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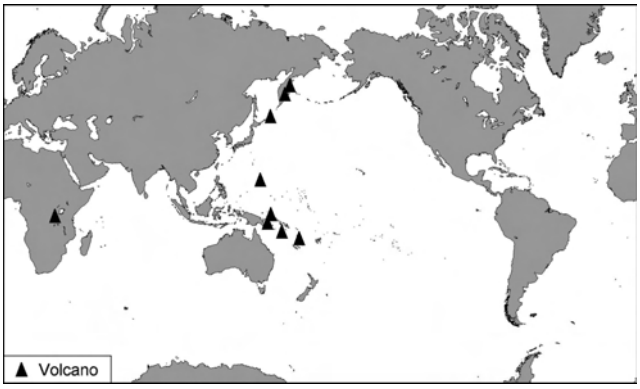

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Epi

Vanuatu (SW Pacific)
16.68°S, 168.37°E; summit elev. 833 m

This is the first *Bulletin* report on Epi, a group of volcanic centers most conspicuously active at a shallow seamount informally known as Epi B. What follows is a brief summary of the geography and the historical eruptions plausibly or clearly attributed to Epi B (Eissen and others, 1991), leading into a synopsis of recent research and activity. The records of the last century and recent observations suggest that Epi B represents a potential hazard for the inhabitants of the coastal villages of eastern Epi Island (roughly 2,000 people).

The island of Epi lies along the Vanuatu island chain between the neighboring islands that include Malekula, Ambrym, and Lopevi to the N, and Efate and Shepherd to the S. The island contains two adjacent Quaternary stratovolcanoes and a smaller cone, as well as the margin of an inferred submarine caldera. The submarine cones Epi A, B, and C lie offshore, 10-16 km NNE from the summit of the island (16.73°S, 168.28°E). The top of Epi B is 13 km NNE of the summit (figure 1).

Violent activity between the islands of Lopevi and Epi was reported in 1920 (William and Warden, 1964). In 1953 a major eruption ejected volcanic material to about 100 m above the sea surface and produced rafts of floating pumice over an area of about 1,000 km^2. A cone may have formed above water, but it would have been quickly destroyed (Warden, 1967). In 1958 discolored seawater was observed in this area (figure 2; Priam, 1958). Another major eruption was observed in July 1960. Until early 2004, the only recorded evidence of activity following the 1960 eruption was discolored water. Activity at Epi B was also confirmed by the British hydrographic vessel HMS *Hydra* in 1974, the French research vessel *Machias* in 1981, the SOPAC cruise of the *S.P. Lee* in 1984, the Russian vessel *Akademik Alexander Nesmayanov* in 1990, the French CALIS project using research vessel *N.O. Alis* in 1991, aerial observations in 1997 (figure 3), and the Australian VAVE project using the research vessel *Franklin* in 2001. Their collective observations showed that the depth of the cone's summit area remained stationary at -34 m. until early 2004 when Epi Island residents observed explosions and surface disturbances (figure 3).

While adjacent to Lopevi, the crew of the fishing vessel *Azur* reported and photographed an explosion rising above the sea surface on 19 February 2004 (figure 4), prompting Vanuatu's Department of Geology, Mines, and Water Resources (DGMWR) to gather eyewitness accounts from the inhabitants of Epi's very isolated E coast about activity. Eyewitnesses told of explosions heard in early 1999(?), fur-

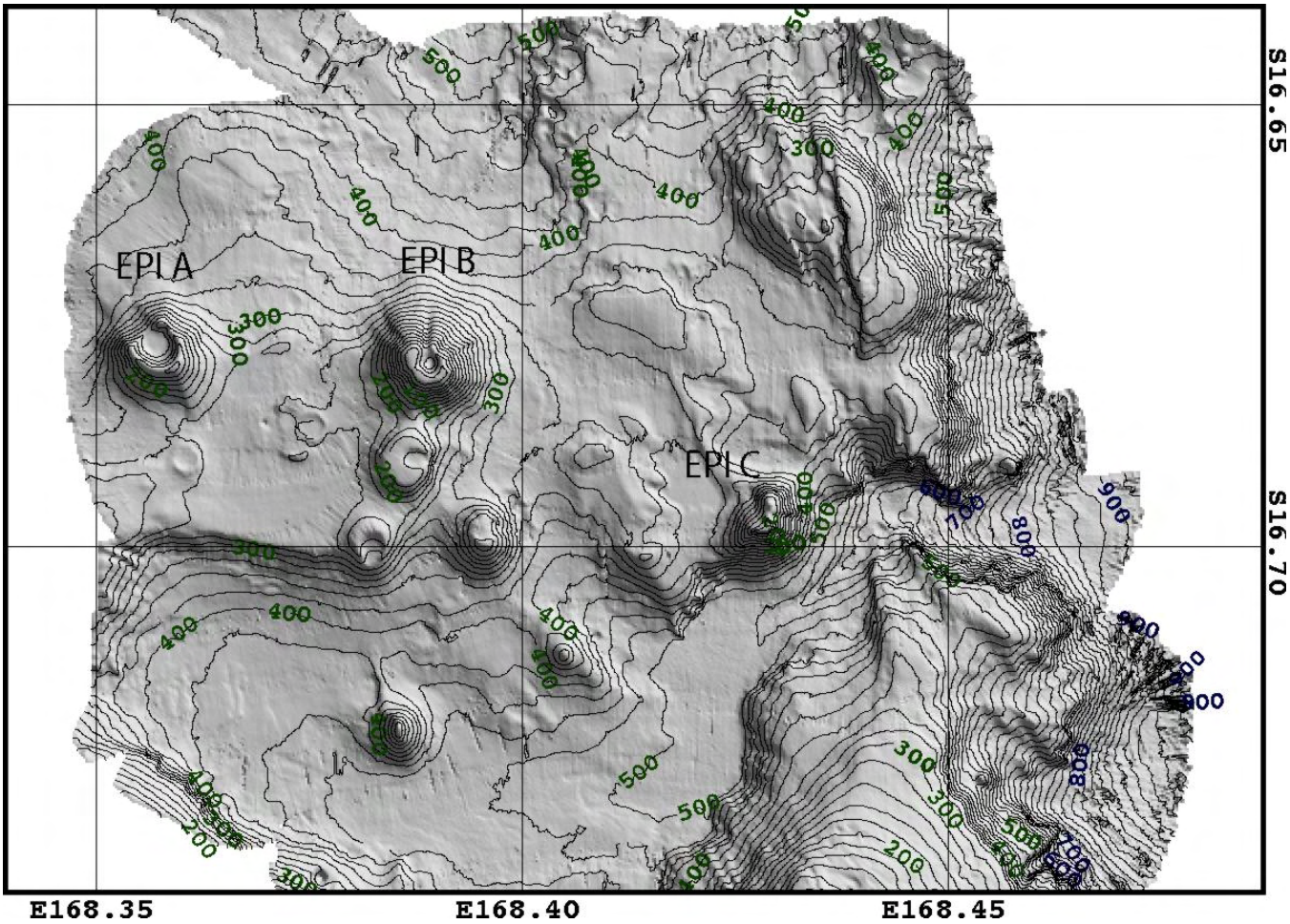

Figure 1. Shaded relief map of the seafloor E of Epi island disclosing Epi A, Epi B, and Epi C seamounts. The map was created from data gathered using a multi-beam swath sounder (on research vessel *Alis* during the VATATERM cruise) on 14 March 2004 (Ballu and others, 2004). Contour interval is 20 m. Courtesy of IRD.

ther explosions and the appearance of floating pumice rafts in March 2002, and an eruption between 16 and 24 February 2004. The latter Epi B eruption was confirmed by the infrasonic recordings of the CEA/DASE (Département d'Analyse et de Surveillance de l'Environnement) geophysics station, located in New Caledonia, more than 600 km away.

Figure 2. The Epi B area seen emitting a circular region of discolored water in December 1958. Copyright Roland Priam; provided courtesy of IRD.

Figure 3. As seen from an oblique aerial perspective, the yellow submarine plume emitted from Epi B as seen in November 1997 (source area at the upper part of the photo). The plume broadened and diffused with distance from the source (towards the bottom of the photo). Copyright Vanair, Andrew Dwyer; provided courtesy of IRD.

In March 2004 the Institut de Recherche pour le Développement (IRD) undertook a cruise (called VATATERM) aboard their research vessel *N.O. Alis*. Using the ship's Simrad EM1002 multi-beam sounder, the project produced the first detailed bathymetric map of the area E of Epi Island (figure 1). The Epi A, B, and C cones (Exon and Cronan, 1983; Crawford and others, 1988) have been interpreted by Crawford and others (1988) as being aligned along the N rim of a vast caldera E of Epi. The new map clearly revealed those distinct cones, and a number of smaller cones and craters between them and Epi Island's NE coast.

The 2004 bathymetric data revealed that Epi B is a ~ 300-m-tall cone with a diameter of ~ 1.8 km at the base (figure 5). The highest point is on the NW rim of the summit crater, at a depth of -34 m, with a broad rim area around 35-40 m depth extending from the NW around the S to the SE side of the crater. The crater is about 150 m in diameter, the crater floor lying at a depth of 90 m. This crater is breached to the N by a ~ 60 m wide gap.

Data recorded in 1974 and 1984 indicated that the Epi B crater was open to the S (Exon and Cronan, 1983) or to the SSE (Crawford and others, 1988). The map resulting from a 2001 hydrographic cruise did not show evidence of a summit crater (McConachy and others, 2001). It is not known if these observations represent real modifications to the crater, because the quality of the earlier measurements, using traditional echo-sounders, is questionable.

Observations during September 2001. Scientists on the Vanuatu Australia Vents Expedition (VAVE) aboard the *RV Franklin* (McConachy and others, 2001) investigated the area immediately SE of the Epi B seamount during September 2001. On 18 September a limited echosounding survey was done, along with a single dip CTD/hydrocast followed by a grab. The latter sample returned an 8-cm-thick layer of pumice (dacite-rhyodacite, 69-72% SiO_2, in composition) on top of 3 cm of brown mud. The hydrocast found high concentrations of methane gas, 68-93 nl/l, in three samples between 250 and 337 m deep. A weak but

Figure 4. The 19 February 2004 eruption of Epi B as seen from the fishing boat *Azur*. The eruption clearly broke the water surface, but is only visible here in the distance as a light-colored disturbance in the direction of the man's arm. Copyright Azur; provided courtesy of IRD.

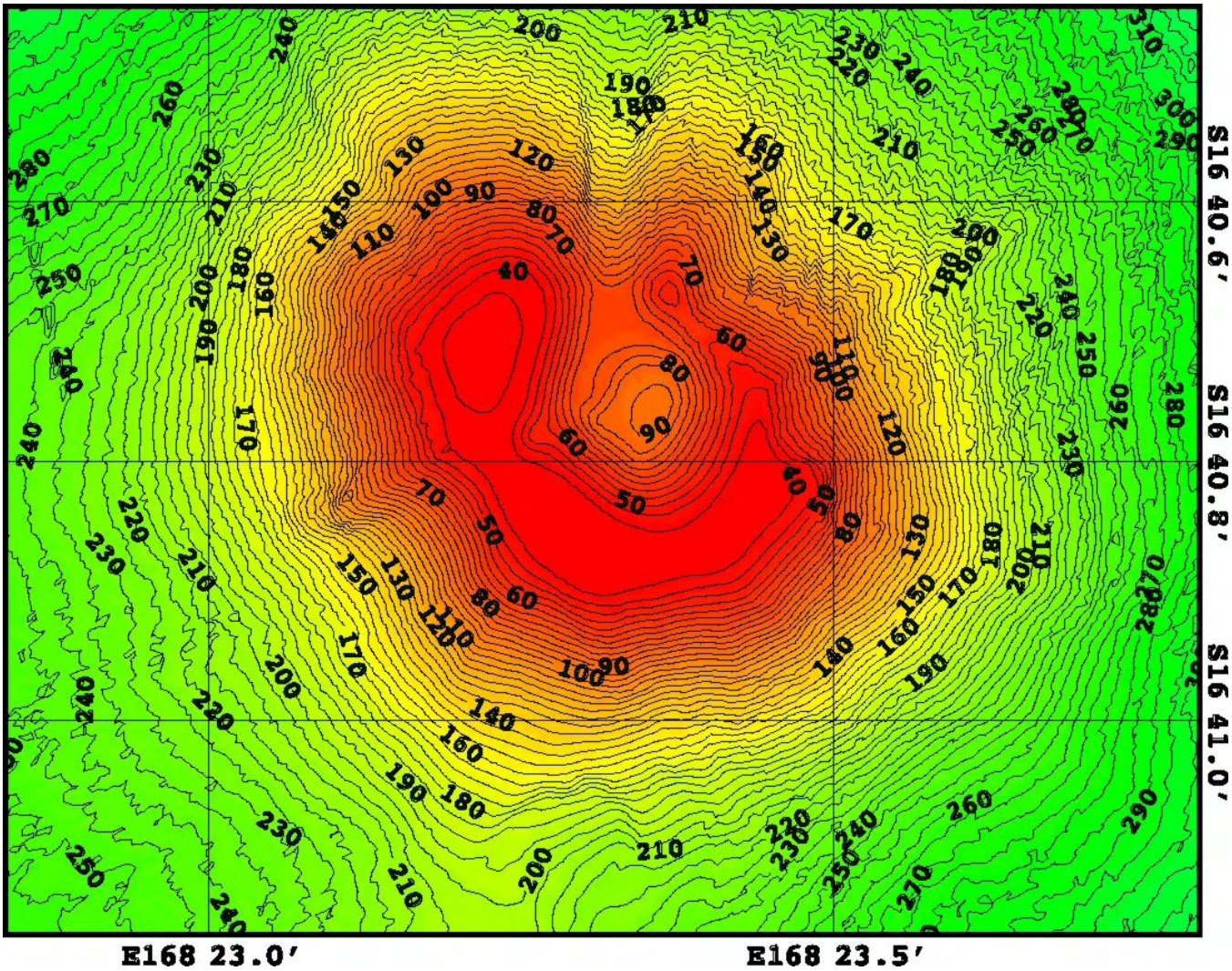

Figure 5. Detailed bathymetry (5 m contour interval) of Epi B seamount acquired by RV *Alis* using a multi-beam swath mapper (Simrad EM1002 sounder) on 14 March 2004. For rough scale, the crater is ~ 150 m in diameter and the narrow N-trending canyon is ~ 60 m wide. The VATATERM cruise and the details of creating and interpreting this map are discussed in Ballu and others (2004).

definite light transmission anomaly was also seen at the lowest point of the cast.

Two days later, on 20 September, a more extensive echosounding survey was made in the area noted on nautical maps as having a shoal at 38 m and discolored water. The survey showed a peak at 34 m depth and two smaller structures to the S around 220 m depth. Comparison of this 2001 bathymetric map with the map created by the 2004 VATATERM cruise (figure 1) shows a correlation of this 34-m peak with the summit of Epi B; the deeper peaks correspond to the smaller cones at about 16.70°S. The team "... obtained a reduction in light transmission at the surface (corresponding to the discoloured water) of around 6% associated with low salinity and higher temperature, another near bottom (below 210 m) of up to 1%, and a narrow upper plume signal at 100 m, with a transmission anomaly of approximately 0.2%." Bottles fired and sampled for geochemical studies revealed a large methane anomaly of up to 80 nl/l near the bottom.

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Background. Epi Island, located slightly W of the main New Hebrides volcanic arc, largely consists of two Quaternary volcanoes, Mount Allombei on the W and Pomare (Tavani Kutali) on the E. Tavani Ruro, an elongated eastern extension of Epi Island, is related to Kuwae caldera to the E. Pomare volcano is the highest point on the island and has three well-preserved subsidiary cones to the E with youthful summit craters. Submarine cones NE of the island have been the source of all historical eruptions. Ephemeral islands were formed during eruptions in 1920 and 1953.

Information Contacts: *Bernard Pelletier*, *Michel Lardy*, and *Philipson Bani*, IRD, BP A5, Noumea, New Caledonia (URL: http://www.mpl.ird.fr/suds-en-ligne/fr/volcan/vanuatu/epi1.htm; Email: Bernard.Pelletier@noumea.ird.fr, Michel.Lardy@noumea.ird.nc, Philipson.Bani@noumea.ird.nc); *Stéphane Calmant*, IRD-LEGOS Toulouse, France (Email: Stephane.Calmant@notos.cst.cnes.fr); *Valérie Ballu*, IPG Paris, France (Email: ballu@ipgp.jussieu.fr); *Esline Garaebiti*, *Sylvain Todman*, *Douglas Charley*, Department of Geology, Mines and Water Resources, Port Vila, Vanuatu (Email: esline@vanuatu.com.vu, charleyd@vanuatu.com.vu, sylvain.todman@free.fr); *Timothy F. McConachy*, CSIRO Division of Exploration and Mining, P.O. Box 136, North Ryde, NSW 1670, Australia (Email: Tim.McConachy@csiro.au).

Rabaul

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

The Rabaul Volcano Observatory has reported that eruptive activity from the Tavurvur crater at Rabaul, which began in early October 2002, ceased on 17 February 2004. Activity during 1-17 February was characterized by emissions of light pale ash clouds with occasional moderate explosions producing thick ash plumes. The plumes rose 1-2 above the summit, resulting in ashfall to the E and NE, including in Duke of York. A slight change in wind direction on 6 and 13-15 February resulted in fine ashfall to the NW over Rabaul city and villages downwind. Occasional weak roaring noises were heard with some of the explosions on 5 and 11 February.

Seismic activity was consistent with the ash emissions, with one high frequency event NE of the caldera on 5 February. 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, a reversal of the long-term trend of slow gradual uplift reported earlier (*Bulletin* v. 28, nos. 3, 9 and 11). During 18-29 February Tavurvur released weak white, and occasional blue, vapor.

A review of MODIS data for the year to 11 May 2004 showed thermal alerts recorded at Tavurvur cone, Rabaul, on 12, 21, and 29 October; 1, 8, 15, and 24 November; 1 and 26 December 2003; and 9 and 25 January 2004.

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 asymmetrical pyroclastic shield volcano are formed by thick pyroclastic-flow deposits. The 8 x 14 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 N and NE caldera rims. Post-caldera eruptions built basaltic-to-dacitic pyroclastic cones on the caldera floor near the NE and W 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 Contacts: *Ima Itikarai* and *Herman Patia*, Rabaul Volcano Observatory (RVO), P.O. Box 386, Rabaul, Papua New Guinea (Email: hguria@global.net.pg); *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).

Ulawun

New Britain, Papua New Guinea
5.05°S, 151.33°E; summit elev. 2,334 m

The Rabaul Volcano Observatory (RVO) reported that activity at Ulawun remained quiet during February 2004. The main vent emitted white vapor at weak to moderate rates. No emissions were reported from the two north valley vents. No noise or night time glow was reported, and seismicity was at a low level. RVO reported in similar terms for the period 15 March-1 April, noting also that tiltmeter mea-

surements recorded a long-term inflationary trend. According to Darwin VAAC, on 12 and 13 April thin ash plumes from Ulawun were visible on satellite imagery at a height of -~ 700 m above the volcano extending ~ 75 E and NE. On 14 April the ash plume rose ~ 3 km altitude and extended ~ 37 km NE. No HIGP-MODIS thermal alerts were recorded at Ulawun over the year to 11 May 2004.

Note that a 16 January 2001 VAAC report of Ulawun emitting a cloud, ashes, and 'flames' ~ 10.6 km altitude, which was not confirmed by satellite imagery or RVO, has not previously been mentioned in the *Bulletin*.

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, also known as the North Son, rises above the N coast of New Britain across a low saddle NE of Bamus volcano, the South Son. The upper 1,000 m of the 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: *Ima Itikarai* and *Herman Patia*, Rabaul Volcano Observatory (see Rabaul); *Darwin Volcanic Ash Advisory Centre (VAAC)*, Commonwealth Bureau of Meteorology, Northern Territory Regional Office, PO Box 40050, Casuarina, NT, 0811, Australia (URL: http://www.bom.gov.au/info/vacc/; Email:darwin.vaac@bom.gov.au).

Pago

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

A message in mid-April from Rabaul Volcano Observatory's assistant director, Ima Itikarai, to Dan Shackelford indicated that their previous Pago report (*Bulletin* v. 29, no. 2), which noted two eruptions on 24 February 2004, was no longer believed to be true. Described activity, especially felt tremors, contradicted instrumental data. After discussions with local observers Itikarai concluded that "the reported activity may not be true." Although no explanation was given for the reports of ashfall or glow, the message noted that the "jet-like noises" may have been low-frequency sounds from local thunderstorms.

(A few days after conveying this information Shackelford, who had fought both heart disease and thyroid cancer, was found dead of natural causes in his suburban apartment in Los Angeles, California).

RVO reports for 15 March-1 April noted that Pago's volcanic and seismic activity remained at low levels. All vents gently released small volumes of 'thin white vapor,' with small amounts of 'blue vapor' from the lower vents on some days. A dull glow was observed on 17 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 Contacts: *Ima Itikarai* and *Herman Patia*, Rabaul Volcano Observatory (see Rabaul).

Manam

NE of Papua New Guinea
4.10°S, 145.061°E; summit elev. 1807 m

The Rabaul Volcano Observatory reported that activity at Manam's two main summit craters remained low to mild during February-April 2004. No HIGP-MODIS thermal alerts were recorded at Manam over the year to 11 May 2004. While RVO noted that the summit was covered in cloud for most of February, when it was clear the craters were releasing white vapor at weak to moderate rates. They reported that February's single explosion occurred at the Southern Crater on the 14th; it was accompanied by a thick gray ash cloud and weak roaring noises. The ash cloud rose several hundred meters above the summit and drifted NW producing fine ashfall. There was no night-time glow observed during the month.

Mild eruptive activity occurred at the Southern Crater over the period 15 March-1 April, with emissions of brown ash on 17, 18, 27, and 28 March. The ash clouds rose ~ 100-300 m above the summit and drifted SE, depositing small amounts of ash in the villages of Boakure and Warisi. Vapor was also emitted from Main Crater. Small low-frequency earthquakes occurred over the report period, with a slight increase in the amplitude of volcanic earthquakes on 24 March. Overall the level of seismicity remained low. RVO continued to advise people to stay away from the four main valleys near the volcano.

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 Contacts: *Ima Itikarai* and *Herman Patia*, Rabaul Volcano Observatory (see Rabaul).

Dukono

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

Dukono, one of Indonesia's most active volcanoes, erupts nearly continually. Unfortunately, satellite-based thermal alerts from MODVOLC processing and NASA's Terra satellite have thus far only occasionally disclosed Dukono activity. MODVOLC data appear on a dedicated website maintained by the University of Hawaii HIGP MODIS Thermal Alerts team. Coppola and Rothery previously reported a significant thermal event on Dukono during 26 August-7 September 2002 (*Bulletin* v. 28 no. 3). This was the first sign of Dukono activity indicated by MODVOLC data since the remote-sensing system began data collection in May 2000. Reports from the Volcanological Survey of Indonesia and the Darwin VAAC (*Bulletin* v. 28 nos 6, 9, 11, and 12) documented ash eruptions during February and June 2003, with activity continuing to at least January 2004.

An updated analysis of MODVOLC data for the observational period August 2000-April 2004 included thermal alerts from NASA's Aqua satellite. Alerts were triggerd for 26 August and 6 and 7 September 2002. They confirmed the August-September 2002 event, but found very little sign of subsequent activity through the end of April 2004. After September 2002 the only thermal alerts were single pixel events only slightly above the MODVOLC detection threshold. They took place on 1 March and 10 November 2003. Inspection of raw MODIS data revealed an additional anomaly on 17 November 2003, but the alert ratio was slightly below the MODVOLC detection threshold.

For an explanation of MODVOLC anomalies see *Bulletin* v. 28 no. 1 or the MODVOLC website. The scarcity of thermal alerts at Dukono, despite the recurrent ash eruptions, indicates the general invisibility (or small size) of any hot feature(s) there. Small to moderate sized ash columns would be unlikely to trigger an alert since they occur in a narrow time window.

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: *MODIS Thermal Alerts team*, 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); *David A . Rothery* and *Charlotte Saunders*, Department of Earth Sciences, The Open University, Milton Keynes, MK7 6AA

Anatahan

Mariana Islands, central Pacific Ocean
16.35°N, 145.67°E; summit elev. 788 m
Local times are = UTC + 10 hours

The first recorded historical eruption at Anatahan began on 10 May 2003. Activity through early October 2003 was reported in several issues of the *Bulletin* (vol. 28, nos. 4, 5, 6, and 9). This report, in large part contributed by scientists of the Commonwealth of the Northern Mariana Islands Emergency Management Office (CNMI/EMO) discusses Anatahan during October 2003 to early May 2004. During October-February, Anatahan's tremor and volcanic seismicity were consistently low, with no apparent eruption signals or precursory events. Later, in March, April, and May clear emissions began, and in April-May 2004 small dome extrusions occurred. There were several peaks in seismicity, such as 2-8 February and shorter episodes on 13-14 February. Much larger peaks in seismicity, the largest in 2004, took place in late April. Many details on the dome extrusions remain undisclosed; however, near the end of this report there are a variety of data from several contributors, including one clear Modis alert (28 April) and a VAAC reports based on satellite observations of a thin plume (24 April).

During overflights in early October 2003 observers saw no ash emissions. The crater vents continued to emit steam and SO_2, and the floor of the crater was in great flux. During periods of rain, the crater floor was covered by sediment-laden water and (or) debris flows. The E crater continued to have an active geothermal system that consisted of mud pots, mini-geysers, and steam jets from the crater walls. In general, emissions continued at a low level.

During early November 2003, regional seismicity was low. For the week of 9-15 December, numerous tiny long-period earthquakes (LPs) were recorded only on the station near the crater, at a rate of ~ 1 every 10 sec. All of these LP events were much smaller than M 0.5, with dominant frequencies of 4-5 Hz. After several months of only very low magnitude LP events, on 1 February 2004 larger ones again began to occur. After increasing slowly in size, they reached M ~ 2, and they took place several times per hour.

Anatahan's seismicity peaked just before 1600 local time on 7 February 2004, with a swarm consisting of up to 15 events occurring per hour. The seismicity then decreased dramatically but remained well above levels of the previous few months. By 1000 on 8 February the maximum magnitude of volcanic earthquakes had diminished greatly from their peak magnitude two days before, but the earthquakes were occurring more often, sometimes as frequently as 1 per minute. The amplitude of low-frequency tremor had also increased considerably. The combined effect was that

the level of seismic energy release around 7-8 February, averaged over hours, remained nearly constant at its peak.

By 9 February the magnitude of the volcanic earthquakes decreased significantly and were no longer visible on the records. The amplitude of low-frequency tremor remained high but decreased some from its peak on 8 February. The total daily seismic energy release decreased somewhat from its peak during the previous few days. From 10 February to 29 March 2004, Anatahan volcanic seismicity, tremor, and energy release were all very low, with no apparent eruption signals.

Volcanic seismicity occurred again 13 February during a 6-hour period, the first such seismicity since the episode of 2-7 February. Short tremor episodes began at 0543 and occurred every 8-12 minutes until 1130 on 14 February, the largest being approximately equivalent to a magnitude M 2 earthquake. From 15 February through 30 March 2004, Anatahan tremor and volcanic seismicity stood at low background levels, with no apparent eruption signals or precursory events.

A seismic swarm began beneath Anatahan Island on 31 March, the third such swarm since the eruption of May-June 2003. The largest earthquakes in the swarm were all smaller than those that occurred during the previous swarm in early February 2004. During 2-3 April the swarm intensified significantly. Most earthquakes were followed by long, tremor-like signals that CNMI scientists believed indicated small emissions of steam, possibly bearing ash and thought to rise to altitudes much less than 1,000 m, though they had no visual confirmation of such emissions at the time.

On 6-7 April, Anatahan volcanic seismicity was the highest since the eruption of May-June 2003, with events as large as M ~ 2.5 usually followed by tremor-like signals. That swarm's level of seismic activity remained high through 23 April.

With regard to the rise in seismicity during early 2004, Scientists of the Commonwealth of the Northern Mariana Islands Emergency Management Office (CNMI/EMO) opined that these events were likely the result of magma degassing and/or moving beneath the recently active crater. The Office of the Governor, CNMI, placed Anatahan Island off-limits and concluded that, although the volcano was not currently dangerous to aircraft, pilots should exercise due caution in Anatahan's vicinity.

Dome, ejecta, and lavas. On 12 April, the presence of a new, rather flat lava dome within a crescent-shaped crater lake was confirmed, as was the occurrence of fresh ejecta within the lowest reaches of the crater. The Hawaii Institute of Geophysics and Planetology (HIGP) web site for MODIS hot-spot satellite imagery showed a thermal anomaly for the volcano on 12 April at 1545 UTC. High seismicity through 23 April suggested continuing effusion of relatively small volumes of new lava onto the crater floor.

At 1052 on 24 April, Anatahan's seismic activity increased abruptly, rising to levels unseen since summer 2003 (3 to 4 times as high as those observed in April 2004). About that time a low-level eruption began producing steam and ash to ~ 600 m and an overflight reported incandescent cracks in a fresh lava flow or dome within the inner crater. The presence of a "cow-pie-shaped" dome within the inner crater was verified later.

The seismicity level increased slowly and fairly constantly on 24-25 April to a level similar to that of the eruption of mid-June 2003. During an overflight on 26 April between 1030 and 1100, Juan Camacho (CNMI/EMO) and Erik Hauri (Carnegie, Margins group) observed regular puffs of yellow-brown steam and ash every 1-2 min, a rate almost identical to that of seismic events recorded during that time. The maximum height of the steam and ash plume was estimated at ~ 600 m.

According to the Washington Volcanic Ash Advisory Center (VAAC), at 0725 UTC on 24 April 2004 a thin plume from Anatahan was visible on satellite imagery ~ 1 km above the volcano and extending ~ 460 km NW; this plume was not observable on satellite images taken at 1502 UTC, later in the same day. The HIGP web site for Modis hot-spot satellite imagery showed a thermal anomaly for the volcano on 28 April at 1545 UTC. On 28 April the seismicity level increased still further, a level ~ 25% more energetic than the previous high of 25 April 2004.

In accord with the elevated seismicity, the dome increased in size, and explosions also apparently increased in size and rate. The seismicity then slowly decreased ~ 25% over the next 5 days until 3 May, when it dropped off suddenly but smoothly by another 40%. Subsequently, over several days, the seismicity recovered somewhat to ~ 50% of the highest level of 28 April. On 5 May 2004 small explosions continued to occur every minute or two, and steam and ash still rose hundreds of meters.

Background. The elongated, 9-km-long island of Anatahan in the central Mariana Islands consists of two coalescing volcanoes with a 2.3 x 5 km, E-W-trending summit depression formed by overlapping summit calderas. The larger western caldera is 2.3 x 3 km wide and extends eastward from the summit of the western volcano, the island's 788 m high point. Ponded lava flows overlain by pyroclastic deposits fill the caldera floor, whose SW side is cut by a fresh-looking smaller crater. The summit of the lower eastern cone is cut by a 2-km-wide caldera with a steep-walled inner crater whose floor is only 68 m above sea level. Sparseness of vegetation on the most recent lava flows on Anatahan indicated that they were of Holocene age, but the first historical eruption of Anatahan did not occur until May 2003, when a large explosive eruption took place forming a new crater inside the eastern caldera.

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Ebeko

Paramushir Island, Northern Kuriles, Russia
50.68°N, 156.02°E; summit elev. 1,156 m
All times local (= UTC + 11 hours)

The last recorded eruption of Ebeko volcano was in 1991. Table 1 summarizes activity on Ebeko from February-April 2004 as reported by observers Leonid and Tatiana Kotenko (observations made on days when clouds did not obscure the volcano).

On 14 April 2004 a fishing craft reported a white gas plume emerging from Tatarinov volcano. That volcano lies near the opposite (southern) end of Paramushir Island. The plume came from Tatarinov's fumarolic field and remained at low altitude following the Tukharka river. Also in the southern part of Paramushir island, the volcanoes Chikurachki (last active 17-18 April 2003, *Bulletin*, v. 28, no. 7) and Fuss Peak (*Bulletin*, v. 12, no. 4) were both reported quiet.

Background. The flat-topped summit of the central cone of Ebeko volcano, one of the most active in the Kurile Islands, occupies the northern end of Paramushir Island. Three summit craters located along a SSW-NNE line form Ebeko volcano proper, at the northern end of a complex of five volcanic cones. Blocky lava flows extend W from Ebeko and SE from the neighboring Nezametnyi cone. The eastern part of the southern crater of Ebeko contains strong solfataras and a large boiling spring. The central crater of Ebeko is filled by a lake about 20 m deep whose shores are lined with steaming solfataras; the northern crater lies across a narrow, low barrier from the central crater and contains a small, cold, crescent-shaped lake. Historical activity, recorded since the late-18th century, has been restricted to small to moderate explosive eruptions from the summit craters. Intense fumarolic activity occurs in the summit craters of Ebeko, on the outer flanks of the cone, and in lateral explosion craters.

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Karymsky

Kamchatka Peninsula, Russia
54.05°N, 159.43°E; summit elev. 1,536 m
All times are local (= UTC + 12 hours)

Intermittent explosions and seismicity above background levels, as also reported in *Bulletin* v. 28, no. 11, continued from 1 January to mid-April 2004, a time interval when the Level of Concern remained at Orange. Occasional explosions occurred without warning, sending ash as high as ~ 7000 m altitude and yielding ashfall locally and beyond the volcano. Ash deposits were detected extending in essentially all directions on various days during the report period. Clouds frequently obscured visual observation of the volcano.

During January 2004 the daily number of local shallow earthquakes varied from lows of 40-80 to highs of 200-300. Similarly, in February, shallow events varied from lows of 30-40 to highs of 160-200. However, in March, particularly after the early part of the month, the highest daily numbers rose to 240-380. The highest daily numbers reached still higher during April, to as high as 300-470.

Up to five ash-gas explosions occurred on specific days during each month. These explosions sent plumes to altitudes of ~ 3-5 km during January (although pilot reports sometimes estimated higher plumes, to 5.5 to 7 km altitude). Plumes rose to ~ 2.5-6.5 km during February and March, and dropping to ~ 2.5-3.5 km during April. Thus, although more daily earthquakes occurred during April, the plume heights then appeared lower than in January-March.

During the week ending 16 January, an ash plume observed by pilots of a local airline rose to 7 km altitude and extended to the S-SW. Pilots also reported ash plumes rising up to 5.5 km altitude on 9 and12 February. On 11

2004	Activity level	Wind direction	Gas-steam plume (meters above crater)	Comment
08 Feb	Quiet	—	—	—
12 Feb	Quiet	—	—	—
23 Feb	—	NW	—	Strong smell of H_2S
03 Mar-04 Mar	—	Weak to N	<150-200	—
12 Mar	—	—	<150	—
16 Mar-17 Mar	—	—	< 200	—
26 Mar	—	Strong to S	—	—
29 Mar	Quiet	—	—	—
31 Mar	—	N	<150	—
02 Apr	Quiet	—	—	—
12 Apr	—	Strong to NE	—	—
15 Apr	—	N	<100	—
19 Apr	—	—	<100	—
28 Apr	—	—	<100	—
29 Apr	—	Strong to N	—	—

Table 1. A summary showing Ebeko activity for February-April 2004. Courtesy of Leonid and Tatiana Kotenko.

Period ending	Seismicity level	Shallow earthquakes (Number / local magnitude)	Deeper earthquakes (Daily number / magnitude / depth)	Tremor velocity (μm/s)
09 Jan 04	above bkgd	~115 / 1.9-2.3	—	4-8
16 Jan 04	above bkgd	~175 / 1.9-2.5	—	7-8 (11-13 Jan); 15-20 (12-15 Jan)
23 Jan 04	above bkgd	~130 / 1.9-2.3	—	6-13
30 Jan 04	above bkgd	~130 / 1.9-2.3	—	3-16
06 Feb 04	above bkgd	~430 / 1.2-2.0	1-5 / Ml = 1.2-2.0 / 3-6 km	1-2
13 Feb 04	above bkgd	~225 / 1.25-2.0	1-5 / Ml < 2.25 / 3-6 km	0.5-1
20 Feb 04	above bkgd	~135 / 1.25-1.7	1-6 / Ml = 1.25-1.85 / 3-6 km	0.4-0.9
27 Feb 04	above bkgd	~160 / 1.25-1.75	~2 / Ml = 1.25-2.25 / 3-7 km 22-25 Feb: ~7 / Ml? / 30 km	0.4-0.6
06 Mar 04	slightly above bkgd	n.r.	26-7 Feb: 6 / Ml = 1.25-2.2 / 3-7 km 26 Feb-1 Mar: ~2 / Ml? / 30 km	0.2-0.5
12 Mar 04	at bkgd	n.r.	38 / Ml = 1.25-1.6 / 30 km	0.2
19 Mar 04	at bkgd	n.r.	~7 / Ml = 1.2-1.7 / 30 km 11-14 Mar: 1 / Ml = 1.5-2.0 / 3-7 km	0.2-0.3
26 Mar 04	at bkgd	n.r.	~2 / Ml = 1.25-1.6 / 30 km 25, 26, 30 Mar: 1 / Ml = 1.2-2.1 / 3-12 km	0.2-0.4
02 Apr 04	at bkgd	n.r.	26, 28, 30 Mar: 1 / Ml = 1.2-2.1 / 3-12 km 25, 26, 30 Mar: ~2 / Ml = 1.25-1.6 / 30 km	0.2-0.4
09 Apr 04	at bkgd	n.r.	~3 / Ml = 1.25-1.85 / 30 km	0.2-0.4
16 Apr 04	at bkgd	n.r.	~10 / Ml = 1.25-1.8 / 30 km	0.2-0.4
22 Apr 04	at bkgd	n.r.	~8 / Ml = 1.25-1.7 / 30 km	0.2-0.4
29 Apr 04	at bkgd	n.r.	~5 / Ml = 1.25-1.75 / 30 km	0.21-0.25

Table 2. Weekly seismic activity at Kliuchevskoi recorded 9 January to 29 April 2004. Some changes in reporting practices shifted around the week ending 27 February. The depth cutoffs for the two earthquake categories (shallow vs. deeper) were not disclosed; n.r. means not reported; Ml refers to local magnitude, and Ml? signifies an unstated magnitude. Courtesy of KVERT.

February, an ash cloud rose to 10 km altitude and drifted 60 km from the volcano. Reports describing 20 February noted ash deposits extending about 35 km S.

According to satellite data from the USA and Russia, thermal anomalies of 1-4 pixels were observed during January and 1-6 pixels during February and March. However, the number of pixels increased from 1 to 10 during early April, the same period when the number of shallow earthquakes was increasing.

Information Contacts: *Olga Girina*, Kamchatka Volcanic Eruptions Response Team (KVERT) (see Ebeko); *Alaska Volcano Observatory (AVO)* (see Ebeko).

Kliuchevskoi

Kamchatka Peninsula, Russia
56.057°N, 160.638°E; summit elev. 4835 m
All times are local (UTC + 12 hours)

Unrest at Kliuchevskoi continued, with occasional and repeated explosions containing ash, gas, and steam that rose as high as 7.8 km altitude during January-April 2004. The alert level remained at orange.

Strombolian activity was reported in the central crater on 11-12 January and may have occurred again during 22-26 January. Gas-steam plumes extended up to 15 km in various directions during the report period; although one containing small amounts of ash, extended 75 km to the SW on 25 January.

Table 2 presents seismicity reported by KVERT including the number of large shallow earthquakes, their local magnitudes (Ml), and the range of tremor velocity. Many weak, shallow earthquakes also occurred each week. In overview, seismicity stood above background until about March, when it dropped to background, remaining there through 29 April. After February, instrumental measure of tremor (tremor velocity, table 2) declined. The details on the number and magnitude of large shallow earthquakes (which on the week ending 6 February had risen to ~ 430 Ml 1.2-2.0) ceased being a reported topic after February, although these earthquakes continued to be mentioned as occurring. Beginning in late February, earthquakes at depths up to 30 km were reported in moderate number ("deeper earthquakes"; table 2).

Gas plumes frequently rose as high as 5.8 km altitude each week, with gas plumes rising 5.8-7.8 km altitude during 24-25 January. Seismic activity continued to be above background level throughout January and February (as it was in December 2003, *Bulletin* v. 28, no. 12), but in mid-March, seismic activity returned to background levels and remained there through April. Ash explosions and plumes rising to 4.9-5.8 km altitude occurred during January but none were reported subsequently, although satellite data indicated an ash plume extending N-NE on 8 April. US and Russian satellites reported weak thermal anomalies (1-7 pixels) during January and February, but no anomalies were reported subsequent to 20 February. Weak fumarolic activity was reported weekly after mid-March.

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Nyamuragira

Democratic Republic of Congo, Central Africa
1.408°S, 29.20°E; summit elev. 3058 m
All times are local (+ UTC + 2 hours)

The Observatoire Volcanologique de Goma (Goma Volcano Observatory, GVO) reported that a new eruption at Nyamuragira began at 0548 on 8 May 2004. Activity started in the summit caldera and later propagated to the N flank. Since July 2003 Nyamuragira had shown abnormal behavior, having an average of 3 distinct seismic swarms per month (see Bulletin, v. 28, no. 9, 10, and 12). The last of these swarms occurred during 4-6 May 2004. The eruption was also preceded by an important high frequency (HF) earthquake felt in the Virunga area at 0144 on 8 May, localized below the N part of Lake Kivu. This event was followed at 0315 on 8 May by a high-amplitude long-period earthquake located N of Virunga. Unusual and significant fumarolic activity from the Nyamuragira caldera was seen from Goma (~ 40 km S) on 2 May 2004.

On its overpass of Nyamuragira at 1056 on 8 May 2004, the Earth Probe Total Ozone Mapping Spectrometer (EP TOMS) detected large SO_2 clouds released by the current eruption of Nyamuragira. However, the situation was complicated by the fact that EP TOMS has recorded SO_2 emissions from Nyiragongo (~ 15 km SSE of Nyamuragira) since October 2002, and therefore some SO_2 from Nyiragongo was also likely to be present. Daily SO_2 amounts observed at Nyiragongo over the past month have been in the range of ~ 5-30 kilotons (kt). An SO_2 cloud was detected extending in several directions from Nyamuragira, containing ~ 30 kt of SO_2. A data gap over eastern Democratic Republic of Congo (DRC) prevented measurements on 9 May, although there was evidence for some SO_2 drifting over northern Tanzania, ~ 720 km from Nyamuragira.

On 10 May at 1055 a broad SO_2 cloud extended up to ~ 180 km W, ~ 360 km S, and ~ 260 km ESE of the volcano, completely covering Rwanda and Burundi, with the highest SO_2 concentrations detected in a zone directed SSE across Rwanda. This cloud contained ~ 190 kt of SO_2. Another data gap on 11 May prevented measurements directly over eastern DRC, but a large SO_2 mass (~ 116 kt) was present W of the data gap, ~ 560 km S of Nyamuragira at its maximum extent. No ash was detected in the volcanic clouds by EP TOMS as of 12 May, and the maximum altitude reached by the SO_2 was unclear. A number of anomalous pixels indicating a hot spot just N of Nyamuragira were observed at 1030 on 9 May from the MODIS (Moderate Resolution Imaging Spectroradiometer) thermal satellite imagery (URL: http://modis.higp.hawaii.edu/).

Overflights attempted by GVO on 8 May failed because of the rainy season's bad weather, but the quick glimpse suggested a significant lava flow descending the N slope. On 9 and 12 May GVO plane overflights and a field mission in the area located to the volcano's N revealed that one active lava lake appeared an unstated distance NNE of the Nyamuragira caldera. This lake, ~ 300 m in diameter, was located in a pit ~ 15 m deep and fed by 4 strong lava fountains. Activity was much reduced by 12 May. The surface was a solid crust with three vents open through it. All vents displayed Strombolian activity with spatter splashing and short lava overflows; accumulation of spatter tends to build low cones.

An eruptive fracture, ~ 2 km long, was found on the N-NW flank of the volcano. Several lava fountains were very active all along the fracture and 4 main cones were building up to heights estimated as 30-50 m. Lava poured from many vents and turned into a main flow directed towards the N-NW, always within the Virunga National Park boundaries. Flows made an intricate delta below the lower cone, turning onto a very wide lava flow that covered an area with a total length estimated to be ~ 12 km. Although this flow continued to move, it failed to threaten any populated areas. Ashfalls were observed in several villages on the W and N sides of the volcano. The activity remained quite strong and apparently stable in comparison with other documented Nyamuragira eruptions.

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

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