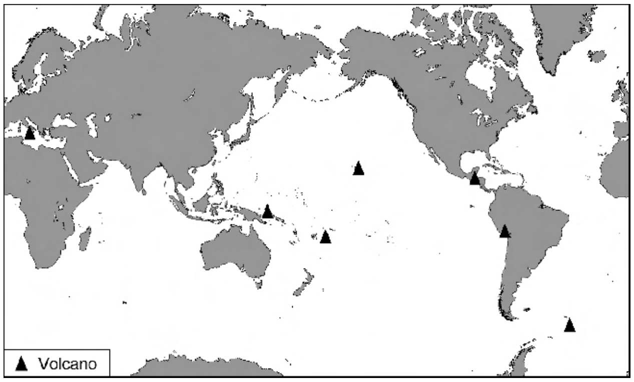
Bulletin of the Global Volcanism Network



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Etna

Italy
37.734°N, 15.004°E; summit elev. 3,350 m
All times are local (= UTC + 1 hours)

The following Etna report from Sonia Calvari and Boris Behncke is based on daily observations by numerous staff members of the Istituto Nazionale di Geofisica e Vulcanologia (INGV). As previously reported here (*BGVN* 31:08), a 10-day-long eruption vented from the base of the Southeast Crater (SEC) in mid-July 2006. Eruptive activity then shifted to the crater's summit vent during 31 August-15 September, leading to lava overflows and repeated collapse on the SEC cone (*BGVN* 31:08).

This report discusses the time period 22 September to 4 November, an interval with multiple episodes of eruptive activity (roughly eight in all, seven of which involved a return of activity at the SEC summit). The activity typically included lava flows and Strombolian eruptions. In general, the eruptive episodes became increasingly brief and vigorous. Eruptions came from the SEC's summit as well as from multiple vents along fractures on the SEC's sides or adjacent to it that developed during the reporting interval.

As mentioned above, in general, during the reporting interval, the renowned SEC summit area was only episodically active. Since the SEC's collapse of September 2006, it has had a breached E wall. During this reporting interval, lava flows escaped the crater through the breach to form narrow rivulets down the steep upper SE flank. Ash from SEC fell on Catania on 30 October.

On 12 October a fissure opened at ~ 2,800-m elevation on the ESE base of the SEC cone, ~ 1 km from SEC's summit. Lava from this vent traveled SE, and a map showing the vents and pattern of flows through 20 November indicated lava extending ~ 2 km from the 2,800-m vent (Behncke and Neri, 2006). The 2,800-m vent also sits along the path of some of the SEC lavas from the summit crater. By late November, a complex flow field from both SEC summit and the 2,800-m vents lay on the SE side of the SEC. The field extended from the summit ~ 3 km, and its distal ends reached the W wall of the Valle del Bove.

Two other important vents began erupting in late October. One was on the SEC's upper S flank. The other, at 3,050 m elevation, stood ~ 1 km SW of the SEC's crater and at a spot ~ 0.5 km from the nearest margin of Bocca Nuova's crater. Although lava emissions from this vent at 3050-m elevation stopped, they later restarted and by 20 November the vent had created a large SW-trending field of lava flows roughly the size of those from the SEC summit and 2800-m vent.

Eruptive behavior 22 September-4 November. During this time interval, the seven episodes determined by eruptive activity at the SEC occurred as follows.

The first episode, which was five days long, started late 22 September from the summit of the SEC. Activity during the first two days was limited to mild Strombolian explosions, but lava began to overflow the SEC's crater on 24 September, spilling onto the cone's SE flank. This activity ceased sometime on 27 September.

The 2nd episode began late the afternoon of 3 October with Strombolian explosions from the SEC summit, which increased in vigor during the following hours. Late that evening lava began to spill down the SE side of the SEC cone adjacent to flows of the previous two episodes. Following a sharp decline in tremor amplitude on the afternoon of 5 October, the activity ended sometime between midnight and the early morning of 6 October.

The 3rd eruptive episode occurred between the evening of 10 October and the evening of the following day. The SEC's summit produced vigorous Strombolian activity and lava again descended the SEC cone's SE flank. A sharp drop in tremor amplitude on the afternoon of 11 October indicated the eruptions imminent cessation.

At the tail end of the 3rd episode, a short eruptive fissure opened with vents at ~ 2,800-m elevation. Monitoring cameras fixed the start of this activity at 2328 on 12 October. The SEC's summit was quiet throughout the following eight days, leaving this burst to be considered as activity late in the 3rd episode, rather than representing the start of the 4th episode in the SEC's sporadic on-and-off behavior.

Trending N90°E-N100°E, the new fissure resided on the ESE flank at the base of SEC, a spot also on the Valle del Bove's W wall. For the first few days, lava was emitted non-explosively, quietly spreading in the upper Valle del Bove and advancing a few hundred meters downslope. Mild spattering on 17 October resulted in the growth of three hornitos on the upper end of the eruptive fissure.

Summit SEC activity marked the 4th episode since 22 September. As lava effusion continued from the fissure vents at 2,800 m elevation, the SEC started a powerful eruption at 0600 on 20 October. Accompanied by a rapid increase in tremor amplitude, vigorous Strombolian eruptions occurred in the central portion of the SEC's summit. A vent near the E rim of the SEC's crater, in the notch created by the collapse events of early September, produced large explosions every few minutes and quickly built a new pyroclastic cone. Lava once more flowed down the SEC's SE side, stopping N of the 2,800-m fissure. At that fissure vent, lava emission continued but appeared reduced compared to the previous days. The SEC ceased issuing lava the same day it began, 20 October.

The 5th episode involving the SEC was preceded on 22 October with a few isolated bursts of ash from the SEC. The episode began with strong activity at 0700 the next day, when the SEC's summit generated vigorous Strombolian discharges and pulsating lava fountains from two vents. The new pyroclastic cone grew rapidly. Lava spilled down the ESE flank of the cone, to the N of the flows formed in the previous episodes.

Coincident with the above eruptions, INGV researchers noted an increased lava emission from the 2,800-m vents. This led to several lava overflows (in an area adjacent to the hornitos formed 17 October).

Although Strombolian activity and fountaining at the SEC diminished on the afternoon of 23 October, strong ash emissions began at around 1700, producing an ESE-drifting plume. Pulsating ash emissions and occasional bursts of glowing tephra continued and, at about 1750, the SEC cone's S flank fractured. Lava escaped from the fracture's lower end, forming two small lobes. The longer lobe reached the base of the cone and then traveled SE, ultimately to reach ~ 1 km from their source at the new fissure. The smaller lobe took a path down the cone slightly to the W, but halted before reaching the base of the cone. The new fissure's lava supply diminished early on 24 October, stopping around noon.

Coincident with the above events, effusive activity continued without significant variations at the 2,800-m vents. The farthest flow fronts reached an elevation of ~ 2,000 m to the NW of Monte Centenari, and extended ~ 2.5 km from their source.

Field observations made on 24 October revealed that part of the new pyroclastic cone had subsided and a new collapse pit, ~ 50 m wide, had opened on the SE flank of the SEC cone, roughly in the center of the largely obliterated collapse pit of 2004-2005.

The 6th episode of SEC activity began in the late afternoon on 25 October. Initially there was an increase in tremor amplitude, as well as both ash emissions and weak Strombolian activity from the SEC's summit. Both the tremor and Strombolian discharges decreased late that evening, but at 0054 on 26 November lava was emitted from a new fissure. This fissure, on the SEC cone's SSE flank, was active only for a few hours and produced a very small lava flow. As has often been the case during the reporting interval, the 2800-m vents continued to discharge lava toward the Valle del Bove.

What was to later become another important effusive vent opened at 0231 on 26 October. The vent developed at ~ 3,050 m elevation in an area ~ 700 m S of the center of Bocca Nuova's crater and ~ 500 m SW of the center of SEC's crater. This spot sits at the S base of the central summit cone below the Bocca Nuova, and ~ 700 m to the W of the fissure that had erupted 2 hours earlier.

Fieldwork carried out on 26 October by INGV researchers revealed that the vent at 3,050 m elevation had formed at the southern end of a fracture field. That field extended across the SE flank of Etna's central summit cone to the W flank of the SEC cone. Lava extruding at the 3050-m vent poured out at a decreasing rate before a pause began on the evening of 26 October.

The 7th episode, 27 October and into early November, was first associated with a new increase in tremor amplitude and corresponding SEC ash emissions on the afternoon of the 27th. These emissions were followed at 0206 on the 28th by the reactivation of the vent at 3050-m elevation. Ash emissions and Strombolian activity occurred from the SEC between 0830 and 1100, but no lava overflows were produced. On the evening of 28 October, both effusive vents at 3,050 and 2,800 m were active.

29 October ash emissions from the SEC became more vigorous during the early morning of the 30th and fine ash fell over inhabited areas to the S, including Catania (27 km from the SEC). Intermittent bursts of glowing tephra were recorded by INGV-CT surveillance cameras, although later analysis revealed that most of the tephra was lithic rather than juvenile. Ash emissions gradually diminished and ceased at around 0800 on 29 October.

Ash was again emitted from the SEC shortly before 1300 on 31 October, and in minor quantities at least once per day through 5 November. No incandescent ejections occurred from this crater after 28 October until the evening of 4 November (during 1830-2005) when weak Strombolian explosions were recorded by the INGV-CT surveillance cameras.

The vent at 3050-m elevation continued to emit lava on 29 October. The effusion rate was estimated as 1 to 5 m^3 per second. Emitted lava descended SW to ~ 2,400 m elevation.

Lava also continued to flow from the 2,800-m vents on the 29th, but the associated lava flow front advancing from these vents had moved little since 24 October. Lava continued to flow from both vents during the first days of November, but the effusion rate had clearly dropped by the 3rd when active flows had retreated upslope from the distal fronts. Similarly, a helicopter overflight on the morning of 5 November disclosed actively flowing lava confined to the uppermost parts of the lava flow fields.

Geologic Summary. 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 volcano, 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 E. 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.

References: Behncke, B., and Neri, M., 2006, Mappa delle colate laviche aggiornata al 20 Novembre 2006 (PDF file on the INGV website).

Information Contacts: *Sonia Calvari* and *Boris Behncke*, Istituto Nazionale di Geofisica e Vulcanologia (INGV), Sezione di Catania, Piazza Roma 2, 95123 Catania, Italy (URL: http://www.ct.ingv.it/).

San Miguel

El Salvador
13.434°N, 88.269°W; summit elev. 2,130 m
All times are local (= UTC - 6 hours)

According to El Salvador's Servicio Nacional de Estudios Territoriales (SNET) activity levels at San Miguel have generally remained similar to those during January 2002 when a minor plume rose above the summit crater (*BGVN* 27:02). The volcano's vigor continued into at least October 2006 at a level slightly at or above the base line of normal activity.

Recent publications have discussed the volcano and its lahar-hazard potential (Escobar, 2003; Chesner and others, 2003; Major and others, 2001). Figures 1 and 2 are taken from the latter publication.

In January 2005 observers saw new fumaroles as well as small landslides on the N and SW wall of the crater. The accumulation of mass-wasted material in the crater led to a rise in the elevation of the crater floor.

During February 2005, weak fumaroles and small rock landslides persisted in the central crater. Digital sensors in-

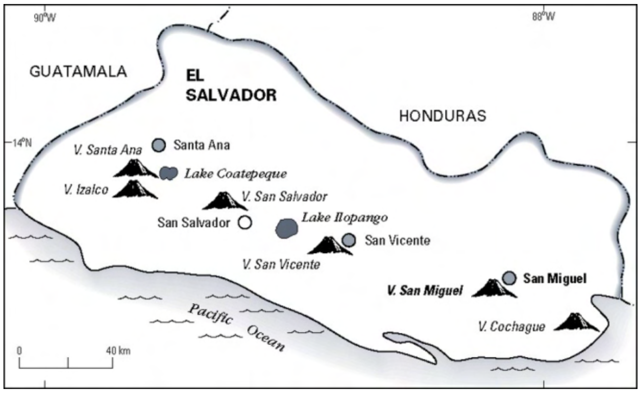

Figure 1. Index map indicating El Salvador's volcanic front and the location of volcan San Miguel. Major cities are also shown (circles). From Major and others (2001).

Figure 3. A photo of San Miguel taken from the N on 22 February 2005 showing the steep sides of the upper slopes and the incised drainages there. Although much of the area on the volcano is rural, hazards could easily affect 40,000 residents living nearby. Courtesy of Servicio Nacional de Estudios Territoriales (SNET).

stalled there recorded fumarolic temperatures in real time. On the outer portions of the cone the terrain is steeply sloping and contains prominent gullies (figure 3).

The SNET reports for March and April 2005 noted that the crater was structurally weak due to the fumarolic activity, ongoing rock alteration, occasional landslides, and fractures on the western plateau. Microseismicity had increased; but it did not exceed typical base-line levels. Workers at the Santa Isabel farm (finca) noted N-flank lahars after heavy rains during March. The N flank contains abundant fine-grained volcanic deposits of the sort easily swept away during times of heavy rain.

Intense rains during May 2005 were associated with tropical storm Adrian (over an unstated interval the meteorological station near the volcano, San Miguel UES, recorded 428 mm of rainfall). As a result of the deluge, fumarolic activity from the crater increased. The crater walls remained intact, but eroded material previously deposited in the central crater that was poorly consolidated had to some degree stabilized. Substantial further compaction, settling, or collapse in the central crater seemed to have ceased by July 2005. During August 2005 the crisis at volcan Santa Ana forestalled visits to San Miguel.

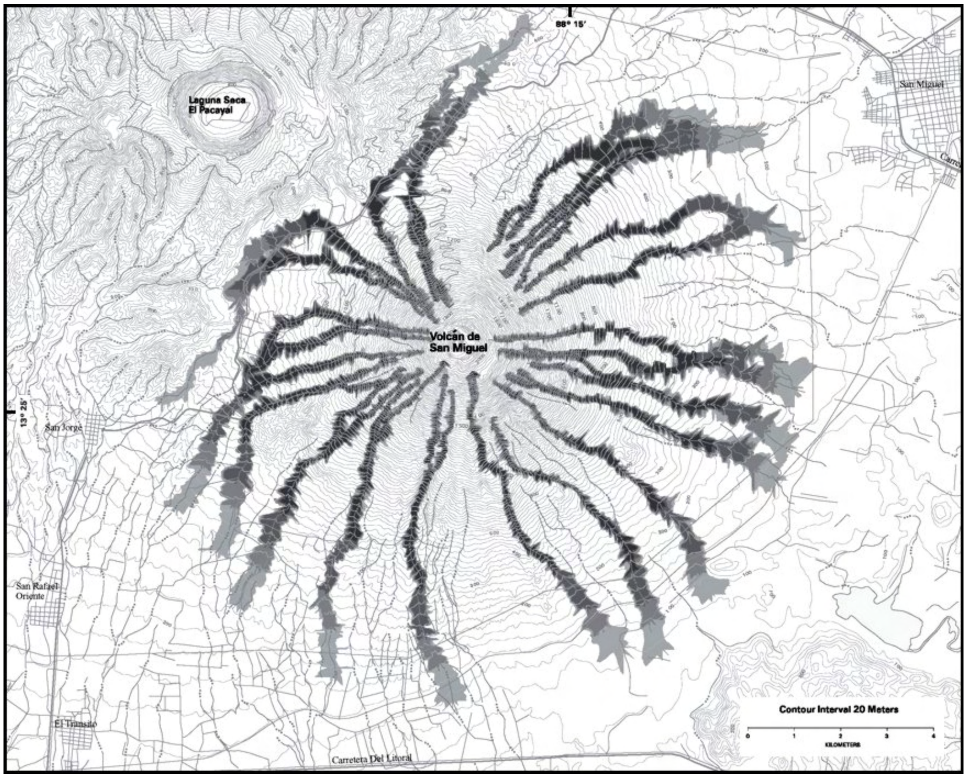

Figure 2. The lahar hazard map of San Miguel depicts likely lahar paths, which are shown as colored or shaded areas. The contour interval is 20 m; the urban center ~ 11 km NE of the summit is San Miguel. From Major and others (2001); their plate 1, cropped, highly reduced, and excluding the key.

A spike in seismic activity occurred during August 2005, with 7,048 long-period earthquakes, compared to July 2005, with 2,239 long-period earthquakes. SNET reports noted that based on monitoring, San Miguel generally remained within its base-line of normal behavior during the reporting interval. Figure 4 shows a histogram of long-period and volcano-tectonic events from the SNET reports for the interval September 2005-June 2006.

On 14 September 2005 a visiting group (OIKOS- Soliradaridad Internacional) made a trek to the summit and videotaped the scene there. SNET said the video disclosed a lack of significant changes in the crater; however, they saw debris-flow deposits in summit drainages on the volcano's outboard flanks. The visitors described both sounds of degassing and moderately intense odors of H_2S. During the course of September the seismic system recorded several minutes of tremor.

The October 2005 SNET report noted that workers at the plantation Santa Isabel noted N-slope lahars associated with rainfall. The lahars were also described as small debris flows; they descended from the high-elevation headwater areas, which are steep sided and narrow. The November report commented about the quantity of debris-flow material accumulating at the base of some N-flank channels. The same report also mentioned that moderate degassing was seen in the crater leaving areas of abundant sulfur, which appeared as yellow zones in one or more fumarolic areas.

The November 2005 report of SNET also discussed substantial landslides inside the crater that were followed by widening of the funnel-shaped area of collapse in the central crater. The landslides had left three distinct perched remnants of the crater floor (small terraces) at various elevations on the crater walls. The crater's western plain (one such terrace of the sort mentioned above) was stable but showed areas of subsidence (figure 5).

Lahar monitoring during December 2005 disclosed erosion of easily mobilized cinders and scoria material on the N to NW flanks during the previous wet season. December seismicity was elevated, but cracks in the crater changed little compared to previous measurements. A field team visited the summit on 11 January 2006 and again in February and found few substantive changes in the crater. On the ascent route during January, the team saw a small recent "fall of material" reaching 40 cm thick. Some fumaroles discharged yellowish gases. During February the team conducted measurements of cracks on the western plain but found few changes, suggesting the headscarp had moved little if at all. February and March tremor episodes were centered at ~ 5 Hz and lasted 1-3 minutes.

The March 2006 SNET report noted small rockslides on the crater's N and S sides and, with the beginning of the rainy season in March 2006, there was a potential for the development of lahars. During the March visit the team found abundant granular material in the gullies on the NW flank, judged to be the result of debris flows. Monitored cracks remained stable.

With the arrival of the wet season in April, lahars and enhanced fumarolic output became apparent. One debris flow intersected a highway. On 23-24 April, 105 mm of rain was recorded at plantation (finca) Santa Isabel. Figure 6 shows the results of one lahar which left a trail of debris during the rainy interval. Earlier in the month on the 16th, a tremor or multi-phase episode lasted over an hour.

Figure 5. (top) A photo of San Miguel taken on 16 November 2005 showing the 'western plain' of San Miguel's crater (a terrace representing a remnant of a former crater floor). A considerable portion of the remaining terrace is in the process of subsidence (slumping). (bottom) A photo of the same area taken on 15 February 2006 (looking S). A zone of local subsidence, a pit along the head scarp, appears in the foreground but the subsidence also includes the region to the left of the large arcuate area extending well beyond the pit and still conspicuous in the upper left edge of the photograph. Courtesy of SNET.

In April 2006, an increase in fumarole degassing within the crater and small landslides contributed to the instability of the deposits on the NW flanks of the volcano. Steam emanated from the fumaroles occasionally forming a weak column that reached the edge of the crater. There was a slight increase in seismicity throughout the month. Seismic activity increased in March and April 2006 (figure 4). Rocks in the crater show intense hydrothermal alteration with a yellowish reddish color. Small rock landslides were observed in the N and S zone of the crater.

During June 2006, the temperature of the fumaroles, opening of cracks and the gas discharge by the crater of the volcano, remained stable. There was an increase of small landslides within the crater. The analysis of the seismicity indicates that the volcano is slightly above its base line of normal behavior. New landslides and cracked rock were ob-

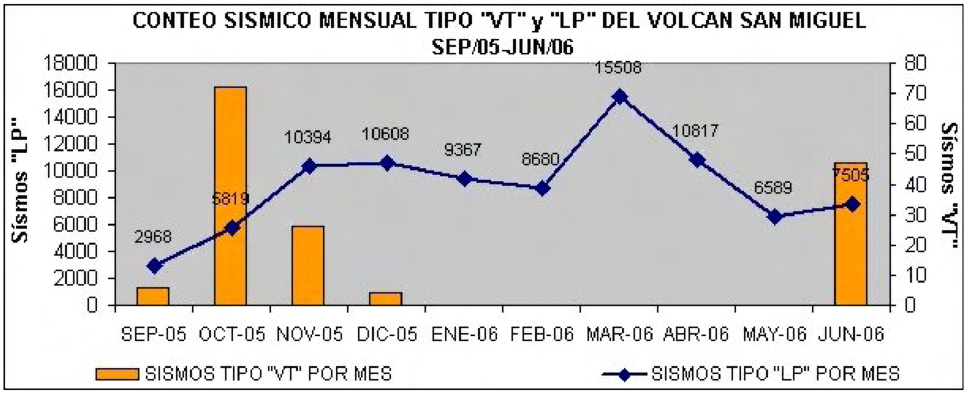

Figure 4. A plot of seismicity at San Miguel during September 2005-June 2006. Courtesy of SNET.

Figure 6. A San Miguel photo showing a part of the freshly scoured upslope channel in the Gato erosional gully. The material deposited in the channel consisted of reworked volcanic rocks and must have descended as a small lahar or debris flow. Several such flows occurred during heavy late-April rains at the start of the rainy season, a few days before this picture was taken. Courtesy of SNET (from their April 2006 report).

served in the walls of the crater (figure 7). Rains have transferred volcanic material down the NW flank. Seismicity gradually increased in both frequency and magnitude beginning on 16 June. 47 VT earthquakes and 7,505 LP earthquakes were recorded, an amount that surpasses those registered in May; but smaller than those registered in March and April (figure 4).

During July 2006, stability continued with respect to fumarole temperatures, crack openings, and gas emissions around the crater. However, the seismicity increased by ~ 70%. Small and sporadic landslides took place inside the crater off the SE to SW walls. Intense hydrothermal alteration in the NW wall was also observed. SNET did not report any lahars during July 2006; however intense rains have continued to remove volcanic material from the NW flanks. The fumarolic field gave off weak emissions.

In August 2006, the monitored parameters such as fumarole temperature, crack opening, and visual estimates of gas discharge maintained normal levels. The seismicity diminished significantly in relation to July.

During September 2006, San Miguel reached a low level of activity. There were no significant changes in the morphology of the volcano as reported in previous months. At the S wall, there were evidence of small rock slides.

A sudden increase in seismicity occurred on 9 October 2006. Contact was made with other observatories and it was determined there were no landslides or rock falls associated with the event. Seismic increases such as 9 October had previously occurred, particularly on 19 June 2003 and from 2-6 May 2004. The 9 October increaes were attributed to gas emission from the crater.

Figure 7. San Miguel's S crater wall exposes zones of altered and fractured rocks. A planar zone of structural weakness appears towards the right. Photo taken on 22 June 2006. Courtesy of SNET.

References: Chesner, C. A., Pullinger, C., Escobar, C. D., 2003, Physical and chemical evolution of San Miguel Volcano, El Salvador. GSA Special Paper 375.

Escobar, C.D., 2003, San Miguel Volcano and its Volcanic Hazards; MS thesis, Michigan Technological University, December 2003. 163 p.

Major, J.J.; Schilling, S.P., Pullinger, C.R., Escobar, C. D., Chesner, C.A, and Howell, M.M., 2001, Lahar-Hazard Zonation for San Miguel Volcano, El Salvador: U.S. Geological Survey Open-File Report 01-395. (Available on-line.)

Geologic Summary. The symmetrical cone of San Miguel volcano, one of the most active in El Salvador, rises from near sea level to form one of the country's most prominent landmarks. The unvegetated summit of the 2,130-m-high volcano rises above slopes draped with coffee plantations. A broad, deep crater complex that has been frequently modified by historical eruptions (recorded since the early 16th century) caps the truncated summit of the towering volcano, which is also known locally as Chaparrastique. Radial fissures on the flanks of the basaltic-andesitic volcano have fed a series of historical lava flows, including several erupted during the 17th-19th centuries that reached beyond the base of the volcano on the N, NE, and SE sides. The SE flank lava flows are the largest and form broad, sparsely vegetated lava fields crossed by highways and a railroad skirting the base of the volcano. The elevation of flank vents has risen during historical time, and the most recent activity has consisted of minor ash eruptions from the summit crater.

Information Contacts: *Carlos Pullinger*, Seccion Vulcanologia, Servicio Geológico de El Salvador, c/o Servicio Nacional de Estudios Territoriales, Alameda Roosevelt y 55 Avenida Norte, Edificio Torre El Salvador, Quinta Planta, San Salvador, El Salvador (URL: http://www.snet.gob.sv/Geologia/Vulcanologia/).

Ubinas

Perú
16.355°S, 70.903°W; summit elev. 5,672 m
All times are local (= UTC - 5 hours)

Ubinas began erupting ash on 25 March 2006 (*BGVN* 31:03 and 31:05); ash eruptions and steam emissions continued through at least 31 October 2006. Eruptive benchmarks during that period included a lava dome in the crater on 19 April. Ashfall in late April forced the evacuation of Querapi residents, who resided ~ 4.5 km SE of the crater's active vent, to Anascapa (S of the summit). Ash columns rose to almost 8 km altitude during May.

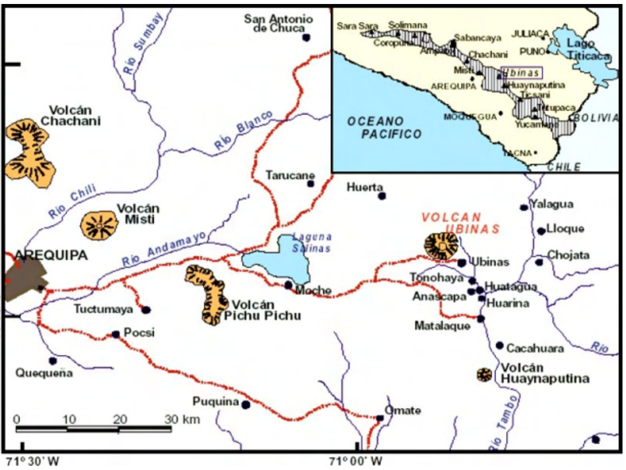

Figure 8. Map indicating the geographic setting of the Peruvian volcanic front (inset) and the area around Ubinas. From Salazar and others (2006).

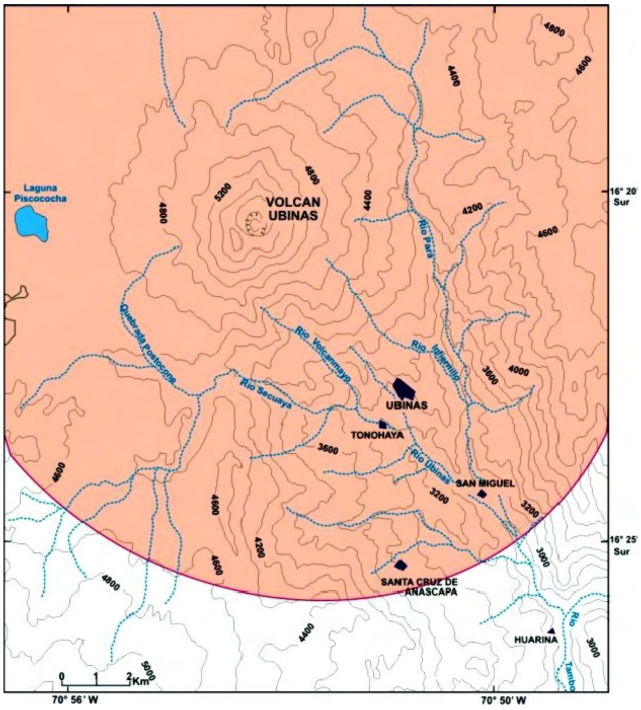

Figure 9. The boundary of identified Ubinas ashfall from the years 1550 to 1969 appears as a curve across the S portion of this map, 10-12 km from the summit crater. Note the SE-sector settlements (and their respective distances from the summit crater) for the district capital Ubinas (6.5 km), Tonohaya (7 km), San Miguel (10 km), and Santa Cruz de Anascapa (~ 11 km), and Huarina (15 km). Map taken from Rivera (1998).

This report discusses ongoing eruptions through 31 October 2006 as drawn from Buenos Aires Volcanic Ash Advisory Center (VAAC) reports and especially from an enlightening 26-page report published in Péru during September 2006 by the Institutio Geológico Minero y Metalúrgico–INGEMMET (Salazar and others, 2006). It includes a detailed digital elevation map with hazard zones.

Background. Ubinas lies 90 km N of the city of Moquegua and 65 km E of the city of Arequipa (figure 8). The bulk of adjacent settlements reside to the SE, and generally at more distance, towards the E. Figure 9 shows a shaded region where airfall deposits took place during the span 1550-1969. The zone of deposits includes some modern settlements.

The geologic map on figure 10 shows the area of the settlements SE of the summit includes large Holocene deposits, including those from debris avalanche(s) at ~ 3.7 ka, and units containing pyroclastic flows. The map also indicates deposits of volcaniclasics, glacial moraines, airfall-ash layers, and lava flows. Extensive Miocene deposits envelope both the NE flanks (Pampa de Para) and SW flanks.

The map of hazard zones (figure 11) indicates a nested, tear-drop shaped set of zones, with comparatively lower inferred hazard to the NE and NW. The SE-trending, elongate area of hazards follows the key drainage in that direction. Elevated hazard zones also follow many of the roads passing through the region.

Eruptions during 2006. Salazar and others (2006) reported that the current eruptive crisis could be divided into three stages. During July 2005-27 March 2006, the eruption was primarily gas discharge rising 100-300 m above the crater. During 27 March-8 April the eruptions consisted of ash emissions and gas produced by phreatic activity (figure 12). After a moderate explosion on 19 April, Ubinas produced ash and gas, and explosions ejected volcanic bombs. Several views into the crater appear on figure 13.

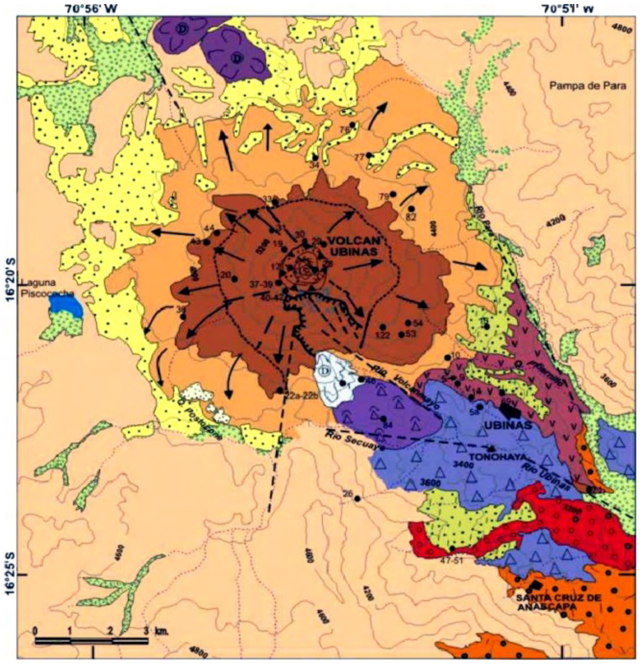

Figure 10. Geologic map of Ubinas shown here without the key, which is available in the original report. From Salazar and others (2006).

On 7 May 2006 a moderate explosion sent ash to ~ 3 km above the summit. Although the situation calmed in the following days, an impressive bomb fell 200 m from the crater on 24 May 2006 (figure 14). Larger outbursts occurred on 29 May and 2 June, prompting the civil defense decision to evacuate residents in the S-flank Ubinas valley, including the settlements of Ubinas, Tonohaya, San Miguel, Huatahua, and Escacha. Residents evacuated were lodged in refugee camps (figure 15).

On 18 June instruments recorded two explosions. Ash clouds discharged; the second one also ejected incandescent blocks ~ 1 km SE of the crater. The early stages of a rising plume seen at 0822 on 18 July appears on figure 16. Similar magnitude ash emissions were noted on 23, 24, and 30 June 2006, and incandescent rocks fell up to 1.2 km from the summit crater. During 10, 17-19, 22, 27 July, and 7 August 2006 there were various explosions (figure 16). Resulting ash clouds extended more than 70 km SE or SW.

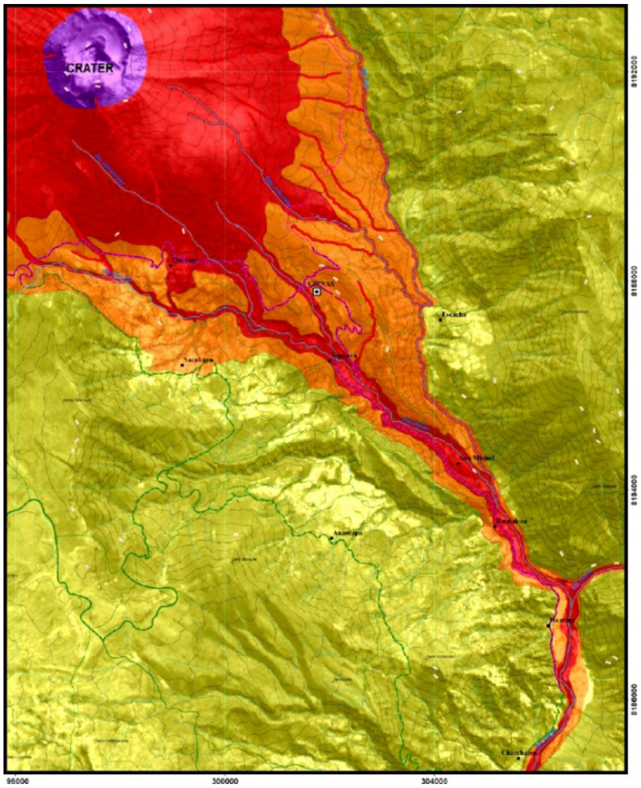

Figure 11. The SE corner of the Ubinas hazard map, showing the central crater, and the hazard zones that follow the main drainage (Rio Ubinas) leading SE through the most populated region close to the volcano. Map key is omitted. Margins of the map note that its construction was a partnership of numerous groups, including French collaborators at Blaise Pascal University and IRD. Taken from Salazar and others (2006).

Figure 12. Ubinas gas emissions as seen from unstated direction on 4 April 2006. From Salazar and others (2006).

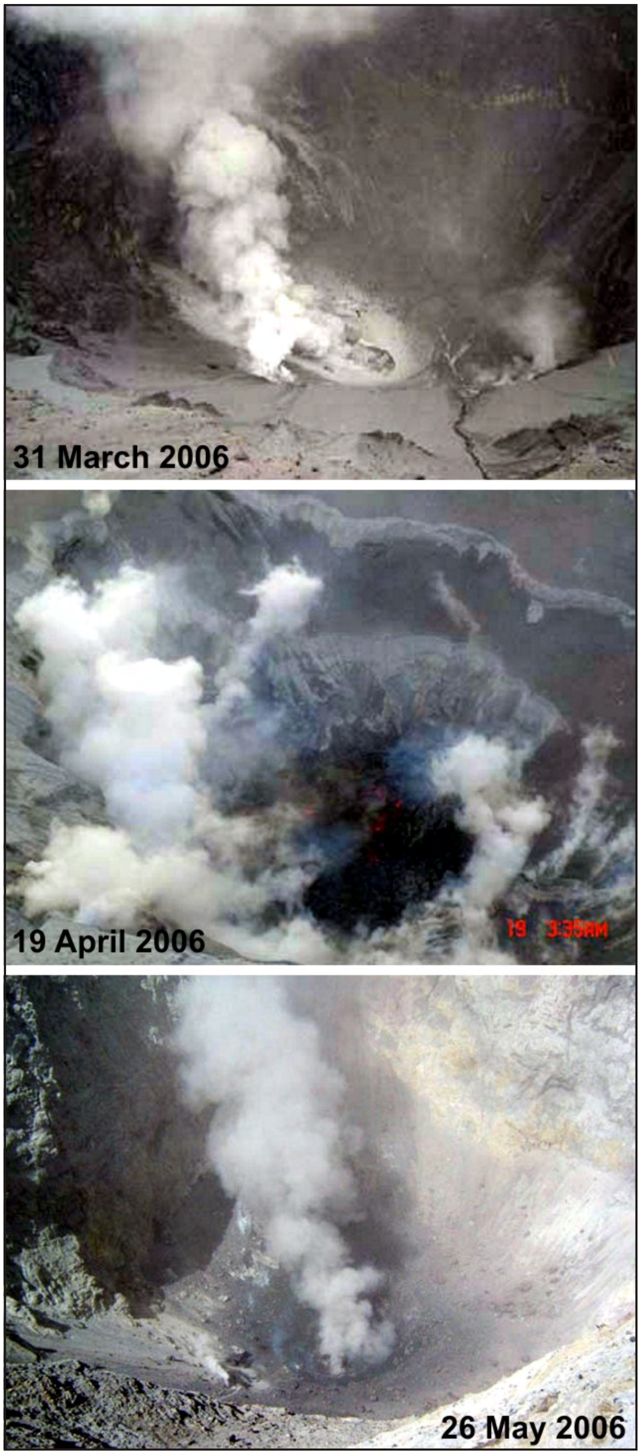

Figure 13. Views looking down into the Ubinas crater on 31 March, 19 April, and 26 May 2006. The former was taken in comparatively mild conditions. The 19 April photo was taken when a 60-m-diameter lava body was first seen on the crater floor (the color version of this photo shows faint red incandescence penetrating the steamy scene). The 26 May captured a relatively clear view of the steaming dome on the crater floor. March and April photos from and Salazar and others (2006); May photo from the INGEMMET website.

Figure 14. Ubinas eruptions in May 2006 ejected volcanic bombs, seen here in their impact craters. A 2-m-diameter bomb (top), struck ~ 200 m from the crater. A crater containing a large, partly buried, smooth-faced bomb is seen in the bottom photo. Numerous bucket-sized angular blocks appear on the far side of the impact crater. Two geologists stand adjacent a ~ 2-m-long block that ended up on the impact crater's rim. The bomb fragments were of andesitic composition. Top photo from Salazar and others (2006); bottom photo from INGEMMET website.

Figure 16. A moderate Ubinas explosion on 18 July 2006 generated this rising ash plume. Courtesy of Salazar and others (2006).

In August 2006, ash plumes reached 4.6-7.6 km altitude and were occasionally visible on satellite imagery. The direction of drift of the ash varied widely. On 12 August, ash dispersed more than 100 km to the SE and S. On 14 August an astronaut on the International Space Station took a picture of the ash plume from Ubinas (figure 17).

The most significant effect on people and the environment has come from ashfall (figure 18). GOES satellite images indicate visible airborne ash for distances greater than 60 km from the vent. Figure 18 indicates net ash accumulation through about August 2006, extrapolating sampling points with concentric circles. The report specifically noted ash thicknesses of 1.5 cm at ~ 4.5 km SE in Querapi, 0.1-0.8 cm in Sacoaya, 0.5-0.8 cm in Ubinas, 0.3-0.4 cm in Anascapa, 0.15 mm in Huatahua, and less than 0.1 cm in Chacchagén. The accumulation has apparently been due to ongoing ashfalls On 13 April, several millimeters of ash dusted all surfaces in Querapi, ~ 4.5 km from the center of the summit crater.

Aviation reports of ash plumes. As summarized in table 1, ash clouds were reported by the Buenos Aires Volcanic Ash Advisory Center (VAAC) on 2 May and then during 2 August through October on a nearly daily basis. The observation sources were usually pilot's reports (AIREPs) and/or satellite images (GOES 12). After 8 August, ash emissions were essentially continuous to 31 October. During the later interval, the aviation color code was generally Red. Plumes rose to 10 km and higher during 23-26 October.

References: Rivera, M., 1998, El volcán Ubinas (sur del Perú): geología, historia eruptiva y evaluación de las amenazas volcánicas actuales: Tesis Geólogo, UNMSM, 132 p.

Figure 15. Settlement camp housing families taking refuge from Ubinas ash. This camp, named Chacchagen, housed people from the S-flank settlements of Ubinas, Tonohaya, San Miguel, Huatahua, and Escacha. Inset shows the ash-dusted face of a local child. Courtesy of Salazar and others (2006).

Rivera, M., Thouret, J.C., Gourgaud, A., 1998, Ubinas, el volcán mas activo del sur del Perú desde 1550: Geología y evaluación de las amenazas volcánicas. Boletin de la Sociedad Geológica del Perú, v. 88, p. 53-71.

Salazar, J.M., Porras, M.R., Lourdes, C.D., and Pauccara, V.C., 2006, Evaluación de seguridad físca de áreas aledañas al volcán Ubinas: INGEMMET (Instituto Geológico Minero y Metalúrgico Dirección de Geología Ambiental, September 2006), 26 p.

Thouret, J.C., Rivera, M., Worner, G., Gerbe, M.C., Finizola, A., Fornari, M., and Gonzales, K., 2005, Ubinas: the evolution of the historically most active volcano in southern Peru: Bull. Volc., v. 67, p. 557-589.

Geologic Summary. A small, 1.2-km-wide caldera that cuts the top of Ubinas, Peru's most active volcano, gives it a truncated appearance. Ubinas is the northernmost of three young volcanoes located along a regional structural lineament about 50 km behind the main volcanic front of Peru. The upper slopes of the stratovolcano, composed primarily of Pleistocene andesitic lava flows, steepen to nearly 45 degrees. The steep-walled, 150-m-deep summit caldera contains an ash cone with a 500-m-wide funnel-shaped vent that is 200 m deep. Debris-avalanche deposits from the col-

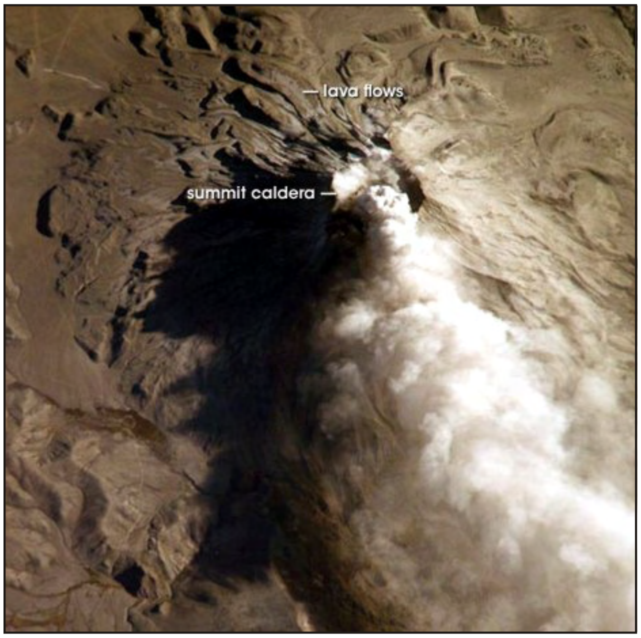

Figure 17. This image taken from the International Space Station (ISS) captures Ubinas discharging a light-colored ash cloud roughly to the S (N is up on this photo). The cloud had been observed earlier on satellite imagery at 0600 local (1100 UTC) on 14 August 2006. One-hour and 45-minutes later (at 1245 UTC), an ISS astronaut took this picture at non-vertical (oblique) angle to the Earth. Pumice and ash blanket the volcanic cone and surrounding area, giving this image an overall gray appearance. Shadows on the N flank throw several older lava flows into sharp relief. (Photograph ISS013-E-66488 acquired with a Kodak 760C digital camera using an 800 mm lens). Photo provided by the ISS Crew.

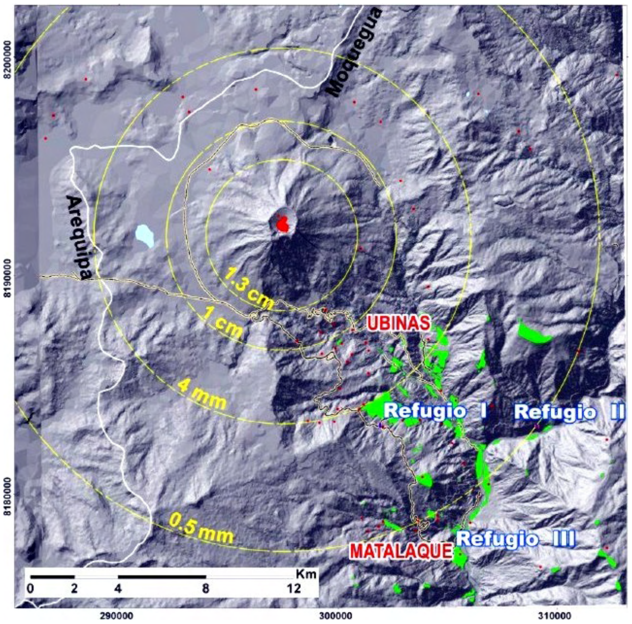

Figure 18. Net ash accumulation around Ubinas from start of eruption in March through about August 2006. Ash has covered agricultural fields in the valley and pastures in the highlands, seriously affecting the two main economic activities in the area, agriculture and cattle ranching; and has caused respiratory and skin problems. Courtesy of Salazar and others (2006).

Observation date (2006)	Eruption details: VA (Volcanic Ash) CLD (Cloud) OBS (Observed) FL (Flight Level)
02 May	VA CLD FL180/200 MOV SE
02 Aug	VA CLD DENSE ASH CLD FL160/230 MOV NE. ASH POORLY DEFINED VISIBLE GOES-12 SATELLITE IMAGE
03 Aug-04 Aug	VA CLD FL220/240 MOV SW
05 Aug	VA CLD OBS FL370 MOV NE
06 Aug-07 Aug	VA CLD OBS. ACTIVITY REPORTED CONTINUOUS AND INCREASING EMISSION FL160/260 SNTR OVER PEAK SPREAD FROM THE SUMMIT IN ALL DIRECTIONS UP TO A DISTANCE OF 20 KM
07 Aug-08Aug	VA CLD OBS FL200 MOV E/NE
10 Aug-14 Aug	VA CLD OBS FL180/245 MOV SE. ASH OBS IN SATELLITE IMAGE
17 Aug-18 Aug	VA CLD FL 160-200 MOV SE/ESE APROX. 60NM
19 Aug	VA CLD FL180/250 MOV SW
20 Aug-21 Aug	VA CLD FL180/230 MOV ESE/SE APROX. 20NM
22 Aug	VA CLD OBS FL180/300 STNR ~ MOV SE
25 Aug-26 Aug	VA CLD OBS FL230/235 MOV S. ASH NOT IDENTIFIABLE ON SATELLITE IMAGERY
28 Aug-30 Aug	VA CLD OBS FL160/250 MOV SE. SATELLITE IMAGERY REVEALED A LIGHT TRACE OF ASH EXTENDING TO SE OF THE SUMMIT
31 Aug	VA CLD OBS FL 160/250 APROX MOV NE~E
01 Sep-23 Sep	VA CLD OBS FL 160/250 MOV NE~E
24 Sep	VA CLD FL300 MOV SSE
27 Sep	VA CLD OBS FL180/230 and up to FL280
01 Oct-11 Oct	VA CLD OBS FL160/180 MOV E~ S
12 Oct-14 Oct	Emissions intermittent VA CLD OBS FL160/220 MOV SE~NE~N
15 Oct-21 Oct	VA CLD FL160~ 240 MOV S~ SE
23 Oct-26 Oct	VA CLD FL180/350 (Unusually high altitude) MOV N~E~W
26 Oct-29 Oct	VA CLD FL180/240 MOV N~NW swing to S
30 Oct-31 Oct	VA CLD FL 280/300 MOV SW

Table 1. Compilation of aviation reports (specifically, 195-Volcanic Ash Advisories, VAAs) on Ubinas and its plumes during May through 31 October. The second column shows some contractions used in the table (eg., "VA CLD FL 160" means "Volcanic ash cloud at Flight Level 160"). Flight Level is an aviation term for altitude in feet divided by 100 (eg., FL 200 = 20,000 feet = ~ 7 km altitude). Courtesy of the Buenos Aires VAAC.

lapse of the SE flank of Ubinas extend 10 km from the volcano. Widespread Plinian pumice-fall deposits from Ubinas include some of Holocene age. Holocene lava flows are visible on the volcano's flanks, but historical activity, documented since the 16th century, has consisted of intermittent minor explosive eruptions.

Information Contacts: *Jersy Mariño Salazar*, *Marco Rivera Porras*, *Lourdes Cacya Dueñas*, *Vicentina Cruz Pauccara*, Instituto Geológico Minero y Metalúrgico (INGEMMET), Av. Canadá No 1470, Lima, Peru (URL: http://www.ingemmet.gob.pe/); *Buenos Aires Volcanic Ash Advisory Center*, Servicio Meteorológico Nacional, Argentina (URL: http://www.ssd.noaa.gov/VAAC/OTH/AG/messages.html); *ISS Crew*, Earth Observations Experiment and the Image Science & Analysis Group, NASA Johnson Space Center, 2101 NASA Parkway Houston, TX 77058, USA (URL: http://www.nasa.gov/centers/johnson/home/index.html); *National Aeronautics and Space Administration (NASA) Earth Observatory* (URL: http://earthobservatory.nasa.gov/NaturalHazards/).

Kilauea

Hawaiian Islands
19.421°N, 155.287°W; summit elev. 1,222 m
All times are local (= UTC -10 hours)

-Lava from Kilauea continued to flow through the PKK lava tube from its source at Pu`u `O`o to the ocean during this reporting period from late August to the end of November 2006. About 1 km S of Pu`u `O`o, the Campout lava flow branches off from the PKK tube. Through November, the PKK and Campout systems fed two widely separated ocean entries named East Lae`apuki and East Ka`ili`ili, respectively. Kilauea's activity during this reporting period included numerous small breakouts from the Campout flow, new skylights along the PKK tube, and variable activity at the ocean entries, including small streams of lava crossing the coastal bench. Intermittant lava fountaining 15 m inland of the W edge of the East Lae`apuki bench was noted in late September-early October. Incandescence was also intermittently visible coming from the East Pond and January vents, the South Wall complex, and the Drainhole vent in Pu`u `O`o's crater. In general, during this reporting period the inflationary trend continued at the summit of Kilauea, in areas S of Halema`uma`u crater and tremors remained at a very typical moderate level at Pu`u `O`o.

During 30 August-12 September, crews reported visible lava streams on the W side of the East Lae'apuki delta and occasionally from the East Ka'ili'ili entry. On 1 September, the East Lae'apuki lava bench was an estimated 22 hectares (54 acres) and East Ka`ili`ili was an estimated 2.3 hectares (5.8 acres). On 30 August, and 1 and 6 September, the Campout flow escaped from the PKK tube. On 11 September, Park Service field crews reported two lava flows visible down the entire length of the pali. Incandescence was intermittently visible from the East Pond and January vents, the South Wall complex, and the Drainhole vent in Pu`u `O`o's crater.

During 13-23 September, lava from the Campout and PKK systems continued to flow off of a lava delta into the ocean and breakout flows were visible on the pali. On 20 September, a tour pilot reported seeing three large lava flows from a breakout 10 m inland from the old sea cliff at East Lae`apuki (figures 19 and 20). On 23 September, incandescence from above Pulama pali in the direction of Pu`u`O`o was likely due to several new and reactivated skylights on the upper PKK tube.

Littoral fountaining on 27 September was reported about 15 m inland of the W edge of the East Lae`apuki bench. Lava jetted about 30 m in the air accompanied by loud rumbling and jetting sounds. Observers reported ground shaking. Over the next couple of days, 3-4 lava streams were visible on the W side of East Lae`apuki entry, as were incidents of tephra jetting and lava fountaining 15-23 m (50-75 ft) high. Glow had been visible from the East Lae`apuki entry and the Campout flow breakout on the pali, but not from the Ka`ili`ili entry. The consistent lack of visible glow from the Ka`ili`ili entry was due to the absence of a very large bench, forcing lava to remain hidden at the base of the seacliff.

Figure 19. Aerial view of the lava bench at East Lae`apuki, looking NE on 20 September 2006. An active lava flow is going over the sea cliff in roughly the center of the arcuate fault scarp in the widest part of the lava bench below it. White steam plumes from the ocean entry were blown towards along the coast towards the left. In the colored version of this shot the adjacent seawater contains a greenish hue. Courtesy of HVO.

Figure 20. A lava flow at Kilauea breaks out to the surface 10 m inland from a sea cliff on 20 September 2006 . The lava pours over the cliff in places as thick curtains and elsewhere as smaller rivulets and dripping falls. After the fall the lava proceeded across the upper bench as a series of braided streams. Toward the left, some readers might claim they see a slender Pelé, dancing with arms upraised. Courtesy of HVO.

Observers reported that on 28 September the floor of the Drainhole vent had been replaced by an overturning lava pond. As of 29 September, a new tube and flow that formed on the E side of the Campout flow extended ~ 180 m. Another flow went W and butted up against the PKK tube. The USGS field crew also found a small stagnant breakout of lava at ~ 60 m elevation. It flowed E to cover a little more of the long-abandoned Royal Gardens subdivision. In the Pu'u O'o vicinity, a new collapse pit photographed in early October had engulfed pre-existing spatter cones (figure 21).

During October and November, breakout flows were intermittently visible on the Pulama pali, at the base of the pali, or on the sea cliff and incandescence from vents in Pu`u`O`o was visible. For example, on 25 October, two separate break-out lava flows were visible on pali. The upper flow at about 320 m (1,050 ft) elevation consisted of 'a'a and pahoehoe and the lower flow at 114 m (375 ft) was solely pahoehoe. On 3 and 4 November, tephra jetted at the tip of the East Lae`apuki bench. On 15 November, breakouts resumed on top of the seacliff after a few weeks without activity. On 18 November, the Drainhole vent twice ejected spatter as high as 25 m above its rim. On 19 November, observers saw small explosions at East Lae`apuki ocean entry as well as well-defined streams of lava entering the ocean. The next evening, six rivers of lava flowed over the bench and into the ocean at the W entry. When weather permitted, incandescence was visible from the East Pond, the South Wall complex, the January vents, and Drainhole vent.

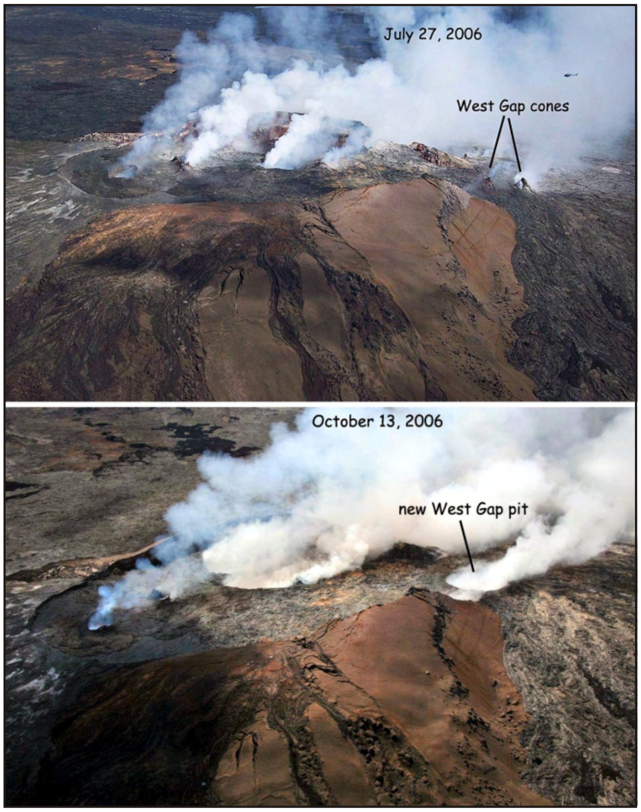

Figure 21. Two views of Kilauea's W gap area illustrating morphologic changes there. (top) Aerial view of Pu`u `O`o taken in July 2006 shows two spatter cones.. Note helicopter above label for scale. (bottom) An aerial photo taken on 13 October 2006 shows a new collapse pit that grew to engulf the spatter cones. The bottom of the pit, which formed on the night of 10 October, is hidden by fume. Courtesy of HVO.

Information Contacts: *Hawaiian Volcano Observatory (HVO)*, U.S. Geological Survey, PO Box 51, Hawaii National Park, HI 96718, USA (URL: http://hvo.wr.usgs.gov/; Email: hvo-info@hvomail.wr.usgs.gov).

Home Reef

Tonga Islands, SW Pacific
18.992°S, 174.775°W; summit elev. -2 m
All times are local (= UTC + 13 hours)

An eruption from Home Reef in early August generated large volumes of pumice that floated to Fiji (over 700 km away) in the following two months; an island was also created (*BGVN* 31:09). Satellite data and imagery have been used to confirm these observations and provide additional information about this event.

Norman Kuring of the MODIS Ocean Color Team identified the earliest clear shot of the pumice raft in a Terra MODIS on 7 August at 2120 UTC (8 August at 1020 Tonga time). The image (figure 22) shows a circular patch of pumice over the eruption site with a small volcanic plume emerging from it. The first indication of pumice raft leaving the eruption site is in the Aqua MODIS image at 0132 UTC on 10 August, but the 9 August overpass was cloudy, so it could have happened earlier. Kuring also compiled other images showing the dispersion of the pumice through 22 August (figure 23).

Kuring also made a preliminary estimate of the area of the pumice raft on 11 August (10 August at 2150 UTC), previously encountered by the *Maiken* (*BGVN* 31:09). A mask was created to cover identifiable areas of pumice, resulting in an area of 9,338 pixels. Each pixel in the image used covers an area of 0.0468 km^2. The calculated total area is approximately 440 km^2 for that time. Note that this estimate does not take into account errors caused by pumice being a high-contrast target (allowing linear patches less than the pixel width to be seen), small isolated patches of pumice that could not be recognized, material hidden by

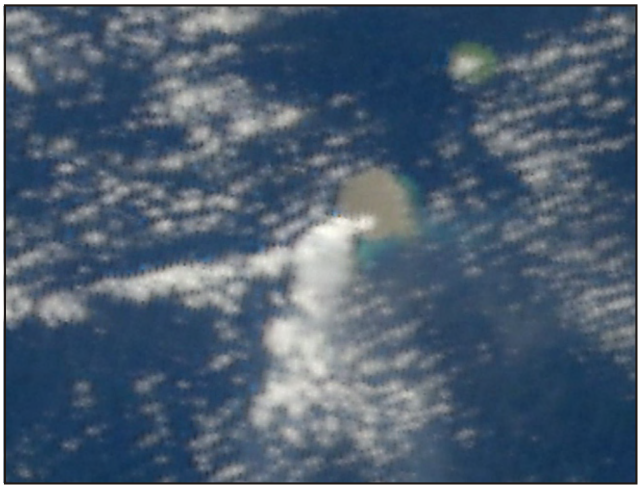

Figure 22. Terra MODIS image taken on 8 August 2006 (local time) showing the early stages of the eruption at Home Reef. A steam plume is visible rising from the southern end of a mass of floating pumice covering an area larger than Late Island to the NW. Courtesy of the NASA Ocean Color Group.

clouds, or fragments suspended in the water column under the surface. In the 8 August MODIS image, the circular area was determined by Bulletin editors to be at least 8 km in diameter, so the area covered was more than 50 km^2.

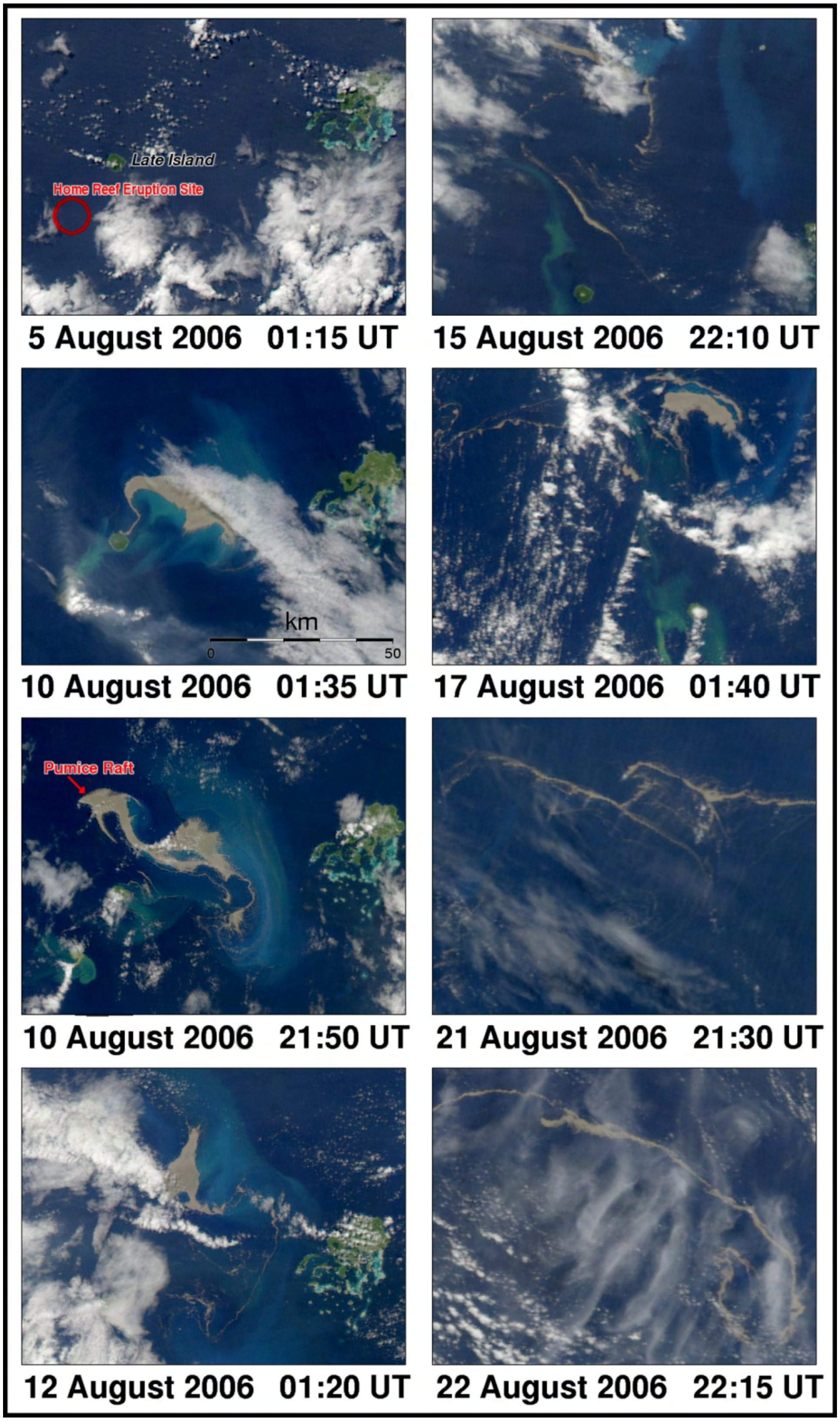

Figure 23. Terra and Aqua MODIS satellite images showing the dispersion of the pumice raft generated by the eruption at Home Reef during 7-8 August. By 10 August a large raft was NE of Late Island. Most of the material stayed in that area through 12 August before breaking up into elongate pieces that began moving W towards Fiji. Courtesy of the NASA Ocean Color Group.

Simon Carn (UMBC) used the Ozone Monitoring Instrument (OMI) on NASA's Aura satellite to constrain the timing of the eruption. OMI detected SO_2 emissions from the vicinity of Home Reef beginning on 8 August. Emissions appear to have peaked sometime during 8-9 August. The total SO_2 mass detected E of Tonga by OMI on 9 August was ~ 25 kilotons. By 12 August there were 3.3 kilotons of SO_2 in the area (figure 24). The emission episode was over by 15 August. HYSPLIT forward trajectories indicated that the SO_2 released on 8 August may have reached altitudes of 5 km or more. Carn also stated that "To our knowledge this is the first example of satellite detection of emissions from a submarine volcano. Significant scrubbing of SO_2 and other soluble volcanic gases is likely during such events."

Terra MODIS data from 4 September 2006 provided by Alain Bernard showed pumice rafts moving SE from Home Reef (figure 25). Pumice that previously followed a similar path was found on beaches in southern Vava'u (*BGVN* 31:09) by 2 September.

Island evolution. No data or reports are available to determine when the island built by the 1984 eruption (*SEAN* 09:02 and 09:04) eroded below the ocean surface. Recent reports from mariners and local fishermen noted that this current eruption had built a new island, implying the absence of an island at that location. An ASTER image inspected by Matt Patrick from 18 November 2005 did not show an island.

An ASTER image of the new island taken on 4 October 2006 (figure 26) has been studied by a number of scientists, including Greg Vaughan (JPL), Matt Patrick (Michigan Tech), and Alain Bernard (Univ. of Brussels). The image clearly shows the island (at 18.991°S, 174.762°W) with large – and NE-directed anomalous areas that are likely caused by volcanic material suspended in the water. The new island is warmer than adjacent Late island. Greg Vaughan provided an annotated version of the image zoomed in on the new island, which he computed then had an area of 0.245 km^2. Vaughan also noted that the "daytime image shows considerable activity in the water around the new Home Reef island [and] a thermal plume in the same shape as the pink colored area in the attached VNIR images (ASTER channels 3-2-1 as R-G-B)." Work by Alain Bernard based on the ASTER thermal bands determined that the hot lake on the island had a maximum temperature of 64.7°C on 4 October. Bernard calculated the island area to be 0.230 km^2 on 4 October. Comparison with another ASTER image from 12 November showed that the island had changed shape and covered an area of 0.146 km^2, a decrease of 0.84 km^2 (figure 27).

Floating pumice observations. Additional pumice sightings have been reported that supplement those described earlier (*BGVN* 31:09). Areas known to have been impacted by the pumice now include Suva Point (where the capital of Fiji, Suva, is located) and Yasawa Island (N of Viti Levu and E of Vanua Levu). By early November pumice from Home Reef had reached Efate Island in Vanuatu.

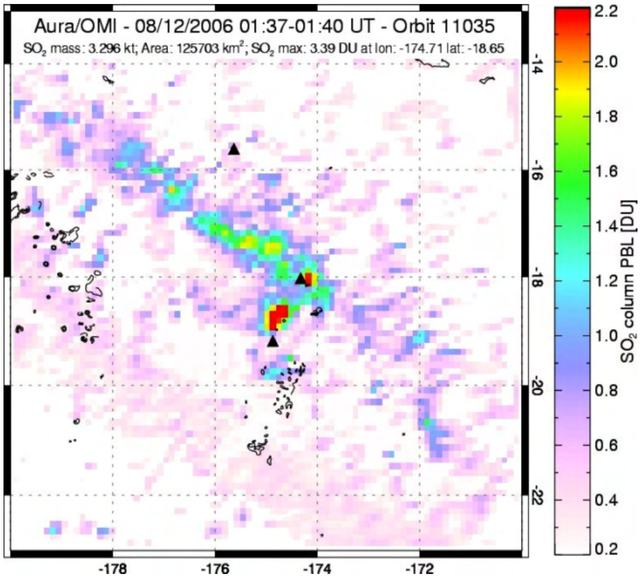

Figure 24. Sulfur-dioxide emissions in the vicinity of Home Reef, 12 August 2006 at 0140 UTC. Data obtained from the Ozone Monitoring Instrument (OMI) on NASA's Aura satellite. Courtesy of Simon Carn.

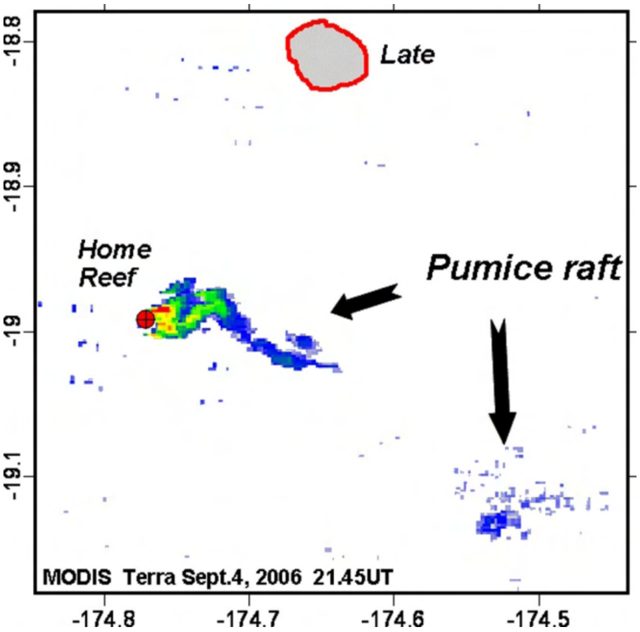

Figure 25. Terra MODIS data from 4 September 2006 showing pumice rafts moving SE from Home Reef. Data was obtained with a simple processing of bands 1 and 2; pixel size is 250 meters. Courtesy of Alain Bernard.

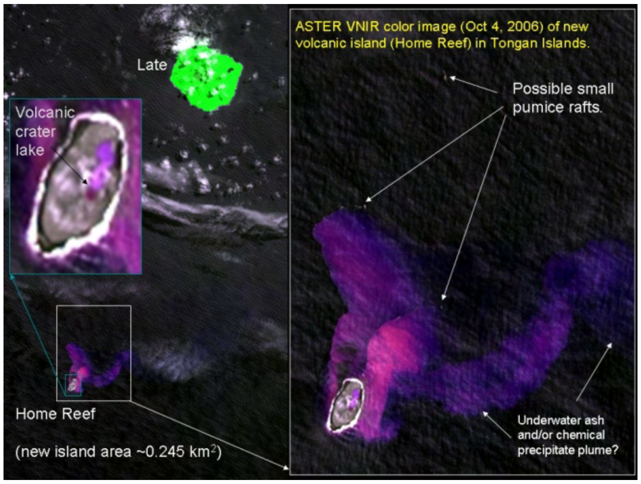

Figure 26. ASTER VNIR image showing the new island at Home Reef on 4 October 2006. A volcanic lake is visible on the island, as are submarine plumes originating from the island. Some possible small pumice rafts can also be identified in this 15-m imagery. Modified from original provided courtesy of Greg Vaughan.

Figure 27. Comparison of the island at Home Reef on 4 October (left) and 12 November 2006 (right) using ASTER imagery. The size of the island decreased approximately 0.84 km^2 over that time period. Courtesy of Alain Bernard.

Crew on the *SV Sandpiper* encountered pumice during transit from Tonga to northern Fiji on 12 September. They went through "large patches" of pumice "all afternoon" while traveling about 200 km over the course of the day. The next evening, after sunset on 13 September, the boat suddenly slowed and the water "looked like a thick chocolate shake." Lights shining down from the rigging (spreader lights) showed that they were surrounded by pumice. The crew observed pumice again on 23 September at the southern end of Vanua Levu.

Wally Johnson was flying from Suva to Taveuni on 19 September and observed large amounts of pumice in the Koro Sea, drawn out into numerous parallel strings in the direction of the prevailing wind and heading towards Taveuni. A fair bit of the pumice had been washed up into ridges on beaches on the NW coast of Taveuni, and up and into pockets on some of the recent basaltic lava flows to the SW. Bernie Joyce forwarded additional reports from Fiji.

On 27 October 2006, Rebekah Mue-Soko reported that the Suva Point area of Viti Levu was filled with pumice as of 27 October, and that it had appeared sometime before 8 October. About 6 November 2006 Lyn and Darcy Smith were on the Fijian island of Yasawa, N of Viti Levu, and reported "a heap of pumice on the beach" which apparently arrived during their one-week visit.

While pumice has persisted in Fiji, some reached Vanuatu. Sandrine Wallez reported pumice on the W coast of Efate Island during the night of 4-5 November. A deposit around 10 cm thick was observed along 40 km of coastline. The largest pumice fragments were the size of a tennis ball. Pumice was still on the beaches in early December (figure 28). Shane Cronin was in Vanuatu in early October when a new batch of fresh pumice washed up on northern Efate beaches. Pumice is commonly being deposited on beaches around Vanuatu, and local residents told Cronin that they thought it was coming from up around the Ambrym-Lopevi area. Douglas Charley (DGMWR - Vanuatu) recorded explosion earthquakes on a portable geophone from south Epi (*BGVN* 29:04) at the beginning of September.

Geologic Summary. Home Reef, a submarine volcano midway between Metis Shoal and Late Island in the central Tonga islands, was first reported active in the mid-19th century, when an ephemeral island formed. An eruption in 1984 produced a 12-km-high eruption plume, copious amounts of floating pumice, and an ephemeral island 500 x 1500 m wide, with cliffs 30-50 m high that enclosed a water-filled crater.

Figure 28. Photograph showing beach deposits of pumice from the August eruption at Home Reef on western Efate, Vanuatu, on 3 December 2006. Courtesy of Sandrine Wallez.

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Rabaul

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

The Rabaul Volcano Observatory (RVO) reported that a large, sustained Vulcanian eruption began at Rabaul at about 0845 on 7 October 2006 (*BGVN* 31:09). A further point regarding that eruption, absent from our previous report, was that some members of the Volcanic Clouds Group (a listserv discussion group) conducted significant observations and initial modeling of the 7 October eruption clouds, including mapping the cloud's sulfur dioxide content and making forecasts of their dispersion. In the Volcaniccloud listserv discussions of the 7 October clouds, Andrew Tupper noted the following: "The cloud was at 16 km (upper troposphere/lower stratosphere) when it passed over Manus on its way NW . . . . However, the north/northeastern parts were initially higher . . . , with the eastward bit clearly stratospheric. There were multiple flights under the cloud over Micronesia for [sic] that reported that was no ash or smell–this puts a lower boundary (~ 10 km) on the cloud, consistent with our view that the bits at cruising levels had gone to the SE."

Since that event and in reference to the time interval for this report, 4 November to early December 2006, RVO has noted that activity continued at Tavurvur at varying intensities. The largest event in the reporting interval took place at 0715 on 14 November 2006; Tavurvur produced a large explosion that rose several kilometers above the cone.

During 4-13 November, mild eruptive activity continued at Tavurvur, with occasional small-to-moderate ash emissions continuing and blowing to the SE. An emission on 11 November consisted of thick white vapor accompanied by occasional small-to-moderate ash clouds that drifted variably to the SE, S, and NW and resulting in fine ash fall downwind. On 12 November the emission was blown W and NW, and on the morning of 13 November the ash cloud drifted N of the volcano.

An explosion occurred at Tavurvur at 0715 on 14 November 2006, accompanied by a thick ash cloud that rose to about 2 km above the summit before drifting NW. The explosion showered the flanks of the volcano with lava fragments, some of which fell into the sea. Fine ash fall occurred at Rabaul Town areas and downwind to the Ratavul and Nonga areas. Continuous ash emission followed the explosion. Seismic activity continued at low levels; however, high-frequency earthquakes continued to occur within the Rabaul caldera. After the large explosion on 14 November, mild eruptive activity continued at Tavurvur, consisting of continuous thick white vapor accompanied by pale gray to gray ash clouds that rose ~ 1.5 km above the summit before drifting variably S and E of Tavurvur. During 16-17 November, continuous thick white vapor accompanied by pale gray ash clouds rose to about 2.5 km above the summit before drifting variably to the NW and E with fine ash falling on settlements downwind, including Rabaul Town. One high-frequency earthquake occurred on 16 November.

Mild eruptive activity continued at Tavurvur during 18-20 November. On 18 November and on the morning of 20 November continuous gray ash clouds rose less than 200 m above the summit before being blown N and NW. Fine ash continued to fall on villages downwind including Rabaul Town. Activity on 19 November consisted of emission of thick white vapor only, accompanied by roaring noises heard between 1130 and 1400.

Quiet generally prevailed at Tavurvur during 20-23 November. Emissions then consisted of thick white vapor accompanied by a small amount of pale gray ash clouds. On 21 November the emissions accumulated in the atmosphere around the caldera causing haze, and on 22 November the emissions rose less than 1,000 m above the summit before drifting W. Fine ash fell on villages downwind. On the morning of 23 November the emission consisted of white vapor rising more than a kilometer above the summit before drifting E.

On 26 and 27 November the activity consisted of gentle sporadic emission of subcontinuous, gray to pale gray ash clouds of varying thickness. The ash clouds drifted NW to W resulting in fine ash fall downwind. From November to 1 December the emission consisted of pale gray to dark gray ash clouds being released more forcefully. The ash clouds rose less than 200 m above the summit before drifting E. On the morning of 2 December the emission consisted thick white vapor and pale gray ash clouds that rose about 2 km before being blown ENE. On 3 December thick pale gray ash clouds that rose about 1 km above the summit were emitted. The ash clouds drifted NE in the morning and then slightly to the W in the afternoon. On the morning of 4 December the ash cloud rose about 2 km before drifting E. Fine ash fall occurred in downwind areas. There was no glow from the volcano visible at night. From late morning to the afternoon of 4 December the activity consisted of emission of thick pale gray ash clouds that rose about 500m above the summit before drifting NW. In the morning of 5 December the ash cloud rose 200 m before drifting E. By mid-morning the ash clouds were rising about 1 km above the summit before drifting NNW, and during the early afternoon the ash clouds drifted briefly to the E and then S before going back to the E by late afternoon. On the morning of 6 December the ash cloud rose about a km before drifting N-NW. The emission was accompanied by loud roaring noises. Fine ash fall occurred in downwind areas including Rabaul..

There was no significant deformation until 10 December. The RVO reported that loud and continual roaring was present from 8 December 2006 until the morning of 9 December, when the roaring became intermittent. The roaring ceased on 10 December and at that time parts of the caldera underwent a rapid ~ 1 cm uplift. On 11 December the volcano was quiet with very little fume. At 0400 on 12 December, a loud explosion occurred with an airwave which shook houses in Rabaul. This event generated a billowing gray column that rose to a maximum of 1,000 m before being blown to the E. Following the 12 December explosion subsidence returned the site's level to that of 9 December. Seismic activity continued at low levels. No high frequency earthquake was recorded.

Table 2 shows the MODIS thermal anomalies observed during 22 October-12 December 2006 (see BGVN 31:09 for earlier October anomalies).

Geologic Summary. The low-lying Rabaul caldera on the tip of the Gazelle Peninsula at the NE end of New Britain forms a broad sheltered harbor utilized by what was the island's largest city prior to a major eruption in 1994. The outer flanks of the 688-m-high asymmetrical pyroclastic shield volcano are formed by thick pyroclastic-flow deposits. The 8 x 14 km caldera is widely breached on the east, where its floor is flooded by Blanche Bay and was formed about 1400 years ago. An earlier caldera-forming eruption about 7100 years ago is now considered to have originated from Tavui caldera, offshore to the north. Three small stratovolcanoes lie outside the northern and NE caldera rims of Rabaul. Post-caldera eruptions built basaltic-to-dacitic pyroclastic cones on the caldera floor near the NE and western caldera walls. Several of these, including Vulcan cone, which was formed during a large eruption in 1878, have produced major explosive activity during historical time. A powerful explosive eruption in 1994 occurred simultaneously from Vulcan and Tavurvur volcanoes and forced the temporary abandonment of Rabaul city.

Information Contacts: *Steve Saunders* and *Herman Patia*, Rabaul Volcanological Observatory (RVO), Department of Mining, Private Mail Bag, Port Moresby Post Office, National Capitol District, Papua, New Guinea (Email:

Date	Time (UTC)	Number of Pixels	Satellite
22 Oct 2006	1220	2	Terra
22 Oct 2006	1520	1	Aqua
27 Oct 2006	1250	1	Terra
16 Nov 2006	1230	1	Terra

Table 2. MODIS thermal Anomalies for Rabaul volcano for 24 October through 12 December 2006. Courtesy of the Hawai'i Institute of Geophysics and Planetology.

hguria@global.net.pg); *Andrew Tupper*, Darwin Volcanic Ash Advisory Centre (VAAC), Bureau of Meteorology, Darwin, Australia (Email: A.Tupper@bom.gov.au); *National Aeronautics and Space Administration Earth Observatory* (URL: http://earthobservatory.nasa.gov/NaturalHazards/); RSAM definition (URL: http://vulcan.wr.usgs.gov/Monitoring/Descriptions/description_RSAM_SSAM.html); *HIGP MODIS Thermal Alert System*, Hawai'i Institute of Geophysics and Planetology (HIGP), University of Hawaii at Manoa, 168 East-West Road, Post 602, Honolulu, HI 96822, USA (URL: http://modis.higp.hawaii.edu/); *Volcanic Clouds Group* (Email: volcanicclouds@yahoogroups.com; URL: http://groups.yahoo.com/group/volcanicclouds/).

Likuranga

New Britain Island, Papua New Guinea
4.95°S, 151.38°E; summit elev. 922 m

Although Likuranga volcano in West New Britain is thought to be of Pleistocene age (i.e. without evidence of eruption in the past 10,000 years; Johnson, 1971, 1970a, b), a boy died of carbon-dioxide (CO_2) asphyxiation in a hole at Bakada village on the volcano's N flank on 21 September 2006. Details of the follow-up investigation came out in a report of the Rabaul Volcano Observatory (Mulina and Taranu, 2006). This report is a condensation of that work. The event serves as a reminder of threats from gas release in volcanic regions, even those areas in repose or unlikely to erupt again. In this case, the linkage to biogenic versus volcanogenic origins of the gas remains equivocal. Likuranga's summit is ~ 13 km NNE of Ulawun's summit (figure 29). The volcano and Bakada village appear in several Google Earth images (figures 30 and 31).

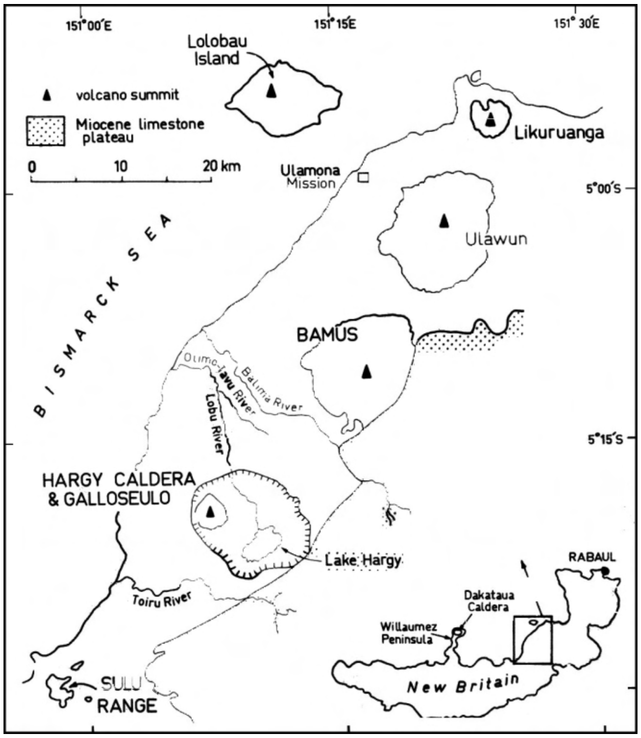

Figure 29. Likuranga sits along the N coast of New Britain island (inset map). The larger figure comprises a sketch map of important features along the coast from Likuranga to the Sulu Range. By far the most frequently active and reported-on volcano on the map is Ulawun, although recent reports have discussed unrest at both Bamus and the Sulu Range (*BGVN* 31:09) and regional seismicity has been high in 2006. This figure was scanned from Johnson (1970b) and modified.

In 2004, a logging company dug a number of holes to build latrines but ceased after finding water at shallow depths. The company ultimately left the area without refilling the holes, which are behind some of the remaining buildings (figure 32). A conspicuous disturbed area corresponded with the reported coordinates of the hole on the zoomed-in image of the village ("hole," figure 32).

Background on gas hazards. Natural sources of CO_2 include volcanic outgassing, the combustion of organic matter, and the respiration processes of living aerobic organisms. CO_2 gas is ~ 1.5 times heavier than air at the same temperature and can collect in depressions, and confined spaces such as caves and buildings. Without wind to ventilate an area, the denser CO_2 displaces the typical atmo-

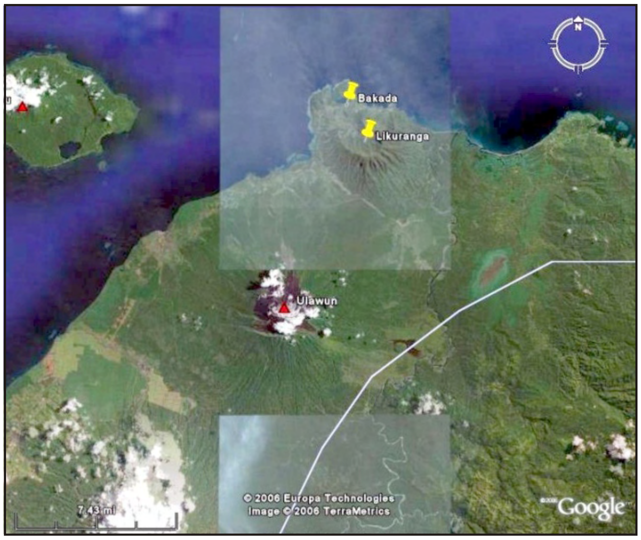

Figure 30. The coastal village Bakada on Likuranga's N flanks. The village, which has few permanent residents but is used as a safe haven by nearby coastal villagers when Ulawun becomes restless. The linked line segments across the image crudely approximate the boundary between East and West New Britain. Courtesy of Google Earth.

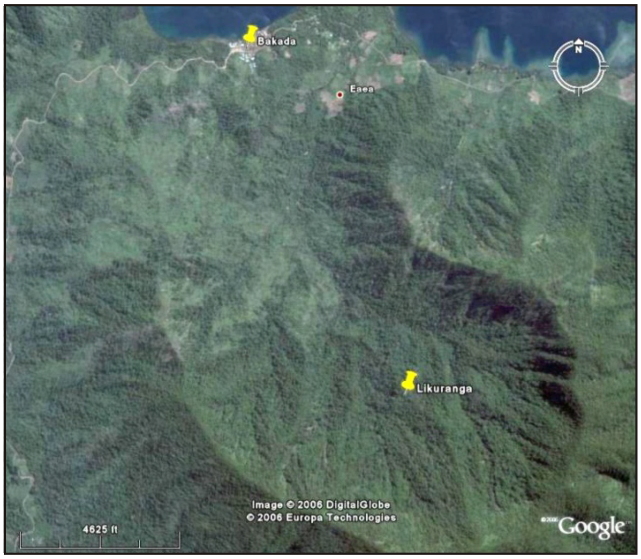

Figure 31. A closer view of Likuranga's N-flank village Bakada. Courtesy of Google Earth.

Figure 32. Although somewhat fuzzy, this zoomed-in view of Bakada shows the Likuranga hole, which was labeled based on coordinates provided in the RVO report . Courtesy of Google Earth.

sphere, causing an oxygen deficiency. For adult occupational exposure, one US agency recommends a ceiling limit of 3 percent CO_2 for up to 10 minutes. Watanabe and Moritea (1998) studied responses of rats to various gases, including CO_2. They discuss various types of asphyxia and the related diagnoses of causes of death.

Although the main component of volcanic gas is usually water vapor, other common volcanic gases can endanger life and property. These can include, as in this case, carbon dioxide (CO_2); and, in an elevated temperature environment, a multitude of other gasses such as sulfur dioxide (SO_2), hydrogen (H_2), hydrogen sulfide (H_2S), carbon monoxide (CO), and hydrogen fluoride (HF). The main dangers to health and life results from the effects of the acids and ammonia compounds on eyes and respiratory systems. The volcanic gases that pose the greatest potential hazard to people, animals, agriculture, and property are sulfur dioxide, carbon dioxide, and hydrogen fluoride.

Tragedy at Bakada village. On 21 September 2006, an 8-year-old boy, with his mother nearby, went down a large (2.6 m deep and 3.4 m wide) hole. He entered the hole trying to rescue his dog, which had fallen in. Witnesses recalled that the boy soon started shaking and screamed for help. A nearby woman went down the hole to rescue the boy and she, too, fell unconscious. Both were pulled from the hole by people at the rim with the aid of a long stick and knotted rope. The boy was dead; his hands a pale color. The woman was still breathing but vomited blood. She was rushed to a health center where she soon recovered. It was estimated that the woman was in the hole for 15 minutes and the boy somewhat longer (though this estimation remains crude as it could not be confirmed by anyone with a watch during the incident).

The following day, 22 September, villagers threw five small animals into the hole and noted that they all died immediately. The villagers also recalled that the previous year an employee of the logging company attempted to burn dried vegetation in the same hole and failed, even after adding waste diesel fuel to assist the process.

Investigation and conclusions. On 25 September RVO scientists arrived in Bakada to investigate the incident. It should be noted that for two days before their arrival there was moderate rainfall in the area. The scientists found that a frog and a dog were moving freely in the hole alongside the remains of the original five animals. The RVO report did not indicate when the frog and dog were put into the hole. In addition, a burning paper lowered into the hole continued to burn on the bottom surface.

On 27 September a return visit by RVO with instruments permitted the measurement of CO_2 emissions from adjacent soil. The results listed in tables 3 and 4 show that the rate of CO_2 emission varied, but generally increased as they approached the hole.

The investigators concluded that CO_2 in the 2.6-m-deep hole caused the boy to die of asphyxiation and the woman attempting to rescue him to enter a semi-conscious state. It was also noted that whereas air currents may keep CO_2 concentrations acceptably low on the land surface, the same

Distance from the hole	Rate of soil CO_2 gas flux emission	
	Rate at ppm per minute	Rate at ppm per second
1 m	270	5.4
5 m	128	2.14
100 m E	54.2	0.9
100 m W	40.6	0.676
250 m W	41.9	0.698

Table 4. Preliminary CO_2 soil flux analyses at various distances from the hole; as measured on 27 September 2006. After Mulina and Taranu (2006).

Duration (minutes)	Concentration of CO_2 (ppm) over period of time (in minutes) as measured from varying distance away from the hole.				
	1 m E Soil temp=28°C	5 m E Soil temp=28°C	100 m E Soil temp=27.2°C	100 m W Soil temp=29.5°C	250 m W Soil temp=27°C
0.0	2000	1380	1130	910	850
0.5	220	1490	1140	930	860
1.0	2350	1530	1160	950	870
1.5	2400	1570	1190	980	900
2.0	2550	1700	1220	990	920
2.5	2725	1730	1250	1010	940
3.0	—	1860	1290	—	970
3.5	—	—	—	—	990

Table 3. Preliminary CO_2 soil flux made with approach to the hole where the child died at Bakada village, Likuranga volcano. The measurements were made ~ 6 days after the tragedy, on 27 September 2006. After Mulina and Taranu (2006).

does not hold true for deep holes. A final conclusion was that external factors such as rain may be able to wash out trapped CO_2 from the air, but the continuing emission of the gas from the soil may lead to further accumulations during dry spells.

The authors recommended that the logging company refill all the holes and that knowledge of this tragedy be made more-widely known to cope with the dangers of toxic gases in volcanic areas. The authors also suggests that carbon isotopic analyses be carried out on the CO_2 released at Bakada to determine if it is of magmatic or biogenic origin.

References: Johnson, R.W., 1971, Bamus Volcano, Lake Hargy Area, and Sulu Range, New Britain: Volcanic Geology and Petrology: Bur. Miner. Resour. Aust. Rec. 1971/55.

Johnson, R.W., 1970a, Ulawan Volcano, New Britain: geology,petrology and eruptive history between 1915 and 1967: Bur. Miner. Resour. Aust. Rec. 1970/21.

Johnson, R.W., 1970b, Likuruanga volcano, Lolobau Island, and associated volcanic centres, New Britain: geology and petrology: Bur. Miner. Resour. Aust. Rec. 1970/42.

Mulina, K., and Taranu, F., 2006, Gas related deaths at Bakada village inside Likuranga volcano, West New Britain on 21st September 2006, report of Rabaul Volcano Observatory.

Watanabe, T. and Morita, M., 1998, Asphyxia due to oxygen deficiency by gaseous substances: Forensic Science International, v. 96, no. 1, p. 47-59.

Information Contacts: *Rabaul Volcanological Observatory (RVO)* (see Rabaul).

Michael

Saunders Island, South Sandwich Islands
57.78°S, 26.45°W; summit elev. 990 m
All times are local (= UTC - 2 hours)

Matt Patrick sent a new Advanced Spaceborne Thermal Emission and Reflection Radiometer (ASTER) image, collected 28 October 2006 over Saunders Island . In his opinion this is the best image collected to date owing to the lack of a plume obscuring the summit crater, which was a problem in all previous images. The improved image provides a clear view of the crater (figures 33 and 34).

Analyzing the VNIR, SWIR, and Thermal Infrared (TIR) (not shown in figures 33 or 34) images together shows that the outer crater is 500-600 m wide, with a 180m high-temperature crater interior. The latter shows up as an SWIR anomaly and may indicate the rough extent of active lava flow being ~ 180 m wide. Matt Patrick chose Villarrica volcano in Chile for comparison to Mt. Michael (figure 35) since it presents a potentially good analogue in terms of morphology and activity style. Maximum radiant heat flux values were similar (up to ~ 150 MW), suggesting that the maximum intensity of activity may be similar. Mt. Michael shows a much lower frequency of thermal alerts, which may be the result of more frequent cloud cover in the South Sandwich Islands or a greater depth to molten lava in the Mt. Michael crater.

Table 5 shows a summary of thermal anomalies and possible eruptions from Moderate Resolution Imagine Spectroradiometer (MODIS) satellites since November 2005. The last reported activity of Mount Michael was noted in the SI/USGS (Smithsonian Institution/U.S. Geological Survey) Weekly Volcanic Activity Report of 12-18 October 2005 (see *BGVN* 31:04). At that time the first MODVOLC alerts for the volcano since May 2003 indicated an increased level of activity in the island's summit crater and a presumed semi-permanent lava lake that appeared confined to the summit crater. Those alerts occurred on 3, 5, and 6 October 2005.

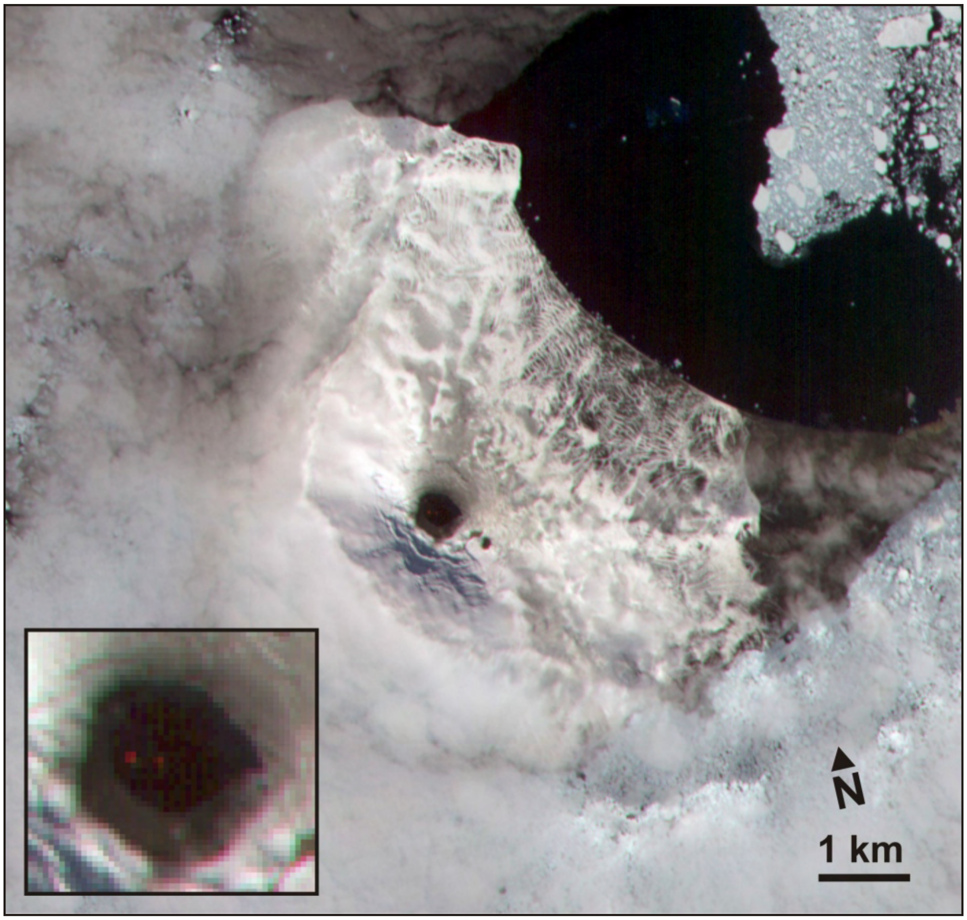

Figure 33. An ASTER image of Mt. Michael created using energy in the visible near-infrared wavelength ("VNIR"; bands 3-2-1, RGB), with the inset showing a closer view of the summit crater. There are two small near-IR anomalies (band 3, 0.807 microns wavelength) in the otherwise dark center of the crater, shown as red spots in the colored image. The two anomalies suggest very high temperatures and support the idea that fresh lava may reside at the surface or a shallow level in the crater. Courtesy of Matt Patrick.

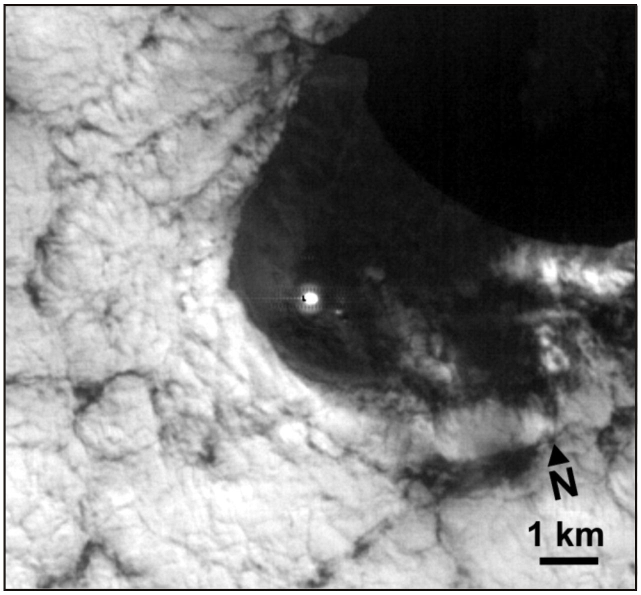

Figure 34. The ASTER Short Wave Infrared (SWIR; band 9, 2.4 microns) image with a conspicuous anomaly at the summit, with numerous saturated pixels. Courtesy of Matt Patrick.

References: Lachlan-Cope, T., Smellie, J.L., and Ladkin, R., 2001, Discovery of a recurrent lava lake on Saunders island (South Sandwich Islands) using AVHRR imagery: Journal of Volcanology and Geothermal Research, vol. 112, no. 1-4, p. 105-116 (authors are members of the British Antarctic Survey).

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

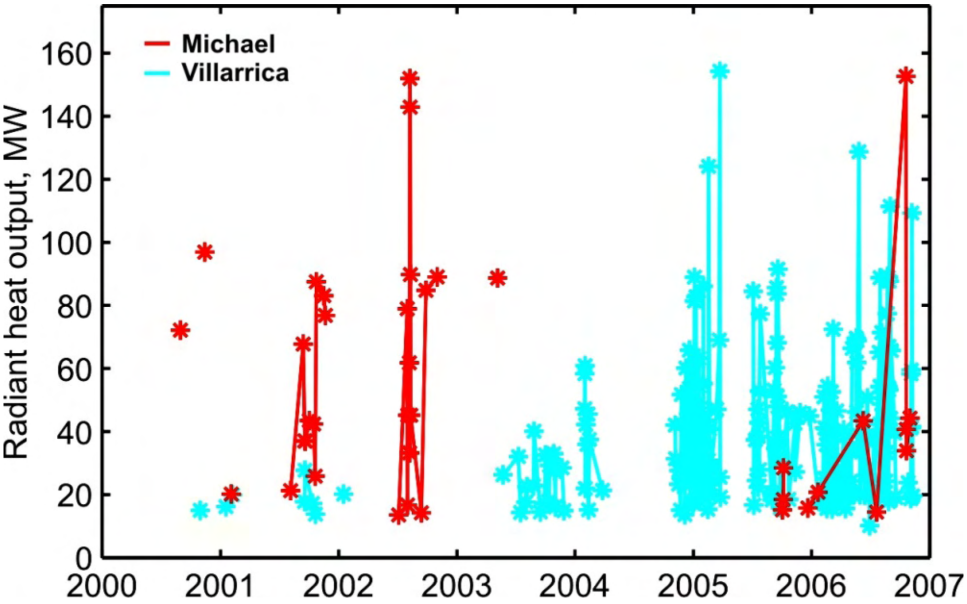

Figure 35. The real-time satellite thermal monitoring (MODVOLC) radiant heat flux values for Michael and Villarrica volcanoes during the period 2000-11 November 2006. Courtesy of Matt Patrick.

Date	Time (UTC)	Number of pixels	Satellite
01 Nov 2006	0125	1	Terra
31 Oct 2006	1600	1	Aqua
21 Oct 2006	1120	1	Terra
20 Oct 2006	0250	2	Aqua
20 Oct 2006	0100	3	Terra
21 Jul 2006	0120	1	Terra
09 Jun 2006	0920	2	Aqua
21 Jan 2006	0100	1	Terra
20 Dec 2005	0100	1	Terra
06 Oct 2005	0115	1	Terra
05 Oct 2005	0220	1	Aqua
03 Oct 2005	0045	1	Terra

Table 5. Thermal anomalies measured by MODIS satellites for Mount Michael for the period 3 October 2005 to 1 November 2006. All of the anomalies appeared on the SW side of the volcano. Courtesy of Hawai'i Institute of Geophysics and Planetology (HIGP) Thermal Alerts Team.

Geologic Summary. The young constructional Mount Michael stratovolcano dominates glacier-covered Saunders Island. Symmetrical 990-m-high Mount Michael has a 700-m-wide summit crater and a remnant of a somma rim to the SE. Tephra layers visible in ice cliffs surrounding the island are evidence of recent eruptions. Ash clouds were reported from the summit crater in 1819, and an effusive eruption was inferred to have occurred from a north-flank fissure around the end of the 19th century and beginning of the 20th century. A low ice-free lava platform, Blackstone Plain, is located on the north coast, surrounding a group of former sea stacks. A cluster of parasitic cones on the SE flank, the Ashen Hills, appear to have been modified since 1820 (LeMasurier and Thomson, 1990). Vapor emission is frequently reported from the summit crater. Recent AVHRR and MODIS satellite imagery has revealed evidence for lava lake activity in the summit crater of Mount Michael.

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