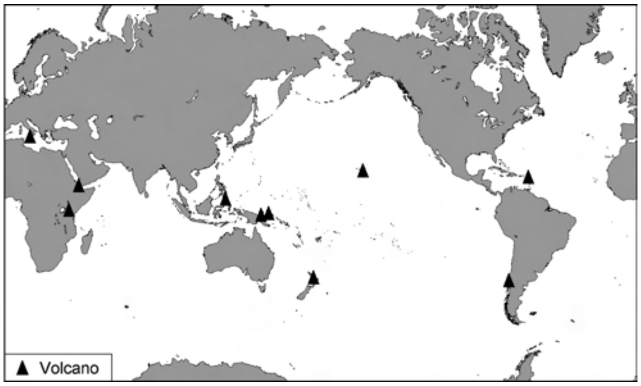
Bulletin of the Global Volcanism Network



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Llaima

central Chile
38.692°S, 71.729°W; summit elev. 3,125 m
All times are local (= UTC - 4 hours)

During late 2002 and early 2003 Chilean scientists at Llaima documented increases in seismicity, fumarolic output, a minor eruption, and pronounced glacial disruption. For example, on 8 January 2003 they found that the ice and snow formerly capping the N and S craters had completely melted. Larger eruptions began in April 2003, depositing pyroclastic material, dispersing numerous ballistic blocks, and creating substantial plumes.

Although this report covers the time interval from January 2002 through most of April 2003, the concern then was that Llaima might erupt with the vigor seen in 1994 (*Bulletin* v. 19, nos. 4 and 5). However, during the 2002-03 reporting interval eruptions remained comparatively modest.

Ice covered, passively degassing. On 26 September and 30 October 2002, scientists from Chile's Volcanic Risk Program and the Volcanologic Observatory of the South Andes (OVDAS) flew over Llaima in response to steady increases in seismicity and fumarolic activity since the end of June 2002. On the 26 September flight they viewed the summit with its N (main) crater, and Pichillaima, the smaller SE-flank cone and its crater. They found only a weak steam plume rising gently from the main crater and attaining little additional height. This was in contrast to typical previous behavior, which consisted of puffs that rose several hundred meters before dissipating.

The 26 September 2002 aerial observations found the internal walls of the main crater draped in ice and snow. Pichillaima lay beneath a cover of clean ice and snow, and its crater emitted only a small gas plume. The overall scene was of quiet, with minor degassing amid frigid conditions.

Views of the main crater rim on 30 October 2002 indicated minor ash on the snow, an irregular, figure-eight-shaped hole emitting gases, and a much larger and optically denser steam plume than on 26 September. Llaima's cover of ice and snow was more complete than noted in October 1998. Thus, by comparison, in late 2002 visible signs of thermal activity had diminished significantly. In contrast to what was typically seen, the crater's ice-covered internal walls lacked escaping gases. Except for seismicity, the ice-bound Llaima seemed stable.

Seismically restless. Despite the lack of visible volcanism or thermal activity, the seismicity in September 2002 was notably greater than in January 2002 (table 1). The frequency of tremor increased from 0.9 Hz in January 2002 (a typical value in times of relative quiet) to 1.2 Hz in September 2002. In describing April 2003 tremor amplitude the OVDAS reports stated that it was about "5-fold larger" than at base level.

Date	Seismicity (RSAM units)	Tremor frequency (Hz)
January 2002	28	0.9
June 2002	20	—
September 2002	57	1.2
December 2002	99	1.2 (during 18-20 December)
Mid-January 2003	93	—
Late January 2003	60	—
April 2003	92	1-2.2
18-19 April 2003	98	—

Table 1. Seismic activity at Llaima summarized as RSAM (Real-time seismic amplitude) values and principal tremor frequencies. In times of relative quiet, baseline values at Llaima are ~ 20 RSAM units and 0.9 Hz. These data were taken from reports by OVDAS-SERNAGEOMIN (which omitted some time intervals).

In September 2002, seismic instruments included two permanent stations (LLAI and MELI) located respectively on Llaima's S flank and S foot. In December 2002, there were two portable seismic receivers placed on the E flank at Lago Verde, which also recorded unrest. The seismicity continued to increase from December 2002 to mid-January 2003 (from ~ 70 to ~ 100 RSAM units). After that, it diminished and stabilized for about two months.

Sudden changes. A flight on 8 January 2003 led OVDAS to see remarkable changes since the late 2003 observations (figure 1). First, the dense fumarole emitted from the main crater was much stronger than the one seen 26 September 2002 (figure 1, top left). Second, the ice and snow had completely melted from main crater's internal

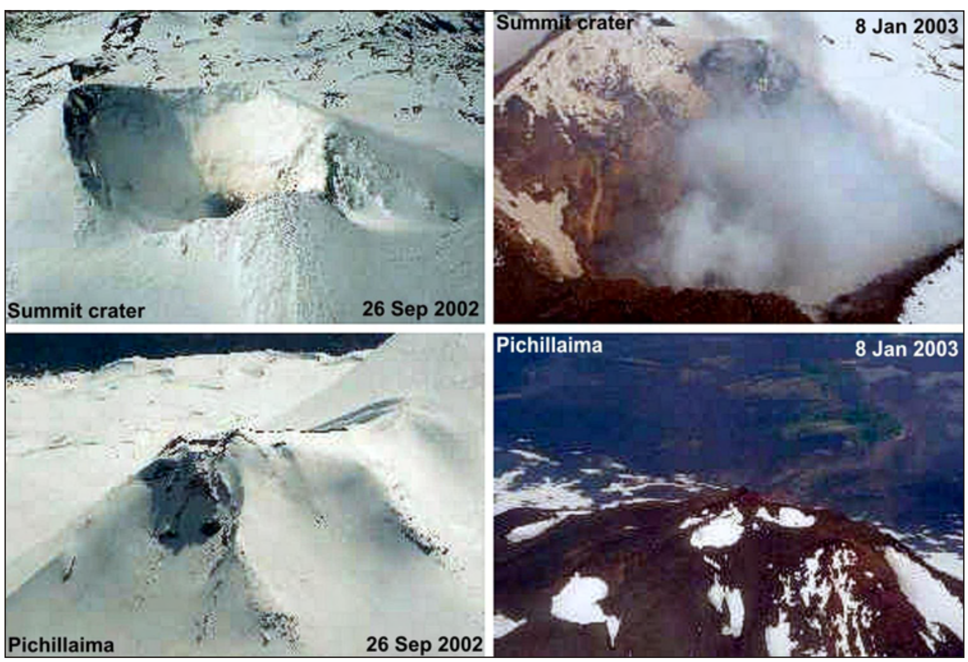

Figure 1. Contrasting views of Llaima's summit crater and Pichillaima as seen on 26 September 2002 (left, top and bottom, respectively) compared to 8 January 2003 (right, top and bottom, respectively). The scenes highlight differing conditions, particularly the melting of ice and snow. On 26 September 2002 snow covered most of the edifice. On 8 January 2003 there was an absence of significant ice and snow from parts of the crater walls, rim, and S flanks, and there were increased emissions of volcanic gases. Courtesy of OVDAS-SERNAGEOMIN.

walls. Third, complete melting of ice and snow had left exposed rock at both the summit and Pichillaima (figure 1, lower right). Fourth, numerous new crevasses had appeared in the cone's glaciers, particularly on the E flank. Down all flanks of the volcano, the 8 January observers saw ice falls, snow avalanches, ice detachments, and rockfalls.

Although the melting came at the time of the annual thaw, the situation on the volcano indicated that processes such as local heating accelerated the melting. Snow had fallen in early October 2002. The absence of ice and snow cover on both the shaded and unshaded sides of Llaima was cited as evidence indicating elevated rock temperature. Observers saw the melting and also noted a halt to any new accumulation of ice and snow deposits. The melting was attributed to magma at depth in the conduit, and considerable heat emerging at the locations where the ice melted.

The report issued 20 January 2003 noted that field work on Llaima's W side (Cherquenco-El Salto) had disclosed deep new crevasses in the glacial ice reaching 1.5 km long. These were affiliated with avalanching from near the main cone's summit to the cone's NW foot (~ 3 km long by 0.5 km wide). Observers also noticed continued signs of thawing, including the appearance of small fumaroles, which they again attributed to the volcano warming.

The next available reports, from the period 9-11 April, came from eye-witnesses. Rodrigo Marín of Conguillío national park, noted "an increase of fumarole activity in the main crater between 9 and 10 April, which was accompanied by ash emission." In addition, from the N slope (Captrén) people heard underground noises.

At 1330 on 10 April a teacher at Los Andes de Melipeuco elementary school noted three ash explosions that reached ~ 500 m above the main crater and dispersed NE. Several others observers noted ash-bearing emissions from the main crater, including one at 1340 and another at 1350. A park ranger noted that around 2100-2200 on 10 April strong and continuous explosions awoke him and ash began to fall on him in the N-slope sector of Captrén. Later, the explosions became more sporadic, and he heard sounds similar to those made by the motion of heavy machinery. This continued into the early morning of 11 April.

The director of the above-mentioned school reported to OVDAS that on 11 April at 0915 he saw "...continuing ash emission from the main crater." Finally, at 1100 on 11 April, OVDAS observatory (Cerro Ñielol-Temuco) staff observed a vertical column, mainly of volcanic gases, which rose to about 600-700 m above the crater rim. This fed a large, horizontal, lenticular cloud ~ 30 km in diameter, the top of which rose to about 3,900 m altitude.

An 11 April helicopter flight disclosed a thin layer of pyroclastic material spread widely across the glaciers on the NE, E, SE, and SW flanks, visible out to distances of ~ 4 km. Impact craters in the ice testified to numerous bouncing and rolling projectiles. Scientists on that flight noted vigorous fumarolic activity and dense clouds with colors and odors indicating the presence of SO_2 and HCl. At multiple spots, small fumaroles had sprouted from the crater walls. The crater floor contained a 50-m-diameter vent emitting gases, but no lava flows had emerged. Although the 9-11-April eruptions were modest, they prompted Llaima's hazard status to rise from Green to Yellow.

Figure 2 portrays further melting and exposure of underlying rock at both the summit (top) and Pichillaima (bottom) on 11 April. When photographed, the ice and snow at Pichillaima had receded by 1.0-1.5 km from its topographic high. Ice margins appeared sub-vertical and engulfed circular melt areas.

Other amazing photos taken 11 April 2003 revealed dramatic changes in glaciers and snow fields (figure 3). Many regions of the ice appeared to be in motion and undergoing acute mechanical failure. Numerous profound crevasses had emerged, including sets of broadly transverse, arcuate crevasses trending from glacial margins and extending well into their axial areas.

On 12-13 April 2003 the main crater issued intense pulsing fumarolic degassing at 1- to 3-minute intervals. Odors and celeste color were again indicative of SO_2 and HCl components; such emissions were noted until 1500 on 13 April. Other processes on those days included mass wasting, sometimes with associated dust, apparent vibrations at the summit, and ballistic discharges from the main crater. At 1310 on 13 April, expulsions intensified and occurred at 1 minute intervals. Plumes blew E.

Continued observations resulted in the recommendation to maintain the Yellow status at least through 16 April as eruptions began to contain significant tephra. Volcanologists expressed concern that the volcano's glacial ice-cover could undergo further melting, which might lead to large and sudden outbursts of water (glacier bursts) traveling down local drainages.

On 16 April at 1453 OVDAS personnel in the Lago Verde area confirmed gaseous emissions were continuing to escape from the crater. They reported that at 1535 these emissions intensified and reached 200 m above the crater

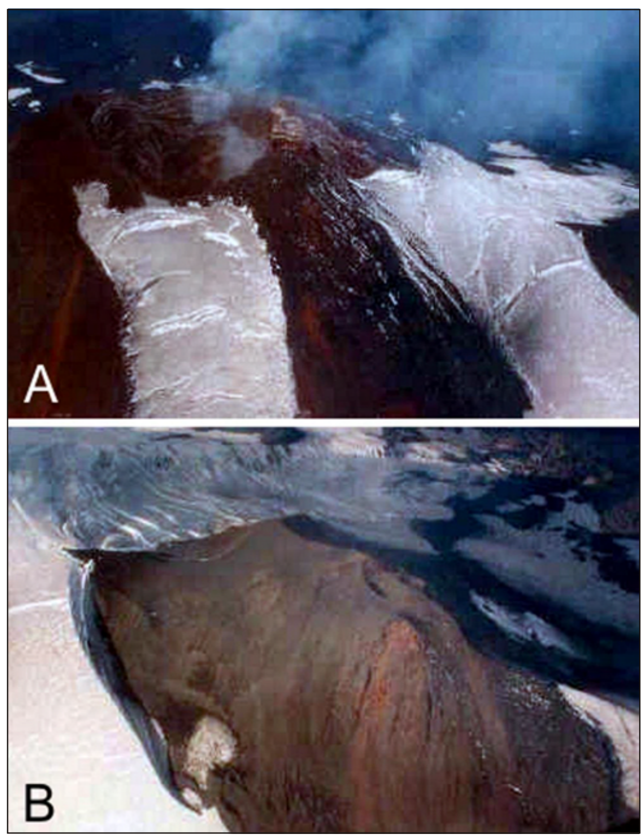

Figure 2. Two vistas of Llaima on 11 April 2003 documenting the rapid ice recession and melting around the main crater and Pichillaima. (A) Rim and flanks of the summit and associated main crater standing with large areas ice free. (B) Pichillaima, nearly ice free and encircled by thick ice at the limit of ice melting. Courtesy of OVDAS-SERNAGEOMIN.

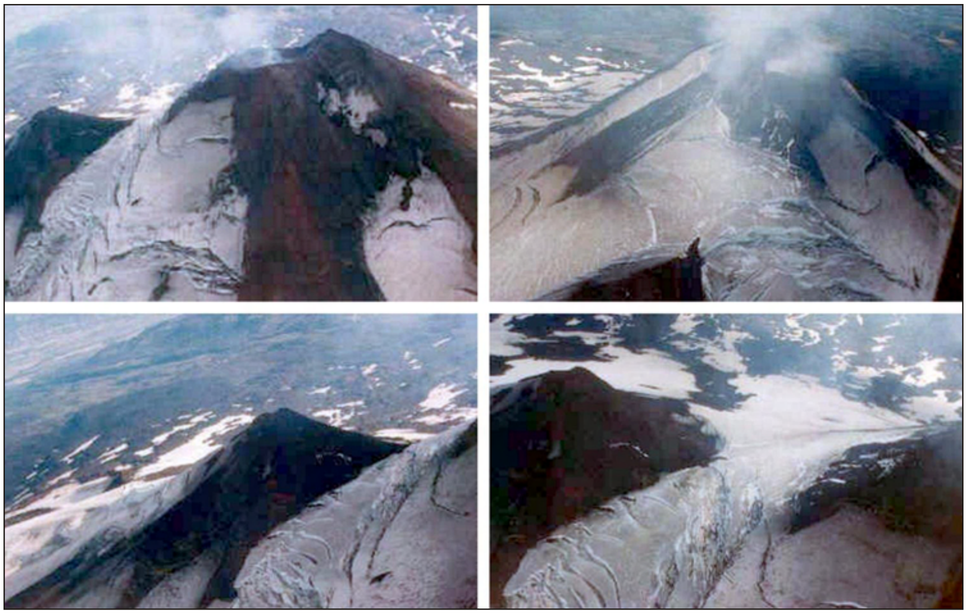

Figure 3. Four views of Llaima from helicopter, taken on 11 April 2003 showing newly exposed rock surfaces, newly created ice-margins, and unstable, rapidly breaking glaciers. Llaima's comparatively temperate late-2002 to early-2003 eruptive phase correlated with these remarkable changes in its alpine glaciers. Courtesy of OVDAS-SERNAGEOMIN.

rim, with the plume blowing SE and being visible for ~ 8 km. They noted that at 1537 gaseous emissions escaped at Pichillaima. On the N (Captrén) side of the mountain at 1704 the observers saw gray-colored fumaroles. During 1130-1355 on 17 April from a point near the Lago Verde they perceived SO_2 and HCl; they witnessed gas emissions to the NE reaching 200 m above the crater rim and spawning a plume visible for ~ 10 km.

The 20 and 23 April 2003 OVDAS reports discussed poor visibility but the permanent stations indicated high-amplitude tremor and considerable seismicity (eg., 98 RSAM units on 18 and 19 April). OVDAS staff interpreted these signals as due to fluids and gases moving in internal conduits. They also pointed out the absence of high- and low-frequency earthquake swarms, signals that generally precede emissions of ash. Small swarms of long-period earthquakes began, however, on 25 April.

Ascent during mid-April 2003. In mid-April 2003 Klaus Bataille (a physicist and seismologist teaching geophysics at the University of Concepción) and his students conducted field work on Llaima. Amid an interval of seismic and volcanic quiet on 18 April they ascended into the region of ice melt near the summit region, and made direct observations relevant to the issue of heat transport. Bataille made the following comments.

"A week after the explosion announced by the OVDAS, we (8 students and myself) went to install two broadband seismic stations to study the evolution of its activity, and we installed a GPS receiver as well. When we finished with the installation, it was a clear day and we decided to climb as much as we could. We began early in the morning [of 18 April] . . . [and] could see from the distance fumaroles coming from the crater, and several vents with vapor and gases coming out from different places, some 200-300 m below the crater, towards the N. We did not find any impediment to continue climbing, neither physical difficulties nor anomalous activity from the crater. Thus the whole group continued up to 300 m below the crater, where four persons stayed due to physical conditions, and five continued up to the crater. The persons who stayed (me included) realized that there was an incredible warm feeling while laying on the ground. This was due to the amount of vapor with some faint smell of sulphur. We could even take off our jackets and shirts, as long as we were laying flat. After lying for a while it was even too hot to [continue]. Fantastic feeling, lying almost on top of the volcano, with a tremendous view, feeling the warmth through the rocks."

Thus, on 18 April, Bataille and students affirmed the previously stated idea of heat emerging to cause the melting and leading to the sudden emergence of crevasses observed since December 2002. A later clarification from Bataille on the mode of heat transfer (viz., "conductive heating," passed through the rocks; or "convective heating," transported by warmed fluids such as gases) resulted in this statement: "I'm not convinced of 'conductive heating' as a direct source for the ice melting, because of the large amount of gases through the system. I'm inclined instead, to believe that melting of the ice is simply due to the large amount of vapor flowing through the loose rocks. However, I agree that [these] gases have to be produced while in contact with hot material, and in this sense [could] be affected by 'conductive heating.' "

Thus, Bataille observed that the rocks in the ice-melt zone around the summit were warm to the touch. He concluded that they were heated by deeper sources and water vapor transported the heat to the surface.

The scientists discussed their results in a subsequent conference paper (Bataille and others, 2003) and on their website, highlighting the seismic and GPS stations installed on Llaima's W and N sides. The former seismic station, near the Refuge Tucapel, began operating on 17-18 April. The latter seismic station, near Captrén, began operating on 19-20 April.

Their recordings lacked earthquakes that could be linked to deeper sources (no fractures nor seismo-tectonic events) during the period between April and the following 4 months. The whole period was dominated by a sequence of tremors due to the activity associated with the crater. Tremor energy decayed gradually in time. The frequencies involved were generally stable, though peculiar and without a good model for their genesis.

Background. Llaima, one of Chile's largest and most active volcanoes, contains two historically active craters, one at the summit and the other, Pichillaima, to the SE. The massive 3,125-m-high stratovolcano has a volume of 400 cubic kilometers. A Holocene edifice built primarily of accumulated lava flows was constructed over an 8-km-wide caldera that formed about 13,200 years ago, following the eruption of the 24 cubic kilometers Curacautín Ignimbrite. More than 40 scoria cones dot the volcano's flanks. Following the end of an explosive stage about 7,200 years ago, construction of the present edifice began, characterized by strombolian, hawaiian, and infrequent subplinian eruptions. Frequent moderate explosive eruptions with occasional lava flows have been recorded since the 17th century.

Reference: Bataille, K., Hermosilla, G., and Mora, D., 2003, (title translated from Spanish) Seismic activity of Llaima volcano: Dominated by phreatomagmatic sources?, 10th Chilean Geological Congress (10° Congreso Geológico), session 5, paper 63, (October 2003, Universidad de Concepción) (also cited in Revista geológica de Chile; ISSN 0716-0208)

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Soufrière Hills

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

The Soufrière Hills volcano was quiet for the last few months of 2003, following activity in May and July that included significant dome growth (*Bulletin* v. 28, nos. 10 and 12). Light ash-venting had last occurred during a period of low-amplitude tremor 3-8 October. A seismic event in mid-January 2004 and a period of tremor and mudflow activity in late February 2004 were followed by renewed eruptive activity on 3 March 2004.

Between 1 October and 18 December 2003 no dome growth was observed, and only a few earthquakes per week were recorded. Beginning 18 December 2003, SO_2 emissions increased markedly from the previous month's average of 500 tons/day (t/d), reaching 3,600 t/d (see table 2). On 18 January 2004, a swarm of low-amplitude long-period (LP) earthquakes began, with ~ 1,000 separate events over an interval of 36 hours. Fewer than 40 of these earthquakes triggered the automatic seismic-detection systems. Another swarm occurred on 30 January, this time lasting about 30 hours. Again, instruments recorded ~ 1,000 separate events; these, however, were much weaker and only four triggered the detection systems.

A period of low-level tremor, consisting of many small LP earthquakes, lasted for about 36 hours beginning 21 February. On 24 February heavy rainfall (10 mm in 2.5 hours) resulted in mudflow activity in the Belham valley; signs of mudflows were also observed in Plymouth.

Beginning the week of 27 February, activity increased significantly. On 2 March, a period of low-level tremor included some small hybrid earthquakes. The tremor continued until afternoon on 3 March, when, at around 1444, seismicity greatly increased and an explosion and collapse event occurred. According to reports from the Montserrat Volcano Observatory (MVO) this was the most significant event since the collapse event of 12-13 July 2003.

The event on 3 March 2004 produced ash clouds that reached altitudes of about 7 km above sea level, and pyroclastic flows were observed in the Tar River, with at least two incidents of flows reaching the sea. Seismicity returned to close to background levels by 1525, but vigorous ash venting continued until the following morning. Low-level tremor accompanied by hybrid earthquakes continued for the next 18 hours, including a series of hybrid earthquakes during the evening of 3 March.

Visual observations first suggested that the 3 March explosion removed the small dome that had grown in the collapse scar in late July 2003. Photographs taken on 28 February and 5 March showed the 3 March collapse to have also removed part of the NW dome remnant originally built up during 1995-1998.

After 3 March, activity remained elevated for several days. A period of low-level tremor occurred on 4 March, beginning at around 1300 and lasting three hours. On 5 March a small explosion was recorded at 1009, followed by a period of ash venting. Between 5 and 12 March activity returned to lower levels, with 1 LP and 15 hybrid earthquakes recorded. On 10 March, however, there was a short (10-20 minutes) period of elevated seismicity early in the morning; later in the day fresh pyroclastic-flow deposits were observed in the upper reaches of the Tar River Valley. During the second half of the week, short episodes of ash and steam venting were periodically observed, and ash fallout occurred as far N as St. Georges Hill.

On 15 March, the Washington VAAC reported a plume of ash extending to the W from the summit. The following day MVO reported a plume extending 250 km (135 nautical miles) W of the volcano. SO_2 emissions fluctuated during February and the first two weeks of March, peaking at 1017 t/d on 1 February and 1250 t/d on 9 March (table 2).

A beautifully illustrated look at the eruption from 1995 to present is now available (Kokelaar, 2002; Druitt and Kokellar, 2002).

Date (2003-2004)	SO_2 emissions (metric tons/day)
05 Dec-11 Dec	300-900
12 Dec-18 Dec	500-3,600
19 Dec-25 Dec	—
26 Dec-01 Jan	500
02 Jan-08 Jan	300
09 Jan-15 Jan	200-590
16 Jan-22 Jan	440 on 22 January (equipment servicing on other days)
23 Jan-29 Jan	500-700
30 Jan-05 Feb	439-1017
06 Feb-12 Feb	350-450
13 Feb-19 Feb	350-650
20 Feb-26 Feb	496-920
27 Feb-04 Mar	480-820
05 Mar-12 Mar	340-1250

Table 2. Summary of SO_2 emissions recorded at Soufrière Hills, 5 December 2003 to 12 March 2004, using an array of three scanning UV spectrometers. Courtesy of Montserrat Volcano Observatory.

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

References: Kokelaar, B.P., 2002, Setting, chronology and consequences of the eruption of Soufrière Hills Volcano, Montserrat (1995-1999), in Druitt, T.H. and Kokelaar, B.P., eds., 2002: The eruption of the Soufrière Hills Volcano, Montserrat from 1995 to 1999. Geological Society London, Memoir No. 21, p. 1-43.

Druitt, T.H. and Kokelaar, B. P., eds., 2002: The eruption of the Soufrière Hills Volcano, Montserrat from 1995 to 1999. Geological Society London.

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

Kilauea

Hawaii, USA

19.425 N, 155.292 W
summit elev. 1,222 m

All times are local
(= UTC - 10 hours)

Kilauea continued to be active at Pu`u `O`o during December 2003 through early March 2004. Figure 4 shows simplified maps and a diagrammatic cross-section on the Island of Hawaii, emphasizing local geography, and known and inferred conditions at Kilauea. During the reporting interval observers noted incandescence and surface lava flows at Kilauea's upper flow field. In general, surface lava flows were not seen on the coastal flat or Pulama pali. Various vents within Pu`u `O`o were active, and new lava flows covered parts of the crater floor. Seismicity at Kilauea has generally included a few small earthquakes recorded at the volcano's summit, along with steady weak tremor. Tremor occurred continuously at moderate levels at Pu`u `O`o.

During 0550 to 0830 on 18 January 2004, a large period of tilt occurred at Kilauea's Pu`u `O`o cone, amounting to 18.1 microradians of net deflation. During this period a fissure opened at the SE base of Pu`u `O`o, trending approximately radial to the cone. Lava was emitted from the fissure and from three to four vents nearby. The initial flow reached about 1.5 km S of the cone. The S side of Pu`u `O`o was cut by many new fractures. The longest fracture constituted the N boundary of a shallow graben (a linear

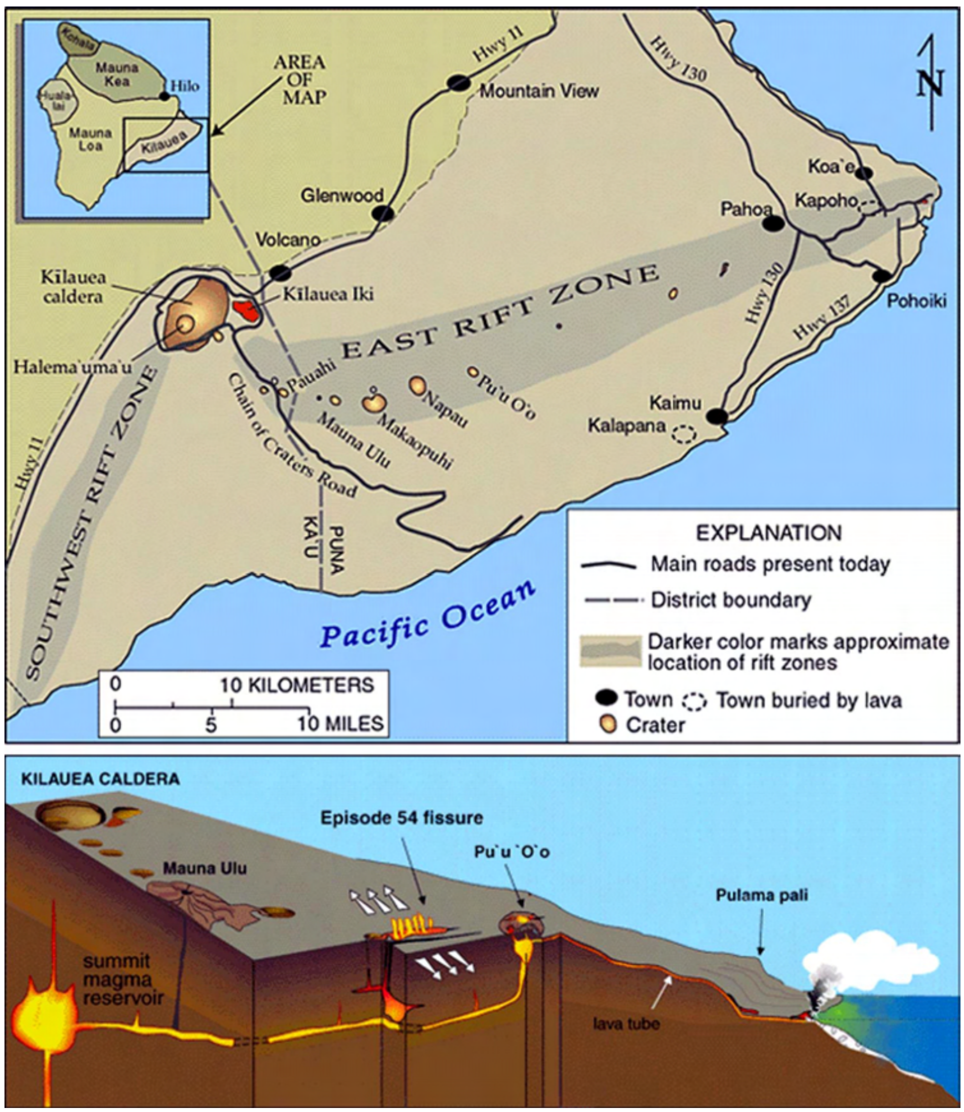

Figure 4. A map and cross-sectional diagram illustrating the island of Hawaii (the 'Big Island,' the largest and southernmost in the Hawaiian chain) showing selected volcanological features and some local geography. The inset shows how the island of Hawaii consists of five volcanoes (old to young): Kohala, Hualalai, Mauna Kea, Mauna Loa, and Kilauea. The larger map emphasizes Kilauea's features. Kilauea is cut by two rift zones, the SW and E rift zones. The east rift zone extends 55 km from the summit caldera to the eastern tip of the Island of Hawaii. The E rift zone contains a string of craters, including Pu`u `O`o. The cross-sectional diagram displays a simplified model of Kilauea's internal structure. Note the location of vents, at Pu`u `O`o and elsewhere, along the SW rift zone. The diagram also shows a lava tube running from Pu`u `O`o to the sea. The map and diagram both omit the details of recent eruptive events; for that, see later figures. Courtesy of the Hawaiian Volcano Observatory, U.S. Geological Survey.

trough bounded by faults) that was ~ 75 m long and up to 1 m deep. Surface lava flows were emitted from the E end of the graben, at the base of Pu`u `O`o. The area S of Pu`u `O`o cone appeared to be quite unstable, so Hawaiian Volcano Observatory (HVO) scientists warned that no one should venture into the area. Seismicity at Kilauea's summit during 15-20 January was at low levels, while tremor at Pu`u `O`o was continuous and at moderate levels. The tremor picked up during the formation of the graben on 18 January. As of 20 January tilt continued to steadily decline following the 18 January deflation event.

On 22 January lava was emitted from the vent formed on 19 January. The vent and lava flow S of Pu`u `O`o cone were named MLK in honor of the activity that began on the American civil rights leader M.L. King Jr.'s birthday (19 January; see figures 5 and 6).

A term that has come into common use at Kilauea is "rootless shield." Local geologists define this as a pile of lava flows built over a lava tube rather than over a conduit feeding magma from within the Earth. Rootless shields along the tube system commonly have flat tops containing shallow lava ponds. In the reporting interval, there were also surface lava flows at the W side of the rootless shield called Amalgamated Bend, a feature located SW of Pu`u `O`o (figure 6). By 26 January there were no surface lava flows at the MLK vent, and incandescence was only visible at the S part of the rootless shield complex. On 23 January moderate-to-strong tremor stopped beneath Kilauea's caldera and lessened at Pu`u `O`o. On 26 January deflation that began on 18 January ended at Pu`u `O`o after reaching 24.7 microradians. This was probably the largest deflation event since early 1997.

During 29 January to 1 February mild volcanic activity occurred at Kilauea, with incandescence visible at vents in Pu`u `O`o's crater and small surface flows on the central or southern part of the rootless shield complex. Starting on 18 January, when the MLK vent formed, the distance across the summit caldera decreased significantly, ending a period of increasing extension rate since the Mother's Day event in May 2002. During the report period, weak tremor occurred at Kilauea's summit along with a few long-period earthquakes. Tremor at Pu`u `O`o remained moderate. During much of February 2004 and into early March, lava flows and incandescence were sometimes visible in Pu`u` O`o's crater and at the

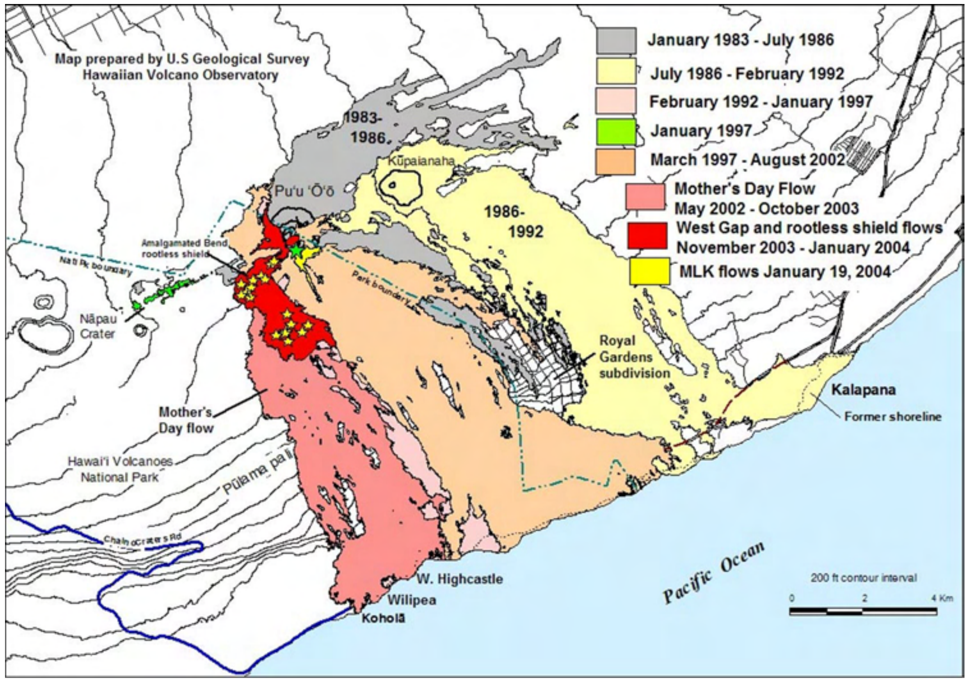

Figure 5. A sketch map showing Kilauea's lava flows erupted during 1983-23 January 2004 activity of Pu`u `O`o and Kupaianaha. Lava flows began erupting from new MLK vent at the base of Pu`u `O`o (star) on 18 January 2004. Stars indicate centers of recently active, or still active, rootless shields in Mother's Day flow. New shields form often and not all shields appear on this map. Courtesy of the Hawaiian Volcano Observatory, U.S. Geological Survey.

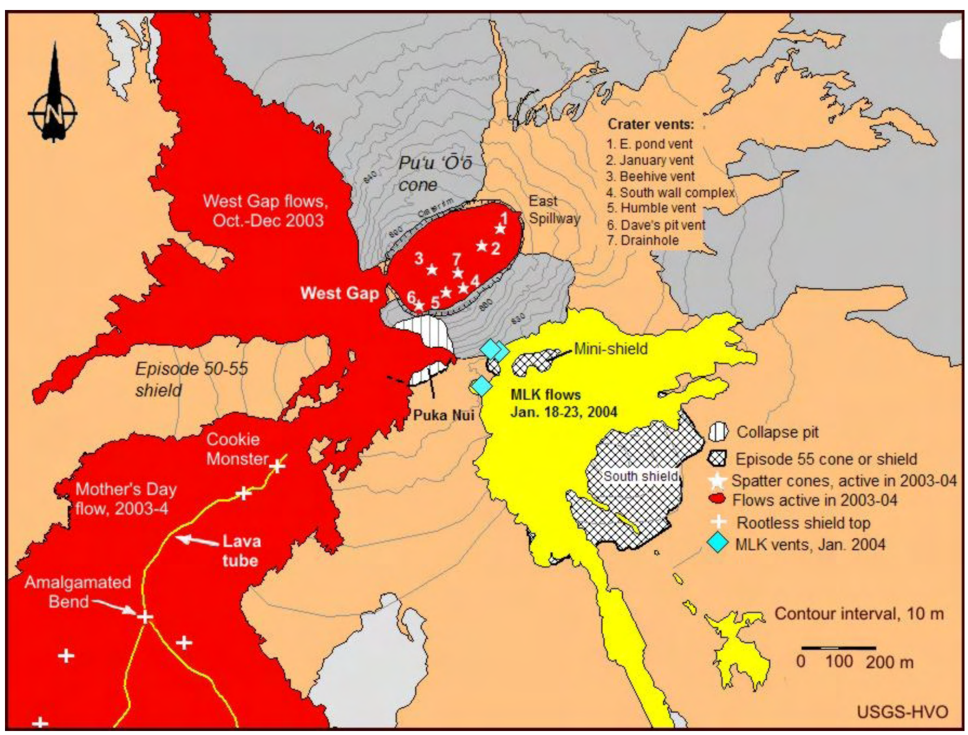

Figure 6. Sketch map of Pu`u `O`o region through 26 January 2004 identifying numerous vents, groups of lava flows, and other features referred to in this and previous issues of the *Bulletin*. Note the names assigned to intra-crater vents in the oval-shaped interior of Pu`u `O`o cone (stars 1-7) and the various rootless shields farther to the W. Courtesy of Hawaii Volcano Observatory, U. S. Geological Survey.

rootless shield complex (an area ~ 0.5 km SW of Pu`u `O`o). Weak background tremor occurred at Kilauea's summit along with a few long-period earthquakes. Tremor at Pu`u `O`o was at moderate-to-low levels. Small deflation and inflation events occurred at the summit and at Pu`u `O`o.

Background. Kilauea shield volcano, which overlaps the east flank of the massive Mauna Loa shield volcano, has been Hawaii's most active volcano during historical time. Eruptions of Kilauea are prominent in Polynesian legends; written documentation extending back to only 1820 records frequent summit and flank lava flow eruptions that were interspersed with periods of long-term lava lake activity that lasted until 1924 at Halemaumau crater, within the summit caldera. The 3 x 5 km caldera was formed in several stages about 1,500 years ago and during the 18th century; eruptions have also originated from the lengthy East and SW rift zones, which extend to the sea on both sides of the volcano. About 90% of Kilauea 's surface is formed of basaltic lava flows less than about 1,100 years old; 70% of the volcano's surface is younger than 600 years. A long-term eruption from the East rift zone that began in 1983 has produced lava flows covering more than 100 square kilometers, destroying nearly 200 houses and adding new coastline to the island.

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

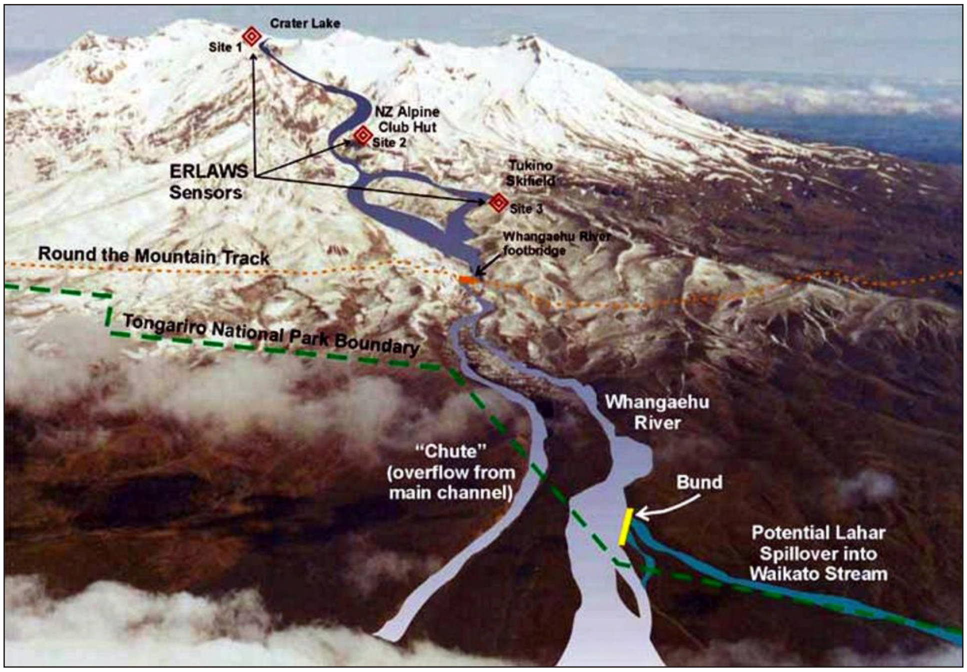

Figure 7. This publicly distributed image was created in response to the threat of lahars descending the Whangaehu Valley at Ruapehu in 2004. In addition to local geography, it shows the location of warning sensors, key bridges, and a critical embankment ("bund") to direct the lahars. The associated information discusses warnings of impending lahars on the order of 1-2 hours before they arrive at critical downstream sites. Courtesy of the New Zealand Department of Conservation.

Ruapehu

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

Citing risks about a lahar expected when an ash dam surrounding Ruapehu's crater collapses, the New Zealand government decided that draining, sluicing, or siphoning the volcano's crater lake to reduce the danger was too hazardous, reported Jo-Marie Brown in *The New Zealand Times* (10, 17, and 19 March 2004). The articles noted that, instead, the government decided to bolster extensive safety measures already in place around the volcano, including improving alarm systems. These new measures should provide warnings of lahar occurrences at least an hour and a half in advance. The government also elected to strengthen bridges and build an embankment to withstand lahars.

The New Zealand Department of Conservation has an extensive outreach to discuss the crater lake-lahar problem (figure 7). They point out that the crater lake on Mt. Ruapehu was refilling after it was emptied by eruptions in 1995 and 1996. This lake lies over the main active vent of the volcano. Before the eruptions, the level of the crater lake was controlled by an outlet that drained water across a sill of lava into the head of the Whangaehu Valley. During the 1995-96 eruptions, this outlet was blocked by 7 m of tephra (fine ash particles and other larger materials ejected by the volcano).

The Department also noted that since March 1999, the crater lake had risen 52 m and was filling at a rate of 5,300 m^3 per day. On 15 March 2004 the lake's surface elevation was reported at 2,527.6 m above sea level. In mid-March 2004 the Department also reported that the lake was then ~ 96% full, a point ~ 2 m below the base of the tephra dam emplaced by the 1995-6 eruptions (the old overflow point). The predicted time for the lake to completely fill was given as early April 2004 to November 2004. An estimated 60 lahars have swept down the mountain's southern side through the Whangaehu Valley in the past 150 years. A lahar in 1953 killed 151 people at Tangiwai. The Department of Conservation reported additional details regarding the crater lake: there was low to normal hydrothermal activity; the water temperature on 15 March 2004 was 35°C; and the lake color was gray.

Background. Ruapehu, one of New Zealand's most active volcanoes, is a complex stratovolcano constructed during at least 4 cone-building episodes dating back to about 200,000 years ago. The 110 km^3 dominantly andesitic volcanic massif is elongated in a NNE-SSW direction and is surrounded by another 100 km^3 ring plain of volcaniclastic debris, including the Murimoto debris-avalanche deposit on the NW flank. A series of subplinian eruptions took place at Ruapehu between about 22,600 and 10,000 years ago, but pyroclastic flows have been infrequent at Ruapehu. A single historically active vent, Crater Lake, is located in the broad summit region, but at least five other vents on the summit and flank have been active during the Holocene. Frequent mild-to-moderate explosive eruptions have occurred in historical time from the Crater Lake vent, and tephra characteristics suggest that the crater lake may have formed as early as 3000 years ago. Lahars produced by phreatic eruptions from the summit crater lake are a hazard to a ski area on the upper flanks and to lower river valleys.

Information Contacts: *The New Zealand Herald,* PO Box 32, Auckland, New Zealand (URL: http://www.nzherald.co.nz/); *New Zealand Department of Conservation*, Private Bag, Turangi, New Zealand (URL: http://www.doc.govt.nz/); *Institute of Geological & Nuclear Sciences (IGNS)*, Private Bag 2000, Wairakei, New Zealand (URL: http://www.gns/cri.nz/).

Langila

New Britain Island, Papua New Guinea
5.525°S, 148.42°E; summit elev. 1,330 m

Langila was last reported in *Bulletin* v. 28 no. 3, following a large ash-bearing explosion on 18 January 2003. MODIS thermal alerts were subsequently recorded on 9 April and 20, 23, 25, and 27 January 2004. One daylight alert was received and omitted (22 September 2003). Daylight alerts posted by the current algorithm are considered less reliable. No corroborative reports of activity have been received from the Rabaul Volcano Observatory or the Darwin Volcanic Ash Advisory Center (VAAC).

Background. Langila, one of the most active volcanoes of New Britain, consists of a group of four small overlapping composite basaltic-andesitic cones on the lower eastern flank of the extinct Talawe volcano. Talawe is the highest volcano in the Cape Gloucester area of NW New Britain. A rectangular, 2.5-km-long crater is breached widely to the SE; Langila volcano was constructed NE of the breached crater of Talawe. An extensive lava field reaches the coast on the north and NE sides of Langila. Frequent mild-to-moderate explosive eruptions, sometimes accompanied by lava flows, have been recorded since the 19th century from three active craters at the summit of Langila. The youngest and smallest crater (no. 3 crater) was formed in 1960 and has a diameter of 150 m.

Information Contacts: *Rob Wright*, *Luke Flynn*, and *Eric Pilger*, MODIS Thermal Alert System, Hawaii Institute of Geophysics and Planetology (HIGP), School of Ocean and Earth Science and Technology, University of Hawaii at Manoa (URL: http://modis.hgip.hawaii.edu/; Email: wright@higp.hawaii.edu, flynn@higp.hawaii.edu, and pilger@higp.hawaii.edu).

Rabaul

New Britain, Papua New Guinea
4.271°S, 152.203°E; summit elev. 688 m
All times are local (= UTC + 10 hours)

The eruptive activity at Tavurvur that began in early October 2002 ceased on 17 February 2004. From 1-17 February the activity was characterized by emissions of light to pale ash clouds accompanied by occasional moderate explosions that produced thick ash plumes. The ash plumes rose 1000-2000 m above the summit before being blown to the E and NE resulting in ashfall in the Duke of York islands, ~ 30 km E of Rabaul.

A slight change in wind direction resulted in fine ashfall over Rabaul Town and villages downwind on 6 and 13-15 February. Occasional weak roaring noises accompanied some of the explosions on 5 and 11 February. From 18 February until the month's end, Tavurvur was only releasing weak white vapor, with occasional blue vapor.

Seismic activity between 1 and 17 February reflected the ash emissions at the summit. One high frequency event occurred on 5 February, located NE of the caldera. Ground deformation indicated a deflationary trend. The real-time GPS and electronic tilt site on Matupit Island, in the center of the caldera, showed a deflationary trend since the middle of the month.

Background: The low-lying Rabaul caldera on the tip of the Gazelle Peninsula at the NE end of New Britain forms a broad sheltered harbor utilized by what was the island's largest city prior to a major eruption in 1994. The outer flanks of the 688-m-high asymmetrical pyroclastic shield volcano are formed by thick pyroclastic-flow deposits. The 8 x 14 km caldera is widely breached on the E, where its floor is flooded by Blanche Bay. Two major Holocene caldera-forming eruptions at Rabaul took place about 7,100 and 1,400 years ago. Three small stratovolcanoes lie outside the northern and NE caldera rims. Post-caldera eruptions built basaltic-to-dacitic pyroclastic cones on the caldera floor near the NE and western caldera walls. Several of these, including Vulcan cone, which was formed during a large eruption in 1878, have produced major explosive activity during historical time. A powerful explosive eruption in 1994 occurred simultaneously from Vulcan and Tavurvur volcanoes and forced the temporary abandonment of Rabaul city.

Information Contact: *Ima Itikarai*, Rabaul Volcano Observatory (RVO), P.O. Box 386, Rabaul, Papua New Guinea (Email: hguria@global.net.pg).

Ulawun

New Britain, Papua New Guinea
5.04°S, 151.34°E; summit elev. 2,334 m

Activity on Ulawun occurs frequently and is monitored and reported from several sources including the Rabaul Volcano Observatory (RVO), the Darwin Volcanic Ash Advisory Center (VAAC), the U.S. Air Force Weather Agency (AFWA), and imagery from several satellites including NOAA GMS (daylight) and MODIS (infrared). The continuing activity after an eruption on 28 September 2000 (see *Bulletin* v.25, no. 8) resulted in *Bulletin* reports every few months since that event (*Bulletin* reports on Ulawun have appeared in nine subsequent issues through the end of 2003).

This issue supplements the *Bulletin* reports with those from the Darwin VAAC archives (table 3), which included information provided from ground, airborne, and space-based sensing. RVO reports that Ulawun remained quiet during February 2004. Emissions from the main vent consisted of white vapor being released at weak to moderate rates. No noise or night-time glow were reported during

Date	Comment
28 Sep 2000	SOURCE: AIREP, AIR NIUGINI, ANK. ERUPTION DETAILS: Volcanic Activity reported at 28/2005Z - Ash plume to 11 km, rapid growth at top, spreading out 30 NM to N to SW. ASH CLOUD: Latest satellite imagery shows possible ash cloud extending 60 NM in an arc from ENE to the WSW.
29 Sep 2000	SOURCE: AIREP, AIR NIUGINI, ANK. ERUPTION DETAILS: There is evidence of volcanic ash on satellite imagery from 28/1800Z
30 Sep 2000	SOURCE: AIREP/Geological Survey Papua New Guinea. The Geological Survey confirms this eruption and notes that limited evacuations have commenced with the prospect of further seismic and eruptive activity. However 29/2230Z ash emissions were limited to infrequent puffs.
01 Oct 2000	SOURCE: AIREP/Geological Survey Papua New Guinea. ERUPTION DETAILS: A Geological Survey report (@ 01/0001Z) noted the summit activity was relatively quiet for last 24 hours. QANTAS AIREP @ 30/0501Z also observed the lack of activity.
29 Apr 2001	SOURCE: AIREP from PNG at 292130Z. ERUPTION DETAILS: Aircraft observed smoke cloud up to 9 km and drifting NW and SW direction out to 50/70 miles radius. ASH CLOUD: Satellite imagery [29/2132Z] shows possible volcanic plume extending 65 NM to the W and 30 NM to the N and S.
30 Apr 2001	ASH CLOUD: Examination of latest satellite imagery [30/0530Z] indicates significant eruption has ceased. Ash plume may reach 14 km.
01 May 2001	SOURCE: Visual and infra-red GMS and NOAA satellite imagery, RVO. ERUPTION DETAILS: RVO advise remains on a high alert level with further eruptions possible. ASH CLOUD: There is no evidence of ash cloud at this time, but widespread cloud in the area is making detection difficult.
03 May 2001	SOURCE: AIREP from PNG 29/4/2001 2130Z. Visual and infra-red GMS and NOAA satellite imagery, RVO. ERUPTION DETAILS: A report by an aircraft of volcanic activity [on 29 April] at about 2130Z with smoke/ash cloud up to 9 km, and confirmed by the RVO and satellites surveillance, initiated a series of Volcanic Advisories. The latest report from RVO this morning states that activity has moderated. ASH CLOUD: Satellite surveillance has not identified any ash cloud since the initial eruption.
28 Aug 2001	SOURCE: GMS/NOAA Satellite Imagery. ERUPTION DETAILS: Ash observed on satellite imagery. Analysis indicates eruption is low level. ASH CLOUD: Ash plume 5 NM wide, extending 15 miles to the S of the summit. Ash expected to be below 4 km.
12 Sep 2002	SOURCE: NOAA/GMS satellite imagery. ERUPTION DETAILS: Small low level plume detected on visible satellite imagery at 11/2100Z. Plume extended 60 NM from summit in the sector NNW to NNE.
18 Sep 2002	SOURCE: GMS satellite imagery. ERUPTION DETAILS: Low level plume detected on visible satellite imagery at 18/2100Z. ASH CLOUD: Very thin plume extends 40 NM to the WSW
19 Sep 2002	SOURCE: GMS satellite imagery. ASH CLOUD: Plume can no longer be detected on latest GMS imagery.
27 Sep 2002	SOURCE: GMS satellite imagery. ERUPTION DETAILS: Ash plume observed on satellite imagery [27/]2030Z. ASH CLOUD: Narrow ash cloud extends 40 NM to SW
28 Sep 2002	SOURCE: GMS satellite imagery. ERUPTION DETAILS: Ash plume observed on satellite imagery 2130Z. ASH CLOUD: Narrow ash cloud extends 20 NM to the NNW.
15 Oct 2002	SOURCE: GMS satellite imagery. ERUPTION DETAILS: Low level ash plume observed on satellite imagery 15/2225Z. ASH CLOUD: Ash plume extends 20 NM N of volcano. Winds indicate plume probably low level.
21 Oct 2002	SOURCE: AIREP PZ-ANF, GMS imagery. ERUPTION DETAILS: Smoke reported in area, and plume observed via GMS imagery. ASH CLOUD: Cloud up to 4 km, extending 5 NM, 30 NM wide to SE.
01 Nov 2002	SOURCE: AIREP. ERUPTION DETAILS: Smoke observed 01/0042Z drifting to NW of volcano at 3 km.
02 Nov 2002	SOURCE: AIREP AIR NIUGINI. ERUPTION DETAILS: Ash observed 02/2030Z drifting to ESE of volcano to 3 km.
11 Apr 2003	SOURCE: NOAA and GMS imagery. ERUPTION DETAILS: Plume evident on 10/2019Z and 11/0357Z NOAA image[s], height estimated below 3 km.
14 Apr 2003	SOURCE: GMS imagery. ERUPTION DETAILS: Possible plume evident on 13/2032Z, 13/2132Z and 13/2225Z [images], height estimated below 3 km
26 Apr 2003	SOURCE: GMS imagery. ERUPTION DETAILS: Possible plume evident on 26/0325Z MODIS as reported by KGWC/ Washington VAAC, height estimated below 4 km.
30 Apr 2003	SOURCE: GMS and MODIS imagery. ERUPTION DETAILS: Possible narrow low level plume evident on 30/0010Z MODIS and 30/0230Z GMS visible image[s], extending 30 NM WNW, height estimated below 3 km.
03 May 2003	SOURCE: KGWC. ERUPTION DETAILS: Ash/steam plume observed on 02/2026Z F13 DMSP Imagery. Plume extends 80 NM W of volcano, height to 4 km.
04 May 2003	SOURCE: NOAA satellite imagery. ERUPTION DETAILS: Thin low level plume observed on 04/2053Z. Plume extends 10 NM SW of Ulawun, height estimated at 4 km.
06 May 2003	SOURCE: GMS satellite imagery. ERUPTION DETAILS: Thin low level plume observed on 06/2032Z.
01 Jun 2003	SOURCE: GOES9 satellite imagery. ERUPTION DETAILS: Thin low level plume observed on [May] 31/2325Z.
18 Jun 2003	SOURCE: AFWA. ERUPTION DETAILS: Faint ash/steam plume seen on 18/2206Z satellite imagery.
20 Jun 2003	SOURCE: NOAA 17. ERUPTION DETAILS: Faint plume seen on NOAA 17 20/0004Z satellite imagery.
20 Jun 2003	SOURCE: NOAA 15. ERUPTION DETAILS: Faint plume seen 20/2050Z.
23 Jun 2003	SOURCE: NOAA 15. ERUPTION DETAILS: Faint plume seen on 23/2120Z.
24 Jun 2003	SOURCE: NOAA 15. ERUPTION DETAILS: Faint plume seen on 24/2057Z.
26 Jun 2003	SOURCE: MODIS. ERUPTION DETAILS: Faint plume seen on 26/0005Z extending 25 NM SW, height estimated at 4 km.
28 Jun 2003	SOURCE: NOAA 15. ERUPTION DETAILS: Faint plume seen on 28/2101Z.
02 Jul 2003	SOURCE: NOAA 15. ERUPTION DETAILS: Thin ash plume to 5 km extending 25 NM WSW of summit on 02/2108Z.
13 Jul 2003	SOURCE: AFWA. ERUPTION DETAILS: Thin ash plume to 4 km moving to the W at 10 knots [10 NM/hour or 18 km/hour].
22 Jul 2003	SOURCE: GOES9. ERUPTION DETAILS: Possible ash plume seen on 22/0130Z visible GOES imagery, extending 30 NM to NW, height estimated at 3 km.

Table 3. Dates of issue and the principal comments in Darwin VAAC reports concerning Ulawun, September 2000-July 2003. Similar or duplicate messages are not shown. In many cases ash cloud trajectory information has been omitted. On this table, the distance unit Nautical Miles (NM) has not been converted to kilometers (1 NM = 1.852 km (exactly)). Courtesy of the Darwin VAAC.

the month. No emission was reported from the two N-valley vents. Seismicity was at a low level.

The VAAC reports contain numerous abbreviations; however, a few of the terms here are in widespread use referring to satellites, meteorology, and various related agencies (NOAA, AFWA, GOES9, MODIS, and KGWC . . . DMSP Imagery, etc.) or AIREP (atmospheric conditions reported from aircraft). "RVO" stands for Rabaul Volcano Observatory. Other terms may be less familiar: "AIR NIUGINI, ANK." refers to a commuter plane in the fleet of the national airline based in Papua New Guinea. The stated dates and times are not local ones, but instead refer to those at the zero (prime) meridian. For example, 04/2240Z means the fourth day of the stated month at 2240 UTC (i.e. "Z," spoken as Zulu, is shorthand for Coordinated Universal Time (UTC).

Background. The symmetrical basaltic-to-andesitic Ulawun stratovolcano is the highest volcano of the Bismarck arc, and one of Papua New Guinea's most frequently active. Ulawun volcano, also known as the North Son, rises above the north coast of the island of New Britain across a low saddle NE of Bamus volcano, the South Son. The upper 1,000 m of the 2,334-m-high Ulawun volcano is unvegetated. A prominent E-W-trending escarpment on the south may be the result of large-scale slumping. Satellitic cones occupy the NW and eastern flanks. A steep-walled valley cuts the NW side of Ulawun volcano, and a flank lava-flow complex lies to the south of this valley. Historical eruptions date back to the beginning of the 18th century. Twentieth-century eruptions were mildly explosive until 1967, but after 1970 several larger eruptions produced lava flows and basaltic pyroclastic flows, greatly modifying the summit crater.

Information Contacts: *Rabaul Volcano Observatory* (see Rabaul); *Darwin Volcanic Ash Advisory Center (VAAC)*, Commonwealth Bureau of Meteorology, Northern Territory Regional Office, PO Box 40050, Casuarina, NT 0811, Australia (URL: http://www.bom.gov.au/info/vaac/; Email: darwin.vaac@bom.gov.au).

Pago

New Britain, Papua New Guinea
5.58 S, 150.52 E; summit elev. 742 m
All times are local (= UTC + 10 hours)

Pago was mainly quiet throughout the month of February 2004. However, two explosions were reported in the early hours of 24 February. The explosions were accompanied by thick dark grey ash clouds from the lower and upper vents. The ash clouds drifted SW of the volcano resulting in fine ashfall downwind. Jet-like noises were also heard at 0140 on 24 February accompanying the explosions. A weak glow was visible from the lower vents.

Background. Pago is a young post-caldera cone that was constructed within the 5.5 x 7.5 km Witori caldera. Extensive pyroclastic-flow deposits are associated with formation of the caldera about 3,300 years ago. The gently sloping outer flanks of Witori volcano consist primarily of dacitic pyroclastic-flow and airfall deposits produced during a series of five major explosive eruptions from about 5,600 to 1,200 years ago. The Buru caldera, which may have formed around the same time, cuts the SW flank of Witori volcano. The post-caldera cone of Witori, Mount Pago, may have formed less than 350 years ago. Pago has grown to a height above that of the Witori caldera rim. A series of ten dacitic lava flows from Pago covers much of the caldera floor. The youngest of these was erupted during 2002-2003 from vents extending from the summit nearly to the NW caldera wall.

Information Contact: *Rabaul Volcano Observatory* (see Rabaul).

Manam

Papua New Guinea
4.10°S, 145.06°E; summit elev. 1,807 m

Activity at Manam's two summit craters remained low during February 2004. The summit area was cloud covered most of the month; however, when clear, both craters were observed releasing white vapor at weak to moderate rates. A single explosion occurred during the month, on 14 February at Southern Crater. A thick dark gray ash cloud and weak roaring noises accompanied the explosion. The ash cloud rose several hundred meters above the summit before drifting NW of the island, resulting in fine ashfall downwind. There was no nighttime glow observed.

Background: The 10-km-wide island of Manam, lying 13 km off the northern coast of Papua New Guinea, is one of the country's most active volcanoes. Four large radial valleys extend from the unvegetated summit of the conical 1807-m-high basaltic- andesitic stratovolcano to its lower flanks. These "avalanche valleys," regularly spaced 90 degrees apart, channel lava flows and pyroclastic avalanches that have sometimes reached the coast. Five small satellitic centers are located near the island's shoreline on the northern, southern and western sides. Two summit craters are present; both are active, although most historical eruptions have originated from the southern crater, concentrating eruptive products during the past century into the SE avalanche valley. Frequent historical eruptions have been recorded at Manam since 1616. A major eruption in 1919 produced pyroclastic flows that reached the coast, and in 1957-58 pyroclastic flows descended all four radial valleys. Lava flows reached the sea in 1946-47 and 1958.

Information Contact: *Rabaul Volcano Observatory* (see Rabaul).

Ruang

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

The 25 September 2002 eruption of Ruang (*Bulletin* v. 27, no.10 and v. 28, no. 8) was, according to the Darwin Volcanic Ash Advisory Center (VAAC), the largest in Indonesia for many years and was well observed by satellite sensors. The eruption cloud reached a height of ~ 20 km, and a pyroclastic flow toward the SE damaged an area 1.6 km². Although no village was hit by the pyroclastic flow, two were heavily damaged by very thick ash material.

The Darwin VAAC and Bureau of Meteorology have published images and animations of the eruption clouds (figure 8). The satellites and images included those from

Aqua/MODIS, GMS Java Animation, and AVHRR sensors. Some ash clouds dispersed towards Singapore and Jakarta. A higher level cloud remained nearly stationary near the tropopause (the top of the troposphere, where most of the Earth's weather occurs). The highest cloud moved eastwards in the stratosphere. The color/shading reflects the strength of the detected ash signal.

The TOMS scientists published an image on their website (figure 9), described as follows: "The TOMS overpass on September 25 was too early to capture the fresh eruption cloud, but ash and SO_2 were evident on the following day. The aerosol signal over S Borneo is at least partly due to smoke from biomass burning; the ash cloud from Ruang can be seen over NE Borneo. A data gap may be obscuring any SO_2 or ash immediately W of Ruang."

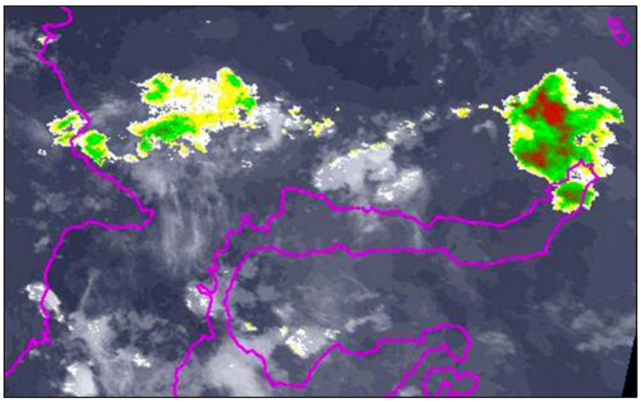

Figure 8. Night-time infrared image of the Ruang eruption processed to highlight volcanic ash. N is towards the top; the local island margins are shown, Sulawesi to the right and Borneo to the left. The enhanced areas disclose the W portion of the plume drifting over Borneo and the higher E ash and gas cloud nearly stationary over the eruption site. A third area of ash and ice cloud is nearly invisible near the bottom center. Courtesy of NASA, NOAA, and the Darwin VAAC.

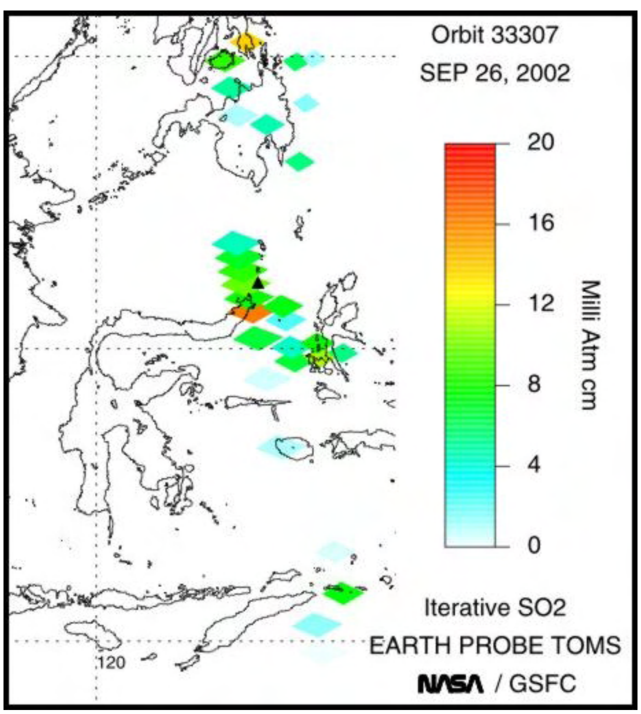

Figure 9. Ruang erupted on 25 September 2002. A pass the next day of the Earth Probe satellite with the Total Ozone Mapping Spectrometer (TOMS) instrument yielded this map of SO_2 concentrations. Courtesy of Simon Carn and Arlin Krueger.

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

Information Contacts: *Darwin Volcanic Ash Advisory Center (VAAC)* (see Rabaul); *Nia Haerani*, Volcanological Survey of Indonesia (see Karangetang); *Simon A. Carn* and *Arlin Krueger*, Joint Center for Earth Systems Technology (NASA/UMBC), University of Maryland, Baltimore County, 1000 Hilltop Circle, Baltimore, MD 21250, USA (URL: http://skye.gsfc.nasa.gov/).

Stromboli

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

According to aviation reports from the U.S. Air Force, the web camera at Stromboli captured shots of light ash emissions on 7 and 11 November 2003. In both cases plumes rose to ~ 2.5 km elevation. The Stromboli Web video camera showed a small explosion on 10 December 2003 that produced a plume to a height of ~ 1 km above the volcano. No ash was visible on satellite imagery.

The Istituto Nazionale di Geofisica e Vulcanologia (INGV) in Catania reported that explosive activity at Stromboli's three summit craters increased after 10 February 2004, leading to significant growth of the cinder cones inside the craters. Several powerful explosions, especially from Crater 1 (the NE crater) and Crater 3 (the SW crater), sent scoriae 200 m above the rims. These powerful explosions led to fallout of fresh bombs and lapilli on Il Pizzo Sopra la Fossa (an area atop the volcano about 100 m above the crater terrace) in early March. As of 8 March, Strombolian activity was occurring at the volcano, with variations in the number and frequency of explosions within normally observed limits, and the intensity of explosions at the higher limit of commonly observed activity.

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

Information Contacts: *Istituto Nazionale di Geofisica e Vulcanologia (INGV)*, Sezione di Catania Piazza Roma 2, 95123 Catania, Italy (URL: http://www.ct.ingv.it/, Email: calvari@ct.ingv); *Toulouse VAAC*, Météo-France, 42 Avenue G. Coriolis, 31057 Toulouse, France (URL: http://www.meteo.fr/aeroweb/info/vaac/, Email: vaac@meteo.fr); *AGI Online* news service, Italy (URL: http://www.agi.it/).

Erta Ale

Ethiopia, Africa
13.60°N, 40.67°E; summit elev. 613 m

In February 2004 an expedition led by German scientists visited Erta Ale. Afterwards, an overflight completed the survey of volcanic activity. Of significance was the discovery that an earlier lava lake had largely disappeared. Information from their report follows.

German scientists were at Erta Ale during 9-13 February 2004. They explored areas around the S crater of the volcano, which for the past several years has contained an active lava lake (see *Bulletins* v. 28, no. 4 and v. 26, no. 12). The S crater retained only a very small fraction of the former lava lake. When visited it stood ~ 15 m in diameter, located roughly in the center of the old lake. Around the small lake were many active gas vents, and there was a hornito, about 2 m tall, on the SE side. Behind its ~ 1.5-m-high walls, the lake's lava changed levels and occasional lava fountains rose to ~ 10 m high.

On 12 February the expedition team descended to the second terrace (~ 90 m below the rim) of the S crater, to the surface of the former lake, and approached the small elevated lake. Samples of newly ejected lava were collected, and some were given to Gezahegn Yirgu at the University of Addis Ababa for analysis. Samples retained by the expedition team showed white crystals, approximately 1-2 mm in size, embedded in black material. On the evening of 12 February the team witnessed an overflow of the little lake, flooding the NW half of the second terrace. Parts of the western lake wall eventually collapsed, causing a lava flood wave as well as more violent fountaining (up to 20 m). This event lasted approximately 2 hours.

The entire crater was fogged by fumaroles, which were mainly active in the SE corner of the first terrace (~ 50 m below the rim). Gas masks were necessary inside the crater. From the smell and (blueish) color, these gases contained a high quantity of SO_2.

No earthquakes were felt during the visit.

On 21 February a low overflight was made across the volcano. There were no more signs of a lava lake, and only three hornitos were active. Although the flight was made during the day, the glow allowed the hornitos to be visible. Upon return, Chris Heinlein noted that he found photos on the web by Luigi Cantamessa showing that during 15-17 November 2003 the lava lake was also largely gone.

Background. Erta Ale is an isolated basaltic shield volcano that is the most active volcano in Ethiopia. The broad, 50-km-wide volcano rises more than 600 m from below sea level in the barren Danakil depression. Erta Ale is the namesake and most prominent feature of the Erta Ale Range. The 613-m-high volcano contains a 0.7 x 1.6 km, elliptical summit crater housing steep-sided pit craters. Another larger 1.8 x 3.1 km wide depression elongated parallel to the trend of the Erta Ale range is located to the SE of the summit and is bounded by curvilinear fault scarps on the SE side. Fresh-looking basaltic lava flows from these fissures have poured into the caldera and locally overflowed its rim. The summit caldera is renowned for one, or sometimes two long-term lava lakes that have been active since at least 1967, or possibly since 1906. Recent fissure eruptions have occurred on the northern flank of Erta Ale.

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Ol Doinyo Lengai

Tanzania, East Africa
2.751°S, 35.902°E; summit elev. 2960 m
All times are local (=GMT + 3 hours)

Activity at Ol Doinyo Lengai has continued intermittently since October 2002 (*Bulletin* v. 27, no. 10). (According to Fred Belton, in that same month, October 2002, Paramount Pictures used the crater to shoot footage for the film "Tomb Raiders II.").

This summary report for 2003 is based on observations made by Joerg Keller, Jurgis Klaudius, Fred Belton, and Christoph Weber, as well as information collected by Celia Nyamweru from visits to the area. Christoph Weber most recently visited Lengai in February 2004, when he collected GPS data for a new, precise crater map (figure 10). He also took temperature measurements of fumaroles and lava flows (see tables 4 and 5), and gathered lava samples to be given to research departments.

Summary of 2003 activity. During the first half of 2003, two new hornitos appeared in the center of the active crater at Ol Doinyo Lengai at the T49 and T58B (T48) locations (see figure 10 and caption). A huge lava pond appeared at these locations and caused several lava flows in all directions. According to Burra Gadiye, a local Lengai observer, by mid-June unusually dramatic activity started at both new hornitos. An expedition led by Frederick Belton in August 2003 reported that strong degassing and rhythmic explosive eruptions threw lapilli, ash, and lava spatter to 100 m above the hornito. Those eruptions, best described as Strombolian, continued until January 2004. They were accompanied by several lava flows and built up the comparatively tall strato-type hornitos at the T49-T56B locations and at the T48-T48B-T58B locations. The summit of T48B stood just above the former T44 hornito, but T44 itself was no longer visible.

Observations during February 2004. An expedition team including Christoph Weber and others visited Lengai for five days, 10-14 February 2004 (figures 11, 12, and 13). The team used GPS to conclude that the summit of the tallest hornito, located in the center area of the active crater at Ol Doinyo Lengai (T49 or T56B location), was at approximately 2,886 m elevation, standing about 33 m above the surrounding crater floor to the N. While this hornito was no longer active, T48B (T58B) contained a lava lake deep inside, which was clearly indicated by noise and tremor. Observers in February noted effusive and lava lake activity. This occurred at the old T49 eruption center, also indicated by the activity of T49B during observation and an active new vent (numbered T49G by Weber, figure 13) at the N flank of T49 (T56B), about half way up from its base to the N side.

Location	Date	Temperature (°C)
T40 lava lake	28 Aug 1999	529
Pahoehoe flow in a tube near T40	01 Sep 1999	519
Aa flow still in motion on flat terrain (60 cm thick)	01 Sep 1999	516
Pahoehoe flow in a tube near T49B	03 Oct 2000	507
Aa flow still in slow motion on flat terrain (25 cm thick)	03 Oct 2000	496
Pahoehoe flow in a tube near T49G	11 Feb 2004	588
Pahoehoe flow in a tube near T49B	12 Feb 2004	579
Aa flow immobile and on flat terrain (15 cm thick)	13 Feb 2004	490

Table 4. Lava temperature measured at Ol Doinyo Lengai by a digital thermometer (TM 914C with a stab feeler, standard K-Type). The instrument was used in the 0-1200° Celsius mode. Calibration was made using the delta-T method, where temperature values are +/- 6°C in the 0-750°C range associated with at least four replicate measurements at one spot. Courtesy of Christoph Weber.

Location	Date	Temperature (°C)
F1	28 Aug 1999	70
Near T49	28 Aug 1999	82
Near T49C	03 Oct 2000	75
F1	03 Oct 2000	69
The hottest cracks in the crater floor	20 Oct 2002	124
F1	20 Oct 2002	78
F1	30 Jun 2003	86
Near T49C	30 Jun 2003	76
F1	12 Feb 2004	88

Table 5. Fumarole temperatures measured at cracks in the crater floor of Ol Doinyo Lengai, using the above-described digital thermometer. Courtesy of Christoph Weber.

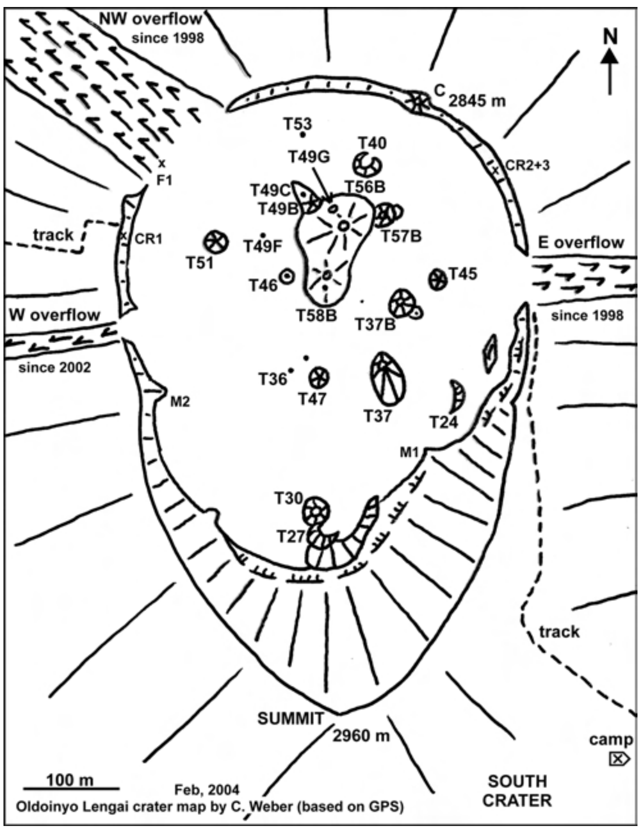

Figure 10. GPS-aided sketch map of the crater at Ol Doinyo Lengai made on 14 February 2004. Note the lava flow paths over the crater's margin on onto the flanks ("overflows") that have started in the past several years. Subsequent figures (photos) help clarify the shapes and sizes of hornitos and other features. Naming conventions are complicated by the crater's rapidly changing landscape, including such processes at hornitos as collapse, clustering, and overlap. For example, hornito T48, which was described as having collapsed in July 2000, lies on the N margin of the hornito labeled as T58B. The lava ponds seen by Hloben in January 2001 are not shown, although some of their locations may coincide with later features. For detailed comparison of crater evolution and naming conventions, consult previous maps (eg., *Bulletin* v. 27, no. 10). Courtesy of Christoph Weber, Volcano Expeditions International and Volcano Hazards Documentation and Logistic Research.

This new activity probably caused two collapses (which left depressions) in the N flank of T49 (T56B), seen since January 2004. The T49G vent, located at the upper collapse, had a steady degassing lava lake with many overflows recorded during the February visit. Lava penetrated the lower collapse at T49 and lava flows reached as far as the NW overflow. On 12 and 13 February the T49B vent spattered lava for hours, feeding lava flows to the W (to the vicinity of T51), and finally escaping into a lava tube system. The lava temperature very close to the lava lake was measured at 588°C. Immobile aa lava flows on flat terrain were measured between 480°C and 500°C (table 5).

On 7 February team members Christoph Weber and R. Albiez were staying at the N slope of the neighboring Karimassi volcano and heard a paroxysm at T48B (T58B) lasting 30 seconds. During the visit on 10 February evidence of this paroxysm included fresh lava spatter and bombs cast around T58B for a radius of ~ 100 m.

Evacuation project at Ol Doinyo Lengai. Contributors to this report belong to a group committed to creating and funding evacuation plans. That group is called Volcano Hazards Documentation and Logistic Research (see Information Contacts). The group is working with the local Masaii and authorities on preparations in case of a dangerous eruption.

Background. The symmetrical Ol Doinyo Lengai stratovolcano is the only volcano known to have erupted carbonatite tephras 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

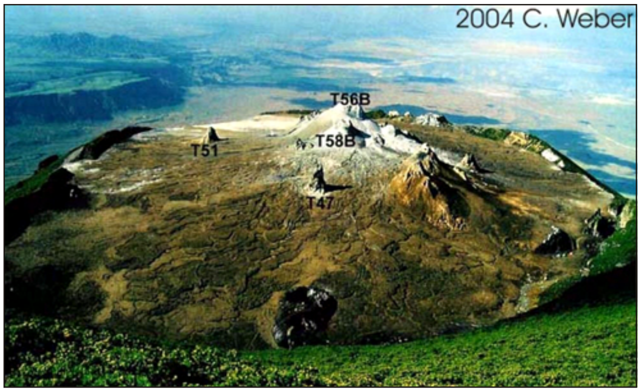

Figure 11. Ol Doinyo Lengai as seen in February 2004 from its summit, looking towards the actively erupting N crater. Courtesy Christoph Weber.

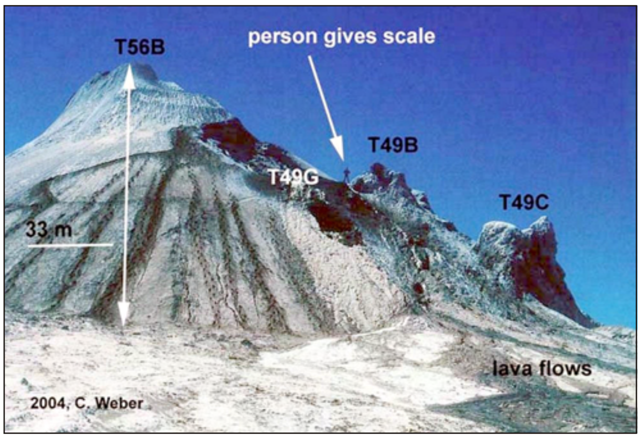

Figure 12. View of the tallest hornito (T56B) at Ol Doinyo Lengai in February 2004. T56B sits in the center of the active (N) crater. The hornito's summit was at 2,886 m elevation. Lava flows are visible in the foreground. Courtesy Christoph Weber.

of the volcano ended about 15,000 years ago and was followed by periodic ejection of natrocarbonatitic 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

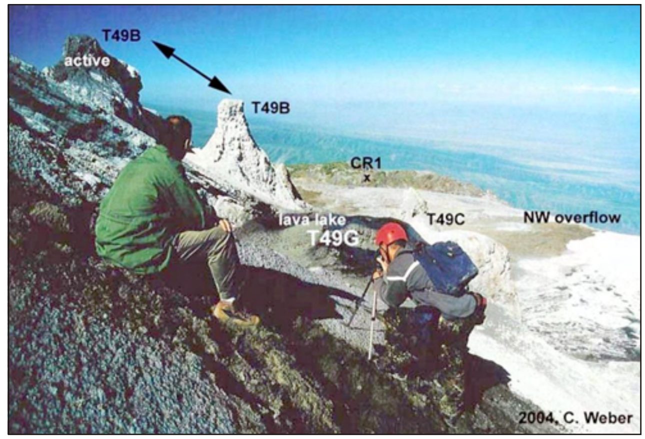

Figure 13. View of Ol Doinyo Lengai looking towards the W, facing the lava lake at T49G and the active peak at T49B. Courtesy Christoph Weber.

depth and morphology of the northern crater have changed dramatically during the course of historical eruptions, ranging from steep craters 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.

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