 11). The following report provides an update on recent activity and additional information about the November eruption, including discussion of a site visit after the eruption and satellite data.

Recent activity. Seismicity was low during mid-December 2002. On 10 January, Instituto Geofísico (IG) reported that several lahars occurred that day in the Marquer and Reventador rivers. Ashfall was reported in the N sector of Quito, ~ 90 km to the WSW. In the afternoon a bluish gas column was observed exiting the crater. IG personnel stated that lava was slowly advancing and that 80-90% of the 3 November 2003 pyroclastic-flow deposits were covered by lahars.

During late February, rain generated mudflows that ended near the Montana River and disrupted traffic on a highway. White steam exited the volcano. Seismicity remained low, and was characterized by bands of harmonic tremor and volcano-tectonic (VT) earthquakes.

Intense rains during the first few days of March caused mudflows and again disrupted traffic. A gas column reached 300-500 m above the summit. Low-level seismicity was characterized by bands of harmonic tremor and a few isolated earthquakes. The seismic station in Copete registered high-frequency signals associated with lahars.

Site visit during 17-19 November 2002. The following report of an investigation of the 3 November 2002 explosion (*Bulletin* v. 27, no. 11) was submitted by Claus Siebe (Instituto Geofísico (IG), UNAM). Siebe, Jesús Manuel Macías, and Aurelio Fernández were able to fly to Quito on 17 November. On 18 November they interviewed Ing. Marcelo Riaño (general manager of the Trans-Equatorial Oil-Pipeline) as well as Patricia Mothes, Minard Hall, and Hugo Yepes (IG).

On 19 November they arrived in El Chaco (~ 34 km from Reventador) and traveled to the confluences of the Ríos Marker and Montana with the Río Coca (both are located 8 km from the crater). A small apron of fresh lahar deposits ~ 300 m wide covered the area adjacent to the Río Marker where the road had been before the 3 November eruption. Several dozens of workers with heavy machinery were trying to make a temporary passage over the gravel and boulder surface for the waiting trucks. For a few minutes they could see for the first and only time a ~ 1-km-high brownish ash column rising from the crater before incoming clouds hindered further visual contact.

“At the time of our visit, the Río Marker was diminished to such an extent that we could jump from boulder to boulder from one side to the other of the stream without getting wet. The vegetation around the confluence of the rivers was completely destroyed, and surviving trees were scorched and defoliated. The base layer of the fresh deposits consisted of up to 2.5-m-thick, partly matrix-supported, partly clast-supported pyroclastic-flow deposit with abundant wood and charcoal fragments (abundant scoriaceous boulder- and gravel-sized clasts were subrounded while dense clasts were angular). This was overlain by a sequence of

several sandy-gravelly lahar units with abundant charcoal supporting larger boulders as well as clasts from the underlying pyroclastic-flow deposit.

About 400 m from the Río Marker, after passing a narrow zone of unaffected vegetation, we were able to reach the Río Montana, where a similar situation was encountered (figure 9). Here, at places the lahar deposits were still steaming with a sulfurous smell. The bridge over the river was destroyed, but the oil pipeline was still basically intact (figure 10). Since the area did not seem safe (the last lahar had been emplaced less than 24 hours prior) the team returned to El Chaco, where they interviewed several people and obtained photographs of the pyroclastic flow and its deposits taken on 3 November 2002 (figures 11-13).

At about 2200 we drove to the summit of a hill (2,959 m elevation) N of Sta. Rosa, 27.5 km from the summit of Reventador. Although the night was clear and we had a good view, the summit was covered by clouds and no incandescence from an advancing lava flow could be seen.

From conversations with personnel from PETROECUADOR, road workers, peasants, etc., the team obtained the following information. Workers from TECHINT, an Argentinian company building a second pipeline parallel to the existing one, were at their campsite near the Río Montana when the eruption started in the early hours of 3 November (it was still dark). The eruption came without prior warning, but they were able to evacuate before strong explosions around 0900 sent pyroclastic flows along the Ríos Montana and Marker. These flows destroyed the road and parts of the new pipeline still under construction. The old pipeline was displaced several meters horizontally but never broke. At places the pyroclastic-flow deposits came to rest in direct contact with the tube. Temperature measurements at points of contact yielded values of 80°C. In subsequent days several lahars came down the Ríos Montana and Marker after heavy rains, further damaging the road (but not the pipeline). The pipeline has continued its operation; it delivers more than 400,000 barrels of oil per day to the Pacific coast.

Inhabitants of the small village of El Reventador, located ~ 12 km downstream from the confluence of the Ríos Montana and Coca voluntarily evacuated their homes when they heard the explosions around 0900.

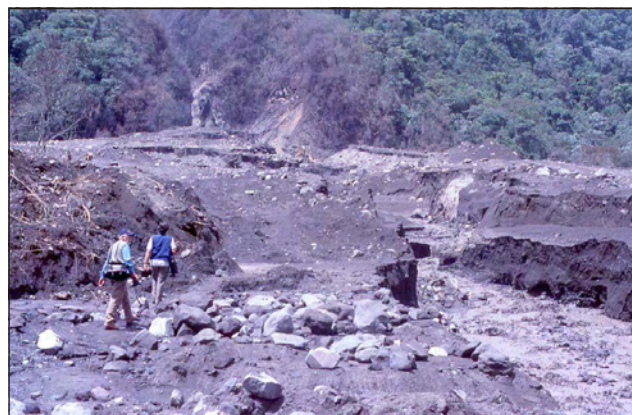


Figure 9. Fresh lahar deposits at Reventador near the confluence of Río Montana with Río Coca on 19 November 2002. According to workers trying to repair the road the still-warm and steaming surface of the lahar deposit shown in the photo was produced during the afternoon of 18 November after heavy rain. This was the 10th lahar event since 3 November. Courtesy of Claus Siebe.

One of the scoriaceous juvenile rock samples collected near the confluence of Río Marker with Río Coca was analyzed by X-ray fluorescence and thin sections were made of the same sample. The results revealed that the rock is an andesite ($\text{SiO}_2 = 58.1\%$) similar in composition to those erupted in 1976 (55-58% SiO_2).

Satellite data. Simon Carn (NASA/UMBC) reported that TOMS observations of the Reventador eruption clouds



Figure 10. Photo looking downstream near the confluence of Río Montana with Río Coca on the ESE flank of Reventador. In the foreground are the fresh lahar deposits. In the middle ground is the destroyed concrete bridge over the Río Montana as well as the oil-pipeline immediately behind. The bulldozer is trying to build a temporary passage for hundreds of trucks waiting on both sides of the road. In the background is the Río Coca with distal-debris avalanche deposit (19,000 Y BP) forming the vegetated hills behind the river. Photo taken on 19 November shortly after 1300 by Claus Siebe. Courtesy of Claus Siebe.



Figure 11. Pyroclastic flow descending Reventador's SE slopes during the morning of 3 November 2002. Photo was taken from the E (Transoceanic road in the foreground). This anonymous photo was purchased at a small hotel in El Chaco. Courtesy of Claus Siebe.



Figure 12. Fresh pyroclastic-flow deposits from Reventador, produced on 3 November 2002, ponding against the bridge over the Río Montana. This anonymous photo was purchased at a small hotel in El Chaco. Courtesy of Claus Siebe.



Figure 13. Distal pyroclastic-flow deposits from Reventador and scorched vegetation along the Transoceanic oil-pipeline near the confluence of the Río Montana with the Río Coca. This anonymous photo was purchased at a small hotel in El Chaco. Courtesy of Claus Siebe.

during 3-4 November suggest modest SO_2 burdens and spatial separation of the emitted SO_2 and ash. Carn, with input from Andy Harris, also constructed a timeline of notable events during 3-6 November along with potentially useful satellite images and overpasses (table 1).

The TOMS overpass at 1543 UTC on 3 November captured the early phase of the eruption. An ash signal was localized over the volcano and a more extensive SO_2 cloud containing ~ 12 kilotons SO_2 was spreading E and W.

At 1632 UTC on 4 November, TOMS detected several distinct cloud masses. A cloud containing no detectable ash and ~ 11 kilotons SO_2 was situated E of Ecuador on the Peru/Colombia border, a maximum distance of ~ 600 km from Reventador beyond which a data gap intervened. A second cloud containing ~ 42 kilotons SO_2 and a weak ash signal was observed over the Pacific Ocean around 700 km from the volcano. The highest ash concentrations were detected in a cloud straddling the coast of Ecuador ~ 260 km W of the volcano that covered ~ 70,000 km^2 . This cloud contained little SO_2 . It is assumed that these clouds (total ~ 53 kilotons SO_2) were erupted on 3 November.

A plume was also detected extending ~ 200 km W of Reventador, containing ~ 10 kilotons SO_2 . Based on high temporal resolution GOES imagery this plume first ap-

peared sometime between 1045 UTC and 1115 UTC on 4 November. Nearby Guagua Pichincha was also reported active at this time by the Washington VAAC, and may have contributed some SO₂; the highest SO₂ concentrations in the Reventador plume were measured in the TOMS pixel covering Guagua Pichincha.

On 5 November neither SO₂ nor ash were detected by TOMS, although a ~ 700-km-wide data gap occurred off the coast of Ecuador. The TOMS orbit was better placed on 6 November but no SO₂ or ash were apparent. However, renewed SO₂ emissions were detected on 7 November.

Background. Reventador is the most frequently active

of a chain of Ecuadorian volcanoes in the Cordillera Real, well E of the principal volcanic axis. It is a forested stratovolcano that rises above the remote jungles of the western Amazon basin. A 3-km-wide caldera breached to the E was formed by edifice collapse and is partially filled by a young, unvegetated stratovolcano that rises about 1,300 m above the caldera floor. 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.

Information Contacts: *P. Ramon, M. Hall, P. Mothes, and H. Yepes*, Instituto Geofísico (IG), Escuela Politécnica Nacional, Quito (Email: geofisico@accessinter.net, URL: <http://www.igepn.edu.ec/>,); *Simon A. Carn*, Joint Center for Earth Systems Technology (NASA/UMBC), University of Maryland-Baltimore County, 1000 Hilltop Circle, Baltimore, MD (Email: scarn@umbc.edu, URL: <http://www.jcet.umbc.edu/>); *Andy Harris*, HIGP/SOEST, University of Hawaii at Manoa, HI 96822 USA (Email: harris@pgd.hawaii.edu, URL: <http://goes.higp.hawaii.edu/>); *Claus Siebe and Gabriel Valdez Moreno*, Instituto de Geofísica, UNAM, Mexico, D.F (Email: csiebe@tonatiuh.igeofcu.unam.mx, valdezmm@servidor.unam.mx); *Jesús Manuel Macías*, CIESAS-Mexico, Juárez 87, Tlalpan, DF. CP14000 (Email: macserr@att.net.mx); *Aurelio Fernández Fuentes*, Centro Universitario de Prevención de Desastres, Universidad de Puebla, Mexico (Email: aureliooff@hotmail.com); *Washington Volcanic Ash Advisory Center (VAAC)*, Satellite Analysis Branch (SAB), NOAA/NESDIS E/SP23, NOAA Science Center Room 401, 5200 Auth Road, Camp Springs, MD 20746 USA (URL: <http://www.ssd.noaa.gov/>).

Date	Time (UTC)	Satellite	Event
3 Nov 2002	0700		Seismic events recorded
3 Nov 2002	0945	GOES-8	Clear- no hot spot
3 Nov 2002	1000		Eruption begins; 3 km ash column, incandescent ejecta
3 Nov 2002	1015, 1045, 1115	GOES-8	Clear-no hot spot
3 Nov 2002	1245, 1315, 1345	GOES-8	Ash
3 Nov 2002	1400		Main eruption phase; pyroclastic flows reported
3 Nov 2002	1415	GOES-8	Ash, ring-shaped cloud?
3 Nov 2002	1445	GOES-8	Ash
3 Nov 2002	1510	MODIS Terra	Ash
3 Nov 2002	1515	GOES-8	Ash
3 Nov 2002	1530	GOME	SO ₂
3 Nov 2002	1543	EP TOMS	SO ₂ , ash
3 Nov 2002	1545, 1615, 1645	GOES-8	Ash
3 Nov 2002	1707	NOAA-16 AVHRR	Ash
3 Nov 2002	1715	GOES-8	Ash
3 Nov 2002	1722	SeaWiFS	Ash
3 Nov 2002	1745	GOES-8	Ash
3 Nov 2002	1810		Ash begins to fall in Quito
3 Nov 2002	1815, 1845, 1915, 1945	GOES-8	Ash
3 Nov 2002	2000		Ash covers large area of Ecuador, reaching coast
3 Nov 2002	2015	GOES-8	Ash, gravity waves?
3 Nov 2002	2045, 2115, 2145, 2215	GOES-8	Ash, gravity waves
4 Nov 2002	0345, 0415, 0445, 0515, 0545, 0615	GOES-8	Cloud-covered
4 Nov 2002	0625	MODIS Aqua	Ash, SO ₂
4 Nov 2002	0645	GOES-8	Cloud clearing- possible hot spot
4 Nov 2002	0710	NOAA-16 AVHRR	Ash
4 Nov 2002	0715, 0745	GOES-8	Hot spot
4 Nov 2002	0815, 0845	GOES-8	Strong hot spot and plume
4 Nov 2002	0915	GOES-8	Strong hot spot and minor plume
4 Nov 2002	0945, 1015	GOES-8	Strong hot and detached minor plume
4 Nov 2002	1045	GOES-8	Hot spot
4 Nov 2002	1115	GOES-8	Ash, strong hot spot and main plume
4 Nov 2002	1145, 1215, 1245, 1315, 1345, 1415	GOES-8	Ash, main plume extends W
4 Nov 2002	1445	GOES-8	Ash, main plume (N arm) reaches coast
4 Nov 2002	1515	GOES-8	Ash
4 Nov 2002	1530	GOME	SO ₂
4 Nov 2002	1555	MODIS Terra	SO ₂
4 Nov 2002	1632	EP TOMS	SO ₂ , ash
4 Nov 2002	1715	GOES-8	Plume still attached to hot spot
4 Nov 2002	1835	NOAA-16 AVHRR	Ash
4 Nov 2002	1845	MODIS Aqua	SO ₂
5 Nov 2002	1645, 1715, 1745	GOES-8	Low-level ash
5 Nov 2002	1815, 1845, 1915	GOES-8	Low-level ash
6 Nov 2002	1530	GOME	SO ₂
6 Nov 2002	1544, 1634, 1545, 1634, 1546	EP TOMS	SO ₂

Table 1. Preliminary timeline of the November 2002 eruption of Reventador, compiled using satellite imagery and information from IG and the Washington VAAC. Courtesy of Simon Carn and Andy Harris.

Galeras

Colombia

1.22°N, 77.37°W; summit elev. 4,276 m

A slight increase in the number of volcano-tectonic (VT) and long-period (LP) events occurred during April through September 2002, although the energy levels diminished. Between October and December 2002, scientists noted a small decrease in VT seismicity and a considerable increase in seismic activity related to fluid-movement. An increase in LP signals, difficult to classify due to their non-typical signatures, coincided with strong rainfall over Pasto and the volcano. The geothermal system at Galeras, with fumarolic zones having temperatures between 100 and 370°C, easily interacts with rainwater, producing exothermic reactions with seismic and near-surface manifestations.

During April-June, there were 191 VT events with a seismic energy release of 1.08×10^{16} erg. Both the number of events and the total energy increased during July-September, when 209 VT events with a seismic energy release of 5.64×10^{15} erg were recorded. In comparison, there were 197 VT events with an energy release of 2.86×10^{15} erg during October-December. The vast majority of the events occurred close to the active crater and in the volcanic edifice. Other earthquakes occurred at depths of 0.2-16 km beneath the summit throughout the second half of 2002.

Volcano-tectonic earthquakes were felt in Pasto on 8 April (2 km deep, M_L 3.6), 17 April (2 km deep, M_L 4.2), 28 April (12 km deep, M_L 3.2), 24 May (8 km deep, M_L 2.3), 21 June (9 km deep, M_L 3.0), 22 July (5 km deep, M_L 2.7), and 1 November (5 km depth, M_L 3.2, 3.8 km from the crater). The 17 April event was followed by 12 aftershocks from the main crater area; the strongest was M_L 2.6. In Consacá, two events were felt on 12 August within 4 minutes of each other (5 km deep, M_L 2.9 and 3.4). The strongest 12 August earthquake was located ~ 6 km SW of the crater. A strong event on 20 December (4 km deep, M_L 3.6) was felt in the town of Yacuanquer and was centered ~ 5 km SW of the active crater.

During April-June, 111 LP events and 82 spasmodic tremor episodes were registered with a total energy release of 2.89×10^{14} erg. Some spasmodic tremor episodes were harmonic, with dominant frequencies of 2.5-2.7 Hz. Seismic events related to fluid movements during July through September had low frequencies between 2 and 3 Hz and high frequencies of 10.5, 12.1, 13.7, and 14.1 Hz. These frequencies appeared all over the local reporting stations. In total, there were 161 registered LP events and 17 spasmodic tremor episodes with a total energy release of 1.1×10^{14} erg. In addition, some spasmodic tremor episodes were of the harmonic type with dominant frequencies of 2.5 and 3.0 Hz. During October-December the frequencies exhibited spikes between 10 and 16 Hz. Sometimes these events showed one or more precursor signals with very short amplitude and appeared in doubles or triplets. The frequencies kept on time over many stations indicating a processes more directly related to the source rather than the path or station site. Overall, there were 1,541 LP events and 209 spasmodic tremor episodes in October-December with a total energy release of 2.65×10^{15} erg.

Reactivation of El Pinta Crater. Slight gas emissions were observed at the end of May from the El Pinta crater (E

of the main crater), inactive since 1991. On 5 June 2002 began the number of daily seismic events increased. A team visiting the summit on 7 June noted an increase in the quantity and pressure of gas emissions at different points of the main crater and in El Pinta. However, temperatures did not show significant variations compared to previous months. Elevated temperatures were observed toward the SW sector of the active cone with values of 340°C at the Las Chavas fumarole field. Also on 7 June spasmodic tremor was registered at the observatory that signified a hydrothermal event. A subsequent field inspection observed a fine layer of ash and precipitate sulfur, besides great gas emission from El Pinta. The material emitted by El Pinta consisted of lapilli, ash, and clay; a high percentage of the sample was pre-existing material. Some reports of gas emissions coincide with spasmodic tremor records at the Galeras observatory site. After 11 June this activity began to decrease. The VT earthquakes that accompanied this activity were located in the main crater zone with depths to 3 km.

Background. Galeras, a stratovolcano with a large breached caldera located immediately west of the city of Pasto, is one of Colombia's most frequently active volcanoes. The Galeras volcanic complex has been active for more than 1 million years, and two major caldera collapse eruptions took place during the late Pleistocene. Longterm extensive hydrothermal alteration has affected the volcano. This has contributed to large-scale edifice collapse that has occurred on at least three occasions, producing debris avalanches that swept to the west and left a large horseshoe-shaped caldera inside which the modern cone has been constructed. Major explosive eruptions since the mid Holocene have produced widespread tephra deposits and pyroclastic flows that swept all but the southern flanks. A central cone slightly lower than the caldera rim has been the site of numerous small-to-moderate historical eruptions since the time of the Spanish conquistadors.

Information Contacts: Marta Calvache, Observatorio Vulcanológico y Sismológico de Pasto (OVSP), IN-GEOMINAS, Carrera 31, #18-07 Parque Infantil, P.O. Box 1795, Pasto, Colombia (URL: <http://www.ingomin.gov.co/pasto/>; Email: ovp@ingomin.gov.co).

Soufrière Hills

Montserrat, West Indies

16.72°N, 62.18°W; summit elev. 915 m

All times are local (= UTC - 4 hours)

During mid-September 2002 through February 2003 at Soufrière Hills, the dome continued to grow, producing numerous rockfalls and small-to-moderate pyroclastic flows. Most of the activity was concentrated on the NE and N flanks, producing numerous pyroclastic flows in White's Ghaut, the Tar River Valley, and Tuitt's Ghaut. Pyroclastic flows and rockfalls also traveled down the W and NW flanks. Ashfall affected surrounding areas, accumulating in thicknesses up to 9 mm. The Washington VAAC issued notices to the aviation community almost daily. Seismicity was dominated by rockfalls (table 2).

Activity during September 2002. Lava-dome growth was directed to the NE during 13-20 September, with fre-

quent rockfalls and small pyroclastic flows sending material to a sector extending from the central Tar River Valley on the E flank to the NE flanks above Tuitt's Ghaut. Some material tumbled through a notch onto the N flank. A major change in direction of extrusion followed a hybrid earthquake swarm between 0703 and 1515 on 19 September. Growth of the previously active NE lobe stagnated during 21–22 September. A near-vertical spine was extruded in the central area around the 21st, possibly indicating a switch in growth direction. On 26 September a swarm of 36 hybrid events occurred between 0330 and 1112. The same day observations revealed a large new dome lobe that had extruded towards the W in the area previously known as Gages Wall. Material spalling off of this lobe produced rockfalls and small pyroclastic flows down Gages Valley that reached up to 1 km.

Notable pyroclastic flows occurred on the evening of 25 September and the morning of the 27th. Growth and rockfall activity then changed towards the N flanks, suggesting a possible stagnation of the recently extruded western lobe. Spectacular incandescence and semi-continuous rockfall activity were observed on the NE and N flanks of the dome on the night of 26–27 September.

On 27 September a 4-hour-period of heightened activity occurred in the afternoon and evening, with small semi-continuous pyroclastic flows traveling down the N flanks and eastwards into the upper portions of Tuitt's Ghaut and then into White's Bottom Ghaut. A newly extruded lobe was visible on 28 September almost directly to the NW with a broad headwall over the N, NW, and W flanks. On the evening of 29 September there was another period of

heightened activity on the N flanks that lasted 1.5 hours, with pyroclastic flows just reaching the sea along White's Bottom Ghaut. It was estimated that during this event only $2\text{--}3 \times 10^6 \text{ m}^3$ of the N edge of the active NW lobe was shed.

The Washington VAAC reported that a low-level ash cloud from an emission at 1510 on 29 September was visible over eastern Puerto Rico on satellite imagery through the following day. On 30 September a light dusting of white ash fell in eastern Puerto Rico at Roosevelt Roads Naval Air Station.

Activity during October 2002. Observations on 1 October revealed that re-growth of the collapsed area had occurred. A brief period of heavy rain on 2 October triggered a moderate-sized mudflow down the Belham Valley. Analysis of seismic data suggested that pyroclastic-flow activity on 2 October began at 1310, and sustained dome collapse continued for 6 hours. Low-energy pyroclastic flows were observed reaching the sea on the Tar River's flanks throughout the collapse, and ash clouds were produced that drifted to the NW. Heavy ashfall occurred in the residential areas of Salem, Old Towne, and Olveston, with deposits up to 9 mm thick. Subsequent observations revealed that this collapse was confined to the E flanks, and that this was again a relatively small event (less than $5 \times 10^6 \text{ m}^3$ of material was shed off of the E side of the dome complex).

According to the Washington VAAC, after daybreak on 3 October there were several reports of ashfall in Puerto Rico, and visible satellite imagery at 1115 confirmed that an ash cloud around 2.4 km altitude covered most of the island. At 1615 the area of very thin ash was not visible on satellite imagery. By the next day, ash from the previous day's emissions had drifted W, and around 0902 it was located over southern Puerto Rico. A thin plume of ash also extended SSW of St. Croix island.

Early in October the NW extrusion lobe of the lava dome grew to the NW, but later growth remained more centralized and there was noticeable bulking up of the lobe's summit area. Talus continued to accumulate behind the NW buttress and in the head of Tyre's Ghaut. Minor mudflow activity occurred on 9 October. The growth of the lava dome towards the NW prompted the evacuation of populated areas along the fringes of the lower part of the Belham Valley (~ 300 people) on 8 and 9 October, and the area was declared part of the Exclusion Zone. A relatively small pyroclastic flow traveled NNE down the flanks on 13 October.

On the afternoon of 22 October intense rainfall at midday produced large mudflows NW in the Belham Valley. At the peak of flow, the entire width of the valley floor at Belham Bridge was flooded and standing waves up to 2.5 m high were observed. By

Date (2002-2003)	Rockfall signals	Hybrid events	Long-period (LP) events	LP Rockfalls	Volcano-tectonic (VT) events
13 Sep-20 Sep 2002	689	67	162	41	1
20 Sep-27 Sep 2002	680	36	260	55	0
27 Sep-04 Oct 2002	811	15	223	51	2
04 Oct-11 Oct 2002*	468	3	77	42	0
11 Oct-18 Oct 2002*	650	2	98	80	1
18 Oct-25 Oct 2002	536	6	120	27	1
25 Oct-1 Nov 2002	670	9	148	72	0
01 Nov-08 Nov 2002	694	3	60	38	0
08 Nov-15 Nov 2002*	409	0	29	8	1
15 Nov-22 Nov 2002	592	2	88	37	1
22 Nov-29 Nov 2002	586	0	44	32	0
29 Nov-06 Dec 2002	354	0	33	43	0
06 Dec-13 Dec 2002	427	6	47	30	0
13 Dec-20 Dec 2002	742	2	50	50	0
20 Dec-27 Dec 2002	760	5	45	30	0
27 Dec-03 Jan 2003	863	3	86	41	1
03 Jan-10 Jan 2003	789	0	120	54	0
10 Jan-17 Jan 2003	606	7	67	42	2
17 Jan-24 Jan 2003	566	0	58	24	1
24 Jan-31 Jan 2003	745	2	177	62	1
31 Jan-07 Feb 2003	882	6	148	114	
07 Feb-14 Feb 2003	840	3	117	78	1
14 Feb-21 Feb 2003	905	8	87	80	1
21 Feb-28 Feb 2003	1078	1	92	85	0

Table 2. Seismicity at Soufrière Hills during 13 September 2002–28 February 2003. *During some weeks, the number of seismic events was under-represented because of problems with the seismic stations. Courtesy MVO.

1430, pyroclastic-flow activity began. For several hours, pyroclastic flows from the N flank of the dome were channeled NE into the upper parts of Tuitt's Ghaut, from where they crossed over into White's Bottom Ghaut. Flows also occurred on the dome's E flank in the Tar River Valley.

The volcano was observed using a remote camera and during a flight on 31 October. The active extruded lobe in the NW continued to steadily grow, bulking out on the N and W sides. Rockfalls and pyroclastic flows traveled down the E and N flanks, particularly within Tuitt's Ghaut and the Tar River Valley. A considerable amount of debris also spalled off the W flank of the active extruded lobe and accumulated in the upper parts of Fort Ghaut.

Activity during November 2002. During early November lava-dome growth on the N part of the dome was less directed, with rockfalls dispersed over the summit and flanks. The lobe shed rockfall debris predominately down Tuitt's Ghaut and Tar River Valley, although also onto the NW flank and into the top of Gage's Valley. According to the Washington VAAC, on 8 November strong pyroclastic flows produced ash-and-gas clouds to a height of ~1.5 km.

On 8 and 9 November pyroclastic flows traveled 900-1,000 m NW into Tyer's Ghaut at the headwaters of the Belham Valley. During 12-15 November, the size and energy of the pyroclastic flows increased slightly. During 15-19 November, small pyroclastic flows traveled 1-1.5 km from the dome every few hours in Tuitt's Ghaut to the NE and in the Tar River Valley to the E. On 29 November the active lobe had a broad whaleback-shaped upper surface, which was oriented towards the NNE.

During 29 November-6 December a number of small, short-lived spines formed at the base of the active lobe in the N part of the dome complex, shedding material E into White's Ghaut and the Tar River Valley. Lava blocks continued to spall off the front of the lobe, shedding material NE into Tuitt's Ghaut and onto the northern talus slope. An average of one moderate-sized pyroclastic flow occurred per day and traveled no farther than 1-1.5 km from the lava dome into Tuitt's and White's ghauts and into the Tar River Valley. During 5-6 December, rockfalls and small pyroclastic flows occurred more frequently on the northern talus slope and on the NW, at the top of Tyer's Ghaut.

Activity during December 2002. A sustained dome collapse began on 8 December at 2045, producing energetic pyroclastic flows down White's Ghaut to the sea at Spanish Point. Ash clouds rose to ~3 km altitude and drifted WNW. In Plymouth and Richmond Hill 4 mm of ash was deposited. Seismicity returned to background levels on 9 December by 0045, and several days of weak tremor occurred.

The collapse scar on the dome's NNE flank, estimated to have had a volume of $4.5 \times 10^6 \text{ m}^3$, was being filled rapidly with freshly extruded lava. Observations on 13 December revealed a large amount of fragmental lava extruded in a northerly direction on the summit. A large spine was also extruded on the NW side of the summit.

During late December spectacular incandescence of the dome was observed on most nights. Activity increased during 18-20 December, and on 19 December mudflows occurred in White River, Tar River Valley, and Fort Ghaut. During 20-27 December extrusion occurred on the N, and occasionally NW, sides of the summit. A large spine was pushed up at the back of the active extruded lobe during the night of 26-27 December, but was not visible by 2 January. The Washington VAAC reported that on 28 December

around 1130 a 3-km-high ash cloud generated from pyroclastic flows drifted over the islands of St. Kitts and Nevis.

Activity during January-February 2003. Activity escalated to very high levels on the night of 27 December. During 27 December-10 January continuous rockfalls and numerous pyroclastic flows spalled off the active extruded lobe on the NNE side of the lava dome. Activity decreased on the night of 2 January to moderate levels on the 3rd.

During mid-January, activity generally declined to a moderate level. During 15-17 January almost all pyroclastic flows occurred in the Tar River Valley, with only minor rockfalls traveling down the dome's NE and N sides. Lava extrusion occurred NE of the lava-dome complex that was associated with rockfalls and small pyroclastic flows down Tar River Valley, White's Ghaut, Tuitt's Ghaut, and on the northern talus slopes. On 18, 20, and 24 January small pyroclastic flows traveled ~1 km down Tyer's Ghaut.

Activity increased during late January. Growth of the active extrusion lobe continued on the N side of the lava dome. The direction of growth was generally towards the NNE, although the focus of rockfall and pyroclastic-flow activity varied from day to day. A pulse of activity occurred at midday on 30 January, during which pyroclastic flows simultaneously descended several flanks of the lava dome traveling to the Tar River Valley, White's Ghaut, Tuitt's Ghaut, and W to Fort Ghaut.

During 31 January-14 February activity remained moderate. Growth of the lava dome was focused on a large, steep lobe directed to the NE. A small amount of rockfall material was directed W towards Fort Ghaut. Rockfalls and small pyroclastic flows also occurred off the N flank of the dome onto the area of Riley's Estate.

During 19-25 February pyroclastic flows and rockfalls were concentrated more on the E flank of the lava dome and in the Tar River Valley, although there were several periods of activity on the N flank, with pyroclastic flows in Tuitt's Ghaut and at the top of Farrell's Plain.

Activity increased slightly during 21-28 February. During an observation flight on 27 February lava-dome growth was concentrated towards the NE. Pyroclastic flows and rockfalls traveled down the lava dome's E and NE flanks via the Tar River Valley and Tuitt's Ghaut. There were also several periods of activity on the N flank, with pyroclastic flows at the top of Farrell's Plain.

SO₂ emission rates varied throughout the report period (table 3), and were especially high following the dome-collapse event on 9 December (2,350 tons per day average).

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 a 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 Road, Camp Springs, MD 20746 USA (URL: <http://www.ssd.noaa.gov/>); *Associated Press*.

Popocatépetl

central México

19.023°N, 98.622°W; summit elev. 5,426 m

All times are local (= UTC - 6 hours)

From November 2002 through mid-February 2003, volcanic activity at Popocatépetl was similar to that during July-October 2002 (*Bulletin* v. 27, no. 10). Activity consisted principally of small-to-moderate eruptions of steam, gas, and minor amounts of ash, and occasional explosions that ejected incandescent fragments for short distances. Larger explosions on 6 November, 18 and 23 December 2003, 9 January, and during 4-10 February 2003 produced ash plumes that reached approximate heights of 4, 2, 2, 3, and 2 km above the crater, respectively. Volcano-tectonic (VT) earthquakes (M 2.0-3.2) occurred frequently, most located to the SE, N, and E at depths up to 7.5 km beneath the crater. Episodes of harmonic and low-amplitude tremor were registered almost daily, typically for a few hours.

Until November, the daily emissions reported by the Centro Nacional de Prevención de Desastres (CENAPRED) typically numbered from as few as 5 to as many as 20. In late November, this number increased markedly with 78 detected on 24 November and 40 the following day. Subsequently the daily number of these small-to-moderate emissions occasionally exceeded 30 through mid-February 2003.

New episodes of low-frequency tremor, beginning on 19 November, signaled the growth of a new lava dome within the crater. Aerial photographs obtained by the Mexican Ministry of Communications and Transportation on 2 December confirmed the presence of a fresh lava dome with a base diameter of 180 m, and a height of ~ 52 m. CENAPRED reported that the explosive activity reported on 18 and 23 December was related to the destruction of the lava dome. Photographs of the lava dome taken on 9 January revealed that the dome's inner crater had subsided. The volume of dome material ejected during the December explosions was calculated to be ~ 500,000 m³.

CENAPRED stated that explosive activity beginning in mid-January was related to the growth of a new lava dome in the crater. On 22 January a significant increase in volcanic microseismicity was recorded. According to the Washington Volcano Ash Advisory Center, on 25 January an ash emission reached ~ 10.7 km altitude. The explosion on 4 February ejected incandescent volcanic material that fell as far as ~ 2 km down the volcano's flanks. Similar emissions continued and were related to partial destruction of the lava dome. According to CENAPRED, as long as there are remains of a lava dome in the crater, a significant chance of further explosive activity remains, including ash emissions and incandescent ejections around the crater. The Alert Level remained at Yellow (second on a scale of three colors) and CENAPRED recommended that people avoid entering the restricted zone that extends 12 km from the crater. However, the road between Santiago Xalitintla (Puebla) and San Pedro Nexapa (Mexico State), including Paso de Cortés, remained open for controlled traffic.

Date (2002-2003)	SO ₂ emissions (tons/day)
13 Sept-20 Sept 2002	85-518
11 Oct-12 Oct 2002	260-520, average of 302
13 Oct 2002	430-860, average of 691
16 Oct 2002	43-173
17 Oct-18 Oct 2002	346-518
19 Oct-21 Oct 2002	85-300
23 Oct-25 Oct 2002	430-500, peak of 1000
25 Oct-27 Oct 2002	45-260
27 Oct 2002	520
27 Oct-01 Nov 2002	25-260
01 Nov 2002	240
02 Nov 2002	208
03 Nov 2002	200
04 Nov 2002	508
06 Nov-07 Nov 2002	220
08 Nov-15 Nov 2002	520-560
15 Nov 2002	160
16 Nov and 17 Nov 2002	340 and 380
18 Nov and 19 Nov 2002	180 and 173
22 Nov-29 Nov 2002	520-1040
24 Nov 2002	170-350
29 Nov-06 Dec 2002	Average 400
29 Nov-01 Dec 2002	Average 280
06 Dec-08 Dec 2002	280
09 Dec 2002	Average 2,350
10 Dec 2002	620
06 Jan 2003	130
07 Jan 2003	200
09 Jan 2003	430
10-17 Jan 2003	~86-1209
10 Jan 2003	~170-520, average ~260
11 Jan 2003	Emissions of ~430 were recorded until mid-morning, but then decreased to ~86 for several hours. In the afternoon they reached ~860-1210 before dropping to ~430-518
12 Jan 2003	~345-605, average ~354
13 Jan 2003	~430-780, average ~490
15 Jan 2003	~430-605, average ~527
18 Jan 2003	300
19 Jan 2003	165
20 Jan 2003	700
21 Jan-24 Jan 2003	270
24 Jan 2003	480
25 Jan-28 Jan 2003	290
29 Jan 2003	560
30 Jan 2003	620
31 Jan-07 Feb 2003	90-170
14 Feb-21 Feb 2003	170-350
21 Feb-28 Feb 2003	400-460
22 Feb 2003	840
23 Feb 2003	1120

Table 3. SO₂ emission rates at Soufrière Hills during 13 September 2002 through 28 February 2003. Courtesy MVO.

Background. Volcán Popocatépetl, whose name is the Aztec word for smoking mountain, towers to 5,426 m 70 km SE of Mexico City to form North America's 2nd-highest volcano. The glacier-clad stratovolcano contains a steep-walled, 250-450 m deep crater. The generally symmetrical volcano is modified by the sharp-peaked Ventorrillo on the NW, a remnant of an earlier volcano. At least three previous major cones were destroyed by gravitational failure during the Pleistocene, producing massive debris-avalanche deposits covering broad areas S of the volcano. The modern volcano was constructed to the S of the late Pleistocene to Holocene El Fraile cone. Three major plinian eruptions, the most recent of which took place about 800 AD, have occurred from Popocatépetl since the mid Holocene, accompanied by pyroclastic flows and voluminous lahars that swept basins below the volcano. Frequent historical eruptions, first recorded in Aztec codices, have occurred since precolumbian time.

Information Contacts: Alicia Martinez Bringas, Angel Gómez Vázquez, Roberto Quass Weppen, Enrique Guevara Ortiz, Gilberto Castelan, Gerardo Jimenez and Javier Ortiz, Centro Nacional de Prevención de Desastres (CENAPRED), Av. Delfín Madrigal No.665. Coyoacan, México D.F. 04360, Mexico (Email: amb@cenapred.unam.mx, gvazquez@cenapred.unam.mx; URL: <http://www.cenapred.unam.mx/>); Servando De la Cruz-Reyna, Instituto de Geofísica, UNAM. Cd. Universitaria. Circuito Institutos. Coyoacán. México, D.F. 04510 (Email: sdela@tonatiuh.igeofcu.unam.mx; URL: <http://www.igeofcu.unam.mx/geofisica.html>); Washington Volcano Ash Advisory Center (VAAC), Satellite Analysis Branch (SAB), NOAA/NESDIS E/SP23, NOAA Science Center Room 401, 5200 Auth Road, Camp Springs, MD 20746 USA (URL: <http://www.ssd.noaa.gov/>); Associated Press.

Shiveluch

Kamchatka Peninsula, Russia

56.653°N, 161.360°E; summit elev. 3,283 m

All times are local (= UTC + 12 hours [or 13 hours in March-June])

During mid-September 2002 through February 2003 at Shiveluch, a lava dome continued to grow in the active crater. Short-lived explosions generally sent gas-steam plumes tens of meters to ~ 3 km above the dome. Seismicity remained above background levels. Earthquakes with magnitudes of ~ 2-2.7, as well as many smaller ones, occurred at depths of 0-6 km (table 4). Thermal anomalies were visible on satellite imagery (table 5). Intermittent spasmodic tremor with amplitudes of $0.3-1.3 \times 10^6$ mps occurred throughout the report period.

Incandescence was observed at the lava dome on 6 October. On 11 November, seismic data indicated possible hot avalanches sending clouds up to 5.5 km above the dome.

During late November and early December, gas-and-steam plumes extended > 10 km to the E and W. On 19 December, short-lived explosions at 1238 and 1514 sent gas-ash plumes to ~ 5.5 km and 5.0 km altitude, respectively. In the first case, pyroclastic flows moved to the SE; in the second, to the S, inside the Baidarnaya river. The runout of both pyroclastic flows was 3 km.

On 28 December 2002, a small amount of light-gray ash was observed on the surface of snow. During early January 2003, plumes extended > 5-10 km to the W and NW. During late February, plumes extended 10-40 km to the SW, S, and SE. Ash was noted in plumes on 24 October, 1, 11, 15, 19, and 20 November, 1, 19, and 24 December, 4 and 25 January, and 15, 17, 25, and 26 February. The Concern Color Code remained at Yellow.

Background. The high, isolated massif of Shiveluch volcano (also spelled Sheveluch) rises above the lowlands NNE of the Kliuchevskaya volcano group. The 1,300 km³ Shiveluch is one of Kamchatka's largest and most active volcanic structures. The summit of roughly 65,000-year-old Strary Shiveluch is truncated by a broad 9-km-wide late-Pleistocene caldera breached to the S. Many lava domes dot its outer flanks. The Molodoy Shiveluch lava dome complex was constructed during the Holocene within the large horseshoe-shaped caldera; Holocene lava dome extrusion also took place on the flanks of Strary Shiveluch. At least 60 large eruptions of Shiveluch have occurred during the Holocene, making it the most vigorous andesitic volcano of the Kuril-Kamchatka arc. Widespread tephra layers from these eruptions have provided valuable

Date (2002-2003)	Earthquakes	Magnitude	Explosions	Plume height above dome
26 Sept-04 Oct 2002	11	2-2.7	38	1-2.5 km
04 Oct-11 Oct 2002	7	2-2.4	16	1-2 km
11 Oct-18 Oct 2002	4	2-2.2	13	1-2.5 km
18 Oct-25 Oct 2002	—	—	10	1.0 km
25 Oct-01 Nov 2002	—	—	8	2 km
01 Nov-08 Nov 2002	—	—	7	2-3 km
11 Nov 2002	6	2.0-2.4	—	—
11 Nov-14 Nov 2002	5	2.0-2.4	7	2-3 km
14 Nov-20 Nov 2002	6	2.0	19	2-3 km
22 Nov-29 Nov 2002	2	1.9	8	1-2 km
29 Nov-06 Dec 2002	—	—	9	1-2 km
06 Dec-13 Dec 2002	3	1.7-2.3	8	1-2 km
13 Dec-20 Dec 2002	1	1.8	7	1-2 km
20 Dec-27 Dec 2002	—	—	6	2-3 km
27 Dec-03 Jan 2003	—	—	25	2 km
03 Jan-10 Jan 2003	—	—	11	1.5 km
10 Jan-17 Jan 2003	—	—	12	2 km
17 Jan-24 Jan 2003	—	—	11	2 km
31 Jan-07 Feb 2003	6	1.6-2.5	—	1.5 km
07 Feb-14 Feb 2003	—	—	10	1.0 km
14 Feb-21 Feb 2003	—	—	17	1.5 km
21 Feb-28 Feb 2003	1	2.1	14	3.0 km

Table 4. Earthquakes, explosions, and plumes at Shiveluch during 26 September 2002 through February 2003. Courtesy KVERT.

time markers for dating volcanic events in Kamchatka. Frequent collapses of dome complexes, most recently in 1964, have produced debris avalanches whose deposits cover much of the floor of the breached caldera.

Information Contacts: *Kamchatka Volcanic Eruptions Response Team (KVERT)*, Institute of Volcanic Geology and Geochemistry, Piip Ave. 9, Petropavlovsk-Kamchatskii 683006, Russia (Email: girina@kcs.iks.ru);

Alaska Volcano Observatory (AVO), a cooperative program of (a) U.S. Geological Survey, 4200 University Drive, Anchorage, AK 99508-4667, USA (URL: <http://www.avo.alaska.edu/>; Email: neal@usgs.gov), (b) Geophysical Institute, University of Alaska, P.O. Box 757320, Fairbanks, AK 99775-7320, USA, and (c) Alaska Division of Geological and Geophysical Surveys, 794 University Ave., Suite 200, Fairbanks, AK 99709, USA.

Date (2002-2003)	Number of pixels	Maximum band-3 temperature	Background temperature	Comment
02 Oct 2002	2-3	40.46-45.48°C	~ -10 to -3°C	A 15 km faint plume extended to the SE
27 and 30 Sep,	2-4	—	—	On 2 October, an 80-km plume extending to the SE was observed in a NOAA16 image
01 Oct-03 Oct 2002	—	—	—	—
05 Oct-07 Oct 2002	2-8	36.81-49.35°C	?-14-0°C	On 6 October, a 111-km plume extended to the SE
09 Oct-10 Oct 2002	2-8	—	—	—
11 Oct-13 Oct 2002	2	15-49°C	-19 to -6°C	—
12 Oct-14 Oct 2002	2-3	—	—	—
21 Oct-22 Oct,	1-8	33-49°C	-20 to -1°C	On 22 October a faint plume extended 125 km to the SE
24 Oct-25 Oct 2002	—	—	—	—
21 Oct-24 Oct 2002	1-5	—	—	NOAA12, NOAA16, and MODIS imagery
27 Oct-30 Oct 2002	2-6	17-36°C	-22 to -6°C	AVHRR
27 Oct-30 Oct 2002	2-6	—	—	NOAA12, NOAA16, MODIS
08 Nov-09 Nov 2002	2-4	34-49°C	-20 to -4°C	AVHRR; On 8 November a faint ~11-km-long plume extended to the SE, visible on band-3
08 Nov and 09 Nov 2002	4, 9	—	—	MODIS
08 Nov-11 Nov 2002	2-4	—	—	NOAA12 and NOAA16
11 Nov and 13 Nov 2002	4-5	40-49°C	-18 to -10°C	AVHRR
11 Nov-13 Nov 2002	2-5	—	—	NOAA12 and NOAA16
13 Nov 2002	4	—	—	MODIS from Sakhalin
16 Nov-19 Nov and 22 Nov 2002	2-6	2-49°C	-26 to -20°C	AVHRR and MODIS; On 17-18 November, 20-km and 70-km-long gas-steam plumes extended to the WNW and SSE, respectively
23 Nov and 25 Nov-27 Nov 2002	1-5	1-49°C	-27 to -20°C	AVHRR and MODIS; on 27 November a 150-km-long gas-steam plume extended to the NE
29 Nov-05 Dec 2002	2-5	-1 to 49°C	-31 to -20°C	AVHRR and MODIS; on 29 November, a possible steam-gas plume extended 80 km to the SSE
01 Dec and 05 Dec 2002	—	—	—	Gas-and-steam plumes extended 40 km and 45 km to the ENE and NNW
09 Dec-12 Dec 2002	2-6	3-39°C	-29 to -20°C	AVHRR and MODIS
13 Dec-17 Dec and 19 Dec-20 Dec 2002	1-6	-15 to 49°C	-34 to -25°C	AVHRR and MODIS
19 Dec-20 Dec and 23 Dec-25 Dec 2002	1-6	10-40°C	-27 to -23°C	—
27, 29, and 31 Dec 2002 and 01 Jan-02 Jan 2003	2-4	-7 to 34°C	-38 to -30°C	On 1 January, a > 10 km plume extending ESE was visible on MODIS imagery
03 Jan-10 Jan 2003	1-6	-8 to 47.5°C	-30 to -13°C	—
10 Jan-13 Jan and 15 Jan 2003	1-7	12-47.5°C	-33 to -20°C	—
17 Jan-22 Jan and 24 Jan 2003	1-4	-2 to 19°C	-27 to -20°C	—
25 Jan-29 Jan 2003	2-7	-2 to 46°C	-25 to -15°C	—
01 Feb-06 Feb 2003	2-6	3-49°C	-24 to -9°C	Gas-steam plumes extended ~40 km to the W and NNE from the dome on 1 and 3 Feb, respectively
07 Feb-13 Feb 2003	1-7	-12 to 49°C	-30 to -12°C	Gas-steam plume extended ~35 km NNW from the dome on 9 Feb
14 Feb-20 Feb 2003	1-6	26-49°C	-33 to 5°C	On 15 Feb a wide gas-steam plume extended > 25 km E; on 16 Feb a narrow plume extended 110 km N; during 16-17 Feb ash and pyroclastic deposits were noted from the S to E slopes; a gas-steam plume extended 30 km W on 19 Feb; a gas-steam plume extended up to 96 km SSW on 20 Feb
21 Feb-28 Feb 2003	2-6	21-49°C	-30 to -8°C	Gas-steam plumes extended up to 50 km to the SSW, SE, and NE during 24-27 Feb

Table 5. Plumes at Shiveluch visible on satellite imagery during October 2002 through February 2003. Courtesy KVERT.

Kliuchevskoi

Kamchatka Peninsula, Russia
56.06°N, 160.64°E; summit elev. 4,835 m

Seismicity was above background levels at Kliuchevskoi during 29 November 2002 through at least 4 March 2003. Tens of earthquakes per day were recorded, mostly at depths of ~30 km (table 6), and intermittent spasmodic volcanic tremor occurred. During December through February, gas-and-steam plumes generally rose up to 2 km above the crater. The Concern Color Code fluctuated between Yellow and Orange, but by the end of the report period remained at Yellow.

Visual observations and video recordings from the town of Klyuchi revealed that a plume from an explosion on 24 December 2002 rose 4 km above the crater and drifted WSW. On 5 January 2003 a faint thermal anomaly, and probable mud flow down the SSE slope were visible on satellite imagery. According to KVERT, the thermal anomaly and mud flow indicated that a lava flow may have begun to travel down the SSE slope. A probable mudflow, seen on the SE slope on 7 January, may have emerged after a short explosion to the SE or E, or after powerful fumarolic activity in the crater. During the week of 26 February–4 March, gas-and-steam plumes rose to low levels and possible ash deposits on the volcano's SE summit were visible on satellite imagery.

Background. Kliuchevskoi is Kamchatka's highest and most active volcano. Since its origin about 6,000 years ago, the beautifully symmetrical, 4,835-m-high basaltic strato-volcano has produced frequent moderate-volume explosive and effusive eruptions without major periods of inactivity. More than 100 flank eruptions have occurred during the past roughly 3,000 years, with most lateral craters and cones occurring on the NE and SE flanks of the conical volcano between 500 m and 3,600 m elevation. The morphology of its 700-m-wide summit crater has been frequently modified by historical eruptions, which have been recorded since the late-17th century. Historical eruptions have originated primarily from the summit crater, but have also included numerous major explosive and effusive eruptions from flank craters.

Date (2002-2003)	Earthquakes per day
29 Nov-04 Dec 2002	Up to 33
06 Dec-13 Dec 2002	12-24
13 Dec-20 Dec 2002	6-12
19 Dec-25 Dec 2002	6-9
26 Dec 2002-3 Jan 2003	3-11
06 Jan-09 Jan 2003	10-23
10 Jan-12 Jan 2003	12-28
13 Jan-15 Jan 2003	33-35
31 Jan-07 Feb 2003	16-39
07 Feb-14 Feb 2003	17-30
13 Feb-19 Feb 2003	14-81
21 Feb-28 Feb 2003	10-14

Table 6. Earthquakes recorded at Kliuchevskoi during 29 November 2002-28 February 2003. Courtesy KVERT.

Information Contacts: Kamchatka Volcanic Eruptions Response Team (KVERT) and Alaska Volcano Observatory (AVO) (see Shiveluch).

Monowai Seamount

Kermadec Islands, Southern Pacific Ocean
25.888°S, 177.188°W; summit elev. -100 m (submarine)
All times are local (= UTC + 12 hours)

Numerous eruptions of Monowai Seamount (also known as Orion Seamount), an active volcano located in the Kermadec Island arc, were detected by the Polynesian Seismic Research (Reseau Sismique Polynésien, RSP) seismic network in Tahiti (figure 14). Strong T-phase waves were recorded at all of the stations in the RSP network (figure 15). The last reports of Monowai eruption activities were in January 1998 (*Bulletin* v. 23, no. 1), June 1999 (*Bulletin* v. 24, no. 6), and May 2002 (*Bulletin* v. 27, no. 5).

Geophysical network. The Polynesian Seismic Network is composed of short-period seismic stations on Rangiroa atoll in the Tuamotu archipelago (stations VAH and PMOR), on Tahiti in the Society Islands (stations PAE, PPT, TVO, and TIAR), on Tubuai in the Austral Islands (station TBI), and on Rikitea in the Gambier archipelago (station RKT). There are also three long-period seismic stations in Tahiti, Tubuai, and Rikitea. In addition, Comprehensive Test Ban Treaty (CTBT) instruments located in Tahiti include a mini-array of micro-barographs, a primary seismic station (station PS18 at Papeete), and a radionuclide station.

Earthquake swarm. A volcanic earthquake swarm started on 1 November 2002 at 1200 UTC with strong explosive T-phase waves recorded by the RSP network (figure 16). The swarm stopped temporarily between 8 and 17 November; a second, very intense swarm started on 17 November (figure 17) and ended on 24 November. From in-

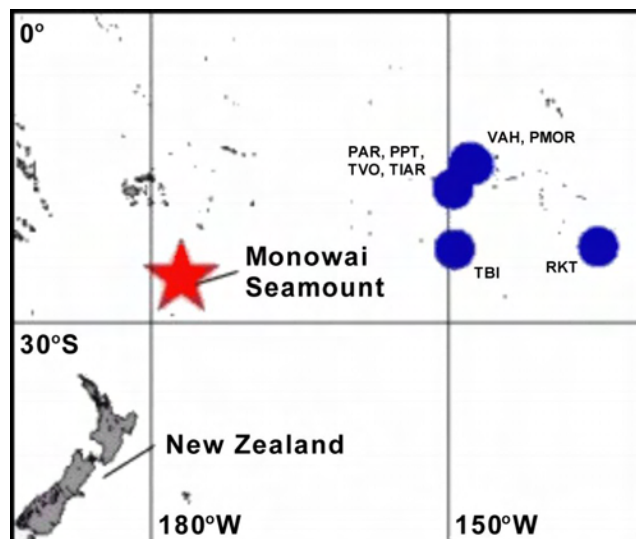


Figure 14. Map of the South Pacific Ocean showing the location of some RSP (Reseau Sismique Polynésien) seismic network stations (circles indicate area of island group with labeled stations) and Monowai Seamount (star). All seismic stations are inland; there are no hydrophones in the network. Stations shown include VAH and PMOR (Tuamotu archipelago), PAE, PPT, TVO, and TIAR (Society Islands), TBI (Austral Islands), and RKT (Gambier archipelago). Courtesy of Laboratoire de Géophysique, Tahiti.

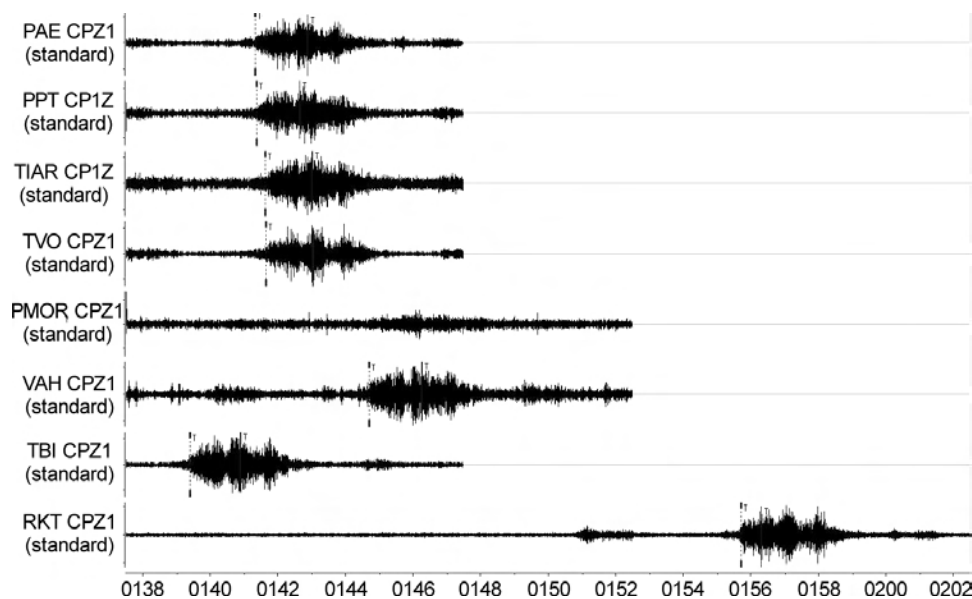


Figure 15. Example of strong T-phase waves detected by the RSP from Monowai, 18 November 2002 (times are UTC). All the seismic stations in the network recorded the wave generated during eruption of the volcano. Note the good signal coherency between most stations. The record at the PMOR station, located in the north of Rangiroa, was masked for the T waves. Courtesy of Laboratoire de Geophysique, Tahiti.

version of T-phase wave arrival times, it was deduced that the swarm was located around Monowai Seamount. Because of the small aperture of the RSP network, the location is poorly constrained in longitude, but well constrained in latitude (figure 18). The source of the T-phase waves is most probably at Monowai.

Regarding T-Phase waves. A short-period wave group from a seismic source that has propagated in part through the ocean is called T-phase or T(ertiary)-wave (Linehan, 1940; Tolstoy and Ewing, 1950; Walker and Hammond, 1998). The wave group propagates with low attenuation as hydro-acoustic (compressional) waves in the ocean, constrained within a low sound speed wave guide (the sound fixing and ranging - SOFAR - channel) formed by the sound speed structure in the ocean. The T-phase signal may be picked up by hydrophones in the ocean or by land seismometers. Upon incidence with the continental shelf/slope, the wave group is transformed into ordinary seismic waves that arrive considerably later than seismic wave groups from the same source that propagated entirely through the solid earth.

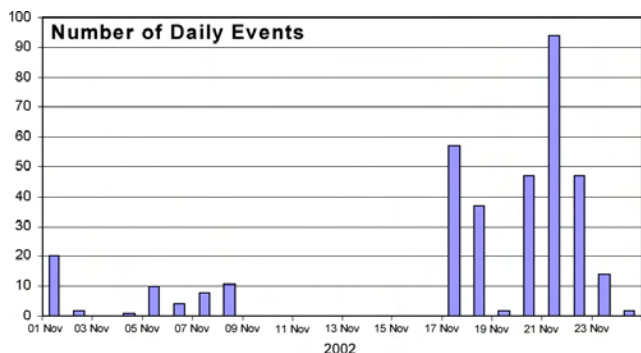


Figure 16. Daily history of the Monowai swarm. The maximum number of daily events was on 21 November, but the higher amplitude T-phase waves were detected during 17-19 November. Courtesy of Laboratoire de Geophysique, Tahiti.

Background. Monowai Seamount rises to a height of about 1,000 m (its peak within 100 m of the sea surface) on the western flank of the Tonga-Kermadec ridge midway between the Kermadec and Tonga Island groups, about 1,400 km northeast of New Zealand. Glassy tholeiitic basalt samples have been dredged from a depth of 120 m near the summit of the seamount (Brothers et al, 1980), and small parasitic cones occur on its N and W flanks. A possible eruption of the seamount was first detected in 1944, and numerous eruptions have been detected from RSP stations since 1977. The latest report of such activities was given in May 2002 (*Bulletin* v. 27, no. 5), when strong T-phase waves suggesting explosive activity were detected by the RSP network. Past surface observations indicating volcanic activity have included water dis-

coloration, vigorous gas bubbling, and areas of upwelling water, accompanied by rumbling noises.

References: Brothers, R.N., Heming, R.F., Hawke, M.M., and Davey, F.J., 1980, Tholeiitic basalt from the Monowai seamount, Tonga-Kermadec ridge (Note): *New Zealand Journal of Geology and Geophysics*, v. 23, p. 537-539.

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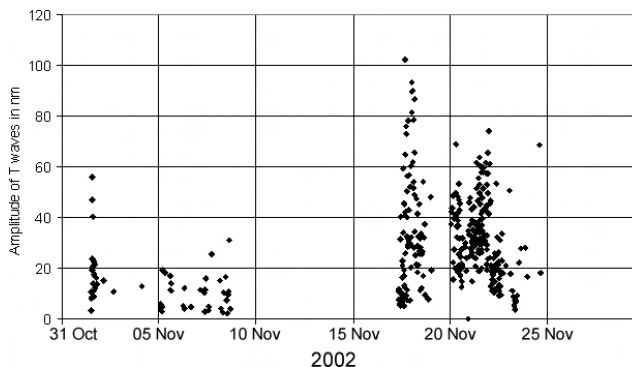


Figure 17. Daily history of amplitude (in nanometers) of Monowai swarm T-phase waves recorded at TVO station on Tahiti. The maximum intensity was between 17 and 19 November. These amplitudes should correlate to ground vibrations generated by the volcanic eruptions. Courtesy of Laboratoire de Geophysique, Tahiti.

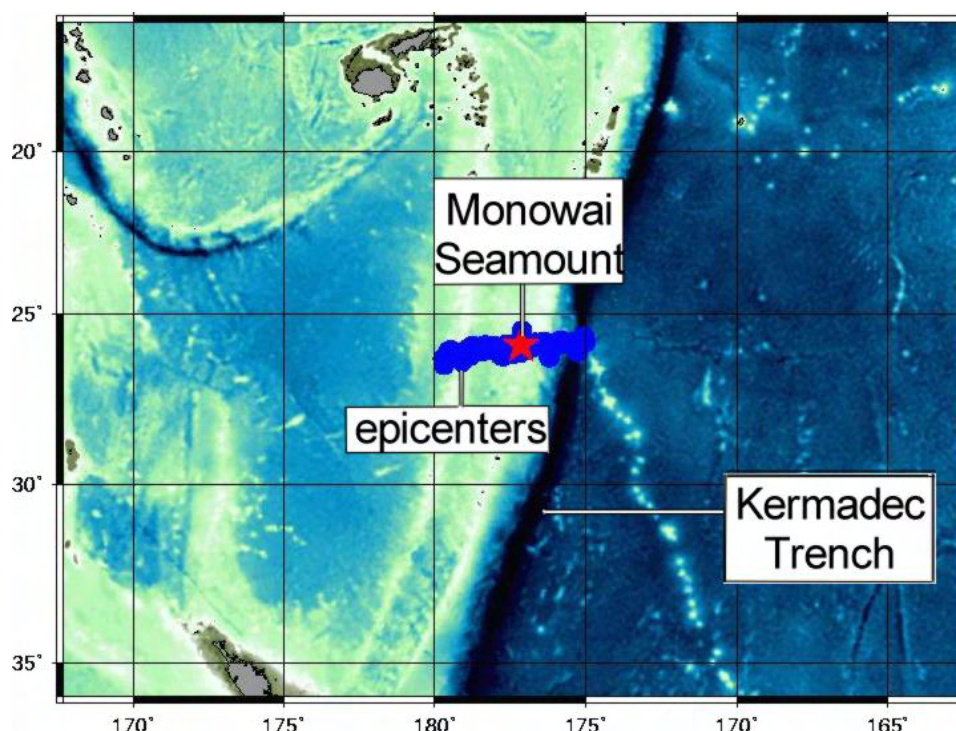


Figure 18. Map showing the best source locations of the swarms using the entire seismic network. The star is Monowai Seamount, and the dots are possible source epicenters. The effect of linearity observed on the epicenters is due essentially to the aperture size of the network, but note that the latitude is well constrained. Courtesy of Laboratoire de Geophysique, Tahiti.

1964-1966: Deep-Sea Research Part II, v. 45, n. 12, p. 2531-2545.

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

White Island

New Zealand
37.52°S, 177.18°E; summit elev. 321 m

Minor volcanic tremor continued, and the plume of steam and gases from the vent remained unchanged through the end of November 2002, according to the Institute of Geological & Nuclear Sciences (IGNS). The output of SO₂ measured on 10 December was 112 ± 36 metric tons per day (t/d); in October the value was 63 t/d. Volcanic tremor continued and was accompanied by minor booming and explosions in the second week of December. After a brief period of increased activity at the start of the next week, volcanic tremor dropped to the weaker levels of tremor observed previously. Weak steam and gas emissions continued through 19 December, along with weak volcanic tremor.

An IGNS report on 7 February 2002 noted continuing minor volcanic tremor and a weak plume of steam and gases from the active vent. Activity increased slightly during 9-16 February. On 12 February mud was being thrown some tens of meters in the air, and ground vibrations could be felt. This corresponded to a period of slightly stronger volcanic tremor. Seismograph readings returned to normal by the 13th. Minor hydrothermal activity continued as of 21

February, and the output of SO₂ had increased to 269 t/d. Seismic tremor steadily declined to low background levels in the last week of the month, though a weak plume of steam and gases was still being emitted.

Seismic tremor levels at White Island remained low on 7 March, but mud was being ejected to low levels around the active vent and a steam plume remained. There were intermittent periods of weak tremor the next week, and SO₂ output was reported to be 267 t/d. Seismic tremor was at a very low level during the week ending on 21 March.

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 off-shore 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: Institute of Geological & Nuclear Sciences (IGNS), Private Bag 2000, Wairakei, New Zealand (URL: <http://www.gns.cri.nz/>).

Ruapehu

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

Between 6 and 16 September 2002 the Institute of Geological & Nuclear Sciences (IGNS) reported that there were four short-lived episodes of volcanic tremor at Ruapehu. The duration of these episodes ranged from 8 to more than 40 hours. Episodes with similar characteristics were recorded previously in 2002 on 21 February (~ 12 hours duration), 17 May (~ 24 hours), 29 May (~ 18 hours), 17 June (~ 24 hours), and 15 July (~ 8 hours). The September events were unusual because there were four tremor episodes in a ten-day period. Another IGNS report on 8 October noted that there had been five short-lived episodes of moderate-strong volcanic tremor since 6 September, with durations of 8 hours to more than 2 days (figure 19). Tremor levels were generally higher than normal background levels starting on 22 September.

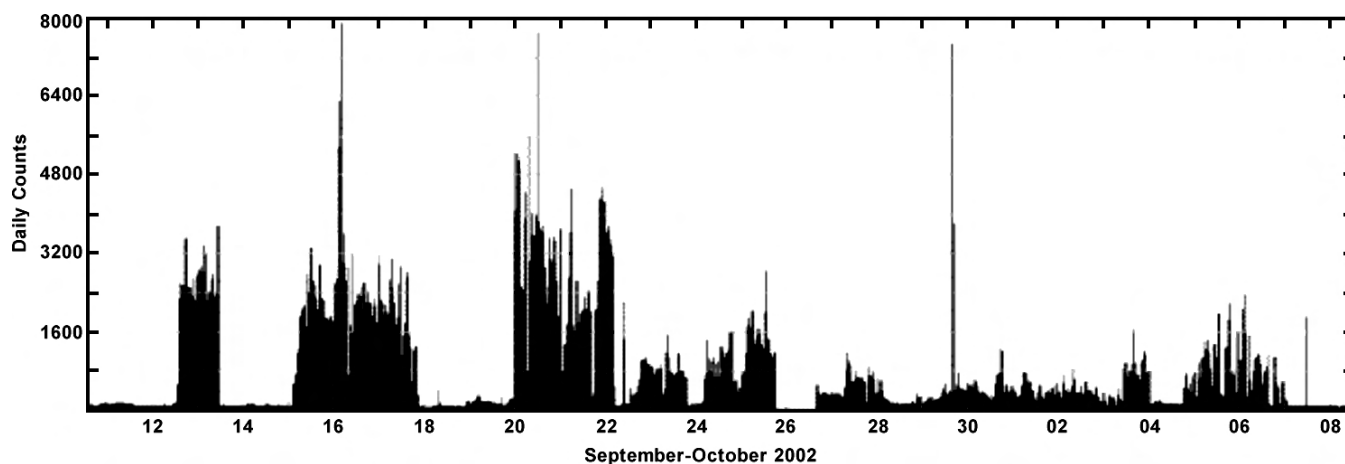


Figure 19. Plot of volcanic tremor amplitudes at Ruapehu, 10 September–8 October 2002. Courtesy of IGNS.

The temperature of Crater Lake during two visits between 16 September and 8 October remained around 19°C, similar to the 19.4°C value measured on 30 August. Intermittent weak seismic tremor continued during November, along with a small number of volcanic earthquakes early in the month. Water temperature of Crater Lake measured during 22–29 November was 24°C, an increase of 5°C from the previous month. Weak tremor continued as of 13 December, accompanied by a small number of minor volcanic earthquakes. Volcanic tremor and earthquakes continued through 19 December, and the water temperature of Crater Lake was reported to be 35°C.

The water temperature measured at Crater Lake at the end of January was 32°C, down 8°C from two weeks earlier (40°C). Minor volcanic tremor continued through February, then steadily declined during 21–28 February to low background levels. On 5 March the temperature measured at Crater Lake had decreased another 2°C to 30°C. The lake was a uniform light gray color with some surface sulfur slicks. Seismic tremor remained at normal levels as of 21 March, but there were periods of moderate tremor on the nights of 14 and 15 March. The temperature of Crater Lake rose to 35°C on 15 March; there were sulfur slicks on the lake surface.

Background. Ruapehu, one of New Zealand's most active volcanoes, is a complex stratovolcano constructed during at least 4 cone-building episodes. The 110 km³ volcanic massif is elongated in a NNE–SSW direction and is surrounded by another 100 cu km ring plain of volcanoclastic debris, including the Murimotu debris-avalanche deposit on the NW flank. A series of subplinian eruptions took place at Ruapehu between about 22,600 and 10,000 years ago, but pyroclastic flows have been infrequent at Ruapehu. A single historically active vent, Crater Lake, is located in the broad summit region, but at least five other vents on the summit and flank have been active during the Holocene. Frequent mild-to-moderate explosive eruptions have occurred in historical time from the Crater Lake vent, and tephra characteristics suggest that the crater lake may have formed as early as 3000 years ago. Lahars produced by phreatic eruptions from the summit crater lake are a hazard to a ski area on the upper flanks and to lower river valleys.

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

Barren Island

Andaman Islands, Indian Ocean, India
12.278°N, 93.875°E; summit elev. 305 m
All times are local (= UTC + 5 1/2 hours)

A team of scientists from India and Italy carried out detailed geological, volcanological, geochemical, and geothermal investigations on Barren Island (figures 20 and 21) during 3–6 February 2003. The scientific team, led by Dornadula Chandrasekharam, included Piero Manetti, Orlando Vaselli, Bruno Capaccioni, and Mohammad Ayaz Alam. The Indian Coast Guard vessel CGS Lakshmi Bai carried the team from Port Blair on 3 February 2003; the journey takes ~ 5–6 hours depending on sea conditions. Because of the great depths around the island, it is not possible to anchor, so the team was ferried to the island in a small rubber boat. After the ship returned on the morning of 6 February, a trip around the island was made to see the steep seaward face of the prehistoric caldera wall.

The volcano consists of a caldera, which opens towards the W, with a central polygenetic vent enclosing at least



Figure 20. Barren Island as seen from the vessel CGS Lakshmi Bai on 3 February 2003. Courtesy of D. Chandrasekharam and others.

five nested tuff cones. Two spatter cones are located on the W and SE flanks of the central cone (figure 22).

An eruption in 1991 ended more than 200 years of quiescence. Another eruption in 1994-95 left two spatter cones on its SE and W flanks. From these vents two aa lava flows poured out, both reaching the sea, during two distinct eruptive phases separated by ashfall. The lava flow created a delta into the sea (figure 23). There has been no documented eruptive activity since 1995, but Indian Coast Guards informed the team of renewed activity (strong gas and possible lava emission) in January 2000. The volcano currently exhibits continuing fumarolic activity. Steaming ground was visible at numerous places on the island.

On 5 February the team climbed the summit of the central cinder cone that showed strongly fumarolic (but not presently active) areas with layers of sulfur deposits (figure 24). The ascent to the crater was relatively difficult since the material on the very steep slope was loose (figure 25). Neither magma nor gas emissions were observed within the

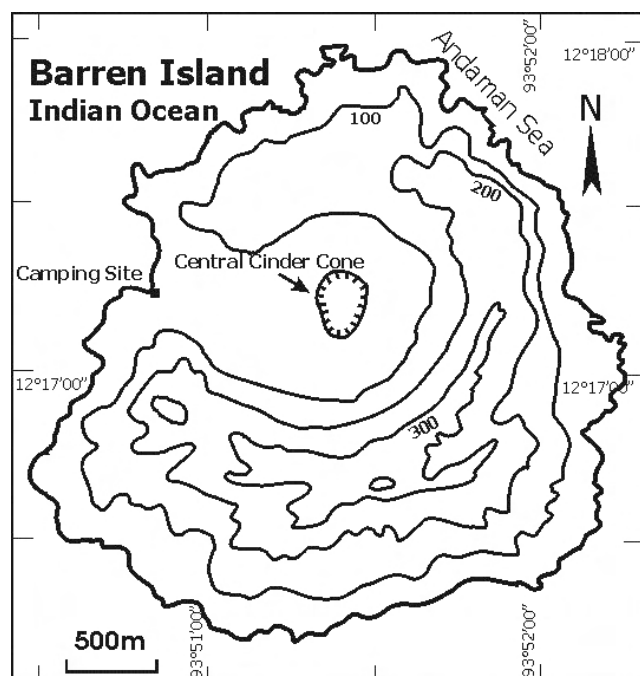


Figure 21. Preliminary sketch map of Barren Island. Courtesy of D. Chandrasekharam and others.



Figure 22. A spatter cone on the SW flank of the central cinder cone at Barren Island around 3 February 2003. Courtesy of D. Chandrasekharam and others.

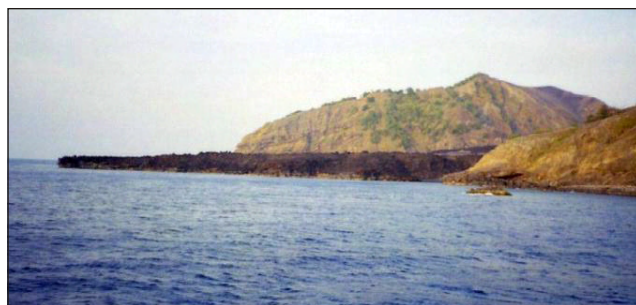


Figure 23. Lava from the 1994-95 eruptions on Barren Island formed a tongue that reached the sea. Courtesy of D. Chandrasekharam and others.

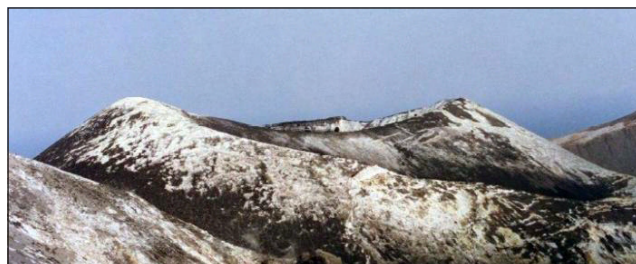


Figure 24. Fumarolic deposit on top of the central cinder cone at Barren Island on 5 February 2003. Courtesy of D. Chandrasekharam and others.

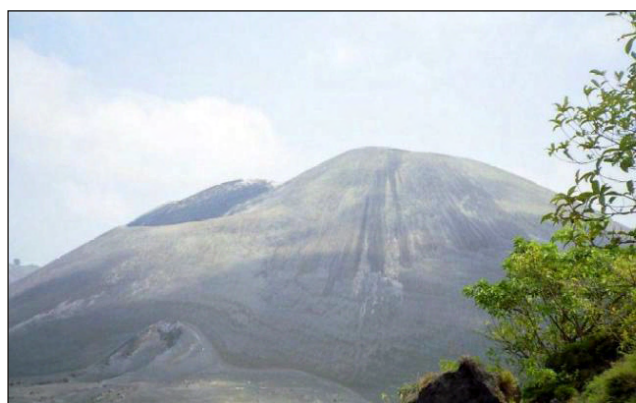


Figure 25. Central cinder cone showing steep slopes at Barren Island on 5 February 2003. Courtesy of D. Chandrasekharam and others.

craters of the different cones. From the middle to the upper part of the W cone, the ground temperature was relatively high ($> 40^{\circ}\text{C}$), and steaming ground was visible at different sites. Fumarolic activity, with temperatures up to 101°C , was mainly concentrated along the upper crater wall of the SW cone. Blue fumes (indicative of SO_2) and the aroma of acidic gases such as HCl were not recorded.

The pre-caldera deposits were characterized by more than five lava flows (prehistoric?) separated by scoria-fall beds and minor ash, tuff, and cinder deposits. The lava flows varied in thickness from 2 to 3 m, whereas the pyroclastic layers vary in thickness from 1 to 4 m. These lava flows could be clearly seen towards the N part of the main caldera. Towards the SE part of the inner caldera a 5-m-wide, NNE-SSW trending dike was observed. This feeder dike was fine-to-medium grained and contains buff-colored olivine, green pyroxene, and plagioclase phenocrysts. The N and NW part of the caldera has been mantled by a ~ 50 -m-thick sequence of breccias and tuff representing syn/post-caldera phreatic and hydromagmatic activity, whereas the products of a small littoral cone occurred mainly towards the W side. The lava flows of the main cal-

dera were highly porphyritic with phenocrysts of green pyroxene (~ 3 cm) and plagioclase feldspars. Several steam vents could be seen within the 1994-95 lava flows. Some of these vents exhibited a lack of steam emanations at the time of the visit.

The outer and part of the inner caldera contains thick vegetation, which escaped the fury of the recent eruptions. Feral goats and rats dominate the island. Two fresh-water springs were discovered towards the SE part of the caldera. This is possibly the fresh water source for the goats living in this island. Chemical analysis indicates that the water from the springs is potable.

Background. Barren Island, a possession of India in the Andaman Sea about 135 km NE of Port Blair in the Andaman Islands, is the only historically active volcano along the N-S-trending volcanic arc extending between Sumatra and Burma (Myanmar). The 354-m-high island is the emergent summit of volcano that rises from a depth of about 2,250 m. The small, uninhabited 3-km-wide island contains a roughly 2-km-wide caldera with walls 250-350 m high. The caldera, which is open to the sea on the W, was created during a major explosive eruption in the late Pleistocene that produced pyroclastic-flow and -surge deposits. The morphology of a fresh pyroclastic cone that was constructed in the center of the caldera has varied during the course of historical eruptions. Lava flows fill much of the caldera floor and have reached the sea along the western coast during eruptions in the 19th century and more recently in 1991 and 1995.

Information Contacts: Dornadula Chandrasekharam, Department of Earth Sciences, Indian Institute of Technology, Bombay 400076, India (URL: <http://www.geos.iitb.ac.in/dchandra/biexp/>, Email: dchandra@iitb.ac.in); Piero Manetti, Italian National Science Council (CNR), Institute of Geosciences and Earth Resources (CNR-IGG), Viale Moruzzi, 1, 56124 Pisa, Italy (Email: manetti@igg.cnr.it); Orlando Vaselli, Department of Earth Sciences, University of Florence, Via G. La Pira, 4 - 50121 Florence, Italy (Email: orlando@steno.geo.unifi.it); Bruno Capaccioni, Institute of Volcanology and Geochemistry, University of Urbino, Loc. La Crocicchia, 61029 Urbino, Italy (Email: b.capaccioni@geo.uniurb.it); Mohammad Ayaz Alam, Research Scholar, Department of Earth Sciences, Indian Institute of Technology, Bombay 400076, India (Email: mdayazalam@iitb.ac.in).

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)

Following the 16 November-3 December 2002 eruption (*Bulletin* v. 27, no. 11), the Observatoire volcanologique du Piton de la Fournaise reported on 19 December that very strong seismicity had continued at a rate of more than 1,000 earthquakes per day. The earthquakes were located a few hundred meters below Dolomieu crater.

MODIS tracking of effusive activity during 2000-2002. The November-December 2002 eruption was detected by the Hawai'i Institute of Geophysics and Planetology MODIS thermal alert system (<http://modis.higp.hawaii.edu/>). The eruption was apparent as a major hot spot in

the SW sector of Reunion (figure 26). The first image on which activity was flagged was that of 1030 (0630 UTC) on 16 November 2002. At that point the flagged anomaly was six 1-km pixels (E-W) by 2-3 pixels (N-S). The hot spot attained roughly the same locations and dimensions on all subsequent images, where hot pixels were flagged on 16 images during November 16-3 December 2002. The exception was an image acquired at 2255 (1855 UTC) on 30 November (figure 26), on which the hot spot attained its largest dimensions of ~ 12 x 5 pixels. The increase in hot spot dimensions towards the end of November is also apparent in the radiance trace (figure 27). However, without examination of the raw images HIGP scientists cannot determine from the hot spot data alone whether this recovery was due to an increase in activity or an improvement in cloud conditions. This was the 6th eruption of Piton de la Fournaise tracked by the MODIS thermal alert (Flynn et al., 2002; Wright et al., 2002) since its inception during April 2000 (figure 28).

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

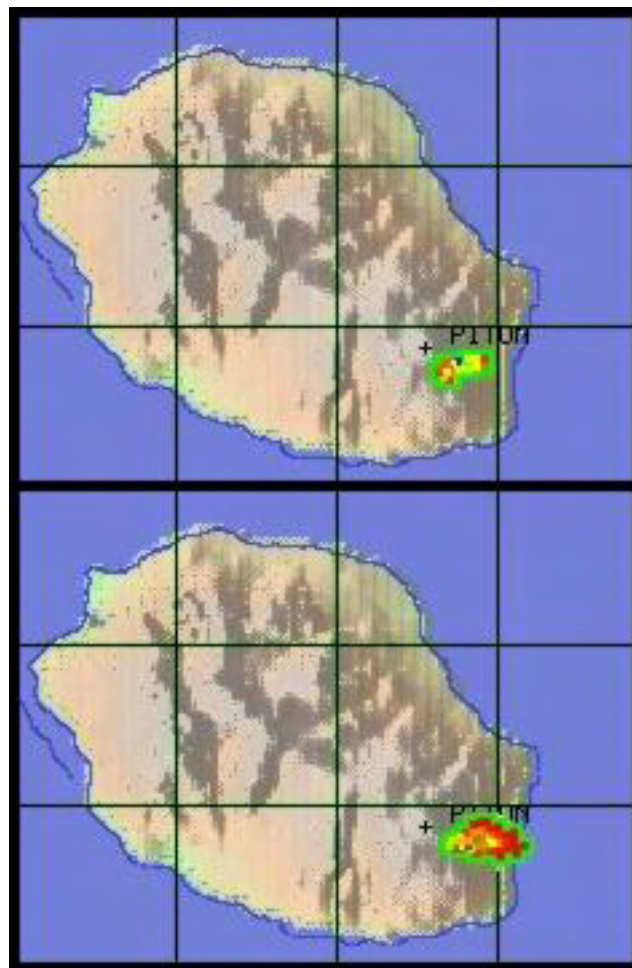


Figure 26. Hot-spot pixels flagged at Piton de la Fournaise by the MODIS thermal alert at 0630 UTC on 16 November 2002 (top) and 1855 UTC on 30 November 2002 (bottom). Courtesy of the HIGP Thermal Alerts Team.

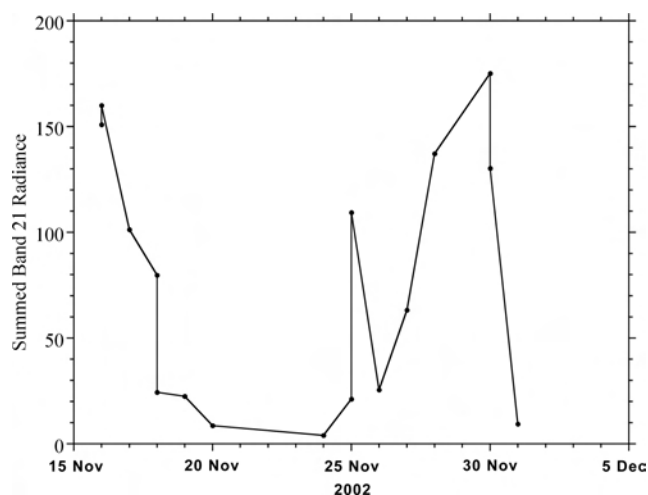


Figure 27. Piton de la Fournaise hot spot radiance detected by MODIS during 15 November-5 December 2002. Courtesy of the HIGP Thermal Alerts Team.

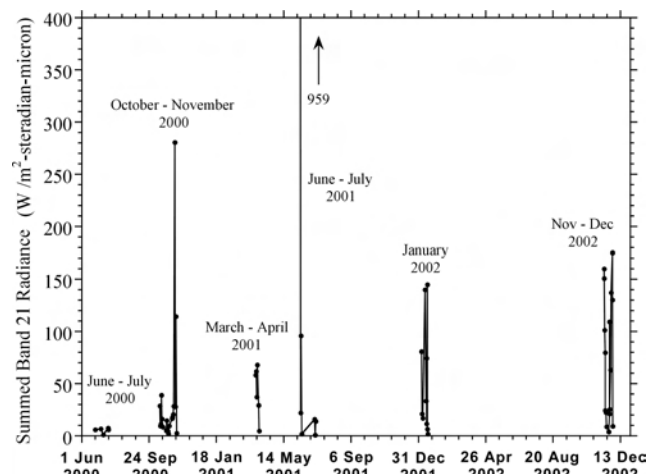


Figure 28. Piton de la Fournaise hot spot radiance detected by MODIS during April 2000-December 2002. Courtesy of the HIGP Thermal Alerts Team.

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.

References: Wright, R., Flynn, L.P., Garbeil, H., Harris, A.J.L., and Pilger, E., 2002, Automated volcanic eruption detection using MODIS: Remote Sensing of Environment, v. 82, p. 135-155.

Flynn, L.P., Wright, R., Garbeil, H., Harris, A.J.L., and Pilger, E., 2002, A global thermal alert using MODIS: initial results from 2000-2001: Advances in Environmental Monitoring and Modeling (<http://www.kcl.ac.uk/kis/schools/hums/geog/advemm.html>), v. 1, no. 3, p. 5-36.

Information Contacts: Observatoire volcanologique du Piton de la Fournaise, 14 RN3, le 27Km, 97418 La Plaine

des Cafres, La Réunion, France (Email: Thomas.Staudacher@iremia.univ-reunion.fr); Andy Harris, Luke Flynn, Harold Garbeil, Eric Pilger, Matt Patrick, and Robert Wright, HIGP Thermal Alerts Team, Hawai'i Institute of Geophysics and Planetology (HIGP) / School of Ocean and Earth Science and Technology (SOEST), University of Hawai'i, 2525 Correa Road, Honolulu, HI 96822, USA (<http://hotspot.higp.hawaii.edu/>, Email: harris@higp.hawaii.edu).

Ol Doinyo Lengai

Tanzania

2.751°S, 35.902°E; summit elev. 2,890 m

Claude Grandpey visited Ol Doinyo Lengai on 29-30 December 2002 during a trip organized by the French agency *Aventure et Volcans*. The group arrived on the crater rim late in the morning and noted a very active lava lake in the T49 vent that began to overflow a few minutes later. The resulting lava flow was ~ 10-15 m wide and reached a length of ~ 50 m before stopping when the overflow ended after a few minutes. The temperature inside the solid flow, measured some 2 hours after it had stopped, was 462°C.

The T49 lake, roughly circular and ~ 5 m in diameter, was extremely active and noisily ejecting blobs of fluid lava (figure 29). This type of activity lasted all day, without additional lava flows. After several hours of careful observations, Grandpey climbed the cone and stood a few meters from the lava lake. He noted that the lake was being fed in an oblique way from a vent on its SW side; the lava would flow to the E inner side before being projected back to the W and splashing out. The pressure of the lava as it splashed against the E side could be felt, and the whole cone was vibrating. In the evening the activity decreased at the lake, and a small vent opened a few meters to the E, emitting occasional vertical squirts of lava. All the time they stayed in the crater, cone T40 kept roaring, but no lava emissions were seen.

After a night of heavy rain, the group visited the crater one more time. No lava flow had occurred during the night. Another lake was still bubbling at T49, at the exact spot where lava was squirting vertically the day before. It was violently throwing blobs of lava on its outer slopes.



Figure 29. Photograph of activity at Ol Doinyo Lengai vent T49, 29 December 2002. Courtesy of Claude Grandpey.

Background. The symmetrical Ol Doinyo Lengai stratovolcano is the only volcano known to have erupted carbonatite tephra and lavas in historical time. The prominent volcano, known to the Maasai as “The Mountain of God,” rises abruptly above the broad plain south of Lake Natron in the Gregory Rift Valley. The cone-building stage of the volcano ended about 15,000 years ago and was followed by periodic ejection of natrocarbonatite and nephelinite tephra during the Holocene. Historical eruptions have consisted of smaller tephra eruptions and emission of numerous natrocarbonatitic lava flows on the floor of the summit crater and occasionally down the upper flanks. The depth and morphology of the northern crater have changed dramatically during the course of historical eruptions, ranging from steep crater walls about 200 m deep in the mid-20th century to shallow platforms mostly filling the crater. Long-term lava effusion in the summit crater beginning in 1983 had by the turn of the century mostly filled the northern crater; by late 1998 lava had begun overflowing the crater rim.

Information Contact: Claude Grandpey, L’Association Volcanologique Européenne (LAVE), 7, rue de la Guadeloupe, 75018, Paris, France (Email: grandpeyc@net-source.fr).

Nyiragongo

central Africa

1.52°S, 29.25°E; summit elev. 3,469 m

All times are local (= UTC + 2 hours)

Nyiragongo was last reported on through late October 2002 (*Bulletin* v. 27, no. 10). This report covers through 21 December, an interval in which the hazard status remained high, with the population asked to exercise vigilance (code Yellow). Included here are reports from the Goma Volcano Observatory (GVO), and from Dario Tedesco and Simon Carn on geochemistry and atmospheric SO₂. Several episodes of strong SO₂ outgassing and unfavorable wind directions caused elevated concentrations of the gas to enter cities and acid rain to damage vegetation and water supplies. High fluorine was found in some rainwater samples. The 24 October 2002 earthquake’s aftershocks and the state of the volcano led to significant stress on the regional inhabitants, including those in Goma.

During the October–December reporting interval, the GVO reports noted that their roughly weekly Nyiragongo observational climbs disclosed considerable changes on the crater’s floor, a spot ~ 700 m down inside the summit crater. Comparisons between photos taken on 24 November and 9 December 2002 revealed the merging of two adjacent molten-surfaced lakes and the birth of another similar, though smaller, lava lake at a point well over 100 m away from the merged ones. The deep crater is often filled with fumes too dense to clearly see the crater floor, and in the above-mentioned cases photographers had just 5 to 10 seconds of moderate visibility to capture their photos. This helps explain why the status and behavior of the lava lakes is often ambiguous (see *Bulletin* v. 26, no. 3).

Adequate visibility during a climb on 18 December revealed that the sole lava lake seen then stood ~ 45 m in diameter, its surface restless and agitated.

In accord with one or more dynamic and molten-surfaced lava lakes on 20 December, SO₂ gas blew into Goma, causing residents to panic. Scoria falls were noted in late October, and in one particular case by residents of the SW-flank settlement of Rusayo at around 1100 on 15 November. It was noted in October that vegetation surrounding the crater’s perimeter, particularly on the W flank, had sustained acid burns from abundant degassing. During October–21 December vapors over the crater frequently glimmered red at night. The 15 November visit disclosed the escape of high-temperature gases and the existence of fissures cutting across the residual platform of 17 January 2002 deposits. Fumaroles along fissures discharged gases. SW-flank fissures were also seen.

GVO summarized the volcano observations for the interval 15–28 December 2002, noting a permanent strong gas plume at 4,200–6,000 m altitudes. They again confirmed a permanent small lava lake, about 50 m in diameter with a central active lava fountain sending molten material to ~ 40 m heights. Minor amounts of Pelé’s-hair ash fell in both Rusayo and Kibati villages. Residents of those villages and Kibumba reported seeing incandescence in the crater.

Residents of Kibati and Kibumba were greatly concerned the night of 27–28 November due to visible glimmer that appeared to be coming toward them from Nyiragongo. The glimmer was benign activity in the crater rather than lava flows descending the flanks. This behavior was associated with lava-lake degassing.

Other observatory projects in late October to late December included the installation and maintenance of lake-level sensors on Lake Kivu, installation of thermal sensors at selected spots, and improved seismic telemetry.

Deformation surveys on 31 October, 2 November, and 13 November 2002 measured the distance between cross-fracture survey points (nails) along the scarps of Monigi, Lemera, and Shaheru. The results indicated that offsets remained comparatively stable, with little change compared to previous measurements (table 7). New cross-fracture measurements were also initiated at the Mapendo station. Data collected in late December continued to lack evidence of new deformation.

Geochemistry. SO₂ fluxes increased during October and November 2002, rising from below detection limits to a few thousands metric tons per day (t/d), then to up to ~ 20,000 t/d. Dario Tedesco suggested that the increase might be due to a more efficient conduit geometry allowing gases access to the surface. The process may have accompanied upward movement of magma or its arrival at the surface.

During the last half of November through 2 December the TOM SO₂ estimates were under reliable detection limits due low concentrations. After that, on 7 and 11 December,

Date	Monigi	Lemera	Virunga	Shaheru	Mapendo
02 November 2002	8.31 m	7.55 m	93.4 cm	14.72 m	—
13 November 2002	8.31 m	7.55 m	93.4 cm	—	15.4 cm

Table 7. Nyiragongo deformation measured along scarps on 2 and 13 November. These reportedly showed strong consistency with preceding measurements. New measurements were initiated at newly established survey points on 13 November. These were in the Mapendo neighborhood (a site towards Gift Bosco) on a revived fracture there. Courtesy of OVG.

Date (2002)	Daily SO ₂ flux (t/d)
16 November- 2 December	Not significant
03 December	< 5,000 (weak signal)
04 December	Data gap - no data over Nyiragongo
05 December	~6,000
06 December	Data gap - no data over Nyiragongo
07 December	~12,000
08 December	Data gap - no data over Nyiragongo
09 December	< 5,000 (weak signal)
10 December	Data gap - no data over Nyiragongo
11 December	< 5,000 (very weak signal)
12 December	Data gap - no data over Nyiragongo
13 December	~11,000

Table 8. SO₂ fluxes at Nyiragongo based on the TOMS instrument. Courtesy of Simon Carn.

respectively, TOMS data measured considerable SO₂, ~ 12,000 and ~ 11,000 metric tons per day (t/d) (table 8).

Thus the degassing had not risen to peak October-November levels, but increased since early December, either in terms of plume altitude, SO₂ concentration, or both. Simon Carn noted that "We are also sometimes seeing discrete SO₂ clouds to the W of the volcano, rather than SO₂ plumes emerging from the volcano, perhaps suggesting discontinuous degassing."

Tedesco also pointed out that the higher SO₂ fluxes accompanied acid rain falling on Goma and surroundings, with some rain samples also containing up to 15 parts per million (ppm) fluorine ion. (For comparison, the U.S. Centers for Disease Control and Prevention recommended a standard in drinking water at 0.7-1.2 ppm, a level that provides a means of preventing tooth decay without compromising public safety.) In December 2002, Goma residents complained about the acid rain, which besides affecting drinking water, put area crops in danger. Accordingly, scientists began collecting rainwater samples with the intent of carrying out regular analyses.

SO₂ blew towards the S on 4 and 5 November exposing people on the upper S flanks. Researchers measured gas concentrations in Goma on 20 November at 20 selected points. They found CO₂ concentrations of 0-4%, and much lower concentrations of CH₄, H₂S, and CO. On 4-5 December the wind carried SO₂ gas into S-flank settlements. During the December, analysis of fumaroles at Sake, Mupambiro, Bulengo, and Himbi revealed similar concentrations to those seen in earlier visits (including the elevated values at Sake/Birere, which in October 2002 measured 35.1% CO₂, and Mupambiro, which on 7 December measured 63.1% CO₂). It was expected that the current rainy season favored enhanced CO₂ flow from the ground.

Nyiragongo summit geochemical surveys in mid-November found temperature elevations of 1°C (except one summit site with a 5.7°C rise). CO₂ concentrations had then risen to 3%. In a fissure called Shaheru, CO₂ concentrations stood at 53%. Methane was found at all sites in dilute concentrations, ~ 0.1 %. H₂S was below the limit of detection at all the visited sites.

The human side of January 2002 volcanism and the 24 October earthquake. Aftershocks to the unusually large earthquake of 24 October 2002 continued to be felt in the

epicentral area through December. For example, Goma residents felt an M 4 tectonic earthquake with a 13 km focal depth on 13 December.

Field excursions in the reporting period revealed that the 24 October 2002 earthquake and aftershocks damaged towns in the Kitembo and Minova areas (including the towns Lwiro and Nyabibwe). The visits suggested that no lives were lost but about ten houses sustained cracks. Residents there still remained in need of humanitarian assistance, including safe housing, food, and medicine.

The December aftershocks were not reported to have caused significant damage; however, an earlier Reuters news article, published on 24 January 2002, described how about six days after the volcanism ceased in Goma, residents there had "flocked to receive aid" at distribution points, many having then gone about a week without food supplies. The news article went on to say, "the UN aims to distribute about 260 tonnes of food, which it says is enough to feed 70,000 people for a week. Each family—of an assumed seven people on average—will receive 26 kg of highly nutritious supplies including maize meal, beans, vegetable oil, and corn soya blend." The aid groups also distributed clean drinking water. The intensity of the volcanic and earthquake disasters had clearly left residents weakened and with reduced food security.

Previous *Bulletin* reports have included relatively few photographs of the scene in Goma due to the January 2002 eruption when lava flows overran the city. Figures 30-33, all sent to us by Wafula Mifundi, are intended to help make up for this deficiency. In many cases within Goma intense fires accompanied the lava flows. Several of the photos provided by Wafula captured these fires, including a devastating fire at a fuel depot, which accompanied an explosion that was widely discussed in the news. The photos presented here omit those of the larger fires and instead illustrate other important aspects of the crisis and its aftermath.

Seismicity. The late October-early November 2002 earthquakes that were interpreted as magmatic, were rela-



Figure 30. During Nyiragongo's January 2002 eruption lavas transected Goma, a city of about a half-million people. The summit of Nyiragongo lies ~ 20 km to the N. In the foreground, middle-ground, and central background lie destroyed buildings and gardens, and what has now become a field of rubble atop the rapidly cooled, thin lava flows of the January eruption. Note that the rubble contains abundant light-colored building material, such as concrete chunks dispersed from downed buildings. Unburned wood and some leaves may represent unburned portions of trees that came into contact with cooler lava surfaces at temperatures below their kindling point. Leaves and other fallen and wind-blown plant debris may have accumulated later. Date of photo is undisclosed. Courtesy of Wafula.



Figure 31. Nyiragongo lavas inundated these structures on 17 January 2002. A family took refuge in the lower portion of the building in the center. Trapped there by lava flows, one or more people died, including an infant. Provided courtesy of Wafula.



Figure 32. This photo shows some of the remarkably thin and mobile lava flows pouring through a narrow chute (behind the car and in line with the left-most opening in the low structure's wall). Below that, the lava spreads and descends across a lawn. Provided courtesy of Wafula.

tively deep, at 10-25 km. Most of these earthquakes occurred in an elliptical area, although some struck ten's of kilometers W of Goma beneath the Bay of Sake in Lake Kivu, an area where previous earthquakes have sometimes occurred.

During the first half of November seismicity dropped significantly. It was noted that the operational seismic network then consisted of seven stations (table 9); an eighth station was not functioning. During November tectonic seismicity returned to normal; however, magmatic seismicity continued. In the week ending on the 9th, magmatic seismicity centered on the N side of Nyamuragira, a zone adjacent its recent eruption. In contrast, during this same interval earthquakes were rare at Nyiragongo, although gas escaping the crater remained visible from Goma, certifying ongoing intra-crater activity. During the week ending on the 16th, some earthquakes were centered about Nyiragongo. During the latter half of December most of the region's high-frequency and volcano- tectonic earthquakes were associated with an epicentral zone stretching from the 24 October major earthquake near Kalehe to W of Nyamuragira. Some HF events also occurred in the Nyiragongo vicinity too.

The seismic reference stations Katale and Rusayo both registered sub-continuous volcanic tremor during much of the reporting interval (table 9). Rusayo station's tremor was

attributed primarily to Nyiragongo, and except for one week in November, it registered the larger share of tremor.

During the week ending 23 November seismicity stayed about the same and tremor dropped considerably, particularly at neighboring volcano Nyamuragira where it was described as feeble (table 9). Banded tremor registered 29 November at the stations of Kunene, Rusayo, Bulengo, Kibumba, and Katale (during 0630–0745 UTC), with the highest amplitude at Katale station, implying Nyamuragira as their source, plausibly a reactivation associated with the 24 October earthquake. Many epicenters also concentrated in the vicinity of that neighboring volcano. On the other hand, epicenters for long-period earthquakes appeared to come from Nyiragongo. The epicenters were determined to a margin of error of ± 2 km.

Background. Nyiragongo is one of Africa's most notable volcanoes. In contrast to the low profile of its neighboring shield volcano Nyamuragira, 3,470-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; features observed since the late-19th century. Two older stratovolcanoes, Baruta and Shaheru, are partially overlapped by Nyiragongo on the N and S. About 100 parasitic cones are located primarily along radial fissures S of Shaheru, E 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 January 2002 lava flows, particularly when they entered the major city of Goma.

Information Contacts: *Kasereka Mahinda, Kavotha Kalendi Sadaka, Celestin Kasereka, Jean-Pierre Bajope, Mathieu Yalire, Arnaud Lemarchand, Jean-Christophe Komorowski, and Paolo Papale*, Goma Volcano Observatory (GVO), Departement de Geophysique, Centre de Recherche en Sciences Naturelles, Lwiro, D.S. Bukavu, DR Congo (Email: ocha.volcan@wfp.org); *Dario Tedesco*, Environmental Sciences Department, Via Vivaldi 43, 81100 Caserta, Italy; *Jacques Durieux*, Groupe d'Etude des Volcans Actifs (GEVA), 6, Rue des Razes 69320 Feyzin, France (Email: jdurieux@chello.fr); *Simon Carn*, TOMS Volcanic Emissions Group, Joint Center for Earth Systems Technology (NASA/UMBC), University of Maryland Baltimore County, 1000 Hilltop Circle, Baltimore, MD 21250 USA (URL: <http://sky.gsfc.nasa.gov>; Email:



Figure 34. Nyiragongo's January 2002 lavas slowly advancing across a road at an intersection. This area of Goma is called Signers rotary point. The sign advertises the Ishango Guest House. Note the lava-immersed but still-standing tree, which at this stage, may have only had substantial burns near the base of its trunk. Provided courtesy of Wafula.

End of week (or fortnight)	Type A High-Frequency	Type C Low-Frequency	Total	Tremor—described or total minutes of tremor with amplitude ≥ 1 mm
Rusayo seismic station				
09 November	86	178	264	5838
16 November	78	185	263	3956
23 November	79	207	286	1435
30 November	33	160	193	2508
07 December	42	137	179	nr
14 December	57	124	181	nr
(28 December)	(88)	(270)	(358)	("Several hours per day")
Katale seismic station				
09 November	137	231	368	3998
16 November	114	328	442	7713
23 November	118	356	474	Feeble (1mm)
30 November	92	239	331	2248
07 December	107	348	455	nr
14 December	120	169	289	nr
(28 December)	(253) swarm to N of Nyamuragira	(513 events)	(766)	("several hours per day")

Table 9. Nyiragongo and Nyamuragira earthquakes and tremor recorded at Katale and Rusayo stations during November–December 2002. The Katale station sits on the E flank of Nyamuragira; the Rusayo station, on the SW flank of Nyiragongo. The dates on the left are for weekly intervals, except the last entry, which is for a 2-week interval (a fortnight). In the last entry, the elevated high-frequency earthquake count at Katale station was due to a swarm to N of Nyamuragira on 27–28 December. Courtesy of GVO.

simon@skye.gsfc.nasa.gov); *Reuters News Service*; *BBC News* (URL: <http://news.bbc.co.uk/>).

Etna

Sicily, Italy

37.73°N, 15.00°E; summit elev. 3,315 m
All times are local (= UTC + 1 hour)

On 27 October 2002 Mount Etna opened on both its northern and southern sides (*Bulletin* v. 27, nos. 10–12), erupting lava from vents about 2,500–1,800 m elevation on the NNE flank and 2,800–2,700 m on the S flank. The N vents emitted two flows that stopped after a few days, the longer of which stretched ~ 5 km. The S vents erupted lighter intermittent lava flows, but showed much stronger and sustained explosive activity that developed two large cinder cones at 2,750 and 2,850 m elevation.

The northern lavas are similar to the tephra erupted from Northeast Crater during the summer of 2002 and, more generally, to the trachybasalts that characterized Etna's activity during the past centuries (Tanguy and others 1997, and references therein). They are typically porphyritic (30–40% phenocrysts), containing numerous millimeter-sized crystals of plagioclase (An 86–65/Or 0.4–2.1), clinopyroxene (En 42.3–37/Fs 11.7–15.5), and fewer ones of olivine (Fo 76–71) and titanomagnetite (Usp 35–43). The silica content is about 47–48% with a "normal" MgO content of about 5% and "low" CaO/Al₂O₃.

The southern lavas are significantly higher in MgO (~ 6.5%) and CaO/Al₂O₃ with fewer phenocrysts that comprise barely 10% of the rock. Olivine crystals are decidedly more magnesian (Fo 82–76), although other minerals are much like those described above, with plagioclase An

80.8–63.8/Or 0.8–1.3, clinopyroxene En 42–34/Fs 12–15.7, and titanomagnetite Usp 37–42.7. It must be pointed out, however, that plagioclase and titanomagnetite are here almost entirely confined within the groundmass, a characteristic that is uncommon in Etnean lavas and characterizes some of the most basaltic samples.

A particularity of the southern 2002 lavas is the presence of destabilized amphibole crystals, together with quartz-bearing inclusions (sandstones) surrounded by a reaction rim of pyroxene and embedded in a rhyolitic matrix. These characteristics are quite similar to those already found in the 2001 lavas emitted at 2,100 m elevation on this same flank (*Bulletin* v. 26, no. 10). The 2002 amphibole is present in rarer and smaller "megacrysts" that do not exceed 2 cm in length and display a reaction rim composed of rhonite, anorthitic plagioclase, and olivine within a silicic and potassic glass. Its chemical composition is similar to that of the 2001 amphibole.

Orthopyroxene was found in a southern flow emitted at the very beginning of the eruption (27 October). The average of 16 microprobe analyses is as follows (Centre de microanalyse Camparis, University of Paris 6): SiO₂, 53.18; TiO₂, 0.23; Al₂O₃, 0.79; Cr₂O₃, 0.04; FeO, 19.43; MnO, 0.80; MgO, 23.52; CaO, 1.72; Na₂O, 0.05; Total, 99.75. The composition is thus hypersthene close to bronzite, typical of basalts or basaltic andesites. Hypersthene here occurs as crystals 0.5–0.7 mm in length, always surrounded by clinopyroxene. The two minerals are not in equilibrium as indicated by their different Mg values (0.69 for Opx, 0.71 to 0.78 for Cpx). This is the first time that such large crystals of orthopyroxene have been observed in lavas of the last tens of thousand years. Orthopyroxene is very rare at Etna, being previously found on only two or three occasions in pre-Etnean basalts about 200,000 years old.

Olivine separates from both N and S lavas (~ 100 crystals each) were microprobed, showing a single distribution

for the N flank of Fo 69-70 for 65% of the crystals. The S lavas have a twofold behavior with Fo 78-81 for 37% of the crystals and Fo 73-75 for 45% of them. These results are similar to what was found between the upper southern 2001 lavas (including the NE flank below Pizzi Deneri) and those emitted at lower elevation (S 2,600 m and S 2,100 m). It is worth noting that the 2,600 m S vent of the 2001 eruption is close (~ 1 km) to the 2,700 m S vent of the 2002 eruption.

Based on these preliminary results, the low porphyritic index added to the whole rock chemical composition and that of the olivine crystals, a common origin is suggested for the southern 2002 lavas and those emitted low on the S flank during the 2001 eruption.

Background. Mount Etna, towering above Catania, Sicily's second largest city, has one of the world's longest documented records of historical volcanism. Historical lava flows cover much of the surface of this massive basaltic stratovolcano, Italy's highest and most voluminous volcano. 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, produce eruptions 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.

Reference: Tanguy, J.C., Condomines, M., and Kieffer, G., 1997, Evolution of the Mount Etna magma: Constraints on the present feeding system and eruptive mechanism: *Journal of Volcanology and Geothermal Research*, v. 75, p. 221-250.

Information Contacts: Roberto Clocchiatti, CNRS-CEN Saclay, Lab. Pierre Süe, 91191 Gif sur Yvette, France (Email: clochiatti@drecam.cea.fr); Jean-Claude Tanguy, Univ. Paris 6 & Institut de Physique du Globe de Paris, Observatoire de St. Maur, 94107 St. Maur des Fossés, France (Email: Tanguy@ipgp.jussieu.fr).

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