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Montagu Island

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

The first recorded eruption of Montagu island (sometimes called Belinda volcano) has continued for more than two years according to satellite thermal imagery (see *Bulletin* v. 28, no. 2). First detected on imagery from the Moderate Resolution Imaging Spectroradiometer (MODIS) satellite on 20 October 2001 by the MODVOLC automated monitoring system at the University of Hawaii Manoa, the eruption appeared to continue with persistent low-level ash emission and occasional lava effusion into at least December 2003.

MODIS thermal anomalies have been present on a regular basis since the 20 October 2001 eruption. Figure 1 shows the MODIS-measured radiative heat output through 2003 (see also Wright and Flynn, 2004). High heat output occurred in August 2002, perhaps corresponding to lava effusion down the W flank of the cinder cone (figure 2). Following a relaxation in heat output levels, values rose again in late 2003, the highest level occurring in October 2003.

High-resolution images from the Advanced Spaceborne Thermal Emission and Reflection Radiometer (ASTER) satellite (15 m pixel size) and the Landsat Enhanced Thematic Mapper Plus (ETM+) (15-30 m pixel size) were used to examine the processes acting on the surface. An ETM+ image on 4 January 2002 showed a ~ 600 m lava flow near the summit of the cinder cone while low-level ash emission ensued. An ASTER image on 1 August 2003 showed a 2-km-long lava flow that was emplaced on the summit ice cover, corresponding, perhaps, to a 25 July 2003 MODIS radiance spike. The flow emanated from the summit of the cinder cone in a NE trend and cut through the ice cover creating a deep gully that confined the flow laterally. The gully, ~ 100 m wide near the source, swelled to a fan-shaped chasm ~ 600 m in diameter. An ash-rich plume was observed and ubiquitous ash cover blanketed the E half of the island. An ASTER image on 7 December 2003 showed the cooling lava flow devoid of snow cover with a small ash plume drifting SE from the summit (figure 2).

The high-resolution ASTER images improved previously published maps, leading to revised estimates of the island's size. Thus, previously reports described the island as 15 x 20 km across, but a better estimate is 10 x 12 km. The previous sketch map (in *Bulletin* v. 28, no. 2) had the correct scale.

The ASTER images also provide some of the first clear views of the island's morphology and some of the recent deposits. The active cinder cone is a small peak situated on the N side of an extensive and gently sloping ice field. This ice field fills the largest caldera known in the island group, a feature ~ 6 km in diameter and filled by permanent ice of uncertain depth. Mount Oceanite forms a conspicuous promontory on the SE corner of the island with a 270-m-diameter summit crater (figure 2).

Satellite remote sensing of remote regions. The South Sandwich Islands are situated well to the E of the southern

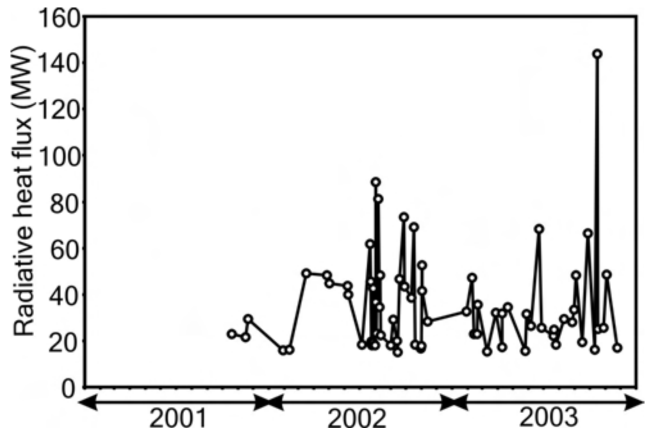

Figure 1. Radiative heat output from Montagu during the period October 2001-December 2003 measured by the MODVOLC monitoring system using MODIS satellite data. Courtesy of the HIGP Thermal Alerts Team, Hawai'i Institute of Geophysics and Planetology (HIGP).

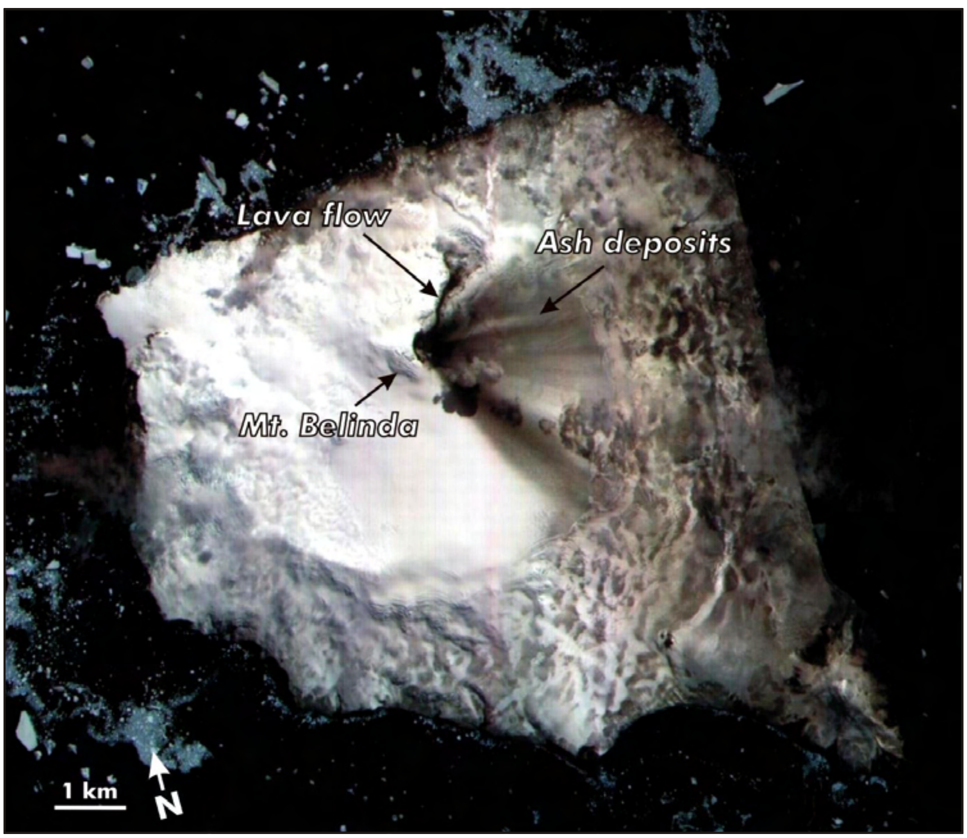

Figure 2. Montagu Island and the surrounding iceberg-laden seas appear in this ASTER satellite image (visual spectrum, bands 3-2-1, 15 m pixel size) take on 7 December 2003. This image shows recent volcanic deposits on Montagu's ice-covered surface. The image will also help refine existing maps. The volcano on the island's lower right-hand extreme is called Mount Oceanite. Courtesy of NASA/ GSFC/ MITI/ ERSDAC/ JAROS, and U.S./ Japan ASTER Science Team.

tip of South America and over 10 degrees N of mainland Antarctica. They comprise a volcanic province called the Scotia arc, formed by the subduction of the South American plate beneath the Scotia plate. Due to this region's inaccessibility, satellite monitoring holds promise as a means to track volcanism there.

Terra (Latin for land) is the name of the Earth Observing System (EOS) flagship satellite that began science operations in 2000. Terra is a multi-national, multi-disciplinary satellite carrying a payload of five remote sensors that are measuring comprehensively the state of Earth's environment and ongoing changes in its climate system. The Terra MODIS sensor detects thermal data and forms part of the satellite monitoring system called MODVOLC. The monitoring system is run by the HIGP Thermal Alerts Team at the University of Hawaii-Manoa.

Another sensor on Terra is ASTER (Advanced Spaceborne Thermal Emission and Reflection Radiometer), an imaging instrument. This sensor, a cooperative effort between NASA and Japan's Ministry of Economy, Trade, and Industry (METI), and the Earth Remote Sensing Data Analysis Center (ERSDAC), provides detailed maps of land surface temperature, emissivity, reflectance, and elevation.

Background. The largest of the Sandwich Islands, Montagu consists of one or more stratovolcanoes with parasitic cones and or domes. The polygonal-shaped island is roughly 10 x 12 km wide with a prominent peninsula at its SE tip. Glaciers extend over much of the island, forming vertical ice cliffs at the sea. Mount Belinda, is the highest point of the island and lies at the S end of a 6-km-wide ice-filled summit caldera. Mount Oceanite, an isolated 900-m-high peak, lies at the SE tip of the island. There was no record of eruptive activity at Montagu until MODIS satellite data in late 2001 revealed thermal anomalies.

References: Wright, R., and Flynn, L.P., 2004, A space-based estimate of the volcanic heat flux into the atmosphere during 2001 and 2002: Geology, v. 32, p. 189-192.

Wright, R., Flynn, L.P., Garbeil, H., Harris, A.J.L., and Pilger, E., (in press), MODVOLC: near-real-time thermal monitoring of global volcanism: Journal of Volcanology and Geothermal Research, Elsevier (2004)

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

Lascar

Chile
23.37°S, 67.73°W; summit elev. 5,592 m

A report discussing Lascar from the Chilean Oficina Nacional de Emergencia, Ministerio del Interiorone (ONEMI) noted that on 9 December 2003 small amounts of fine ash discharged from fumaroles at Lascar. The following day activity was at normal levels, with only gas and steam emitted. On the morning of 10 December observers noted a 400-m-high, gray-colored, fumarolic plume. No increased seismicity was recorded. Eruptions were previously noted at Lascar during October 2002. At that time the volcano was the subject of several months of field studies (*Bulletin* v. 28, no. 3).

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. An older, higher stratovolcano 5 km to the east, Volcán Aguas Calientes, displays a well-developed summit crater and a probable Holocene lava flow near its summit (de Silva and Francis 1991). 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 that extended up to 8.5 km NW of the summit.

Information Contact: *National Office for Emergencies* (Oficina Nacional de Emergencia, "ONEMI"), Ministry of the Interior, Beaucheff 1637, Santiago, Chile (URL: http://www.onemi.cl/).

Sabancaya

southern Peru
15.78°S, 71.85°W; summit elev. 5,967 m
All times are local (= UTC + 5 hours)

As previously reported in *Bulletin* v. 28, no. 5 no deformation had been observed during mid-1997 through December 2001. In mid-2003 observers saw evidence of recent ash emissions.

On 31 July 2003, during a commercial flight from Cusco to Arequipa, Mike Sheridan observed ashfall deposits on fresh snow at Sabancaya volcano. The flight path was S of the volcano on a cloud-free day, and fresh snowfall had occurred a day or two before. Ashfall deposits blanketed the cone's summit and, on the NE side, extended to the volcano's base. Two days later, when traveling by car, Sheridan and Jean-Claude Thouret observed the ash from the E. They saw ash down to ~ 5,000 m elevation. The ash blanket appeared comparable to those observed at Sabancaya in the 1990s.

Background. Sabancaya, located on the saddle between 6,288-m-high Ampato and 6,025-m-high Hualca Hualca volcanoes, is the youngest of these Holocene volcanic centers. Sabancaya is the only one to have erupted in historical time. The indian name for the volcano ("tongue of fire") was already established when first mentioned in 1595, suggesting eruption prior to that time. Holocene activity has consisted of plinian eruptions followed by emission of voluminous trachytic and dacitic lava flows, which form an extensive 15-km-wide apron around the volcano. Records of historical eruptions of Sabancaya date back to 1750.

Information Contacts: *Michael F. Sheridan*, SUNY at Buffalo, Dept. of Geology, Buffalo, NY 14260 (mfs@acsu.buffalo.edu); *Jean-Claude Thouret*, Centre de Recherches Volcanologiques, 5 rue Kessler, 63038 Clermont-Ferrand, France (Email: thouret@opgc.univ-bpclermont.fr).

Tungurahua

Ecuador
1.467°S, 78.442°W; summit elev. 5,023 m

A comprehensive summary of activity at Tungurahua (figure 3) over the period January-16 December 2003 was reported in *Bulletin* no. 28 v. 11. During 17-23 December, volcanic activity continued at relatively high levels, with

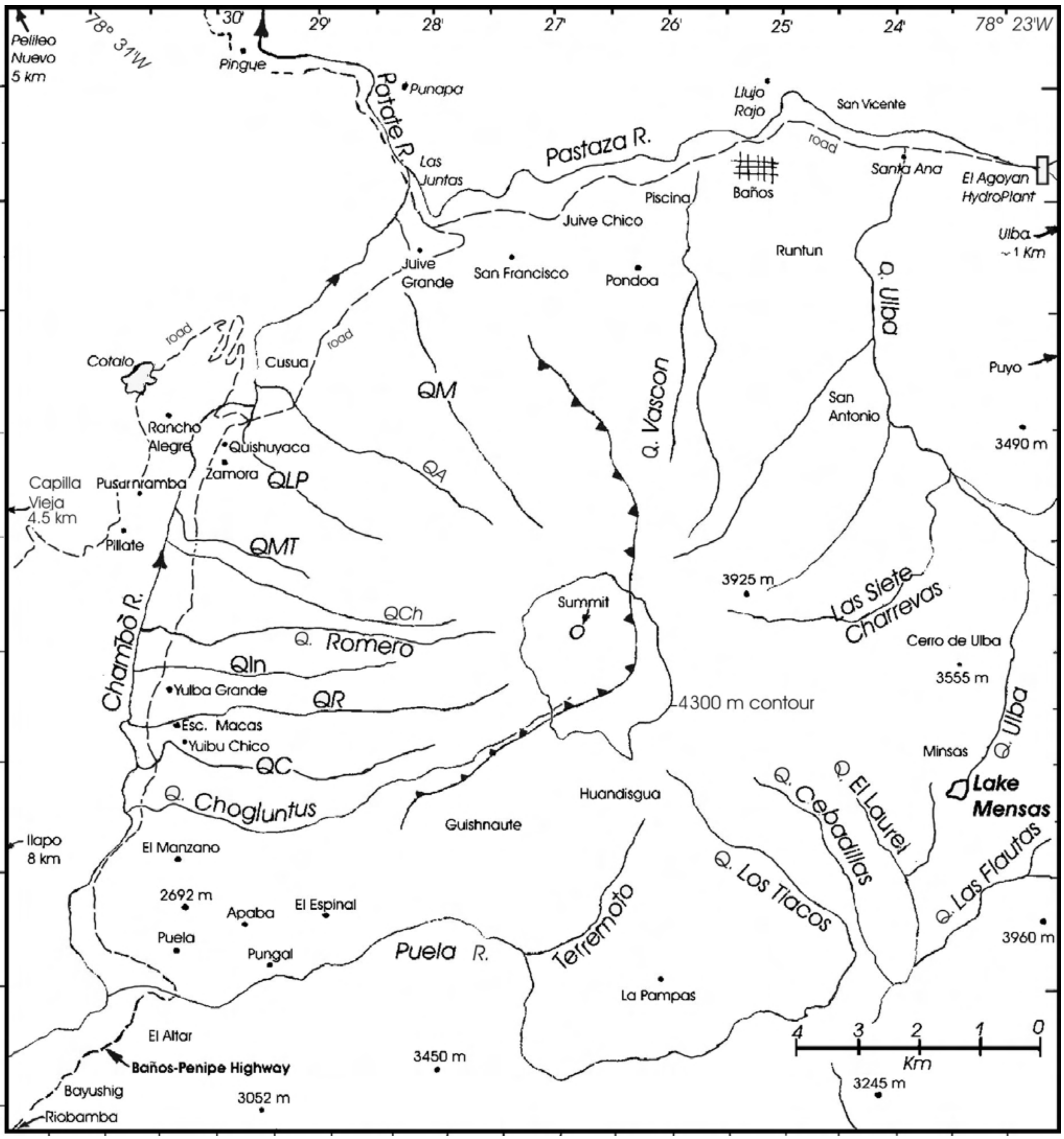

Figure 3. A map of Tungurahua emphasizing local roads, settlements, and drainages (*quebradas* in Spanish). Some of the latter are abbreviated as follows (counterclockwise from N): QA = Quebrada Achupashal, QC = Quebrada Confesionario, QM = Quebrada Mandur, QMT = Quebrada Motilones, QLP = Quebrada La Piramide, QPU = Quebrada Palma Urcu, QR = Quebrada Rea. The map is a composite of various published maps, particularly those by Hall and others in a previously referenced publication. The one contour shown, at 4,300 m elevation on the upper flanks, was the approximate limit of glacial ice when the 1:25,000 Tungurahua topographic map sheet was made for the Instituto Geográfico Militar in 1984. At the time of this report Pete Hall noted that remaining glacial ice was only apparent in restricted regions near the summit crater.

5-19 moderate explosions and 62-83 long-period earthquakes each day. A signal from a lahar was recorded in the Cusúa sector NW of the volcano during the afternoon of 18 December. According to the Washington VAAC, during late 2003-early 2004, plumes from Tungurahua were visible on satellite imagery to a maximum altitude of ~ 7.5 km.

During 24-30 December the volcano emitted gas, and ash accompanied by low seismicity. On 28 December an emission sent a plume to 1.5 km above the summit, drifting E and NE. Ash fell in the Runtún sector E of the volcano. Emissions on 28 December deposited ash in Runtún and the city of Baños. On 30 December aircraft personnel reported seeing an ash cloud ~ 800 m above the volcano. According to the Washington VAAC, ash was visible on satellite imagery to a maximum altitude of ~ 8 km.

Emissions of gas, and ash, with low-level seismicity (12-14 long-period earthquakes per day), continued over the period 31 December to 5 January. Plumes rose to a maximum height of 3 km above the crater on 31 December and an emission on 4 January caused minor ash fall in the Puela sector (SW). Similar conditions applied in the week 7-13 January. On 8 January, emissions reached ~ 1 km above the volcano, traveling W and SW, and emissions on 12 January deposited ash in the Bilbao, Cusúa, Pillate, Ulba, Pondoa, Baños, Juive, Ambato, and Patate sectors (figure 3 and table 1). Gas, and ash emissions continued over 14-19 January, with emissions to ~ 1 km above the crater containing variable amounts of ash drifting to the N and NE, accompanied by low seismicity. Similar conditions applied over the week 21-26 January. On 22 January at 0626 an explosion sent a plume to ~ 2 km above Tungurahua. On the evening of 24 January ash fell in the areas of Puela and Penipe (~ 8 km SW); and during 24-25 January ash fell in Riobamba (~ 30 km SW). Patricia Mothes of Ecuador's Geophysical Institute reported on 30 January that the volcano was very quiet with no explosions since the previous Saturday, and that a country-wide drought caused extensive fires.

Bulletin editors have compiled a sketch map focused on Tungurahua's geography and a table showing other commonly used place names mentioned in this and previous reports (figure 3 and table 1). Tungurahua, and adjacent Holocene volcanoes El Alfair and Sangay, all lie to the S within Sangay National Park. On maps, roads are absent from Tungurahua's S and E flanks but pass around the W and N flanks. With regard to glacial ice, figure 3 shows the extent of ice depicted in 1984. Regarding the extent of glacial ice at the present time, Pete Hall noted that ice had been retreating from all summits in Ecuador (as in many other places, presumably due to global warming of the atmosphere). In discussing Tungurahua's alpine glacier, Hall made this comment: "The ice cap that was only on the tip top summit of the cone prior to [Tungurahua] entering into activity is still there, but buried under meters of black ash. We can still spot it when explosions in the crater eat away at it from the crater side. Occasionally we see ice on the outer flank, but only at the summit. Thus the ice cap is exceedingly small . . . ~ 300 m in diameter . . .."

Figure 4 shows the vulnerable N-flank town of Baños. It is the largest settlement in close proximity to Tungurahua. A host of gravity-driven processes could bury portions of the town in minutes.

Background. Tungurahua, a steep-sided stratovolcano that towers more than 3 km above its northern base, is one of Ecuador's most active volcanoes. Three major volcanic edifices have been sequentially constructed since the mid-Pleistocene over a basement of metamorphic rocks. Tungurahua II was built within the past 14,000 years following the collapse of the initial edifice. Tungurahua II itself collapsed about 3,000 years ago and produced a large debris-avalanche deposit and a horseshoe-shaped caldera open to the west, inside which the modern glacier-capped stratovolcano (Tungurahua III) was constructed. Historical eruptions have been restricted to the summit crater. They have been accompanied by strong explosions and sometimes by pyroclastic flows and lava flows that reached populated areas at the volcano's base. Prior to a long-term eruption beginning in 1995 that caused the temporary evac-

Figure 4. Oblique view looking at the town of Baños, 8 km N of Tungurahua's summit on the Pastaza River, June 2003. Copyrighted photo used with permission of Tim Travis.

Town or Location	Distance & Direction	Town or Location	Distance & Direction
Ambato	31 km NW	Pelileo	8 km N
Baños	8 km N	Penipe	~15 km SW
Bilbao	8 km W	Pillate	8 km W
Cevallos	23 km NW	Puela	8 km SW
Cotalo	8 km NW	Puyo	50 km E
Cusúa	8 km NW	Quero	22 km NW
Guaranda	64 km SW	Riobamba	30 km S
Juive	7 km NNW	Rio Negro	26 km ENE
Latacungo	63 km NNW	Runtun	6 km NNE
Matus	11 km SSW	San Juan	40 km WSW
Macas	100 km SSE	San Juan de Pillate	9 km W
Mocha/Yanayacu	25 km W	Santa Fe de Galan	15 km WSW
Overo	20 km WNW	Valle del Patate	15 km NW

Table 1. A list showing settlements and their approximate distances and bearing from Tungurahua's summit. Many of these have been referred to in previous *Bulletin* reports with their locations undisclosed. Information sources included various maps, previously cited references, and Patricia Mothes of the Geophysical Institute.

uation of the city of Baños at the N foot of the volcano, the last major eruption had occurred from 1916 to 1918, although minor activity continued until 1925.

Information Contact: *Geophysical Institute* (IG), Escuela Politécnica Nacional, Apartado 17-01-2759, Quito, Ecuador (URL: http://www.igepn.edu.ec/); *Washington Volcanic Ash Advisory Center (VAAC)*, Satellite Analysis Branch (SAB), NOAA/NESDIS E/SP23, NOAA Science Center Room 401, 5200 Auth Rd., Camp Springs, MD 20746 USA (URL: http://www.ssd.noaa.gov/); *Tim Travis*, 973 Sleepy Hollow Ct., Greenwood, IN 46142, USA (Email: website@downtheroad.org; URL: http://www.downtheroad.org/).

Kavachi

Solomon Islands
9.02°S, 157.95°E; summit elev. -60 to +15 m

This report covers activity at Kavachi submarine volcano since the eruptions in August to mid-September 2001 and on 27 November 2001 (*Bulletin* v. 26, no. 11). It includes information from Corey Howell of *The Wilderness Lodge* on the island of Gatokae (Nggatokae), ~ 35 km NE of Kavachi, and a research cruise of the Commonwealth Scientific and Industrial Research Organization (CSIRO) (McConachy and others, 2002).

On his visit to the site of the volcano on 25 November 2001, Howell described a colored stain in the seawater. His photo of the setting portrays a calm sea surface without visible agitation and very little froth floating on the surface; the stain rose from depth. Elsewhere on his website he commented about trolling and catching fish within upwelled material on this date: "Trolling around the vent at Kavachi delivered the goods once again with 23 large rainbow runner, two Spaniards, [bara]cuda, and bigeye trevally-112 kilos [kg] of fish, which fed the entire village. We dropped two very large Spaniards, both taking the lure right in the middle of the vent upwelling, and saw countless sharks, runner, trevally, and yellowfin."

Howell noted that explosive eruptions occurred daily during 27 November-13 December 2001. Strong monsoon winds prevented visits then. In discussing regional weather patterns he noted that the prevailing monsoon westerly winds common at Kavachi from December to March reach 15-18 knots, increasing to 25-30 knots during torrential rain squalls. Conditions become choppy with seas 1-2 m with an underlying 2-3 m SW groundswell. Seas such as these could influence erosion at Kavachi.

Howell visited Kavachi again on 14 and 28 January 2002, and he passed some 15 km from Kavachi on 17 January 2002. In his summary of those observations and visits, written on 30 January 2002, Howell noted that he had measured the summit's current depth at 60 m. He saw a continuous stream of sulfur, small fragments of volcanic rock, and gases escape, resulting in a vigorous dirty-yellow to light-brown upwelling at the surface. Columns of bubbles rose to the surface and slicks of sulfur prevailed down-current, forming an extensive plume of discolored water several kilometers in length. Occasional explosive eruptions produced columns composed of and occasionally ash, rock, and water, rising to a height of ~ 1 km and visible for at least 40 km.

He went on to say that the vent had emitted a range of loud sonic cracks and booms at intervals of 2-15 minutes. These sounds were loud and clear to witnesses standing in the boat but were heard best in the water, leading to "a sensation that can only be described as being shot point-blank with a high-powered rifle *sans* pain." Below 10 m water depth divers heard a continual barrage of different sounds coming from the vent. Several powerful earthquakes were felt on nearby Gatokae Island during this observation period (November 2001-January 2002); however, the large regional earthquake that struck Port Vila, Vanuatu, was not felt on the island. When Howell visited Kavachi on 14 January he noted a slick of unidentified materials coming from the vent column. On 28 January he saw extensive trails of yellow sulfur extending down current.

CSIRO conducted two echo-sounding bathymetric surveys of Kavachi a bit over 22 months apart, enabling morphologic comparisons. The earlier survey took place on 14 May 2000 (research cruise FR04/00, Project SHAARC; McInnes and others, 2000) (see *Bulletin* v. 25, no. 4). The later survey occurred on 28 March 2002 (research cruise FR03/2002, Project SOLAVENTS 2002; McConachy and others, 2002).

Comparing the 2000 to the 2002 bathymetry (figure 5 (top and bottom)) showed that Kavachi had changed, in places significantly. In 2002 the summit had dropped to clearly well below sea level, compared with 3 m below in 2000. Some lower parts of the volcano appeared to be at lesser depths, perhaps due to mass wasting carrying material downslope and depositing it there. The CSIRO 2002 cruise kept some distance from the summit area, and the shallowest point surveyed was just E of the summit at 85 m depth. Neither of the cruises crossed over the apex of the Kavachi summit.

During the CSIRO 2002 cruise an unusual rise in the surface seawater temperature was recorded NW of the summit area and scum resembling oil slicks was noted on the surface in places. Methane analyses of water collected through hydrocasts (a technique where sample bottles are lowered by a cable) suggest hydrothermal sources on the flanks of Kavachi. A bottom grab sample taken at 95 m depth just E of the summit gave off a pungent hydrogen sulfide odor; the black volcanic sand recovered contained small specks (up to pea size) of yellow sulfur and traces of pyrite. A second grab sample, collected NW of the summit, contained gravel-size pieces of more altered, gray to cream colored rock as well as black volcanic sand and gravel. A third grab sample SW of the summit contained black volcanic sand and gravel, but no evidence of native sulfur or sulfide.

About a fortnight after their 28 March 2002 visit, the crew received an email from Howell (dated 18 April 2002), in which he noted that observers on the weather coast of Gatokae (the island's SW side, which faces toward Kavachi) reported eruptions each day that week except Monday. The eruptions usually occurred only once or twice in a 24-hour period.

Howell visited Kavachi again on 16 March 2002, finding the summit then at a depth of 34 m. He determined the summit's coordinates using a Garmin GPS (global positioning system) with a nominal accuracy of ~ 9 m. When this position was plotted on the map generated by the CSIRO 2002 cruise and contoured, Kavachi appeared quite conical in shape with a prominent SW ridge defined by the 350 m

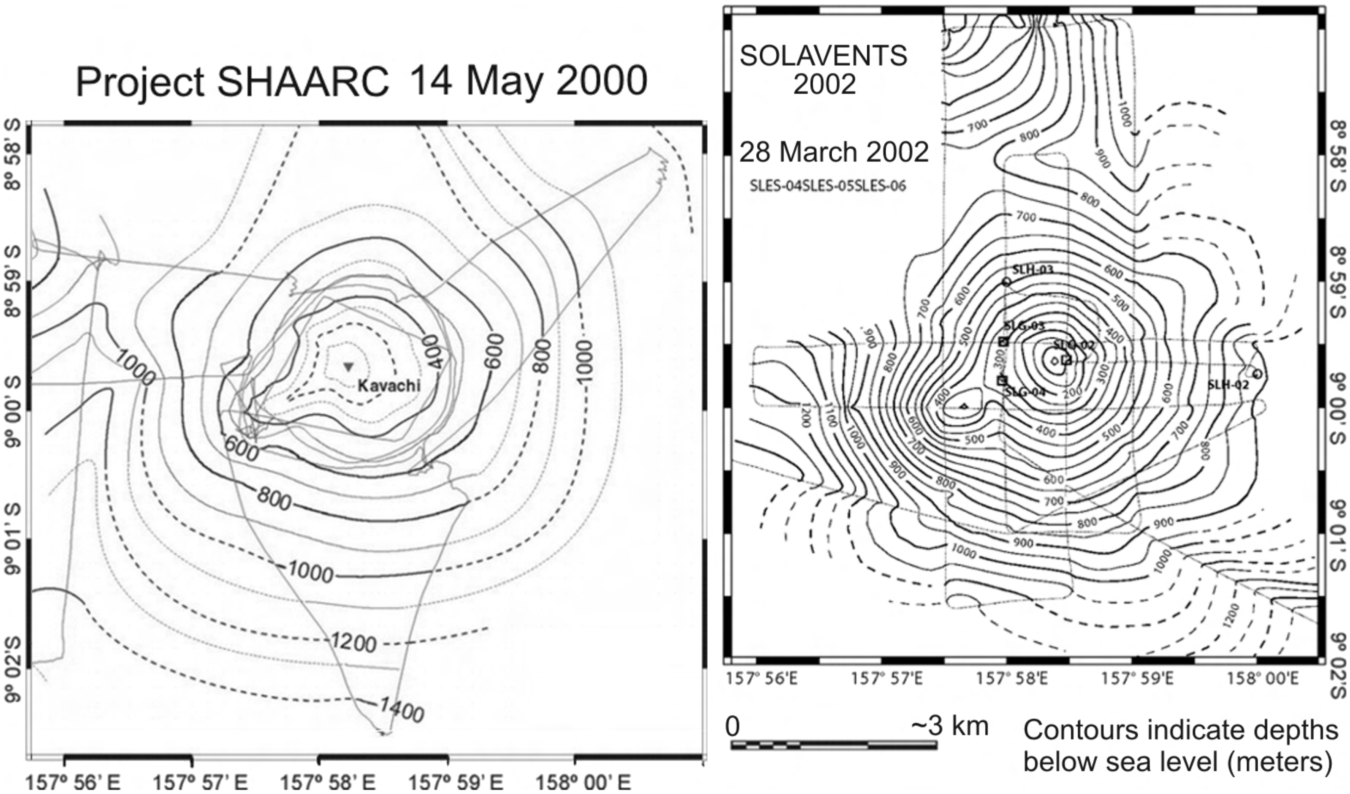

Figure 5. Bathymetric maps of Kavachi made by the CSIRO Project SHAARC cruise on 14 May 2000 (left) and the CSIRO Project SOLAVENTS cruise on 28 March 2002 (right). For both maps the fine lines represent ship's tracks during echo soundings. Contour intervals on the SHAARC map are 100 m, for the SOLAVENTS map, 50 m. The SOLAVENTS map shows locations of hydrocast samples (SLH) and bottom grab samples (SLG). Courtesy of Tim McConachy, CSIRO.

contour. Howell's work placed the new summit ~ 315 m E of its previous location (fixing it at 8°59.64'S, 157°58.409'E; whereas the 2000 SHAARC research cruise fixed it at 8°59.65'S, 157°58.23'E).

According to Howell, during October to November 2002 Kavachi ultimately rose to form an island 10-15 m above sea level. In accord with this emergence from the sea, Wright and others (in press) noted four alerts in the MODIS-MODVOLC satellite thermal detection system during November 2002. Howell stated that subsequently the island eroded in late-season SE seas and swells. When visited on 16 November 2003, Howell found the summit at ~ 32 m below sea level, a significant change from the island seen three months earlier.

Date	Summit depth (-), or elevation (+), relative to sea level	Source
14 May 2000	-2 to -5 m	CSIRO
28 Jan 2002	-60 m	Howell
16 Mar 2002	-34 m	Howell
28 Mar 2002	Well below sea level	CSIRO
Oct/Nov 2002	+10 m	Howell
~ Aug 2003	+15 m	Howell
16 Nov 2003	-32 m	Howell

Table 2. A compilation listing the stated elevations and depths of Kavachi's summit over a 3 ½-year period. Courtesy of Tim McConachy (CSIRO) and Corey Howell (The Wilderness Lodge).

In summary, table 2 shows discontinuous observations of elevation/depth of the summit of Kavachi over a period of about 3.5 years (2000-2003).

References: McConachy, T.F., Yeats, C.J., Arculus, R.J., Beattie, R., Belford, S., Holden, J., Kim, J., MacDonald, L., Schardt, C., Sestak, S., Stevens, B., and Tolia, D. (edited by C.J. Yeats), 2002, SOLAVENTS-2002, Solomons Australia Vents Expedition aboard the RV Franklin, 26 March-21 April 2002: CSIRO Exploration and Mining Report 1026F, Final Cruise Report FR03-2002, 456 p.

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McInnes, B.I.A., Arculus, R., Massoth, G., Baker, E., Chadwick, J., DeRonde, C., McConachy, T., Posai, P., and Qopoto, C., 2000, Project SHAARC, Investigation of submarine, hydrothermally active arc volcanoes in the Tabar-Lihir-Tanga-Feni Island and Solomon Island chains: CSIRO Exploration and Mining Open File Report 762F, 20 p.

Wright, R., Flynn, L.P., Garbeil, H., Harris, A.J.L., and Pilger, E., (in press), MODVOLC: near-real-time thermal monitoring of global volcanism, Journal of Volcanology and Geothermal Research, Elsevier (2004)

Background. Kavachi, one of the most active submarine volcanoes in the SW Pacific, occupies an isolated position in the Solomon Islands far from major aircraft and shipping lanes. Kavachi, sometimes referred to as Rejo te Kvachi ("Kavachi's Oven"), is located S of Vangunu island only about 30 km N of the site of subduction of the Indo-Australian plate beneath the Pacific plate. The shallow submarine basaltic-to-andesitic volcano has produced ephemeral islands up to 1 km long many times since its first recorded eruption during 1939. Residents of the nearby islands of Vanguna and Nggatokae (Gatokae) reported "fire on the water" prior to 1939, a possible reference to earlier submarine eruptions. The roughly conical volcano rises from water depths of 1.1-1.2 km on the N and greater depths to the S. Frequent shallow submarine and occasional subaerial eruptions produce phreatomagmatic explosions that eject ash, and incandescent bombs above the sea surface. On a number of occasions lava flows were observed on the surface of ephemeral islands.

Information Contacts: *Timothy F. McConachy*, CSIRO Division of Exploration and Mining, P.O. Box 136, North Ryde, NSW 1670, Australia (Email: Tim.McConachy@csiro.au); *Corey Howell*, The Wilderness Lodge, P.O. Box 206, Honiara, Solomon Islands (Email: thewildernesslodge@hotmail.com; URL: http://www.thewildernesslodge.org/).

Raung

Indonesia - Java
8.1258°S, 114.042°E; summit elev. 3,332 m

Raung volcano was last discussed in *Bulletin* v. 27, no. 7, when a pilot reported ash plumes to 4.6 km altitude in early June 2002. That issue of the *Bulletin* also noted a Volcanological Survey of Indonesia (VSI) comment that Raung had been erupting for at least a decade, with recent eruptions being events within a single, broader eruptive period.

The Darwin Volcanic Ash Advisory Center (VAAC) subsequently received reports that on 12 August 2002 ash was visible drifting NW of Raung around the summit level. The summit was partially obscured by clouds and no ash was identified on satellite imagery. On 25 August 2002, based on pilot observations and satellite imagery, the VAAC reported a visible ash plume rising to about 9.2 km, drifting to the W at high levels and to the E at lower levels.

The Darwin VAAC has an archive of their reports available on their website. Those for Raung are summarized in table 3. The last set of reports (25 August 2002) discussed a plume becoming increasingly diffuse over a 16.5-hour interval.

Date	Text from Volcanic Ash Advisory
30 Jul 1999	INFORMATION SOURCE: AIREP reported plume height to FL 150 [~ 4.6 km altitude] and drifting to SW. ASH CLOUD: 30/1025UTC IR satellite imagery shows cloud in the area with possible extension to the SSW. Nature of this extension not discernable.
09 Jul 2000	INFORMATION SOURCE: AIREP QFA123. ERUPTION DETAILS: Ash cloud active with growing plume reported at 09/0920 UTC. Height unknown. ASH CLOUD: Visible satellite imagery at 09/0830 UTC shows Mt. Raung surrounded by scattered low-level clouds with a possible low-level ash plume extending 25 kilometres to the northwest. No evidence is visible on subsequent imagery
02 Jun 2002	INFORMATION SOURCE: AIREP QANTAS, GMS Satellite Imagery. ERUPTION DETAILS: Ash plume to FL150 [~ 4.6 km altitude] reported 02/0825Z, drifting south at 15 knots. OBS ASH DATE/TIME: 02/0825Z. OBS ASH CLOUD: Ash cloud not identifiable from satellite data.
05 Jun 2002	INFORMATION SOURCE: Satellite Imagery. ERUPTION DETAILS: Possible ash cloud below FL150 [~ 4.6 km altitude] drifting south at 10/15 knots. OBS ASH DATE/TIME: 04/2240Z. OBS ASH CLOUD: Ash cloud identifiable from satellite data.
07 Jun 2002	INFORMATION SOURCE: Satellite Imagery. ERUPTION DETAILS: Possible ash cloud below FL150 [~ 4.6 km altitude] drifting SW at 10/15knots. OBS ASH DATE/TIME: 06/2334Z.OBS ASH CLOUD: Ash cloud identifiable from satellite data extending SW from Ruang 10NM either side of a line S0800 E11400 S0850 E11360.
12 Aug 2002	INFORMATION SOURCE: AIREP QFA29 via QANTAS OPERATIONS, GMS/NOAA satellite. ERUPTION DETAILS: Ash plume to FL120 [~ 3.7 km altitude] reported at 12/0920Z, drifting northwest. OBS ASH DATE/TIME: 12/0920Z. OBS ASH CLOUD: Ash cloud not identifiable from satellite data. Summit partially obscured by cloud.
25 Aug 2002	INFORMATION SOURCE: AIREP QFA29, NOAA16 SATELLITE. ERUPTION DETAILS: Ash plume to FL300 [~ 9.1 km altitude] reported 25/0734Z drifting west, low-level drift towards the east. OBS ASH DATE/TIME: 28/0611Z. OBS ASH CLOUD: S0807 E11402 S0812 E11342 S0807 E11335 S0800 E11347 S0807 E11402.
25 Aug 2002	INFORMATION SOURCE: AIREP QFA29, NOAA16 SATELLITE, GMS SATELLITE. ERUPTION DETAILS: Ash plume to FL300 [~ 9.1 km altitude] reported 25/0734Z drifting west,low-level drift towards the east. OBS ASH DATE/TIME: 25/1332Z OBS ASH CLOUD: FL100/350 [~ 10.7 km altitude] S0735 E11122 S0817 E11119 S0805 E11017 S0731 E11031 S0735 E11122.
25 Aug 2002	ERUPTION DETAILS: Ash plume to FL300 [~ 9.1 km altitude] reported 25/0734Z drifting west, low-level drift towards the east. OBS ASH DATE/TIME: 25/1932Z OBS ASH CLOUD: FL100/350 [~ 10.7 km altitude] S0700 E11000 S0800 E11000 S0800 E10630 S0700E10630 S0700 E11000. Ash cloud getting more diffuse and difficult todefine with satellite imagery.
25 Aug 2002	INFORMATION SOURCE: AIREP QFA29. NOAA/GMS SATELLITE. ERUPTION DETAILS: Ash plume to FL300 [~ 9.1 km altitude] reported 25/0734Z drifting west, low-level drift towards the east. OBS ASH DATE/TIME: 26/0132Z OBS ASH CLOUD: Ash cloud not visible on satellite imagery.

Table 3. Dates and principal comments in Darwin VAAC reports concerning Raung, July 1999-February 2004. Dates and times are not local but instead refer to the Prime Meridian, for example 04/2240Z means the fourth day of the stated month at 2240 UMT. Similar or duplicate message are not shown. In general, ash cloud trajectory information has been omitted. In a few cases the VAAC delineated bounding area surrounding an observed ash cloud ("OBS ASH CLOUD"), delineated with a series of latitude and longitude coordinates (eg. S00700, E11000; which translates to 7 degrees S, 110 degrees E). In the original reports, altitudes were given in shorthand (eg. FL 100, which corresponds to 10,000 feet altitude; 3,048.0 m altitude, but typically not known to better than two significant figures and thus here rounded to ~ 3.0 km altitude). Courtesy of the Darwin VAAC.

Background. Raung, one of Java's most active volcanoes, is a massive stratovolcano in easternmost Java that was constructed SW of the rim of Ijen caldera. The 3332-m-high, unvegetated summit of Gunung Raung is truncated by a dramatic steep-walled, 2-km-wide caldera that has been the site of frequent historical eruptions. A prehistoric collapse of Gunung Gadung on the west flank produced a large debris avalanche that traveled 79 km from the volcano, reaching nearly to the Indian Ocean. Raung contains several centers constructed along a NE-SW line, with Gunung Suket and Gunung Gadung stratovolcanoes being located to the NE and W, respectively.

Information Contacts: *Darwin Volcanic Ash Advisory Center (VAAC)*, Bureau of Meteorology, Northern Territory Regional Office, PO Box 40050, Casuarina, NT 0811, Australia (URL: http://www.bom.gov.au/info/vaac/; Email: darwin.vaac@bom.gov.au); *Nia Haerani*, Volcanological Survey of Indonesia (VSI), Jalan Diponegoro No. 57, Bandung 40122, Indonesia (Email: haerani@vsi.dpe.go.id; URL: http://www.vsi.dpe.go.id/).

Aso

central Kyushu, Japan
32.881°N, 131.106°E; summit elev. 1,592 m

Japan Meteorological Agency (JMA) reports for July 2003 noted ash-bearing eruptions from Aso (*Bulletin* v. 28, no. 10). The 10 or 11 July 2003 eruption was followed by seismically inferred phreatic eruptions a few days later, and a mud eruption on 14 January (the end of this report interval).

Seismic signals during 12-14 July implied there had been about five small phreatic eruptions. Continuous volcanic tremor started at ~ 1400 on 27 July. The JMA report of 28 July 2003 noted that seismometers had recorded ~ 100 isolated tremors. Earthquakes also occurred, at a rate of ~ 10 per day. On 28 July, lake water in Crater 1 was gray colored with a temperature of 76°C and with boiling regions in its central area.

A later JMA report noted a mud eruption in Crater 1 at 1541on 14 January, the first such eruption since July 2003. Associated tremor also occurred. Small amounts of very fine ash from this eruption were seen in Takamori, a town ~ 10 km ESE of the crater. The report noted that thermal activity had risen since last year, causing the water level in the crater to decrease about 40% below normal. The hazard status rose from 2 to 3, and accordingly, authorities restricted tourists from the area within 1 km of the crater.

Background. The 24-km-wide Aso caldera was formed during four major explosive eruptions from 300,000 to 80,000 years ago. These produced voluminous pyroclastic flows that covered much of Kyushu. A group of 17 central cones was constructed in the middle of the caldera, one of which, Naka-dake, is one of Japan's most active volcanoes. It was the location of Japan's first documented historical eruption in 553 AD. The Naka-dake complex has remained active throughout the Holocene. Several other cones have been active during the Holocene, including the Kometsuka scoria cone as recently as about 210 AD. Historical eruptions have largely consisted of basaltic to basaltic-andesite ash emission with periodic strombolian and phreatomagmatic activity. The summit crater of Naka-dake is accessible by toll road and cable car, and is one of Kyushu's most popular tourist destinations.

Information Contacts: *Volcanological Division*, Japan Meteorological Agency (JMA), 1-3-4 Ote-machi, Chiyoda-ku, Tokyo 100, Japan (URL: http://www.kishou.go.jp/english/); *Fukuoka District Meteorological Observatory*, Japan Meteorological Agency (JMA), 1-2-36 Oohori, Chuo-ku, Fukuoka 810-0052, Japan (Email: yamasato@met.kishou.go.jp, n-uchida@met.kishou.go.jp).

Etna

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

Although Etna's 2002-3 eruption was previously discussed in *Bulletin* v. 27, nos. 10-12; v. 28, no. 1, Boris Behncke subsequently posted a report to his website highlighting some further observations and interpretations. His report presented many photos, including two taken by astronauts aboard the International Space Station (figures 6 and 7). His report drew on published or soon-to-be published material (Acocella and others, 2003; Behncke and Neri, 2003; Branca and others, 2003; and Dellino and Kyriakopoulos, 2003). Extracts from Behncke's summary follow.

Behncke puts the eruption's start date a few hours earlier than previously reported, enough to shift the start date from early 27 October to late on 26 October. While mountain guides who visited the craters on Saturday 26 October noted nothing unusual, an intense earthquake swarm at shallow depth within the volcano began at about 2125 that day. Tremors woke hikers at the Hotel "Le Betulle" at Piano Provenzana, a spot at ~ 1800 m elevation on the NE flank; they abandoned the seriously damaged building. At dawn on 27 October those who still remained at Piano Provenzana noted large E-W trending fractures cutting across the paved parking lot of the tourist complex. According to Behncke, the first eruptive vents to become active during this eruption opened at 2345 h on 26 October, on the upper southern flank, and immediately began to produce intense explosive activity.

Italy ended daylight saving time at 0100 UTC on Sunday 27 October (0200 local time). The change moved the clock back one hour, from 0200 to 0100 local time. Few if any important events were noted during the 60-minute interval of the time change. Later, however, at approximately 0230 h on 27 October a few persons watching the summit of Etna noted the sudden onset of high lava fountaining from the northern base of the Northeast Crater. The fountaining lasted only a few minutes.

Etna's 2002-2003 eruptions have been described as unusual, differing in four key respects. First, this was one of the most explosive eruptions in recent times. Pyroclastic material comprised more than half of the total volume of erupted products, contrasting with Etna's most recent eruptions, which mainly extruded lava.

Second, the 2002-2003 eruption discharged two different types of magma. The fissures on the NE rift produced magma of the sort normally produced by Etna over the past few centuries, while the vents on the S flank produced a magma rich in amphibole, a water-bearing mineral relatively rare in Etna's recent products. Amphibole also clearly appeared in the 2001 lavas (*Bulletin* v. 26, no. 10), and in products erupted in 1892 at Monti Silvestri, and 1763 at Montagnola. All of these vented on the S flank.

Third, some scientists have correlated large-scale flank slip and magma uprise. Specifically, on 22 September, the E flank of the volcano began to slip toward the Ionian Sea, with movement occurring mainly on the Pernicana fault system (Neri et al., 2003). This displacement is thought to have allowed magma to migrate from the central conduit system into the NE Rift, although a second, larger flank slip event was necessary to permit magma uprise to the surface. This occurred not only on the NE rift, but also on the S flank, where magma came from the eccentric reservoir previously active in 2001. Thus, the eruption can be interpreted as having been triggered by the flank slip, in contrast with the 2001 eruption, which was preceded by the forceful uprise of a dike from the eccentric reservoir, and possibly was triggered by regional tectonic compression (Acocella et al., 2003). One of the most important discoveries during the events of late 2002 and early 2003 was that the Pernicana fault system is not only 9 km long, as previously believed, but extends from the NE rift down to the Ionian Sea, and possibly continues offshore, over a distance of at least 18 km (Neri and others, 2003).

Fourth, N flank lava flows invaded a tourist complex and adjacent forest for the first time in the historic record. An important landmark in this region is the northern Monte Nero, which sits ~ 6 km N of Etna's summit, includes a crater of the 1646 eruption, and is a local high at 2,049 m elevation. It is easily confused with S- and SE-flank features bearing identical or similar names. The northern Monte Nero lies ~ 2 km W of Piano Provenzana and the surrounding forest called Ragabo. These latter environs had not been invaded by

Figure 6. A photo of Etna during the 2002-2003 eruption looking SE and downward from ~ 400 km altitude on 30 October 2002 from the International Space Station (ISS-5). A large dark tephra column appears in the top center, rising from the upper S flank and then blowing toward the left (E). A much smaller gray-white plume rose just in front of the tephra column; it discharged from the summit craters. Appearing in the central foreground are two distinct white plumes that issued from along the NE Rift, and some lower, dispersed, low-density plumes. Smaller, lower plumes towards the photo's lower-left center came from forest fires. On the ground surface, the youngest lava flows appear darkest; some pyroclastic cones on the outer flanks are also visible. Future studies may disclose whether the brown-colored region beneath the tephra column in the upper-left quadrant of the photo was due to factors such as diffuse clouds, camera angle, and lighting geometry, or due to falling tephra descending from the plume. (Image ISS005-E-19024.) Courtesy of Earth Sciences and Image Analysis, NASA-Johnson Space Center (on their website see "Earth Sciences and Image Analysis Photographic Highlights").

Figure 7. A broader view of Etna's 30 October ash plume taken looking SE and downward from the International Space Station at ~ 400 km altitude, showing large portions of Sicily in the middle to foreground. According to the NASA Earth Sciences and Image Analysis team, the plume followed a curved path from Etna, first blowing SE, and then blowing S towards Africa at higher altitudes. They also noted that ashfall was reported in Libya, more than 560 km distance from Etna. Note the fainter, lighter-colored plumes from the NE Rift vents, which were also seen in the previous figure. (Image ISS005-E-19016.) Courtesy of Earth Sciences and Image Analysis, NASA-Johnson Space Center (on their website see "Earth Sciences and Image Analysis Photographic Highlights").

lava flows for many centuries. Eruptions on the NE Rift, which looms above the Provenzana plain, had occurred as recently as 1911, 1923, and 1947, but their lava flows had taken a more westerly course, leaving Piano Provenzana and the forest unharmed.

Tourist facilities were constructed at Piano Provenzana during the late 1960s to early 1970s. The associated ski area became popular among locals because, lying on the northern flank of the volcano, it received and preserved more snow than its southern-flank counterpart, and owing to wind patterns, it received fewer tephra falls. On Christmas 1985 an earthquake along the Pernicana fault (a few kilometers to the northeast of Piano Provenzana) destroyed the Hotel "Le Betulle," killing one person. That earthquake accompanied an eruption in the Valle del Bove, but the latter was very small and did no damage. Hotel "Le Betulle" was rebuilt to sustain higher seismic loads and it became the hub of Etna's N-flank tourism.

The 2002-3 eruption produced a number of small scoria cones along the fissure on the NE Rift and a cluster of huge cones at the vents on the S flank. The latter have completely changed the topography of what was once known as the "Piano del Lago" ("Plain of the Lake", indicated as "PDF" on the map in *Bulletin* v. 26, no. 10). Until 27 October 2002 this area bore the scars of the 2001 eruption, most of it being covered with virtually inaccessible lava flows and various pyroclastic cones. In early November 2002 the formerly rugged surface was transformed into a rolling plain of ash, which facilitated excursions on foot. The area was subsequently covered by rugged new lava flows. Etna's old abandoned cable car station (partially destroyed by an eruption in 1983) was buried by the lowermost of the new cones. A new souvenir shop and bar erected by mountain guides early in 2002 at 2,760 m elevation vanished under the cover of pyroclastics, although the Torre del Filosofo mountain hut at 2,900 m elevation is still standing. In the past, the Piano del Lago offered a splendid panorama of the summit cone complex, but this view became largely concealed by the new cones along the fissure at 2,700 m elevation. The largest of these cones, formed at a spot that was 2,750 m in elevation prior to the eruption, now stands about 200 m higher, and a second cone slightly up slope is nearly as tall. The sheer size of these new cones dwarfs that of Monte Josemaria Escrivà, which formed in 2001 and had been a prominent feature.

Behncke and Neri (2002) presented initial estimates for the volume of products emitted during the 2002 eruption. They indicated ~ 30 million cubic meters of lava, nearly two-thirds of which was emitted on the S flank. They also indicated that 40 million cubic meters of pyroclastics, were nearly exclusively emitted from the S-flank vents. In terms of magma volume, this is not an enormous eruption for Etna, but it ranks among the more significant of recent decades.

Outlook and interpretations. The 2002-2003 eruption came 1.27 years after the beginning of the 2001 eruption. Between 1971 and 1993 flank eruptions occurred at a mean interval of 1.7 years (Behncke and Neri, 2003). Etna's historical eruptive behavior has undergone significant fluctuations during the 400 years of reasonably complete documentation. It seems that flank eruptions tend to occur in series, and the 2001 eruption could be interpreted as the first in a new eruptive series, analogous to the sequence of 13 flank eruptions witnessed between 1971 and 1993. According to this interpretation, more such eruptions will occur at relatively brief intervals over a period of 10-20 years. By this model, the 2002-2003 eruption was the second in the new series, implying a third in the not too distant future.

The volcano was extensively fractured during both eruptions, which may allow magma to rise much more easily under the flanks of the edifice, and has grown progressively more active during the past 50 years. It is erupting more frequently and more vigorously than during the 280 years before 1950, and its productivity, or output, is increasing. Flank eruptions must thus be expected to occur at intervals ranging from 1 to 3 years, and some of them might be much more voluminous and potentially hazardous than the latest two eruptions.

The 2002-2003 eruption was one of the most explosive flank eruptions in the past 150 years, and it shows that Etna is a potentially explosive volcano, as it has been historically. Nearly all of the flank eruptions of the past 100 years have been relatively benign with mostly lava emissions; thus the local population has been lured into the belief that Etna is a "good volcano." But a short look at the record of its historically documented eruptions shows that the rather effusive, non-explosive behavior of the 20th century was, in fact, unusual.

Part of the explosivity of the 2002-2003 eruption might be due to the water-rich nature of the magma rising from a reservoir located below the S flank. This magma was comparatively gas rich, in contrast to the magma erupted from the central conduit system (and on the NE flank), which had degassed to some degree during the months before the eruption. The fact that this magma has appeared for the second consecutive time might be taken as an indicator that future eruptions will be fed from the same reservoir and therefore could be as explosive. However, an additional factor controlling the explosivity of an eruption is the interaction of magma with external water, such as a shallow aquifer. This was the case during the 2001 eruption (at Monte Josemaria Escrivà), and it was probably again the case at the new cones at 2750 and 2800 m elevation on the S flank. In fact, ash from the first day of the 2002-2003 eruption that arrived on the Greek island of Cefalonia during the following 24 hours was determined to be of phreatomagmatic origin (Dellino and Kyriakopoulos, 2003)

Eruptive activity at Etna quieted on 28 January, but in terms of seismicity, the volcano remained restless. Some of the continuing seismic activity was due perhaps to the adjustment of the edifice to the major displacements at the beginning of the eruption, or it may have started to recharge for its next eruption. Seismicity dropped to relatively low levels in the spring of 2003, but since mid-June 2003 was again slightly elevated.

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

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