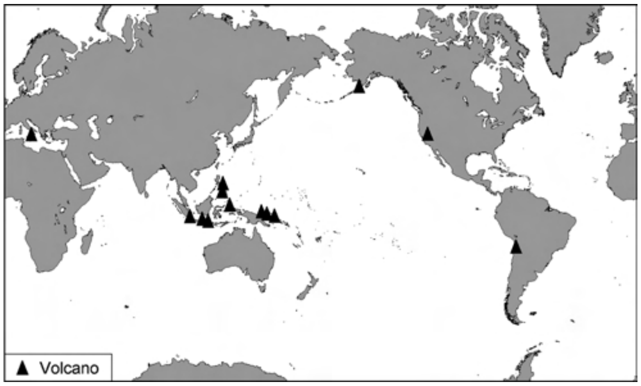

Mayon (Philippines) *Small as*

Mayon

Luzon, Philippines
13.247°N, 123.685°E; summit elev. 2,462 m
All times are local (= UTC + 8 hours)

Until 11 October 2002, no significant volcanic activity had been reported since eruptions in June and July 2001 (*Bulletin* v. 26, no. 8). Subsequent deflation, combined with declining seismicity and sulfur dioxide flux, resulted in the Alert Level being lowered to 0 (no eruption is forecast in the foreseeable future, but entry in the 6-km radius Permanent Danger Zone (PDZ) is not advised because phreatic explosions and ash puffs may occur without precursors) in February 2002 (*Bulletin* v. 27, no. 4).

Mayon remains intermittently active, with tremor episodes, a small ash puff in October 2002, steam emission in January 2003, and an explosion and ash plume in March 2003. Small ash explosions on 5 May and 6 April will be described in the next *Bulletin*.

Activity during October 2002. At 0635 on 11 October 2002 the volcano produced a small ash puff that reached 500 m above the summit crater. The small ash cloud from this minor explosion quickly diffused and drifted E without noticeable deposits on the slopes. The ash puff followed a series of imperceptible volcanic tremors that began in the early hours of 22 September and occurred sporadically until the last tremor was recorded on 9 October. The 11 October report from the Philippine Institute of Volcanology and Seismology (PHIVOLCS) also noted that slight swelling of the volcano's edifice was detected by an electronic tiltmeter on the S flank. However, the Alert Level remained at 0.

A 30 October notice from PHIVOLCS indicated that the number of volcanic earthquakes, although imperceptible, remained significantly above background levels since the ash emission of 11 October. Another notable observation was the occurrence of small volcanic tremors and consistent inflation detected by electronic tiltmeters, which suggested that magma was intruding into the volcano. Gas output from the summit had increased from recent emission rates of ~950 metric tons per day (t/d) to ~2,200 t/d on 29 October. Because of these consist

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white steam clouds rose 50 m above the active crater and drifted SW and SSW. No corresponding significant earthquake activity accompanied the event; the seismic network detected only two small low-frequency volcanic earthquakes in the preceding 24 hours. PHIVOLCS interpreted the activity as being hydrothermal in nature at shallow levels in the crater, with no indication of active magma intrusion. Details of the ash emission that occurred “last week” were not provided.

Alert Level 1 signifies that there could be possible ash explosions in the coming days or weeks. For this reason, PHIVOLCS reiterated that the public should avoid entering the 4-km-radius Permanent Danger Zone.

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

Information Contact: *Philippine Institute of Volcanology and Seismology (PHIVOLCS)* (see Mayon).

Rabaul

New Britain, Papua New Guinea
4.271°S, 152.203°E; summit elev. 688 m

Eruptions at Tavurvur continued to occur throughout January-March 2003. The eruptions were characterized by forceful and convoluted, sub-continuous, light to pale gray ash cloud emissions at irregular intervals. The following was provided by the Rabaul Volcano Observatory.

Activity during January 2003. During the first several days of January (except the 4th), activity was similar to late December 2002. The eruptions consisted of sub-continuous ash emissions occurring at intervals ranging from a few minutes to ~10 minutes. Many of the ash emissions were sustained for 1-2 minutes. On the 4th, activity was at a low point, shown by the fewest ash emissions of the month. Between 8 and 17 January, the pattern of eruption changed slightly to a mixture of events. The sub-continuous ash emissions persisted, but forceful emissions began as well, although not in significant numbers. A complete change in the pattern of eruptive activity began on the 18th. The sub-continuous ash emissions reduced significantly and the sharp forceful emissions became more prominent. They occurred at very short intervals of 2-4 minutes. This pattern of activity was maintained until the 26th. A lot of the forceful emissions between 20 and 26 January were accompanied by low roaring noises. Noises were also heard on the 7th. After 26 January, the magnitude of the forceful emissions eroded and activity changed back to sub-continuous ash emissions at slightly longer intervals. This trend of summit activity continued until the end of the month.

Ash plumes from the eruptive activity rose variably in height. Those from the forceful emissions rose to a maximum of about 1,500 m, while ash plumes from the sub-continuous emissions rose to several hundred meters above the summit. Variable winds blew the ash plumes to the E and SE (1-14 and 22-31 January), and N and NW (15-21 January). Rabaul Town and villages that are located N and NW from Tavurvur had fine ashfall between 15 and 21 January. The S and SE drifting ash fell mainly in the sea; however, very fine specks of it fell on Cape Gazelle including the nearby Tokua Airport, ~20 km from Tavurvur.

Seismic activity reflected the summit activity. Both the sharp forceful and the sub-continuous ash emissions generated seismic waves characteristic of their nature. Seismic waves associated with the forceful emissions had greater amplitudes reflecting greater energy. Average duration of this type of event was about 40-50 seconds. On the other hand, events associated with the sub-continuous ash emissions had lower amplitudes, and their duration ranged between one and several minutes. Only one volcano-tectonic earthquake was recorded.

During the month ground-deformation measurements showed deflation. Real-time GPS measurements showed 5-8 mm of deflation. The electronic tiltmeter showed a few microradians of down-tilt towards the perceived uplift center SE of Matupit Island and SW of Tavurvur.

Activity during February 2003. Forceful ash emissions were observed in February, but not as abundantly as in January. In February, ash emissions were slightly more frequent during the first few and last few days of the month. The emissions occurred at intervals of 4 and 10 minutes. The longest duration for an ash emission during these periods was about 4-6 minutes. Between 5 and 24 February activity fluctuated, and ash emissions occurred at intervals of several minutes. The longest duration for an ash emission during this period was about 15 minutes. This does not necessarily imply that the amount or volume of ash contained in the emissions was consistent throughout the entire duration of emission. Rather, there was higher ash content in the initial stages of the emissions, which faded thereafter to white to pale gray emissions with very little ash content.

Plume heights were similar to those in January. During the month ash plumes were blown mainly to the E and SE, and occasionally to the SW. On 3 and 4 February, some ash plumes drifted N and NW, resulting in fine ashfall in Rabaul Town and nearby villages farther downwind.

Seismic activity was dominated by the long-duration, low-amplitude, tremor-type events, associated with the convoluted, sub-continuous ash emissions. The duration of these events ranged between 2 and 19 minutes. Only one high-frequency, volcano-tectonic earthquake was recorded.

Real-time GPS measurements fluctuated in February. During the first half of the month, measurements showed an inflationary trend. This is a rebound from the month-long deflationary trend observed in January. During the second half of February, movements changed to show deflation. The electronic tiltmeter fluctuated showing no obvious trends.

Activity during March 2003. The general level of eruptive activity in March had minor fluctuations but did not deviate much from previous months. Activity during the first two weeks was a continuation of the last few days of February. Thereafter, activity waned slightly, with ash emissions occurring at slightly longer intervals, with the exception of a couple of half-days on 15 and 16 March, when ash emissions were a bit more frequent. At the same time forceful-type emissions began until about the 23rd, when rates of sub-continuous ash emissions picked up again slightly, surpassing the activity for the first two weeks of the month. The slightly increased level continued until the end of the month. A handful of forceful emissions also occurred.

Ash plumes from the March activity rose 500-1,500 m above the summit before they were blown mainly to the SE. Most ash fell immediately downwind near Tavurvur and the deserted Talvat village. Lighter ash particles drifted farther downwind and fell in the sea.

Seismicity reflected the summit activity. It consisted mainly of low-amplitude tremor-type events with durations ranging from a couple of minutes to about eight minutes. These events were associated with sub-continuous convoluted ash emissions. Short duration, higher amplitude events associated with forceful ash emissions were also recorded but were outnumbered by the former event type. Four volcano-tectonic earthquakes were recorded during the month on the 2nd (2) and 3rd (2).

Ground-deformation measurements in March showed a more distinct and consistent sense of surface movement. Both the realtime GPS and electronic tilt measurements showed inflation. The long-term trend between January and March, as per realtime GPS measurements, was characterized by diurnal-type fluctuations of peaks and troughs, the range being about 20 mm between the highest peak and lowest trough. The cumulative movement for the three-month period was deflation of ~8 mm.

A M_L 6.8 tectonic earthquake occurred on 11 March. The quake, located about 120 km SE from Rabaul in offshore southern New Island, and was felt strongly at Rabaul with MM VI. It caused minor landslides in parts of the Gazelle Peninsula.

Background. The low-lying Rabaul caldera on the tip of the Gazelle Peninsula at 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 east, where its floor is flooded by Blanche Bay. Two major Holocene caldera-forming eruptions at Rabaul took place about 7100 and 1400 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
5.05°S, 151.33°E; summit elev. 2334 m

The main summit crater continued to release variable amounts of thin-to-thick white vapor during January-March 2003, and no activity was observed from the N valley vent that formed in May 2001. Heavy rains during February and especially on the 19th, 21st, 22nd, and 24th, caused debris flows on the NW side of Ulawun. The debris channeled into Namo creek and later swept down to the coast. Along its course it overflowed into Ubili village. Muddy water flowed into six houses built on concrete floors and left a thin sheet of dried mud a few centimeters thick.

The long-term deformation trend based on measurements from an electronic tiltmeter is slow deflation of the summit area. No significant changes were noted in January. In February there was 2 µrad of deflation, and measurements showed a very small amount (~2-3 µrad) of deflation between the beginning of March through the 25th. After that the trend became steady.

Seismic activity had been low through January-February, but an increase was evident starting on 2 March. This was shown by an increase in RSAM values on the same day. The increased activity remained at low to moderate levels between 2 and 12 March. After that, it declined gradually, reaching low levels on the 20th. Due to technical problems with the only seismograph to monitor Ulawun, no analogue waveforms were recorded, making it difficult to ascertain the type of seismicity associated with the increased RSAM values. However, it is assumed that another of the sporadic volcanic tremor episodes recorded since the September 2000 and April 2001 eruptions was the cause.

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 1000 m of the 2334-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 Contact: *Ima Itikarai*, Rabaul Volcano Observatory (RVO) (see Rabaul).

Pago

New Britain, Papua New Guinea
5.58°S, 150.52°E; summit elev. 742 m

The eruption that began in August 2002 continued during early 2003 with lava effusion through at least 28 February and vapor emissions. The following is from the Rabaul Volcano Observatory.

Activity during January 2003. No field or aerial observations of the caldera or lava flow were made in January. However, blue vapor was observed throughout January from the NW-most lava-producing vent and other vents along the NW-SE-trending fissure system, suggesting that hot lava was near the surface and presumably still flowing. Besides the blue vapor emissions, variable amounts of white vapor were released. Evidence of dead and dried vegetation downwind of the fissure system indicated that hazardous gases, such as sulfur dioxide, were present in the vapor emissions. The dead vegetation is restricted to an area extending 1-2 km to the S (downwind). This is unlike similar vegetation effects during the SE-wind season, which extended as far as 10 km to the NW from the source of the vapor emissions. Occasional low roaring noises were heard on 9, 21, 22, 25, and 26 January.

Seismic activity was relatively steady with no significant deviation from the background levels determined since the permanent seismic network was established in early October 2002. Earthquakes consisted mainly of volcano-tectonic (VT) events averaging 45 per day, with a low of 18 (recorded on the 20th) and a high of 71 (on the 4th). The events occurred randomly over each day. Low-frequency earthquakes were recorded on some days; a maximum of six events was recorded on the 18th.

Airlink began to use Hoskins airport in the latter half of January after winds began to blow away from the airport. Furthermore, the absence of ash emissions since August and early September 2002 made conditions favorable. The decision to re-use the airport followed information provided by RVO to the Papua New Guinea Civil Aviation Authority and aviation industry.

Activity during February 2003. An aerial inspection on 28 February showed that lava effusion continued from the NW-most vent of the fissure system (figure 1). The lava flow had two lobes. The main lobe was directed initially to the N but later curved to a northeasterly direction, dictated by topographic features of the Witori caldera floor. On 28 February it appeared that horizontal lateral flow of this lobe had stopped after it reached a topographic barrier. As a result, the lava flow began to gain height along its entire northern portion. The height of the flow was estimated to be ~25-33% of the height of the ~240-m-high Witori Caldera wall. The second lobe of the lava flow, which flowed to the S, showed slow progress. Between October 2002 and February 2003 it advanced only a few hundred meters. The thickness of this flow was ~30-40 m. As of 28 February the total volume of erupted lava from this single vent was estimated to be ~0.09-0.12 km^3.

Emissions of minor to moderate volumes of white vapor continued from all vents along the fissure system. The lower vents to the NW released more vapor than the upper ones to the SE. Small amounts of blue vapor were released from the lava-producing vent. Because the vapor emissions were blown S and SE, vegetation within 2 km downwind turned brown. No ash emissions were produced during the month. Low jet-roaring noises were heard on 4, 9-11, 13, and 21 February. Hoskins airport continued to be used by Airlink in February.

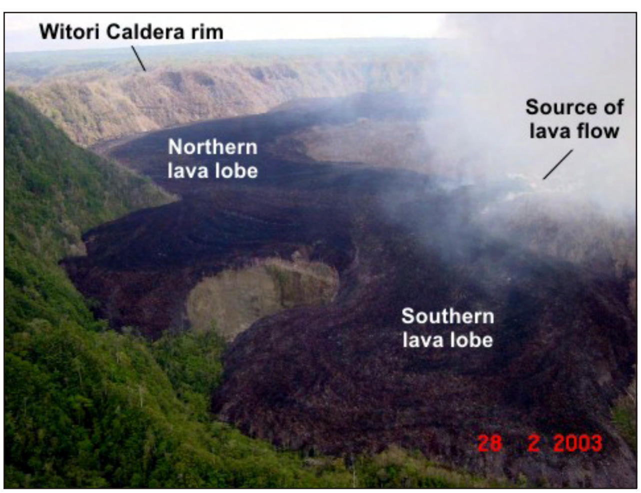

Figure 1. Lava flow lobes from the NW-most vent of the fissure system on 28 February 2003. The view is to the N. The white cloud at the top right of the photo is caused by vapor emissions from the line of vents on the fissure system. Photo by Ima Itikarai, RVO.

Seismic activity was low during the month. Earthquakes were mainly volcano-tectonic. The daily count was ~30 compared to 45 in January. Most of the earthquakes were very small ones, but moderate-sized events were recorded on 1 (2 events), 10 (2), 12 (1), and 18 February (6). The six earthquakes on the 18th were recorded within a time span of 1.5 hours. A handful of low-frequency earthquakes were also recorded on the 6th (2), 10th (1) and 11th (1).

Activity during March 2003. No field or aerial observations of the lava flow were made in March, so it is uncertain whether lava effusion from the NW-most vent continued. The upper vents continued to release weak emissions of thin white vapor. The lower vents released weak to moderate emissions of white vapor and bluish vapor emissions on 13, 18, 23, and 28-30 March, indicative of hot material. Low roaring noises heard on 13, 16, 18, 23, and 29 March did not accompany explosive activity. No seismic recordings were made in March.

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 3300 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 5600 to 1200 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: *Ima Itikarai*, Rabaul Volcano Observatory (RVO) (see Rabaul).

Langila

New Britain, Papua New Guinea
5.525°S, 148.42°E; summit elev. 1330 m

The summit area was obscured by rain and clouds on many days in January and February. During clear days (4-5, 8-16, 18-21, and 25 January; 1-9 and 13-17 February), Crater 2 released weak to moderate emissions of white and white-gray vapor. Occasional ash-laden gray-brown and forceful dark gray emissions were produced on 10 and 14 January, respectively. The forceful emissions on the 14th were accompanied by low roaring noises. On 18 January a large explosion produced a thick dark ash column that penetrated the atmospheric clouds over the summit area. Occasional white-gray and gray-brown ash-laden emissions were observed on 1-6 February. On 3 and 4 February the same vent forcefully ejected dark gray ash clouds. Night glow was observed at Crater 2 on 14 and 15 January; some of the glow on the 15th changed into weak incandescent lava projections. Variable weak to bright red glow was observed at night on 3-6 and 14 February. On 3 February the glow fluctuated. Low rumbling noises were only heard on 6 February. Crater 3 released thin white vapor gently on 9-10, 12-13, and 19 January, and during 3-4, 6-9, 14, and 16 February. No emissions were observed on other clear days. There was no seismic recording.

Background. Langila, one of the most active volcanoes of New Britain, consists of a group of four small overlapping composite 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 Contact: *Ima Itikarai*, Rabaul Volcano Observatory (RVO) (see Rabaul).

Manam

off the N coast of New Guinea, Papua New Guinea
4.10°S, 145.061°E; summit elev. 1807 m

The summit area of Manam was obscured by rain and atmospheric clouds on most days during January-March 2003, making it difficult to observe emissions from the two summit craters. When clear, the Main Crater released small-to-moderate volumes of thin white vapor. Southern Crater generally released small-volume white emissions. Seismicity was low. Small low-frequency earthquakes were recorded on most days. Slightly greater numbers of earthquakes occurred on 16, 17, 23, 25, and 27 January. Some volcano-tectonic earthquakes were recorded on 11 (1), 12 (1), and 16 January (3); the events on the 16th were larger than the others. No volcano-tectonic earthquakes were recorded in February, and there was no seismic recording during March.

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 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: *Ima Itikarai*, Rabaul Volcano Observatory (RVO) (see Rabaul).

Dukono

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

The last reported activity at Dukono consisted of a plume that reached 6 km altitude on 25 September 1995 (*Bulletin* v. 20, no. 10). Post-May 2000 MODIS data suggested a significant event during 26 August-7 September 2002. During that period, anomalies rose well above alert detection threshold, triggering 10 thermal alerts. All of the alert pixels were located within a 1-km radius.

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

Information Contacts: *Diego Coppola* and *David A. Rothery*, Department of Earth Sciences, The Open University, Milton Keynes, MK7 6AA, UK (Email: d.coppola@open.ac.uk, d.a.rothery@open.ac.uk). Thermal alerts courtesy of the HIGP MODIS Thermal Alerts Team (URL: http://modis.higp.hawaii.edu/).

Ibu

Halmahera, Indonesia
1.48°N, 127.63°E; summit elev. 1,325 m

The last reported activity at Ibu included ash emission and mild ash explosions in September 1999. A May 2000 photo showed a lava dome covering the crater floor. MODIS data after May 2000 indicated thermal alerts during 28 May-3 October 2001 (figure 2). The series of alerts was consistent with continued inflation of, or extrusion onto, this dome. Note that the alert was barely above threshold, and it is likely that Ibu was just below detection threshold through 2002. A discussion of the MODIS technique was included in *Bulletin* v. 28, no. 1.

Background. The truncated summit of Gunung Ibu stratovolcano along the NW coast of Halmahera Island has large nested summit craters. The inner crater, 1 km wide and 400 m deep, contained several small crater lakes through much of historical time. The outer crater, 1.2 km wide, is breached on the N side, creating a steep-walled valley. A large parasitic cone is located ENE of the summit. A smaller one to the WSW has fed a lava flow down the western flank. A group of maars is located below the northern and western flanks of the volcano. Only a few eruptions have been recorded from Ibu in historical time, the first a small explosive eruption from the summit crater in 1911.

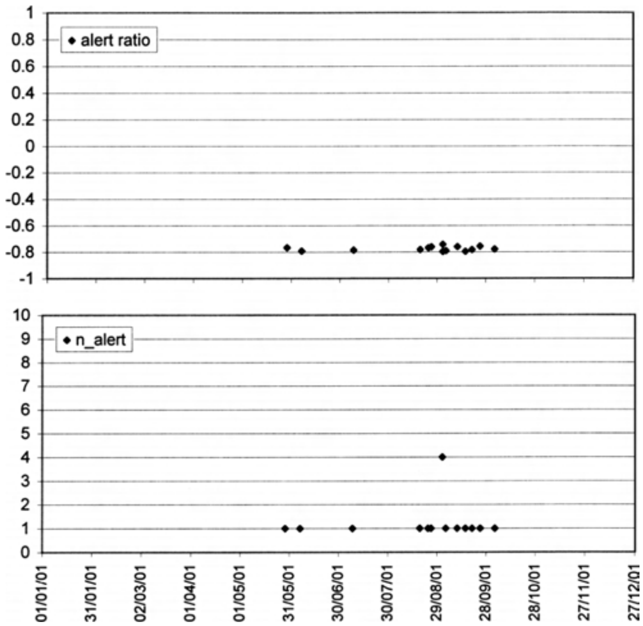

Figure 2. MODIS thermal alerts on Ibu during 2001. Thermal alerts collated by Diego Coppola and David Rothery; data courtesy of the Hawaii Institute of Geophysics and Planetology's MODIS Thermal Alert Team.

An eruption producing a lava dome that covered much of the floor of the inner summit crater floor began in December 1998.

Information Contacts: *Diego Coppola* and *David A. Rothery*, Department of Earth Sciences, The Open University, Milton Keynes, MK7 6AA, UK (Email: d.coppola@open.ac.uk, d.a.rothery@open.ac.uk). Thermal alerts courtesy of the HIGP MODIS Thermal Alerts Team (URL: http://modis.higp.hawaii.edu/).

Agung

Bali, Indonesia
8.34°S, 115.51°E; summit elev. 3,142 m

Thermal anomalies were detected by MODIS throughout 2001 and 2002 in zones proximal to the summit of Agung. The first alert occurred on 23 September 2001 when two alert-pixels were detected with a maximum alert ratio of -0.789. Larger anomalies were detected on 12 August 2002 (two alert-pixels with maximum alert ratio of -0.429) and 5 October 2002 (one alert-pixel with alert ratio of -0.536). All the alerts seem to occur outside the summit crater, with the possible exception of 5 October 2002, and are more likely to represent fires than volcanic activity.

Fumarolic and solfataric activity (restricted to the crater) generated a thin white plume in July 1989 (*Bulletin* v. 14 no. 07) and occasional seismicity recorded in November 1989 (*Bulletin* v. 14 no. 11). No volcanic activity has been reported recently by the Volcanological Survey of Indonesia.

Background. Symmetrical Agung stratovolcano, Bali's highest and most sacred mountain, towers over the eastern end of the island. The volcano, whose name means "Paramount," rises above the SE caldera rim of neighboring Batur volcano, and the NE and SW flanks of Agung extend to the coast. The 3,142-m-high summit of Agung contains a steep-walled, 500-m-wide, 200-m-deep crater. The flank cone Pawon is located low on the SE side of Gunung Agung. Only a few eruptions dating back to the early 19th century have been recorded from Agung in historical time. Agung's 1963-64 eruption, one of the world's largest of the 20th century, produced voluminous ashfall and devastating pyroclastic flows and lahars that caused extensive damage and many fatalities.

Information Contacts: *Diego Coppola* and *David A. Rothery*, Department of Earth Sciences, The Open University, Milton Keynes, MK7 6AA, UK (Email: d.coppola@open.ac.uk, d.a.rothery@open.ac.uk). Thermal alerts courtesy of the HIGP MODIS Thermal Alerts Team (URL: http://modis.higp.hawaii.edu/).

Ijen

eastern Java, Indonesia
8.058°S, 114.242°E; summit elev. 2,386 m
All times are local (= UTC + 7 hours)

During 9 December 2002-26 January 2003, the Volcanological Survey of Indonesia (VSI) reported that seismicity at Ijen was dominated by shallow volcanic and tectonic earthquakes (table 1). The number of weekly volcanic earthquakes decreased significantly in December compared to July-November 2002 (*Bulletin* v. 27, nos. 8 and 11). One deep volcanic earthquake was registered during 13-19 January. Continuous tremor occurred throughout the report period. The Alert Level remained at 2.

Thermal anomalies were detected by MODIS throughout 2001 and 2002 adjacent to the Ijen (Kendeng) caldera. The center coordinates of the alert-pixels are widely dispersed, so it seems likely that these represent fires. Alerts occurred in August-September 2001, May 2002, and September-October 2002. The biggest anomaly occurred on 19 October 2002 close to Kawah Ijen, the only currently known locus of activity in the complex. This was characterized by four alert-pixels with a maximum alert ratio of +0.568. This is an extremely high ratio and is comparable to that seen elsewhere during lava effusion. However, VSI confirmed that there was no eruption that day, only a bush fire that also damaged seismic sensors.

Background. The Ijen volcano complex at the eastern end of Java consists of a group of small stratovolcanoes

Date (2002-2003)	Shallow volcanic earthquakes (B-type)	Tectonic earthquakes	Tremor amplitude
09 Dec-15 Dec 02	—	—	0.5-12 mm
16 Dec-22 Dec 02	1	2	0.5-8 mm
23 Dec-29 Dec 02	3	—	—
30 Dec-05 Jan 03	13	3	0.5-6 mm
06 Jan-12 Jan 03	13	3	0.5-6 mm
13 Jan-19 Jan 03	1	7	0.5-4 mm
20 Jan-26 Jan 03	9	7	0.5-1 mm

Table 1. Seismicity at Ijen during 9 December 2002-26 January 2003. Courtesy VSI.

constructed within the large 20-km-wide Ijen (Kendeng) caldera. The N caldera wall forms a prominent arcuate ridge, but elsewhere the caldera rim is buried by post-caldera volcanoes, including Gunung Merapi stratovolcano, which forms the 2,799-m-high point of the Ijen complex. Immediately W of Gunung Merapi is the renowned historically active Kawah Ijen volcano, which contains a nearly 1-km-wide, turquoise-colored, acid crater lake. Picturesque Kawah Ijen is the world's largest highly acidic lake and is the site of a labor-intensive sulfur mining operation in which sulfur-laden baskets are hand-carried from the crater floor. Many other post-caldera cones and craters are located within the caldera or along its rim. The largest concentration of post-caldera cones forms an E-W-trending zone across the southern side of the caldera. Coffee plantations cover much of the Ijen caldera floor, and tourists are drawn to its waterfalls, hot springs, and dramatic volcanic scenery.

Information Contacts: *Dali Ahmad*, Volcanological Survey of Indonesia (VSI), Jalan Diponegoro No. 57, Bandung 40122, Indonesia (Email: dali@vsi.esdm.go.id; URL: http://www.vsi.dpe.go.id); *Diego Coppola* and *David A. Rothery*, Department of Earth Sciences, The Open University, Milton Keynes, MK7 6AA, UK (Email: d.coppola@open.ac.uk, d.a.rothery@open.ac.uk). Thermal alerts courtesy of the HIGP MODIS Thermal Alerts Team (URL: http://modis.higp.hawaii.edu/).

Arjuno-Welirang

eastern Java, Indonesia
7.73°S, 112.58°E; summit elev. 3,339 m

Thermal alerts detected by MODIS within the 2001-2002 period occurred only during August-October 2002 (figure 3) in the summit area. The first alert occurred on 13 August 2002 when a single alert-pixel had an alert ratio of -0.542. On 10 October the anomaly consisted of two alert-pixels with a maximum alert ratio of -0.409, and on 21 October the anomaly was characterized by six alert-pixels (clustered SW of the summit) with a maximum alert ratio of -0.571.

The Volcanological Survey of Indonesia reported that the volcano was at Status Level I (no activity) in October 2002. No observations were reported, but only distant tectonic earthquakes were detected at the seismograph station.

An explosive eruption took place in the NW part of Gunung Welirang in October 1950, and eruptive activity was reported on the NW flank (Kawah Plupuh) in August 1952. Steam plumes from the summit of Welirang were photographed from space on 13 September 1991 (*Bulletin* v. 16, no. 8) and in mid-November 1994.

Background. The twin volcanoes of Arjuno and Welirang anchor the SE and NW ends, respectively, of a 6-km-long line of volcanic cones and craters. The Arjuno-Welirang complex overlies two older volcanoes, Gunung Ringgit to the east and Gunung Linting to the S. The summit areas of both Arjuno and Welirang volcanoes are unvegetated. Additional pyroclastic cones are located on the N flank of Gunung Welirang and along an E-W-trending line cutting across the southern side of Gunung Arjuno that extends to the lower SE flank. Fumarolic areas with sulfur deposition occur at several locations on Gunung Welirang.

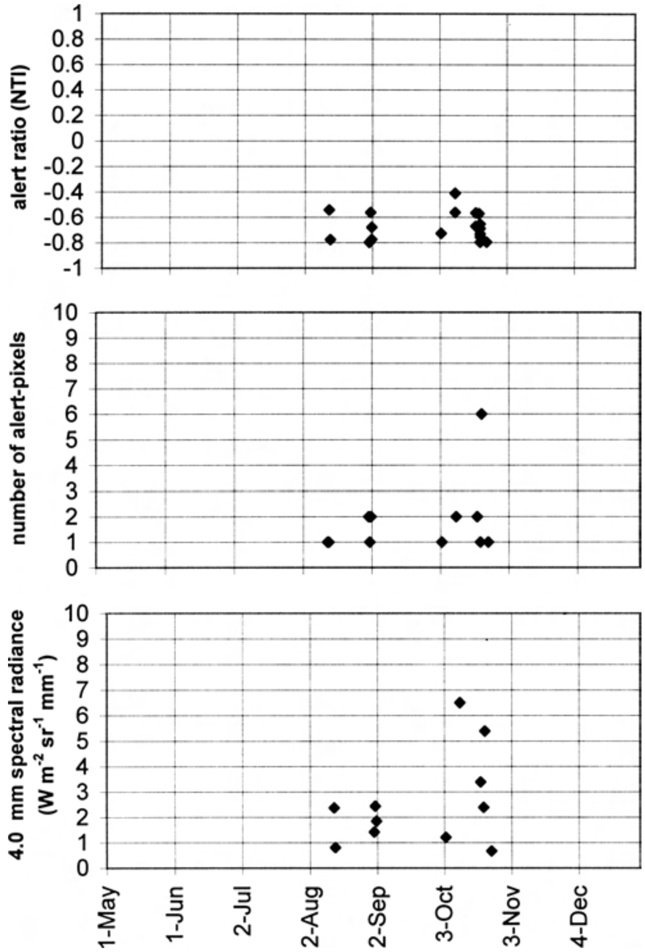

Figure 3. MODIS-detected alerts on Arjuno-Welirang during May-December 2002. Thermal alerts collated by Diego Coppola and David Rothery; data courtesy of the Hawaii Institute of Geophysics and Planetology's MODIS Thermal Alert Team.

Information Contacts: *Dali Ahmad*, Volcanological Survey of Indonesia (VSI), Jalan Diponegoro No. 57, Bandung 40122, Indonesia (Email: dali@vsi.esdm.go.id; URL: http://www.vsi.dpe.go.id); *Diego Coppola* and *David A. Rothery*, Department of Earth Sciences, The Open University, Milton Keynes, MK7 6AA, UK (Email: d.coppola@open.ac.uk, d.a.rothery@open.ac.uk). Thermal alerts courtesy of the HIGP MODIS Thermal Alerts Team (URL: http://modis.higp.hawaii.edu/).

Kawi-Butak

eastern Java, Indonesia
7.92 S, 112.45 E; summit elev. 2651 m

MODIS thermal alerts at Kawi-Butak during 2001 and 2002 occurred only in August and October 2002 mostly to the SE of the summit. These almost certainly represent fires rather than volcanic events. The biggest detected alert occurred on 12 October and was characterized by seven alert-pixels with maximum alert ratio of -0.298. These alert pixels were in a group including the summit and the N flank, and are the best candidate for an eruption, though it is unlikely that an eruption of the kind required to trigger such an alert (a significant lava dome or flow) would have gone unreported. The Volcanological Survey of Indonesia confirmed that there was no eruption at Kawi-Butak on 12 October 2002 and that the thermal alert was indeed caused by a bush fire.

Background. The broad Kawi-Butak volcanic massif lies immediately E of Kelut volcano and S of Arjuno-Welirang volcano. The 2,551-m-high Gunung Kawi was constructed to the NW of 2,868-m-high Gunung Butak. No historical eruptions are known from either volcano, but both are primarily of Holocene age.

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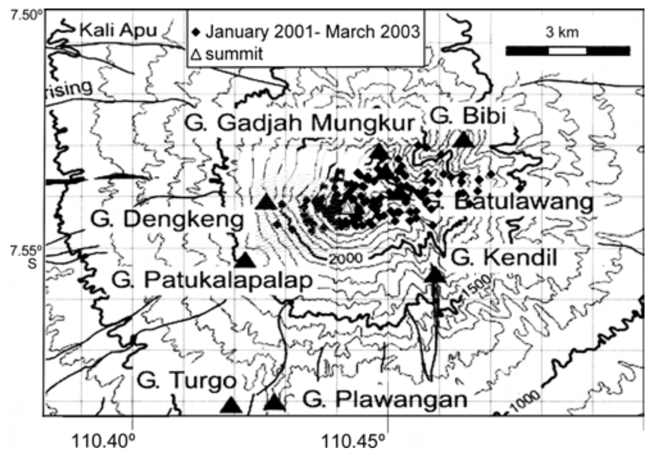

Figure 5. Center coordinates of alert-pixels on Merapi, relative to the published summit location. Grid squares are 1 km. Thermal alerts collated by Diego Coppola and David Rothery; data courtesy of the Hawaii Institute of Geophysics and Planetology's MODIS Thermal Alert Team.

Merapi

central Java, Indonesia
07.54°S, 110.44°E; summit elev. 2,911 m
All times are local (= UTC + 7 hours)

During late July-1 September 2002, the Volcanological Survey of Indonesia (VSI) reported frequent lava avalanches and plumes up to 550 m above the summit of Merapi (*Bulletin* v. 27, no. 9). No further reports were issued by VSI through at least March 2003.

MODIS thermal alerts during 2001 and 2002 indicated continuous activity through mid-January 2002 (figures 4 and 5). This period was characterized by dome collapse and hot avalanches (*Bulletin* v. 26 nos. 1, 7, and 10, and v. 27, no. 2). Pyroclastic flows occurred too frequently to correlate them with the MODIS alerts, for which data are collected only about once per day (weather permitting). There were no alerts detected during the rest of 2002 except for late March-late May, which corresponded to a temporary renewal of pyroclastic flows before a quieter second half of the year (*Bulletin* v.27, nos. 6 and 9).

Background. Merapi, one of Indonesia's most active volcanoes, lies in one of the world's most densely populated areas and dominates the landscape immediately N of the major city of Yogyakarta. Merapi is the youngest and southernmost of a volcanic chain extending NNW to Ungaran volcano. Growth of Old Merapi volcano beginning during the Pleistocene ended with major edifice collapse perhaps about 2,000 years ago, leaving a large arcuate scarp cutting the eroded older Batulawang volcano. Subsequently growth of the steep-sided Young Merapi edifice, its upper part unvegetated due to frequent eruptive activity, began SW of the earlier collapse scarp. Pyroclastic flows and lahars accompanying growth and collapse of the steep-sided active summit lava dome have devastated cultivated lands on the volcano's western-to-southern flanks and caused many fatalities during historical time. The volcano is the

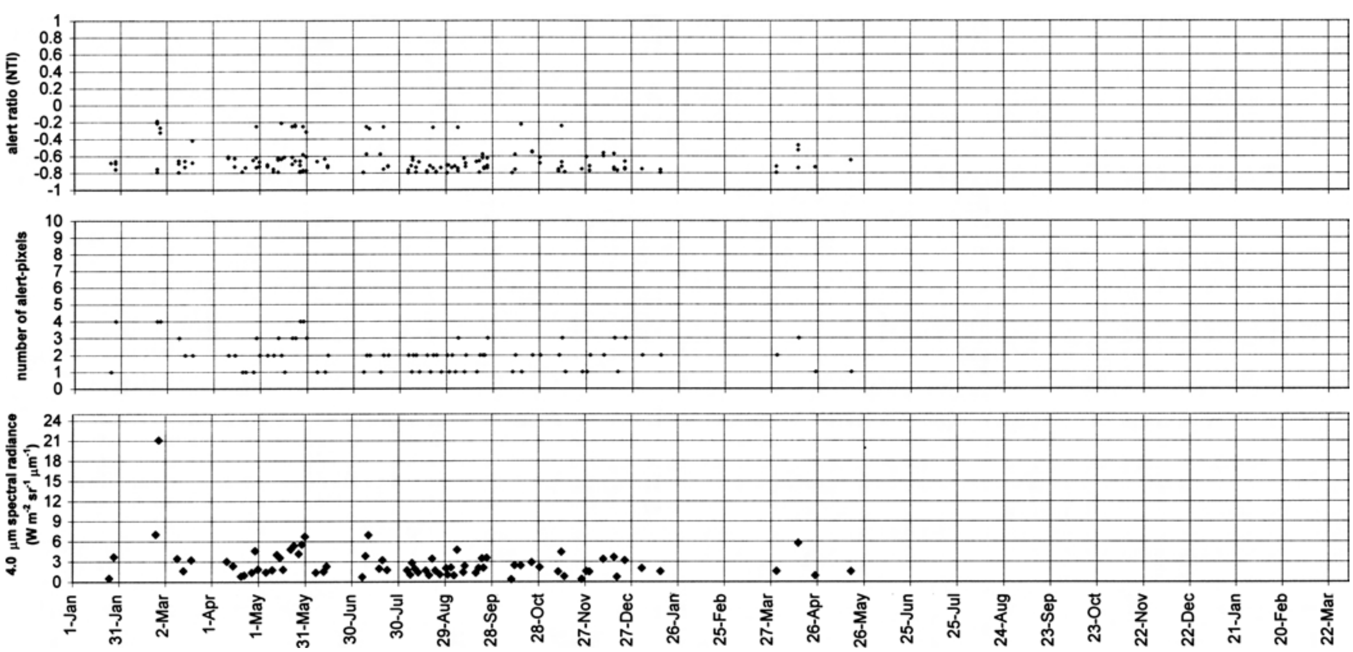

Figure 4. MODIS-detected alerts on Merapi during 2001-2002. Thermal alerts collated by Diego Coppola and David Rothery; data courtesy of the Hawaii Institute of Geophysics and Planetology's MODIS Thermal Alert Team.

object of extensive monitoring efforts by the Merapi Volcano Observatory of the Volcanological Survey of Indonesia.

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Krakatau

Sunda Strait
6.10°S, l05.42°E; summit elev. 813 m

Seismicity at Krakatau was dominated by volcanic and tectonic earthquakes during 30 December 2002-23 March 2003 (table 2). The hazard status remained unchanged at Alert Level 2.

Throughout 2001 and 2002, MODIS thermal alerts for Krakatau occurred only during July-September 2001. The first alert occurred on 31 July when one alert pixel was detected with an alert ratio of -0.793. The anomalies increased during August and on 9 August the anomaly consisted of two alert-pixels with a maximum alert ratio of -0.306. Other major anomalies occurred on 1 September (four alert-pixels with maximum alert ratio of -0.327) and on 17 September (two alert-pixels with maximum alert ratio of -0.284). These anomalies correspond to an increase of activity at Krakatau characterized by ash and bomb emission during August 2001 and an increase in the number of explosion and volcanic earthquakes during the first half of September 2001, reported by the Volcanological Survey of Indonesia (*Bulletin* v. 26, no. 9, and v. 27, no. 9). The coordinates of the centers of the alert pixels are tightly grouped around the summit of the main cone. Bearing in mind that each pixel represents radiance from an area of ground more than 1 km across, the alert pixels could represent radiance from the active vent or from hot ejecta close to the vent.

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

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Date (2002-2003)	Deep volcanic (A-type)	Shallow volcanic (B-type)	Tectonic
30 Dec-05 Jan 03	3	14	1
06 Jan-12 Jan 03	14	60	3
13 Jan-19 Jan 03	5	68	2
20 Jan-26 Jan 03	9	30	3
27 Jan-02 Feb 03	12	45	7
03 Feb-09 Feb 03	2	49	2
10 Feb-16 Feb 03	6	53	1
17 Feb-23 Feb 03	10	26	2
24 Feb-02 Mar 03	11	15	1
03 Mar-09 Mar 03	4	28	2
10 Mar-16 Mar 03	2	13	2
17 Mar-23 Mar 03	5	58	3

Table 2. Seismicity at Krakatau during 30 December 2002-23 March 2003. Courtesy VSI.

Panarea

Italy
38.63°N, 15.07°E; summit elev. 421 m

On 3 November 2002, intense degassing caused bubbling activity near the small islet of Lisca Bianca, very close to the island of Panarea (*Bulletin* v. 27, no. 10). On 13-14 November 2002, observers Orlando Vaselli (University of Florence), Bruno Capaccioni (University of Urbino), and Piermaria Luigi Rossi (University of Bologna) noted 10 points of boiling water when they visited the area to sample gas emissions.

Geochemical monitoring and research is being regularly performed by the Fluid Geochemistry group from the Osservatorio Vesuviano (Istituto Nazionale di Geofisica e Vulcanologia), led by Giovanni Chiodini. Submarine gas emissions were sampled during 29-30 November and 10-17 December 2002, as well as 23-24 January and 9-11 February 2003. Samples obtained during March, April, and May have not yet been analyzed. Chiodini noted that although the intensity of emissions decreased after 5 November 2002 (*Bulletin* v. 27, no. 10), the gas flux remained much higher than before the November event. That observation, along with chemical variations in gas samples, indicate that the process is ongoing. Research results posted on the Osservatorio Vesuviano website provide additional details, analytical findings, and hypotheses about these phenomena.

Background. The mostly submerged Panarea volcanic complex lies about halfway between Stromboli and Lipari in the eastern part of the Aeolian Islands. The 421-m-high island of Panarea, the smallest in the Aeolian Archipelago, lies on the western side of a shallow platform whose shelf margin is at about 130 m depth. A series of small islands breach the surface to form the Central Reefs, the rim of a crater 2 km east of Panarea whose shallow submerged floor contains Roman ruins. The submerged Secca dei Pesci lava dome lies at the SE end of the platform, and the rhyolitic Basiluzzo lava dome rises 165 m above the surface at the NE end, along a ridge trending towards Stromboli volcano. The Panarea complex was constructed in two main stages; initial effusive activity that produced lava domes, and an explosive stage. The youngest dated products of the Panarea complex are airfall-tephra deposits dated at between 42,000 and 13,000 years ago; some of these tephra deposits originated from other volcanoes. Vigorous hydrothermal activity has continued at fumarolic fields at several locations on the submerged platform.

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Lascar

Chile
23.37°S, 67.73°W; summit elev. 5,592 m
All times are local (= UTC - 3 hours)

An international team of scientists conducted an interdisciplinary research project at Láscar from 13 October 2002 to15 January 2003. The group of scientists from Argentina, Chile, Italy, Puerto Rico, United Kingdom, and the United States, includes volcanologists who have directly observed the volcano from before the 1993 eruption (*Bulletin* v. 18, no. 4). During the first part of the project the team took the first ever direct measurements of fumarole temperatures and gas compositions within the crater, which are to be compared with measurements acquired through remote sensing techniques. The combination of direct and ground- and satellite-based measurements at very different spatial scales will hopefully corroborate results from the different techniques. A significant change in crater geometry over the last few years was identified through comparison with work carried out by Gardeweg and others (1993) and Matthews and others (1997).

Visual observations. On 26 October 2002 small explosive eruptive events (reaching heights of 300 m above the crater) were observed at 0905, 0910, and 0915 by both the remote-sensing team 7 km SE of the vent and the direct sampling team on the crater rim (figure 6). Winds from the NW rapidly dispersed the ash cloud. On 27 October at 0845, loud noises were heard, and an ash plume was observed by people 7 km NW of the volcano. At 1340 a much more vigorous explosion produced a plume that rose at least 1,500 m above the vent (figure 7), which was observed by the volcanologists from Pozo Tres, 60 km NW.

On 1 November 2002 the direct-measurement team reached the crater for a second time to collect gas samples. Comparison with previous descriptions (Gardeweg and others, 1993; Matthews and others, 1997) and photographs taken by J.G. Viramonte at the beginning of the 1990's indicated that after the 2000 eruption (*Bulletin* v. 25, no. 6;

Figure 6. Photograph of an ash eruption at Lascar on 26 October 2002 seen from the crater rim. Courtesy of Franco Tassi.

Figure 7. Photograph of an eruption at Lascar on 27 October 2002 seen from "Pozo Tres." Courtesy of J.G. Viramonte.

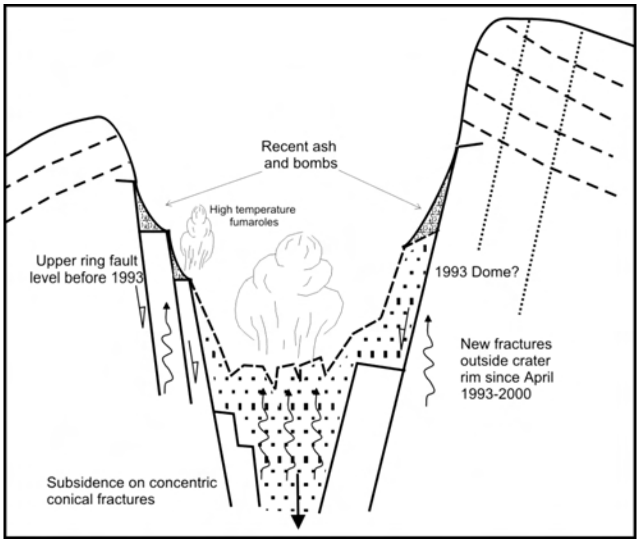

Figure 8. Cross-section sketch of the Lascar crater showing fractures, high-temperature fumaroles, and areas of recent ash and bombs. Courtesy of J.G. Viramonte.

http://www.unsa.edu.ar/varias/lascar; http://www.conae.gov.ar) several changes in crater morphology and locations of the high-flux fumaroles occurred. The dome had collapsed by several tens of meters, producing a deep, steep, hole ~200 m in diameter and 200 m deep, with a number of large fumaroles around the internal rim and at the base (figure 8). Observations suggest that Lascar is presently at or near the climax of the "dome subsidence phase," as described by Matthews and others (1997). There was no evidence of new dome emplacement after the July 2000 eruption.

Direct techniques. Team members from Universita' degli Studi di Firenze (Italy), Universidad Nacional de Salta (Argentina), and Universidad Catolica del Norte (Chile) took, for the first time, direct temperature measurements of Lascar's fumaroles and collected gas samples using vacuum bottles filled with a 4N NaOH + 0.15N CdOH solution (Montegrossi and others, 2001). Sampled fumaroles were aligned along the upper collapse ring fault in the NW internal flank of the active crater (figure 9). A maximum temperature of 385°C was measured. Preliminary results indicate a very high concentration of acidic gases, with a paucity of water vapor. A more complete analysis, performed by gas chromatography and mass spectrometry, will be done in the Department of Earth Sciences at the Univ. Firenze.

Remote-sensing techniques. Team members from Michigan Technological University (MTU), Cambridge, and Universidad Nacional de Salta (UNSa) provided a suite of state-of-the-art ground-based instruments, including a miniature UV spectrometer that utilizes Differential Optical Absorption Spectroscopy (DOAS), a MICROTOPS II sun-photometer, and a Kestrel 4000 weather station. The instruments will help provide a more complete understanding of S-bearing species, and their fates in a high, dry atmosphere. The mini UV spectrometer provides an open path line-of-site burden of SO_2 through spectral analysis (Galle and others, 2002; Edmonds and others, 2002), which can be used to derive SO_2 emission rates (using the plume's speed and width). The sun-photometer will provide information about the plume's liquid- and solid-phase species, specifically sulfate aerosol. The aerosol's spectral signature can be used to derive the particle size distribution from the spectral optical depth (Watson and Oppenheimer, 2000). The weather station, in conjunction with the other instruments, will elucidate the effects of Lascar's high, dry, and extremely transmissive atmosphere upon SO_2 conversion rates. The team will also derive SO_2 burdens and emission rates using satellite imagery from NASA's ASTER (Advanced Spaceborne Thermal Emission and Reflection Radiometer) sensor.

Lascar provides an opportunity to study the effects of an end-member atmosphere upon volcanic plumes with the aim of better understanding the fates of volcanic species in the high troposphere (and hence the lower stratosphere). The DOAS is an exciting new instrument, first applied to volcanic studies by volcanologists from the Montserrat Volcano Observatory (MVO), Cambridge University (UK), and Chalmer's University of Technology (Sweden) that is now rapidly replacing the older, bulkier, and much more expensive correlation spectrometer (COSPEC). This experiment is a continuation of that work in a new and different environment.

Future work. The Cambridge team planned to begin a new round of remote studies in early 2003, using the DOAS system and sun-photometers, in particular to investigate evolution of the aerosol phase of the plume. The direct gas sampling by the Florence, Salta, and Del Norte team will be

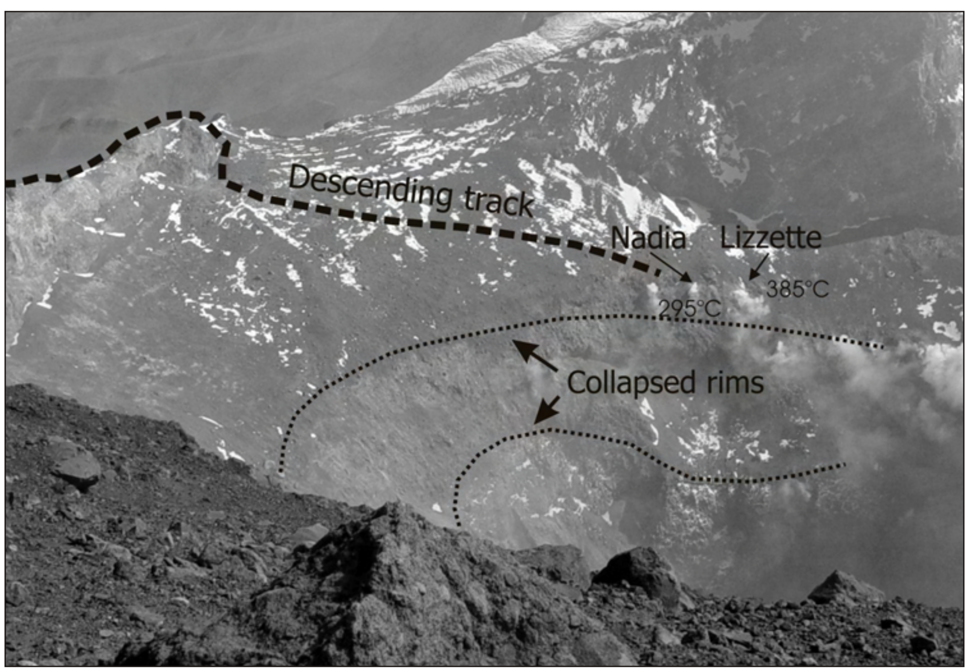

Figure 9. Photograph of the NW side of the Lascar crater, modified to show the collapsed rims and fumarole sampling locations in October 2002. Courtesy of Franco Tassi.

repeated, hopefully in 2003. The group, led by the MTU and UNSa contingent, plan to use recently acquired ASTER data to investigate SO_2 emission. Hotspot activity will be studied using ASTER, MODIS, and GOES data. A study of the morphological evolution of the crater is planned for the near future, hopefully incorporating previous investigators' work on cyclic activity at Lascar.

Background. Lascar is the most active volcano of the northern Chilean Andes. The andesitic-to-dacitic stratovolcano contains six overlapping summit craters. Prominent lava flows descend its NW flanks. Lascar consists of two major edifices; activity began at the eastern volcano and then shifted to the western cone. The largest eruption of Lascar took place about 26,500 years ago, and following the eruption of the Tumbres scoria flow about 9,000 years ago, activity shifted back to the eastern edifice, where three overlapping craters were formed. Frequent small-to-moderate explosive eruptions have been recorded from Lascar in historical time since the mid-19th century, along with periodic larger eruptions that produced ashfall hundreds of kilometers away from the volcano. The largest historical eruption of Lascar took place in 1993 and produced pyroclastic flows up to 8.5 km NW of the summit.

The current active vent, the deepest of six nested summit craters, is 800 m in diameter and over 400 m deep. Matthews and others (1997) discussed Lascar evolution in four phases starting at ~50 ka. The last significant eruptions occurred in April 1993 (Gardeweg and Medina, 1994; Viramonte and others, 1994; Deruelle and others, 1995, 1996) and July 2000 (*Bulletin* v. 25, no. 6; http://www.unsa.edu.ar/varias/lascar; http://www.conae.gov.ar).

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Long Valley

California, USA
37.70°N, 118.87°W; summit elev. 3,390 m

The following are summaries from the U.S. Geological Survey (USGS) of activity at Long Valley during 2001 (Hill, 2001) and 2002 (Hill, 2002). Summaries of activity during 1996, 1997, and 1998 are found in *Bulletin* v. 22, nos. 11-12 and v. 24, no. 6; activities during 1999 through 2000 are found in *Bulletin* v. 26, no. 7. Figure 10 shows some of the locations mentioned in this report.

Summary of activity during 2001. Activity levels in Long Valley caldera and vicinity were incrementally lower in 2001 than in 2000, thus continuing the trend of extended quiescence that began toward the end of 1999. Low-level seismic activity within the caldera typically included five or fewer earthquakes per day large enough to be located by the online computer system. Most were smaller than M 2.0, and none were as large as M 3.0; the largest was a M 2.8 earthquake beneath the southern margin of the caldera 800 m N of Convict Lake on 21 May. Seismic activity in the Sierra Nevada S of the caldera continued to be concentrated within the aftershock zone of the 1998-99 sequence of three M 5 earthquakes. The 2001 activity (figure 11) included eight earthquakes of M 3.0 or larger. The largest was the M 3.4 earthquake of 2 December located near the epicenter of the M 5.6 earthquake of 15 May 1999.

Mid-crustal long-period (LP) volcanic earthquakes continued to occur at depths of 10-25 km beneath the W flank of Mammoth Mountain (figure 12), although at a much reduced rate compared with the peak in activity in 1997-98. Some 60 LP earthquakes were detected during 2001, with over 15 of these occurring in a cluster on 10 February.

Deformation within the caldera was limited to continuing slow subsidence of the resurgent dome at a rate of roughly 1 cm/year. All together, the center of the resurgent dome has lost some 2 cm in elevation since inflation stopped in late 1998, leaving the center of the resurgent dome roughly 75 cm or so higher at the end of 2001 than in the late 1970's. The continuous strain and deformation monitoring networks detected no short-term deformation transients during the year. The same is true for the magnetometer networks.

The diffuse carbon dioxide (CO_2) degassing at the Horseshoe Lake tree-kill area (*Bulletin*, v. 22, no. 11) and other sites around the flanks of Mammoth Mountain has shown no significant change over the past several years. The total CO_2 flux continued to fluctuate ~200 tons per day, with the Horseshoe Lake area contributing roughly 90 tons per day.

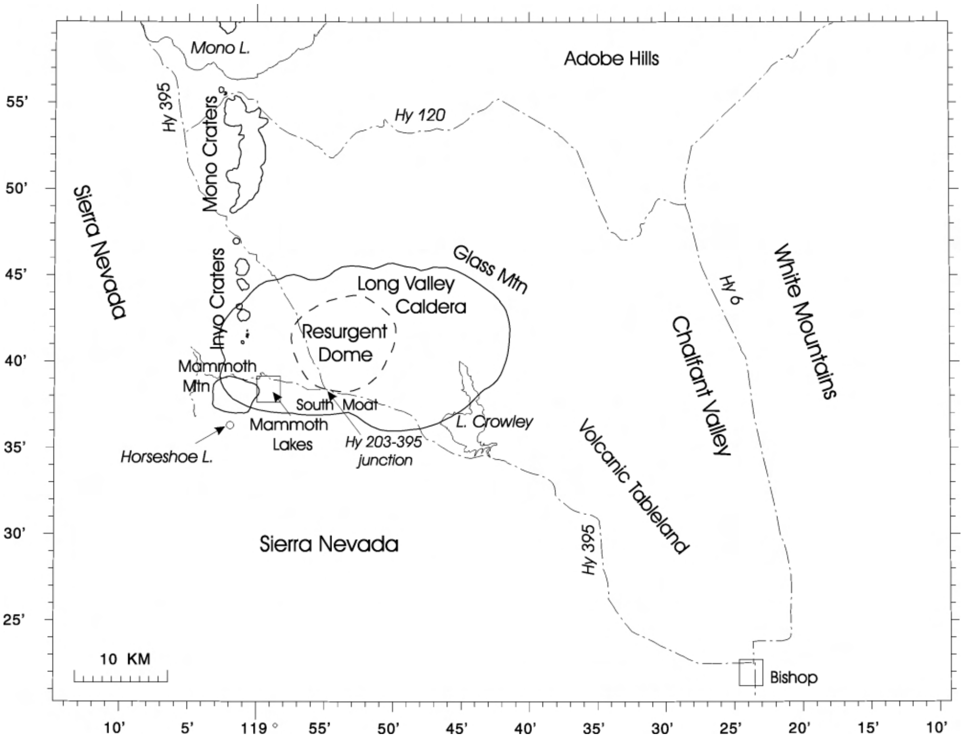

Figure 10. Map of the Long Valley caldera area. Courtesy of USGS.

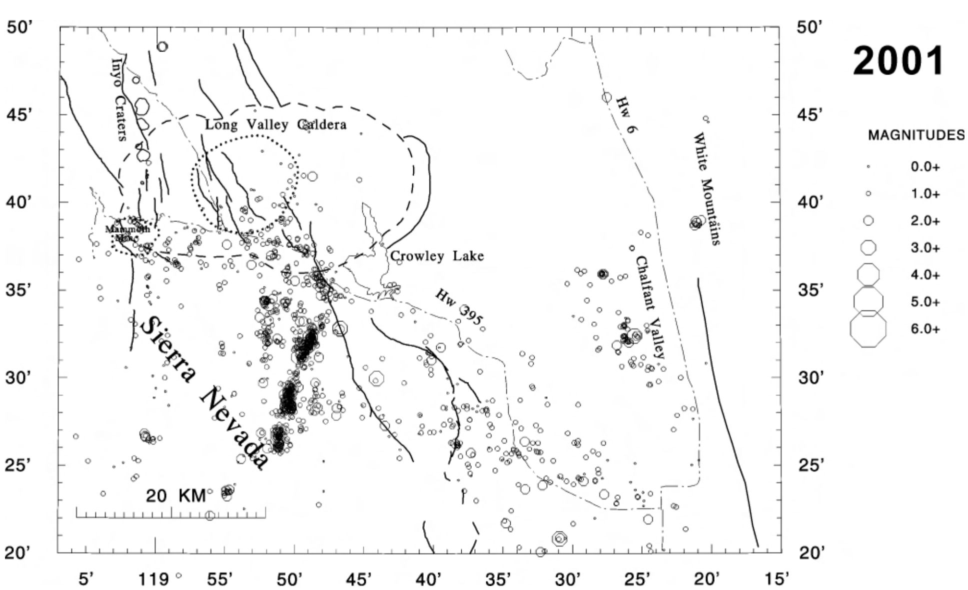

Figure 11. Earthquake epicenters in the Long Valley region for the year 2001. Courtesy of USGS.

The lull in caldera unrest over the past couple of years has provided the Long Valley Observatory (LVO) an opportunity to look back over the wealth of data collected during the previous two decades of activity and to investigate the nature and significance of the processes driving the unrest, toward the goal of assessing future unrest episodes and their significance in terms of potential volcanic hazards. Data from the intense unrest during the 1997-98 episode in the S moat, for example, indicate that fluids (magmatic brine or perhaps magma) played a central role in this activity. This underscores the value of a closely integrating the seismic, deformation, and hydrologic monitoring efforts.

Summary of activity during 2002. Activity in 2002 was dominated by the onset of renewed inflation of the resurgent dome following nearly three years of gradual subsidence. Earthquake activity within the caldera, which remained low through the first half of the year, showed a slight increase through the second half. Of particular note was the response of the caldera to the shear and surface waves generated by the M 7.9 Denali Fault earthquake of 3 November 2002 in the form of a burst of some 60 small earthquakes beneath the S flank of Mammoth Mountain, a coincident strain transient consistent with aseismic slip on a normal fault beneath the E flank of the mountain, and an earthquake swarm the following day in the S moat that included the first M 3.0 earthquake since 1999. This is the third time Long Valley has shown a well-documented response to large, distant earthquakes, the first two being with the M 7.4 Landers earthquake of 28 June 1992 and the M 7.2 Hector Mine earthquake of 16 October 1999. No other significant changes occurred within the caldera during the year. Both the carbon dioxide flux from the flanks of Mammoth Mountain and the rate of deep long-period (LP) volcanic earthquakes beneath Mammoth Mountain showed little change from previous years. The LVO detected no very-long-period (VLP) earthquakes during 2002.

Beginning around the first of the year, both the 2-color EDM and continuous GPS data for the baselines radiating from the CASA monument turned from gradual contraction to renewed extension that persisted through the year at rate of 2.5-3.0 cm/year. This rate is comparable to extension rates that prevailed through the mid-1990's. Cumulative uplift of the center of the resurgent dome associated with this extension has returned to its 1999 value of roughly 80 cm with respect to the late 1970's.

Earthquake activity within the caldera remained low through the first half of the year averaging fewer than five earthquakes per day, most with M 2.0 (figures 12 and 13). The largest event within the caldera during this period was a M 2.8 earthquake on 15 March located in the W lobe of the S moat seismic zone, 1.6 km S of the 203-395 Highway junction. Activity increased slightly in mid-June beginning with a cluster of small earthquakes beneath the W flank of Mammoth Mountain on 26 June that included four events of about M 2. A number of small (M 2) events with the appearance of LP earthquakes occurred at shallow depths (less than 2 km) beneath the southern section of the resurgent dome during the last half of August.

The most notable activity began with a burst of over 60 small earthquakes of M 1 beneath the S flank of Mammoth Mountain as the surface waves generated by the M 7.9 Denali Fault, Alaska, earthquake of 3 November 2002 passed through just 17 minutes after the mainshock rupture. At the same time, the borehole dilatometers detected a 0.1-microstrain strain transient that is consistent with slow (aseismic) slip on a normal fault at a depth of about 7 km beneath the W flank of Mammoth Mountain. As with the caldera activity remotely triggered by the M 7.4 Landers earthquake of 28 June 1992 and the M 7.2 Hector Mine earthquake of 16 October 1999, this strain transient is much larger than can be explained by cumulative slip for the 60 or so earthquakes of M 1 triggered by the Denali Fault earthquake. The following day, 4 November, the largest earthquake swarm in the S moat of the caldera since 1998 developed as a sequence that included six earthquakes of M 2 and one of M 3.0. This S-moat swarm was unusual in that it occurred in a relatively aseismic section of the S moat, focal depths of the swarm earthquakes were unusually shallow (4 km), and the NNW lineations of the swarm epicenters cuts across the prevailing WNW-trend of the usual S-moat swarm activity. The latter was also true for the swarm activity triggered by the M 7.4 Landers earthquake of 1992. This S-moat earthquake swarm was not accompanied by detectable strain changes. Mid-crustal long-period (LP) earthquakes have continued at depths of 10-25 km beneath Mammoth Mountain at a fairly steady rate over the past three years. Occasional bursts of activity included 12-15 events per week.

Diffuse emission of carbon dioxide from the flanks of Mammoth Mountain showed little change from previous years. Emission rates estimated for the Horseshoe Lake tree-kill area continued to fluctuate between 50 and 150 tons of CO_2 per day, with an average flux of 100 tons per day since 1995. The Horseshoe Lake area produced roughly one-third of the total CO_2 flux from the flanks of Mammoth Mountain.

Values for the helium isotope ratio $^3He/^4He$ from samples taken in early and mid-2002 from the Mammoth Mountain Fumarole (MMF), located at 3,000 m elevation

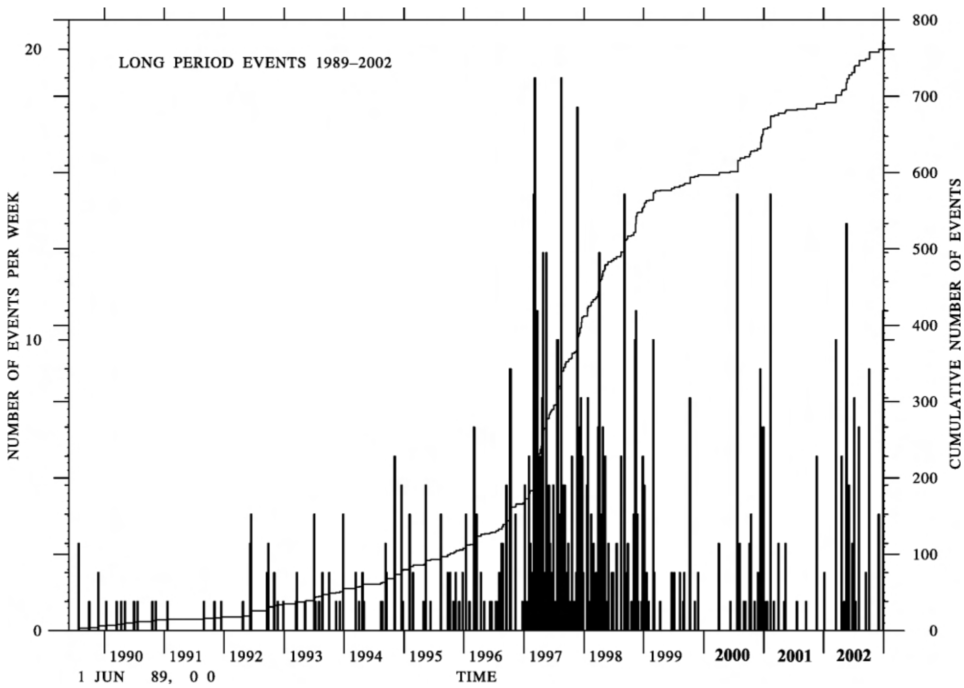

Figure 12. Time history of deep (depth 10-25 km) LP earthquakes in the Long Valley caldera beneath Mammoth Mountain from 1989 through 2002. Vertical bars indicate number of LP earthquakes per week (left axis) and the continuous curve shows the cumulative number of events (right axis). Courtesy of USGS.

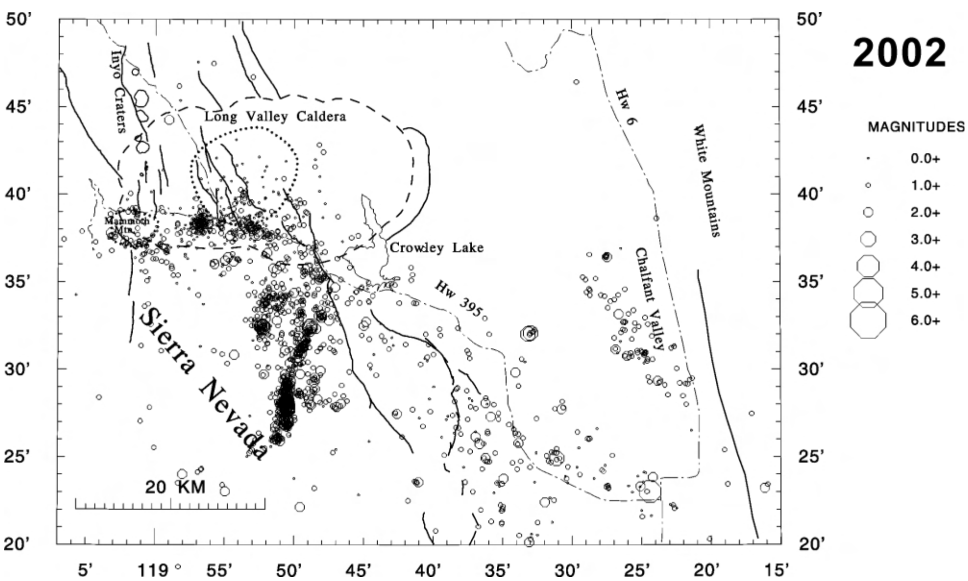

Figure 13. Earthquake epicenters in the Long Valley caldera region for 2002. Courtesy of USGS.

some 300 m E of the Chair 3 ski lift, averaged 5.5, or essentially the same as the 2001 values. These values are significantly higher than the 1999 value of 3.0. The increase with respect to 1999 is consistent with an increase in the magmatic component in the gas emissions from the fumarole. Whether the elevated values for 2001-2002 are related to the very-long-period (VLP) volcanic earthquakes that occurred at a depth of 3 km beneath the summit of Mammoth Mountain in July and August of 2000 remains to be seen.

Seismic activity in the region surrounding Long Valley caldera continued to be dominated by earthquakes in the SSW-trending aftershock zone of the June and July 1998 and the May 1999 earthquakes in the Sierra Nevada S of the caldera. Activity within this aftershock zone included a cluster of earthquakes near the southern end of the zone centered just E of Grinnell Lake that began on 6 June and persisted through the end of the month. Elsewhere, a M 3.7 earthquake on 15 July just 3.2 km NNW of Bishop produced felt shaking throughout the Bishop area. Earthquakes of M 2.9 and 3.5 on 12 December were located beneath the Volcanic Tableland 19 km NNW of Bishop.

An updated revision of the USGS *Response Plan for Volcanic Unrest in the Long Valley Caldera – Mono Craters Region, California* was released in March 2002 as USGS Bulletin 2185. This bulletin is available in print and in electronic form at ttp://geopubs.wr.usgs.gov/bulletin/b2185/.

References: Hill, D.P., 2001, Long Valley Observatory quarterly report October-December 2001 and annual summary for 2001: Long Valley Observatory, U.S. Geological Survey, Menlo Park, CA (URL: http://lvo.wr.usgs.gov/Annual/lvc_01.html).

Hill, D.P., 2002, Long Valley Observatory quarterly report July-September and October-December 2002 and annual summary for 2002: Long Valley Observatory, U.S. Geological Survey, Menlo Park, CA (URL: http://lvo.wr.usgs.gov/Quarterly/qrt_rpt3-4-02.html).

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Veniaminof

Alaska Peninsula, USA
56.17°N, 159.38°W; summit elev. 2,507 m

An increase in seismicity since mid-December was a constant trend through February 2003 (*Bulletin* v. 28, no. 1). During the week of 7 March, discrete seismic events occurred at a rate of about 1-2 events per minute. On 11 March, a 4-hour period of continuous seismic tremor was followed by 17 hours of discrete seismic events and 3-4-minute-long tremor bursts. This culminated with another 4-hour period of continuous tremor on 12 March. Seismic activity later that week was characterized by discrete small-amplitude events occurring every 1-2 minutes. Satellite images collected during clear periods on 4, 6, 7, and 12 March did not reveal any elevated surface temperatures, ash emissions, or ash deposits. Observers in Perryville, 35 km S of Veniaminof, reported no significant plume or other signs of volcanic activity on 12 March. Consistent elevated seismicity, with small-amplitude discrete events every 1-2 minutes continued during the week of 21 March.

Seismicity declined during the last week of March, characterized by very low-amplitude tremors. Satellite images collected during numerous clear periods that week did not reveal any elevated surface temperatures, ash emissions, or ash deposits. There was a dramatic decrease in volcanic activity during the week of 4 April. However, short periods of volcanic tremor and low frequency events were still recorded. This continued into the week of 11 April, prompting the lowering of the level of concern. The Alaska Volcano Observatory (AVO) announced a code color of green, under which the volcano is classified as dormant with normal seismicity and fumarolic activity occurring.

Background. Massive Veniaminof volcano, one of the highest and largest volcanoes on the Alaska Peninsula, is truncated by a steep-walled, 8 x 11 km, glacier-filled caldera that formed around 3700 years ago. The caldera rim is up to 520 m high on the north, is deeply notched on the west by Cone Glacier, and is covered by an ice sheet on the south. Post-caldera vents are located along the NW-SE zone bisecting the caldera that extends 55 km from near the Bering Sea coast, across the caldera, and down the Pacific flank. Historical eruptions probably all originated from the westernmost and most prominent of the two intra-caldera cones, which reaches an elevation of 2156 m and rises about 300 m above the surrounding icefield. The other cone is larger, and has a summit crater or caldera that may reach 2.5 km in diameter, but is more subdued and barely rises above the glacier surface.

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