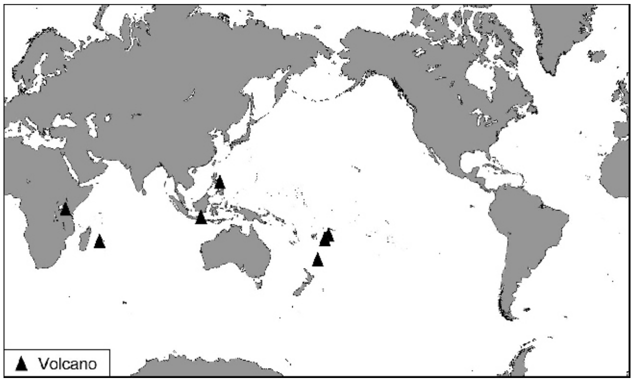
Bulletin of the Global Volcanism Network



Volume 34, Number 2, February 2009

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National Museum of Natural History

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The text of the *Bulletin* is also distributed through the Volcano Listserv (volcano@asu.edu).

Hunga Tonga-Hunga Ha'apai

Tonga Islands, SW Pacific
20.57°S, 175.38°W; summit elev. 149 m
All times are local (= UTC + 13 hours)

A new eruption from multiple vents on and near Hunga Ha'apai Island began producing ash and steam plumes sometime in the late afternoon of 17 March 2009. The early stage of the eruption was photographed by Steven Gates (figures 1 and 2) at 1804 on 17 March while flying from Vava'u to Tongatapu. Coordinates provided by the Chathams Pacific pilots accurately located the activity as being near the islands of Hunga Tonga and Hunga Ha'apai, about 55 km NNW of Tongatapu Island, where the capital, Nuku'alofa, is located. The pilots had not observed any activity on the way to Vava'u approximately 90 minutes earlier, nor did pilots on previous flights that morning.

According to Matongi Tonga news, the Tonga Defence Services reported the eruption to the Geological Division of the Ministry of Lands on 17 March. Government geologist Kelepi Mafi noted that "sharp tremors" had been recorded by their seismic instruments during the previous three weeks, though the seismicity could not be directly linked to the eruption. Quotes by Mafi indicated that, based on seismicity, the submarine eruption may have started on 16 March. However, initial reports of steam plumes seen on that day were incorrect, as were reports of the eruption being 10 km SW on Tongatapu.

As reported by Agence France Presse (AFP), radio journalist George Lavaka viewed the eruption from a game-fishing boat operated by Lothar Slabon on the afternoon of 18 March. He described an island completely covered in black ash, coconut tree stumps, and dead birds and fish in the surrounding water. Video and photographs taken by passengers on that boat clearly showed a submarine vent offshore to the S and another vent some distance away on the NW part of the island (figure 3). Activity increased during the hour that the boat was present, during which time both vents exhibited strong Surtseyan explosions (figure 4), an eruption type named for Surtsey volcano off the coast of Iceland. As the eruption from the offshore vent became stronger, the plume included larger amounts of steam, produced base surges along the ocean surface, and ejected bombs (figure 5). Fortunately the boat left the area just as the eruption escalated and volcanic bombs began falling around them.

A science team led by Mafi observed the eruption site at Hunga Ha'apai from a boat on 19 March. By that time, as reported by AFP, tephra had filled the gap between the submarine vent, originally about 100 m offshore, and the island, adding hundreds of square meters of land. Residents on Tongatapu reported orange glow from the eruption on the night of 19 March.

Figure 2. Closeup aerial photograph of the Hunga Ha'apai eruption at 1804 on 17 March 2009. Horizontal plumes on the ocean, tephra fallout, and discolored water can be seen. Courtesy of Steven Gates.

Aviation reports. A New Zealand Dominion Post article on 19 March noted that flights were disrupted and rerouted around the activity following warnings from Airways New Zealand and MetService NZ.

The Wellington VAAC issued an aviation notice on 18 March based on ground observations from the Tongatapu airport of a plume rising to an altitude of 7.6 km at 0659 that morning; ash was not seen in satellite data. Later that day, at 1330, a plume seen on MODIS satellite imagery was within 1 km of the vent and moving NE. A similar plume was reported based on MODIS and ground observations to an altitude of 4.5 km at 1600. Airport observers continued

Figure 1. Aerial photograph showing the eruption plume from Hunga Ha'apai island at 1804 on 17 March 2009. The island of Hunga Tonga is the dark linear feature at lower right. Courtesy of Steven Gates.

to report a plume to 5 km altitude at 1000 on 19 March, and to 4 km at 1700, but with a band of ash extending 2.5 km NE from the volcano to 2.4 km altitude.

D. Tait, a pilot for Air Chatham, noted that at 1700 on 19 March frequent eruptions were ejecting black ash, sometimes to a height of 300 m. The main white eruption plume was rising to about 4 km altitude and drifting ENE, to a distance of almost 500 km as seen in MODIS satellite imagery. He also observed that widespread ash and haze was trapped below an inversion layer at about 2 km altitude. On 20 March, a VAAC report at 1140 indicated a steam plume to 4 km but no visible eruption.

Pilot Tait reported that at 1015 on 21 March the island was covered by weather clouds, the crater was not visible, and there was no vertical plume; haze was again below an inversion layer at 1.5 km altitude. No eruptions were seen during the 15 minutes the island was visible on the return flight around 1250. However, steaming continued, with the plume rising to 1.8 km altitude. A new eruptive episode was reported by Tongatapu airport observers at 1409 on 21 March that sent an ash plume 800 m high.

Figure 3. Photograph of a steam-and-ash plume rising from Hunga Ha'apai Island and a submarine vent to the S erupting black tephra. View is looking NW on 18 March 2009. Photo from unknown photographer on the Sloban boat provided by Dana Stephenson/Getty Images on boston.com.

Figure 5. Photograph of the offshore Hunga Ha'apai vent during a strong eruptive event on 18 March 2009. Bombs with trailing ash plumes can be seen falling from the eruption cloud, which is producing base surges along the ocean surface. Photo from unknown photographer on the Sloban boat provided by Dana Stephenson/Getty Images on boston.com.

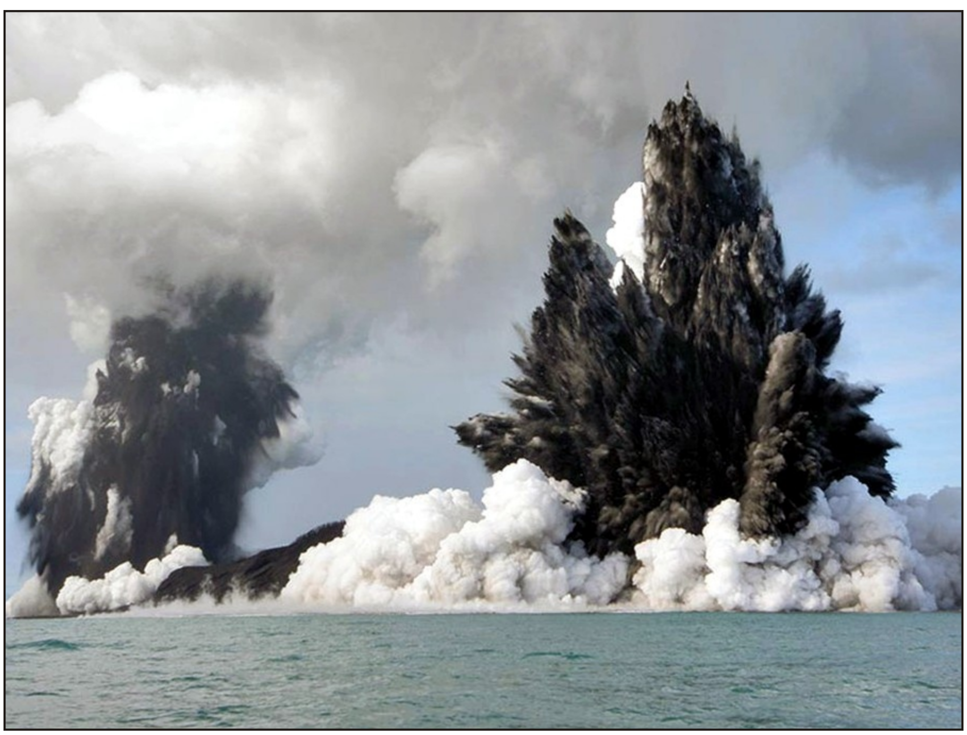

Figure 4. Photograph showing dark ash-laden Surtseyan eruption plumes from both Hunga Ha'apai vents. View is looking NNE on 18 March 2009. Photo from unknown photographer on the Sloban boat provided by Dana Stephenson/Getty Images on boston.com.

Geologic Summary. The small islands of Hunga Tonga and Hunga Ha'apai cap a large seamount located about 30 km SSE of Falcon Island. The two linear andesitic islands are about 2 km long and represent the western and northern remnants of the rim of a largely submarine caldera lying east and south of the islands. Hunga Tonga and Hunga Ha'apai reach an elevation of only 149 m and 128 m above sea level, respectively, and display inward-facing sea cliffs with lava and tephra layers dipping gently away from the submarine caldera. A rocky shoal 3.2 km SE of Hunga Ha'apai and 3 km south of Hunga Tonga marks the most prominent historically active vent. Several submarine eruptions have occurred at Hunga Tonga-Hunga Ha'apai since the first historical eruption in 1912.

Information Contacts: *Steven Gates*, Tradewind Island Sailing, Private Bag 63, Neiafu, Vava'u, Tonga (URL: http://www.manuoku.com/); *Wellington Volcanic Ash Advisory Centre (VAAC)*, Meteorological Service of New Zealand Ltd (MetService), PO Box 722, Wellington, New Zealand (URL: http://www.metservice.com/vaac/, http://www.ssd.noaa.gov/VAAC/OTH/NZ/messages.html); *The Dominion Post* (URL: http://dompost.co.nz/); *Matongi Tonga Online*, PO Box 958, Nuku'alofa,

Tonga (URL: http://www.matangitonga.to/); *Agence France Presse (AFP)* (URL: http://www.afp.com/); *The Boston Globe*, Boston, MA, USA (URL: http://www.boston.com/).

Tofua

Tonga Islands, SW Pacific
19.75°S, 175.07°W; summit elev. 515 m
All times are local (= UTC +13 hours)

An increased number of satellite-based MODVOLC thermal alerts occurred at Tofua (figure 6) on nine days during March to November 2008, as compared with alerts on three days in 2004, none in 2005 or 2006, two days in 2007, and one day in 2009 (as of 5 April). All of these infrared-derived alerts have been in the same area, a zone several kilometers N of the lake near the 5-km-diameter caldera's N rim, a region where numerous cones and craters reside. One or more of those cones was steaming in a 1990 image. In that image, this area appears steep and largely rocky, an unlikely location for repeated fires (figure 7). Eyewitness views of glow, scoria and spatter ejections from in the crater of Lofia cone during 1993, 2004, and 2009 suggest that at least some if not all the MODVOLC alerts are credible signatures reflecting the minimum level of volcanism at Tofua.

Previous reports in the *Bulletin* on Tofua covered aspects of activity during portions of 1979, 2000, and 2006 (*SEAN* 04:06, 04:12; *BGVN* 26:12, and 31:06, respectively). Taylor and Ewart (1997) compiled a chronology of Tongan eruptions.

Observations during 1993. Mary Lyn Fonua sent the following summary regarding a visit to Tofua in 1993. "It was quite a long time ago that we did a photographic feature on Tofua in May 1993 for our *Eva* magazine. Pesi, my husband, went there on [29 April 1993] on a two seater amphibian aircraft piloted by Peter Goldstern that landed on the crater lake. There was a smoking vent on the side of the volcano and thick yellowish smoke pouring out of the wall of the crater. They felt the island rumbling. There were hot thermal pools to bathe in. I seem to remember Pesi saying that ... it was possible to see a glow from volcanic activity in the crater at night. About 10 people were living on the island at the time, on the southern tip of the island .... There was forest and scrub on some parts of the island."

The above description of visible glow presumably came from the Lofia vent area just N of the lake. Vegetation and permanent or itinerant inhabitants suggests that some of the outlying thermal alerts discussed below might have been false-positives due to fires. Nicole Keller, of Woods Hole Oceanographic Institution, also notes that Tongans often communicate from island to island using fires.

Observations during 2004. Nicole Keller sent the following information about her October 2004 visit. "The only fumaroles were located inside Lofia crater–not at all accessible. None of the other, smaller cones around Lofia were active in any way (no obvious signs of degassing, no sulfur smell), but definitely had some alteration features that suggest they were hydrothermally altered in the past. Every few minutes there was a rumbling, and every now and again (1-time to 2-times per hour) there was a bigger explosion projecting juvenile scoria over the crater rim." Similar activity was seen by John Caulfield in May 2006 (*BGVN* 31:06), but without the scoria showers.

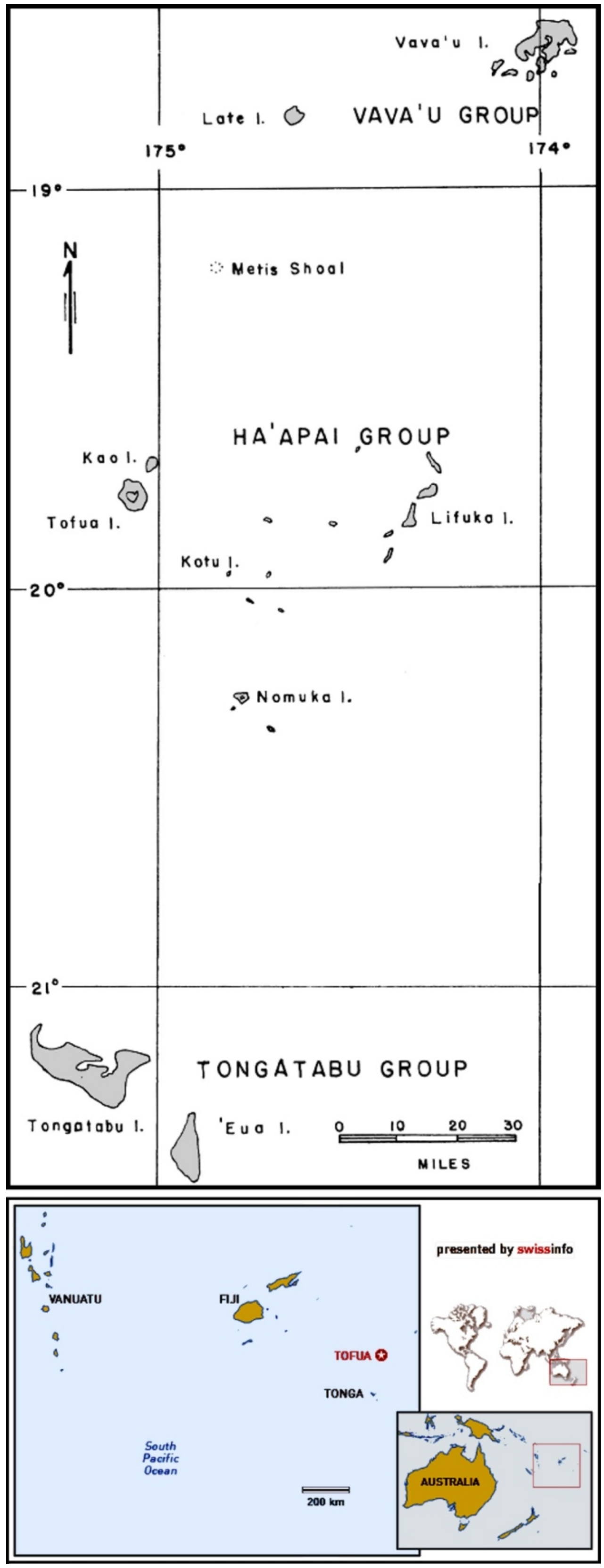

Figure 6. A set of index maps and a larger map of the main part of the Tonga Archipelago. The latter shows the location of Tofua Island in the western part of the Ha'apai Island Group. From Bauer (1970).

Figure 7. Aerial photograph of Tofua volcano showing the steaming Lofia cinder cone. Courtesy of the Tonga Ministry of Lands, Survey, and Natural Resources, 1990 (published in Taylor and Ewart, 1997).

Date (UTC)	Time (UTC)	Pixels	Satellite
19 Mar 2004	1020	1	Terra
10 May 2004	1300	1	Aqua
29 May 2004	1025	1	Terra
15 Mar 2007	0125	1	Aqua
22 May 2007	1025	3	Terra
07 Mar 2008	1015	1	Terra
07 Mar 2008	1320	1	Aqua
21 Jun 2008	1050	2	Terra
21 Jun 2008	2145	1	Terra
22 Jun 2008	1305	2	Aqua
23 Jun 2008	1040	1	Terra
04 Jul 2008	1020	1	Terra
22 Aug 2008	0140	1	Aqua
23 Aug 2008	0045	1	Aqua
20 Nov 2008	1310	2	Aqua
21 Nov 2008	1045	1	Terra
08 Mar 2009	1030	1	Terra

Table 1. Satellite thermal alerts (MODVOLC) for Tofua volcano from 19 March 2004 through 6 April 2009. No alerts were measured between 30 May 2004 and 14 March 2007. Courtesy of HIGP Thermal Alerts System.

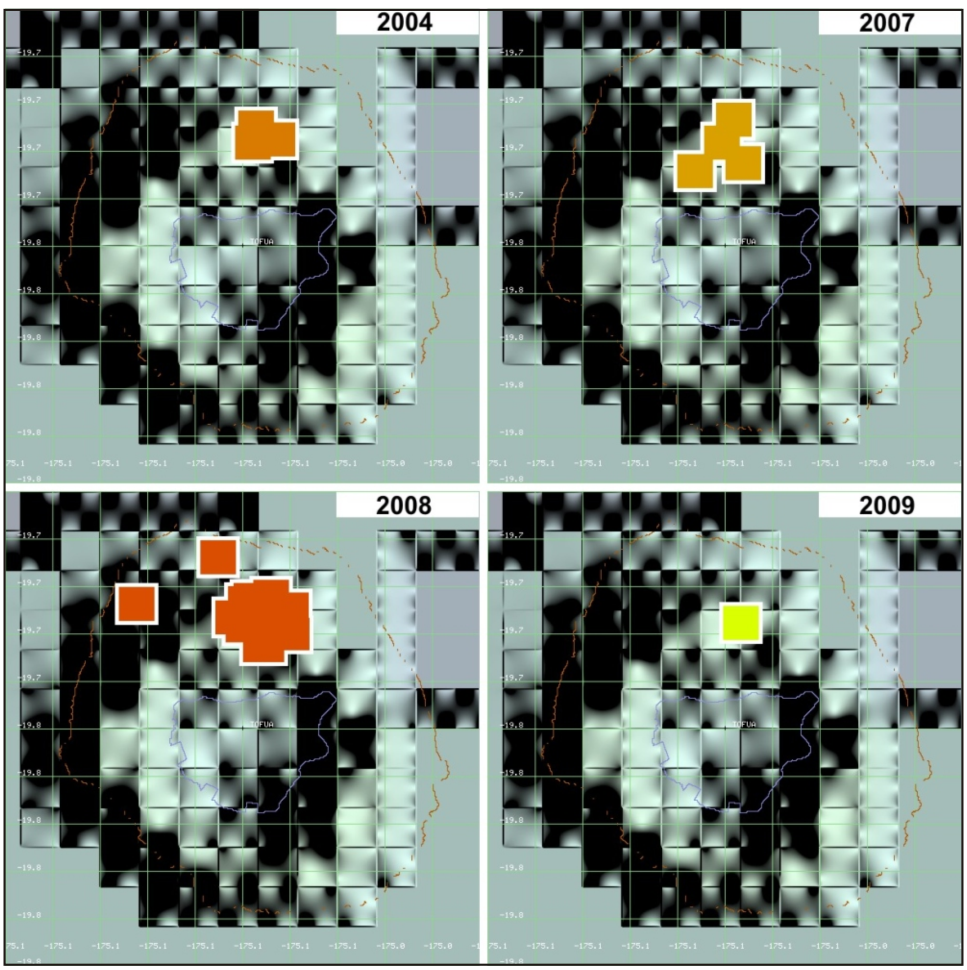

Figure 8. Graphic depiction (by year) of satellite thermal alerts (MODVOLC) for Tofua volcano from 19 March 2004 through 6 April 2009. No alerts were measured between 30 May 2004 and 14 March 2007. Images show alerts during 2004, 2007, 2008, and 2009. Courtesy of HIGP Thermal Alerts System.

MODVOLC data, 2004-2009. Satellite thermal data over Tofua revealed the absence of thermal alerts between 30 May 2004 and 18 March 2007. The MODVOLC alerts mentioned above began 19 March 2004 (table 1 and figure 8). The maps reveal repeating alerts at and adjacent to the N-caldera cone (Lofia). The October 2004 *in-situ* observations from Keller confirm that the 19 March and 10 and 29 May 2004 MODVOLC alerts were probably due to volcanism. Given the pattern of small ongoing eruptions from a deep crater at Lofia as discussed by visitors during 1993, 2004, and at some point during 2008-2009, it is likely most of the MODVOLC alerts reflect volcanism at Tofua.

The HIGP Thermal Alerts System listed approximately 190 pixels ~ 45 km SE of Tofua Island on 17 January 2009. Rob Wright of the MODIS/MODVOLC team explained that these were artifacts over the ocean due to reflected sunlight (see http://modis.higp.hawaii.edu/daytime.html). “The last field in the MODVOLC text alert file is a sunglint vector. When this number is over 12 degrees it means that the MODIS sensor was ‘looking’ within 12 degrees of the specular angle (like being blinded by a mirror when the sun-mirror-eye angle is just right). In this case the mirror is the water surface. We leave them off the map because they are not real hot-spots. We leave them in the text alert file because our 12 degree threshold errs on the side of caution, and other workers may want to use a less restrictive threshold." On the date in question the glint vector was between 1 and 3.

Observations during March 2009. Swiss adventurer Xavier Rosset reported a clear description of minor eruptive activity at Tofua. His audio dialog, posted 13 March 2009, referred to his visit to the active cone during the preceding week, although the exact date of observation was unclear. At that time the crater was about 80-100 m deep and the same in diameter. Three openings of undetermined size displayed an orange glow. Lava ejections from these vents rose 10-50 m high and were accompanied by loud noises. Photos taken by Rosset (figures 9 and 10) show the active cone with lava in the bottom. Rosset's 27 March 2009 dialog discusses a strong earthquake in the region (Mw 7.6 on 20 March, centered ~ 45 km SE of Tofua), which caused several rockfalls on the island. He visited the volcano in the afternoon and, looking into the active crater, saw few noticeable changes.

Figure 9. Photo of Xavier Rosset in front of the active Lofia cinder cone at Tofua, March 2009. The caldera lake resides in the background. Courtesy of X. Rosset.

Figure 10. Photo looking down into the vertical-walled Lofia crater to an orange-colored, circular zone of lava on the floor, March 2009. Courtesy of X. Rosset.

References: Bauer, G.R., 1970, The Geology of Tofua Island, Tonga: Pacific Science, v. 24, no. 3, p. 333-350.

Morrison, C., 29 May 2008, Xavier Rosset, 300 days alone on an island: The Islomaniac website (http://www.the-islomaniac.com/).

Taylor, P.W., and Ewart, A., 1997, The Tofua Volcanic Arc, Tonga, SW Pacific: a review of historic volcanic activity: Aust Volc Invest Occ Rpt, 97/01, 58 p.

Geologic Summary. The low, forested Tofua Island in the central part of the Tonga Islands group is the emergent summit of a large stratovolcano that was seen in eruption by Captain Cook in 1774. The first Caucasian to set foot on the 515-m-high island was Capt. William Bligh in 1789, just after the renowned mutiny on the *Bounty*. The volcano's summit contains a 5-km-wide caldera whose walls drop steeply about 500 m. Three post-caldera cones were constructed at the northern end of a cold fresh-water caldera lake, whose surface lies only 30 m above sea level. The easternmost cone has three craters and produced young basaltic-andesite lava flows, some of which traveled into the caldera lake. The largest and northernmost of the cones, Lofia, has a steep-sided crater that is 70 m wide and 120 m deep and has been the source of historical eruptions, most recently during 1958-1960. The fumarolically active crater of Lofia has a flat floor formed by a ponded lava flow.

Information Contacts: *Hawai'i Institute of Geophysics and Planetology (HIGP) Thermal Alerts System*, School of Ocean and Earth Science and Technology (SOEST), Univ. of Hawai'i, 2525 Correa Road, Honolulu, HI 96822, USA (URL: http://hotspot.higp.hawaii.edu/); *Mary Lyn Fonua*, Matangi Tonga Online, Vava'u Press Ltd., Tonga (URL: http://www.matangitonga.to/); *Xavier Rosset* (URL: http://www.xavierrosset.com/); *Paul W. Taylor*, Australian Volcanological Investigations, P.O. Box 291, Pymble, NSW, 2073 Australia (URL: avitaylor@mpx.com.au); *Nicole S. Keller*, Department of Geology and Geophysics, Woods Hole Oceanographic Institution, Woods Hole, MA, USA.

Curtis Island

Kermadec Islands, SW Pacific
30.542°S, 178.561°W; summit elev. 137 m
All times are UTC

Olivier Hyvernaud reported that recent T-phase waves, recorded by the Laboratoire de Géophysique in Tahiti, originated from near Curtis Island (figure 11) and had waveforms suggesting a volcanic origin. The first of these hydroacoustic waves recorded on the Polynesian seismic network were a brief swarm of seven short strong events on 17 January 2009. On that day the network received the signals between 1706 and 1717 UTC. In addition, a single event was received 19 January 2009 at 0753 UTC. The best preliminary location for these events was 30.49°S, 178.55°W, a position 5-6 km NNE of Curtis Island and well within the area of the larger caldera structure.

On the New Zealand GNS Science website there is a brief discussion and two photos of Curtis Island, noting a short visit there, thermal activity, nearby mineral-rich volcanoes, and that it lies adjacent to a chain of submarine volcanoes (eg. Smith, 1988). They also stated "The benefit in studying this remote outcrop is the insight it gives into the composition of these underwater vents, while being relatively straightforward to measure in comparison."

On 1 April 2009 Brad Scott (GNS) added that they were not aware of any activity at this time. The island is remote and GNS personnel do not visit on a regular basis. The activity on the island is solfataric. He also noted that the island is composed of pyroclastic-flow (ignimbrites) deposits from an unknown nearby source.

No thermal alerts have been measured by the MODVOLC system for Curtis Island since at least the beginning of 2004 and through 1 April 2009.

References. Smith, I., 1988, The geochemistry of rock and water samples from Curtis Island volcano, Kermadec group, southwest Pacific: Journal of Volcanology and Geothermal Research, v. 34, no. 3-4, p. 233-240.

Geologic Summary. Curtis and nearby Cheeseman Island are the uplifted portion of a submarine volcano astride the Kermadec Ridge. The age of the small islands is considered to be Pleistocene, and rocks consist dominantly, if not entirely, of andesitic pyroclastic-flow deposits (Lloyd, 1992). Curtis Island, only 500 x 800 m in diameter and 137-m high, contains a large, fumarolically active crater whose floor is only 10 m above sea level. Reports of possible historical eruptions probably represent episodes of increased thermal activity. Geologic studies have documented a remarkable uplift of 18 m of Curtis Island during the past 200 years, with 7 m of uplift occurring between 1929 and 1964 (Doyle et al., 1979). An active submarine magmatic or solfataric vent is believed to exist near Curtis Island, but its activity cannot unequivocally be associated with Curtis volcano (Lloyd, 1992).

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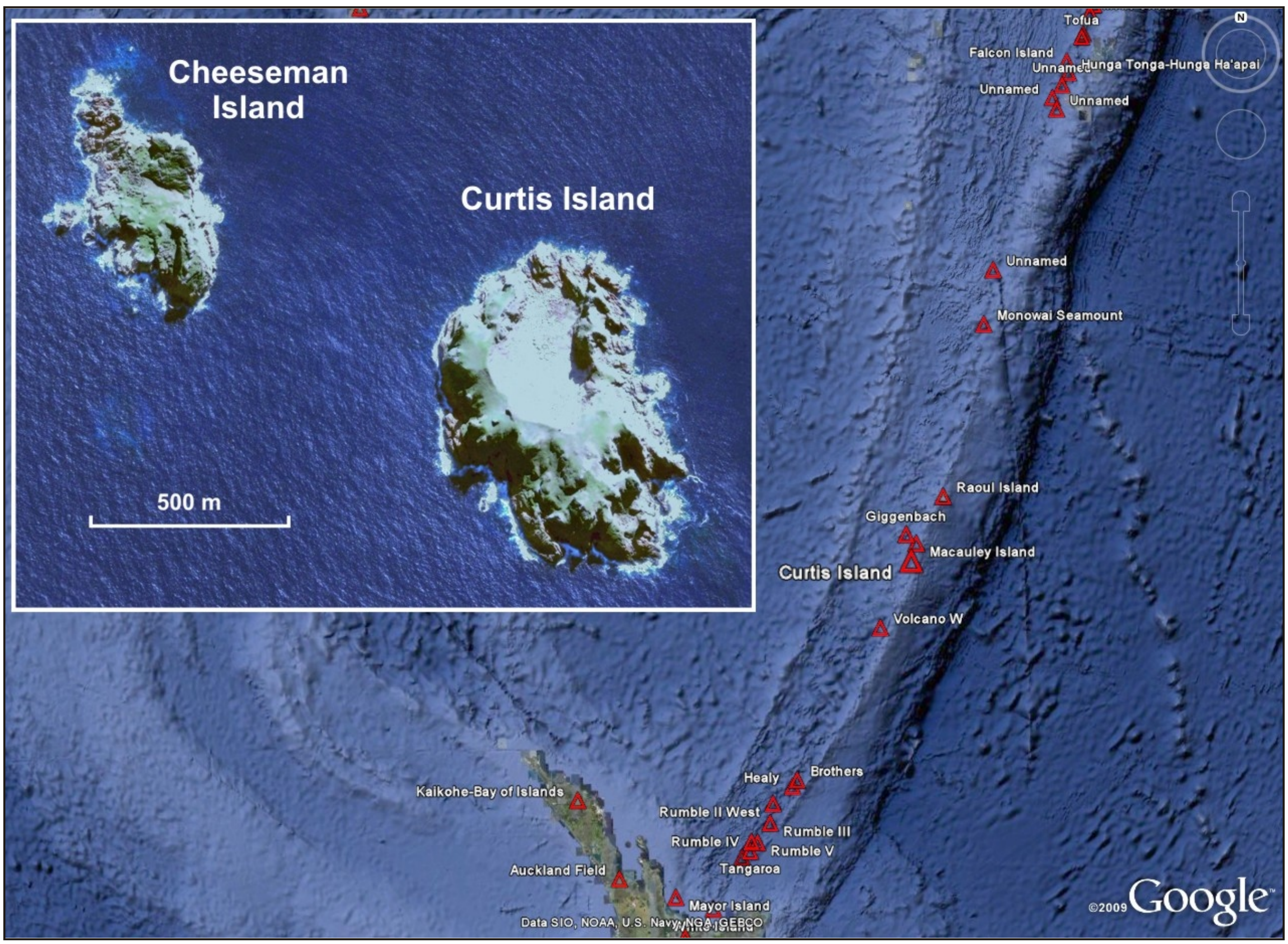

Figure 11. Satellite imagery showing Curtis and Cheeseman Islands (inset) along the Kermadec Island chain north of New Zealand. Curtis Island is approximately 900 km NE of New Zealand. Volcano locations from GVP database. Inset map image acquired 10-11 May 2006 by DigitalGlobe. Imagery courtesy of Google Earth.

Ijen

Java, Indonesia
8.058°S, 114.242°E; summit elev. 2,799 m
All times are local (= UTC + 7 hours)

Our previous report on Ijen (*BGVN* 32:09) discussed the findings of a field visit during 6 July-2 August 2007 by researchers from Simon Fraser University, McGill University, and the Institut Teknologi Bandung (ITB). During their visit, this team documented degassing and increasing fumarole temperatures.

This team again conducted fieldwork at Ijen during 18 July-7 August 2008. This report discusses their findings. The East Java volcano is the scene of sulfur mining and a highly acidic lake.

Fumarole mound. In comparison to 2007, the fumarole mound of Kawah Ijen had changed substantially. The sulfur mining company had installed new pipes and constructed supporting walls. Combined with frequent spraying of water to cool the pipes, this has completely changed the surface coating of the mound. Furthermore, changes at the dome were noted. One area was flat in 2007, but sub-vertical in 2008, indicating an uplift of approximately 1 m. Uplift was also apparent in other areas, but could not be quantified.

Temperatures of the fumaroles were similar to those recorded in 2007. The exit temperature at the pipes varied between 150 and 230ºC, with the highest values at pipes in flaming fumaroles (occasional flaming at pipe exits was observed when wind speed was low). Fumarole temperatures varied from 300ºC (white fumes) to more than 580ºC (flaming), but were highly variable with the weather conditions.

New fumarolic activity was observed W of the fumarole mound, both on the slope leading down to the lake and on the flank of the escarpment bordering the mound on the W (figure 12). According to the sulfur miners, these fumaroles appeared at the end of summer 2007. Temperatures were between 90 and 96ºC and the fumaroles were coated in sulfur needles (figure 12). The location suggests a westward migration of the system.

Giggenbach-bottles, condensates, silica tubes, and rock samples were collected on the fumarole mound. Measurements of SO_2, CO_2, and H_2O in the fumes at the foot of the fumarole mound were also made using a multi-gas instrument (Shinohara, 2005).

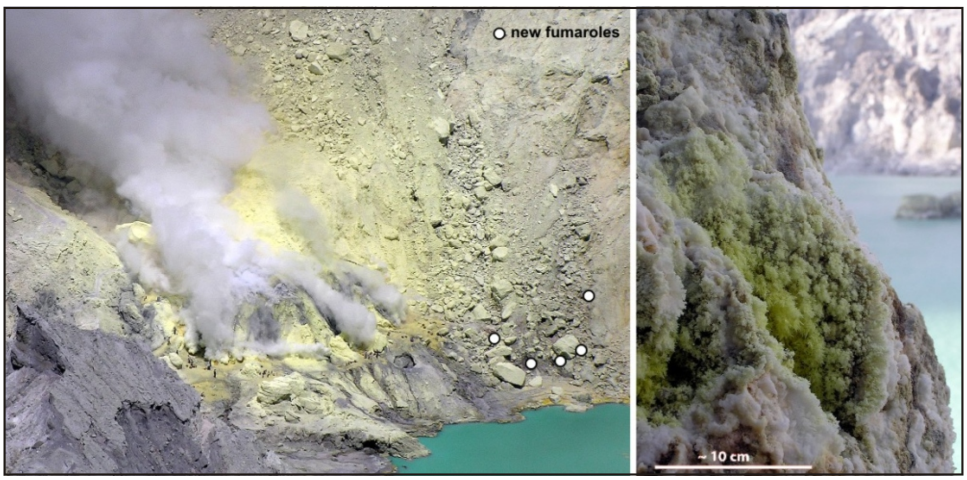

Figure 12. (left) Overview of the Kawah Ijen fumarole mound showing the locations of the new fumaroles (small dots). (right) Close up (with scale) of one of the new fumaroles on the flank of the escarpment bordering the mound on the W. Courtesy of the McGill University, Simon Fraser University, and the Institut Teknologi Bandung (ITB) research team.

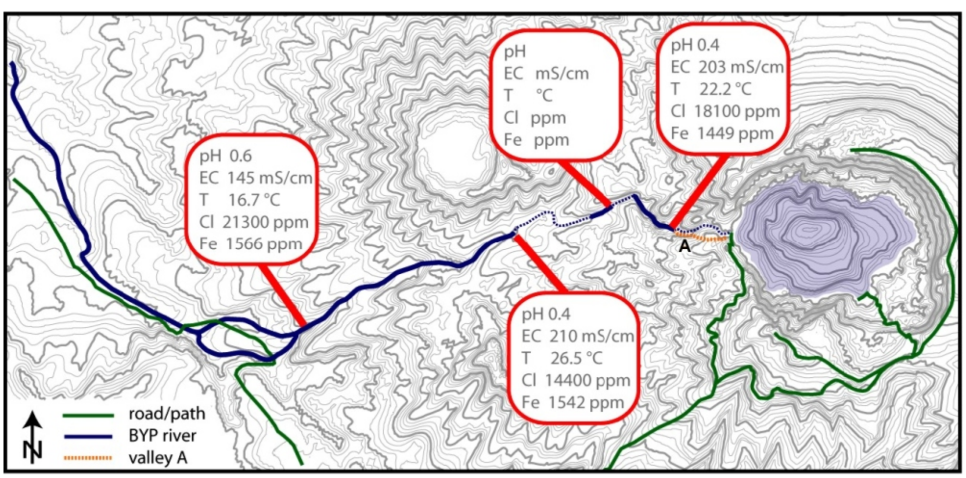

Figure 13. Overview map of Ijen showing the upstream part of the Banyu Pahit river, including locations of various springs as well as the pH, temperature (T), and EC of the water. The Cl and Fe content was determined by colorimetry. Courtesy of the McGill University, Simon Fraser University, and the Institut Teknologi Bandung (ITB) research team.

Gas ratios and flux measurements. The ratios of $H_2O/CO_2/SO_2$ gases in the fumarole gases were measured using a portable multi-gas sensor built at Simon Fraser University. A Licor IR spectrometer measured CO_2 concentrations, an InterScan electochemical cell sensor measured SO_2 contents, and a Vaisala P-T-RH weather station measured the H_2O content of the plume. When compared to magmatic gas ratios estimated from undegassed melt inclusion data, the fumarole gases appear to span a range from relatively dry (H_20-poor) and CO_2-enriched compositions to H_2O-enriched, CO_2-poor compositions. All gas compositions were highly depleted in SO_2.

Giggenbach gas samples from previous surveys (VSI unpublished data, Delmelle and Bernard, 2000) confirm that the gases from the mound have variable H_2O/CO_2 ratios. This trend cannot be explained by mixing of the gases with various amounts of atmosphere because nitrogen contents in the gas phase do not correlate. The Giggenbach data also confirms that the gases were depleted in total sulfur (SO_2 + H_2S + minor species) relative to magmatic ratios. These observations were consistent with the precipitation of sulfur-bearing compounds in the lake (Delmelle and Bernard, 2000).

The total flux of SO_2 gas from the fumarole mound was measured using a FLYSPEC (portable UV spectrometer) and averages 200 tons/day. This translates to an average of 720 tons/day of CO_2 and 3,900 tons/day of H_2O released into the atmosphere. Combining the SO_2 flux with the S_{total}/element ratios in the gas measured with the Giggenbach bottles, the authors estimated the flux of certain metals and halogens into the atmosphere to be 10 tons/day Cl, 25 g/day Hg, and 1,000 g/day Se.

Lake and Banyu Pahit river. Crater lake conditions were the same as last year. Lake level was approximately 10 cm higher, water temperature at the foot of the fumaroles was 37-39ºC and pH and electrical conductivity (EC) were -0.01 and 312.6 mS/cm, respectively. The acid spring in the valley next to the fumarole mound was also unchanged, with a temperature of 50ºC, pH of 1.72, and EC of 20.1 mS/cm. Measurements of the gas bubbling up from the springs indicated that it contained more than 100 ppm SO_2 and 2 wt. % CO_2.

The team conducted a transect along the Banyu Pahit river from the dam on the western end of the lake, to where it meets the Paltuding-Pelalangan road. This revealed that the actual source of the river is a set of springs about half-way along this transect (figure 13), with the water emerging from a cliff on the E flank of the valley from between two lava flows. Two sets of earlier springs are present, one immediately below the dam with abundant gypsum deposits, and another where the first valley from the E merges with the Banyu Pahit (valley A in figure 13).

Mapping along this transect revealed a thick sequence of phreatic, phreatomagmatic, and lahar deposits, as well as three distinct lava flows. Tracing these deposits upstream shows that they descended the Banyu Pahit valley, except for the most upstream part, where they follow valley A instead. This valley is blocked by a lava flow where it meets the lake, indicating that this flow postdates the deposits in the valley and that the section of the Banyu Pahit river immediately below the dam is relatively recent. The position of the second set of springs at the end of valley A may indicate that fluids are still making use of this original valley.

The team collected numerous samples of spring water, Banyu Pahit water, rocks and sediments along this part of the river to determine its sources and pathways. Preliminary field measurements are shown in figure 13.

Geophysical changes, summer 2006-2008. The gravity and differential GPS network of nine stations spread around the active crater, one at Paltuding and one at the volcanic observatory outside Ijen caldera were re-occupied each year. While no significant vertical deformation was observed on any of the stations, the dynamic gravity shows very strong variations between each year (figure 14). The mean error on gravity data was around 20 microGal, while the largest error was always less than 80 microGal. Between 2006 and 2007, the gravity change was of ~ 1,200 microGal (~ 1.2 mGal) and at the summit between 2007 and 2008 at ~ 300 microGal. This is in contrast to the "typical" gravity change of tens to hundreds microGal seen on active volcanoes (e.g., Rymer and others, 2005). At Ijen these changes are attributed to underground and surface water. Three arguments support this hypothesis, as follows.

First, Kawah Ijen hosts a large and deep lake (~ 30×10^6 m^3) (Takano and others, 2004), whose surface level changes over the years. While the survey was made during the dry season each year, there was still some change visible on shoreline of the lake. No accurate measurements were made until summer 2008.

Second, the water table, located on the E flank, flows towards the lake. No data of water depth existent for this water table, but the water flow generates a natural electrical current, which were measured each year by self-potential. As with the gravity variation, similar changes were observed on the electrical profile around the active crater. Between 2006 and 2007, a significant decrease of the SP anomalies (~ 120 mV) on the N and E crater rim was observed. (*BGVN* 32:09), while between 2007 and 2008, these anomaly increased (~ 70 mV) to an intermediate level, between 2006 and 2008.

Third, no significant deformation was observed since 2006 on the summit of Kawah Ijen.

The geophysical survey indicated that both gravity (figure 14) and self-potential (*BGVN* 32:09) show compatible variations during 2006-2008. There was a decrease of both gravity and self-potential between 2006 and 2007, followed by an increase between 2007 and 2008. This finding sug-

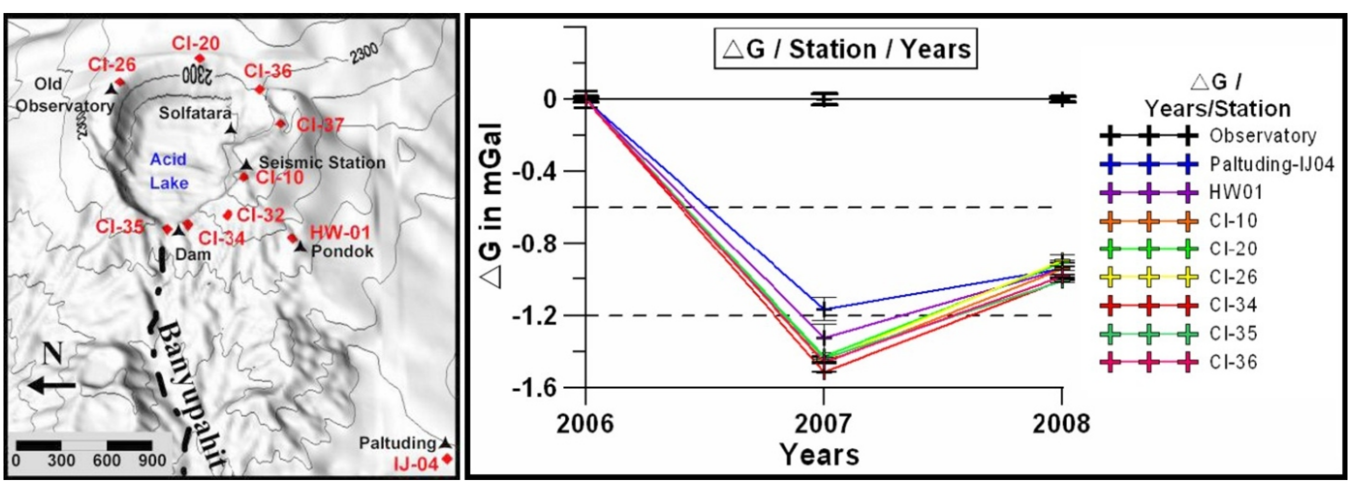

Figure 14. (left) Gravity survey stations from summer 2006 to summer 2008 on Kawah Ijen. The observatory station is the reference station, which was located outside the Ijen caldera at the volcanic observatory (SE corner of map). Stations labeled CI are around the crater rim. (right) Changes in gravity (G, in milliGals) at for nine stations with respect to the years 2006-2008. Courtesy of the McGill University, Simon Fraser University, and the Institut Teknologi Bandung (ITB) research team.

gests that these variations were due to changes of the lake and fresh groundwater flowing from Gunung Merapi toward Kawah Ijen lake.

References: Delmelle, P., and Bernard, A., 2000, Downstream composition changes of acidic volcanic waters discharged into the Banyupahit stream, Ijen caldera, Indonesia:Journal of Volcanology and Geothermal Research, v. 97, p. 55–75.

Rymer, H., Locke, C.A., Brenes, J., and Williams-Jones, G., 2005, Magma plumbing processes for persistent activity at Poás Volcano, Costa Rica: Geophysical Research Letters, v. 32, p.. L08307, doi:10.1029/2004GL022284.

Shinohara, H., 2005, A new technique to estimate volcanic gas composition: plume measurements with an estimate of volcanic gas composition: plume measurements with a portable multi-sensor system: Journal of Volcanology and Geothermal Research, v. 143, p. 319-333.

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

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Mayon

Luzon, Philippines
13.257°N, 123.685°E; summit elev. 2,462 m
All times are local (= UTC + 8 hours)

Our last report on Mayon (*BGVN* 32:05) discussed an eruption from 13 July to early October 2006, along with deadly lahars down Mayon's flanks caused by a typhoon that struck the Philippines on 30 November 2006. On 25 October 2006, the Philippine Institute of Volcanology and Seismology (PHIVOLCS) lowered the hazard status to Alert Level 1 (low level unrest).

The U.S. Air Force Weather Agency (AFWA) reported that an eruption had occurred on 4 June 2007. It sent a steam-and-ash plume seen on satellite imagery up to 4 km altitude, which blew toward the SW.

There were no further reports on Mayon until August 2008. On 10 August PHIVOLCS reported a mild explosion that produced an ash plume that rose to an altitude of 2.7 km and drifted ENE. According to PHIVOLCS, seismic activity during the weeks before the explosion had increased slightly and incandescence at the crater had intensified. Some inflation of the volcanic edifice also was apparent. The seismic network recorded the ash ejection as an explosion-type earthquake that lasted for one minute. Immediately after the explosion, visual observation becomes hampered by the thick clouds. Precise leveling surveys during 10-22 May 2008 compared to 17 February-2 March 2008 showed the edifice inflated.

A news account in *The Philippine Star* described the explosion as phreatic and ash bearing, based on discussions with PHIVOLCS staff.

Geologic Summary. Beautifully symmetrical Mayon volcano, which rises to 2,462 m above the Albay Gulf, is the Philippines' most active volcano. The structurally simple volcano has steep upper slopes averaging 35-40 degrees that are capped by a small summit crater. The historical eruptions of this basaltic-andesitic volcano date back to 1616 and range from strombolian to basaltic plinian, with cyclical activity beginning with basaltic eruptions, followed by longer term andesitic lava flows. Eruptions occur predominately from the central conduit and have also produced lava flows that travel far down the flanks. Pyroclastic flows and mudflows have commonly swept down many of the approximately 40 ravines that radiate from the summit and have often devastated populated lowland areas. Mayon's most violent eruption, in 1814, killed more than 1200 people and devastated several towns.

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Piton de la Fournaise

Réunion Island, Western Indian Ocean
21.231°S, 55.713°E; summit elev. 2,632 m
All times are local (= UTC + 4 hours)

This report summarizes the caldera collapse and extensive lava effusion at Piton de la Fournaise (PdF) during May-June 2007 and events beginning in August 2008, which led to a new eruption on 12 September 2008. Additional eruptive activity and unrest continued into January 2009.

Observations from 2007. A caldera collapse during early April 2007 (*BGVN* 32:12) deepened and enlarged to a depth of 350-360 m to engulf most of the Dolomieu crater floor. Peltier and others (2007; and in press) noted that the area of collapse encompassed 82 x 10^4 m^2, an area 11% larger than the crater prior to April 2007. Post-collapse calculations by the Observatoire Volcanologique du Piton de la Fournaise / Institut de Physique du Globe de Paris (OVPDLF/IPGP) indicated that the caldera's downward movement involved a volume of 120 million cubic meters. On the SE flank lava flows up to 30-40 m thick and covered an estimated 4 km^2, making this event one of PdF's largest historical eruptions. The collapse changed the stability of the summit massif; as a result, during most of 2007, access to Dolomieu was prohibited due to the high risk of collapse of the crater walls.

OVPDLF reported that the eruption ceased on 1 May 2007 but that seismicity continued during 2-7 May at and below the summit, and also indicated a large number of landslides from the Dolomieu crater walls. Two earthquakes occurred on 4 May; one was M 3.8. Light tremor and several significant earthquakes persisted throughout May and were considered to be the result of a collapse at depth. GPS information showed a contracting of Dolomieu. The larger summit earthquakes, observed since the end of April, were considered to be precursors of such a movement. On 13 May a helicopter pilot reported that part of the edge of the crater had fallen.

There were no major events until 20 June 2007 when a large number of earthquakes were recorded, including several below sea level. Throughout the rest of 2007 and the first half of 2008, PdF remained relatively quiet.

Observations from 2008. Renewed seismicity was observed by OVPDLF/IPGP in early August 2008. General seismicity was high, with up to 100 seismic events per day and some magnitudes as high as M 3. Significant seismic events were recorded on 4 and 15 August. No deformation was observed on 4 August by the inclinometer or permanent GPS network; however a small seismic event on 15 August lasted a little more than 2.5 hours and deformation was detected at the top of Dolomieu. By 18 August seismicity had decreased and deformation was no longer detected.

Seismic activity beneath the summit was again detected on 31 August and deformation was detected at the top of Dolomieu. By 2 September seismicity had decreased. Seismicity during 8-9 September was characterized by hundreds of earthquakes. Permanent GPS measurements indicated inflation since August and a N-S widening of the Dolomieu crater by 6.5 cm.

On 12 September OVPDLF reported an eruption accompanied by small episodes of tremor. Although initial field observations confirmed increased degassing on the S-W Dolomieu crater and H_2S in the air, no lava was found within the crater. Small amounts of SO_2 were detected by the OVPDLF/IPGP NOVAC network on the Enclos Fouqué caldera rim. Aerial observation noted lava flows escaping from a crack in the W slope in the crater; a small lava lake formed at the bottom of the crater. On 13 September, 95 earthquakes occurred, including three of M 1.5-1.8 and nine of M 1-1.5 (others were smaller). The next day 94 earthquakes occurred at the summit.

More seismic events were detected during 15-16 September 2008 and numerous landslides occurred shortly thereafter, but these may have been facilitated by heavy rains. On those days, a total of 296 earthquakes were recorded. Seismicity and SO_2 degassing continued.

An eruption took place during 21 September-2 October 2008. On 21 September, lava flows issued from the fissure about halfway up the W wall of Dolomieu crater. The lava flow ponded at the bottom. A strong concentration of SO_2 was detected near the edge of the crater. On 22 September Pele's hair was found around the summit area and the lava flow rate decreased. No further earthquakes were observed after the beginning of the eruption and the volcanic activity was confined within the Dolomieu crater. The eruption of lava flows declined on 23 September.

During 24-30 September lava flows issued from the W crater wall continued to pond at the bottom of Dolomieu crater. Based on air photos acquired on 25 September, the lava flow was an estimated 180 m long by 100 m wide and about 30 m thick. The erupted volume was about 300,000 m^3. On 26 September, lava fountaining from the fissure was no longer visible, but bubbling lava in the cone was observed. During that week tremor was relatively light and lava flows remained confined to the Dolomieu crater.

The eruption came to an end on 2 October and tremor decreased significantly. A total volume of lava emitted during this 10-day eruption was estimated at about 850,000 m^3 based on analysis of aerial photographs. During the eruption only one small deflation episode was recorded.

On 20 October a seismic crisis began beneath the summit accompanied by weak deformation. Subsequent quiescence followed until 31 October when another seismic crisis was characterized by hundreds of earthquakes.

A new eruption began on 28 November 2008 from the vent halfway up the W wall of Dolomieu crater. The lava flows ponded at the bottom of the crater and covered about 50 percent of the 21 September lava flow. A small quantity of Pele's hair was deposited inside Bory crater.

On 14 December, the OVPDLF/IPGP recorded a strong seismic crisis under the volcano with several hundreds of earthquakes. However, substantial deformation was absent. An eruption commenced on 15 December from two fissures inside Dolomieu, halfway up the N and NE wall beneath "La Soufrière" and about 200 m below the crater rim. The eruption was sporadic and weak.

OVPDLF reported that during 22-28 December 2008 lava continued to issue at a high rate from an active vent on the N side of Dolomieu crater, beneath "La Soufrière" and about 200 m below the crater rim. Gas plumes often reduced visibility. On 24 December, a small cone formed at the vent and occasionally produced lava fountains that fed a small lava lake. GPS monitoring equipment indicated stable conditions. Throughout the eruption volcanic tremor was quite variable. Around this time, ten lava flows were visible on the inner flanks of the crater and a plume was visible. No fresh lava was visible at the cone on 29 December. The degassing was quite strong and sometimes Dolomieu was filled with bluish gas; a plume was visible on the webcam.

Observations from 2009. Tremor initially decreased in January, though by the 2nd it was increasing again. Tremor stabilized below levels seen on 15 December 2008, and remained at that level through at least 22 January, suggesting that eruptions continued.

References: Peltier, A., Staudacher, T., Bachélery, P., Cayol, V., in press, The April 2007 eruption and the Dolomieu crater collapse, two major events at Piton de la Fournaise (La Réunion Island, Indian Ocean): Journal of Volcanology and Geothermal Research (proof copy available online).

Peltier, A., Staudacher, T., and Bachélery, P., 2007, Constraints on magma transfers and structures involved in

the 2003 actity at Piton de La Fournaise from displacement data: Journal Geophys. Res., v. 112, p. B03207, doi: 10.1029/2006JB004379.

Geologic Summary. The massive PdF basaltic shield volcano on the French island of Réunion in the western Indian Ocean is one of the world's most active volcanoes. Much of its >530,000 year history overlapped with eruptions of the deeply dissected Piton des Neiges shield volcano to the NW. Three calderas formed at about 250,000, 65,000, and less than 5,000 years ago by progressive eastward slumping of the volcano. Numerous pyroclastic cones dot the floor of the calderas and their outer flanks. Most historical eruptions have originated from the summit and flanks of Dolomieu, a 400-m-high lava shield that has grown within the youngest caldera, which is 8 km wide and breached to below sea level on the eastern side. More than 150 eruptions, most of which have produced fluid basaltic lava flows, have occurred since the 17th century. Only six eruptions, in 1708, 1774, 1776, 1800, 1977, and 1986, have originated from fissures on the outer flanks of the caldera. The Piton de la Fournaise Volcano Observatory, one of several operated by the Institut de Physique du Globe de Paris, monitors this very active volcano continuously.

Information Contacts: *Laurent Michon* and *Patrick Bachélery*, Laboratoire GéoSciences Réunion, Institut de Physique du Globe de Paris, Université de La Réunion, CNRS, UMR 7154-Géologie des Systèmes Volcaniques, La Réunion, France; *Thomas Staudacher* and *Valérie Ferrazzini*, Observatoire Volcanologique du Piton de la Fournaise (OVPDLF), Institut de Physique du Globe de Paris, 14 route nationale 3, 27 ème km, 97418 La Plaine des Cafres, La Réunion, France (URL: http://ovpf.univ-reunion.fr/); *Joan Marti*, Institute of Earth Sciences "Jaume Almera," Consejo Superior de Investigaciones Cientificas, Barcelona, Spain.

Ol Doinyo Lengai

Eastern Africa
2.764°S, 35.914°E; summit elev. 2,962 m
All times are local (= UTC + 3 hours)

Recent reports on Ol Doinyo Lengai provided observations from several climbing groups and pilots after the energetic eruptions during 2007-early 2008, events which included extra-crater lava flows and Plinian-style eruption clouds with heavy ashfalls. In contrast, eruptions during the previous 40 years mainly remained confined to the summit crater. The latest reported observations were made during April-September 2008 (*BGVN* 33:08) .

Since then, owing to the increased difficulty and hazard of both ascent and close proximity to the volcano, tourism and consequent reporting has sharply dropped off. However, some brief reports summarizing the observations of guides that escorted hikers to the summit were available for October and December 2008, and January 2009.

A team of US and Tanzanian geologists assembled at the request of the Government of Tanzania reported on their investigations. That report includes photos of lava flows and an isopach map of 2007-2009 tephra deposits found W of the volcano. Some of those tephra deposits were 17 cm thick, and during September 2007-March 2008 tephra falls caused thousands of residents to evacuate. Many residents had returned by mid-January 2009.

D'Oreye and others (2008) used synthetic aperture radar interferometry (InSAR) to study the geodetic behavior of several African volcanoes. They identified co-eruptive deformation at Lengai as well as a rift diking event in northern Tanzania.

Ascents and views of summit behavior. On 6 October 2008 French and Belgian climbers guided by Burra Amigadie observed a large mass of rock collapse into the active N crater. The mass fell from the crater's inner N wall. On 12 October 2008 climbers guided by Olomelok Naandato heard strong thundering noises and sensed tremors while ~ 150 m from the peak. On 26 October, thick steam from the crater was seen from a distance. The local government advised people not to climb the mountain until the situation normalized.

On 27 December 2008 ejection of the steam had subsided significantly and the mountain was considered generally calm despite small, periodic ash showers. Mountain climbing resumed. During 7-12 January 2009 climbers saw short-lived fumaroles emanating from the crater accompanied by moderate roaring sounds and tremors.

USGS and Tanzanian joint visit. During 18-22 January 2009 a team investigated the recent volcanism's impact. The team's members (see Information Contacts) came from the US Geological Survey (USGS) and US Agency for International Development, Office of Foreign Disaster Assistance, Volcano Disaster Assistance Program (VDAP); they joined geoscientists from the Geological Survey of Tanzania (GST) and Disaster Officials from the Disaster Management Department in the Prime Minister's Office. During their stay near Lengai, the team noted a small amount of steam occasionally rising from the N crater, and narrow plumes of white steam over the northern uppermost slopes.

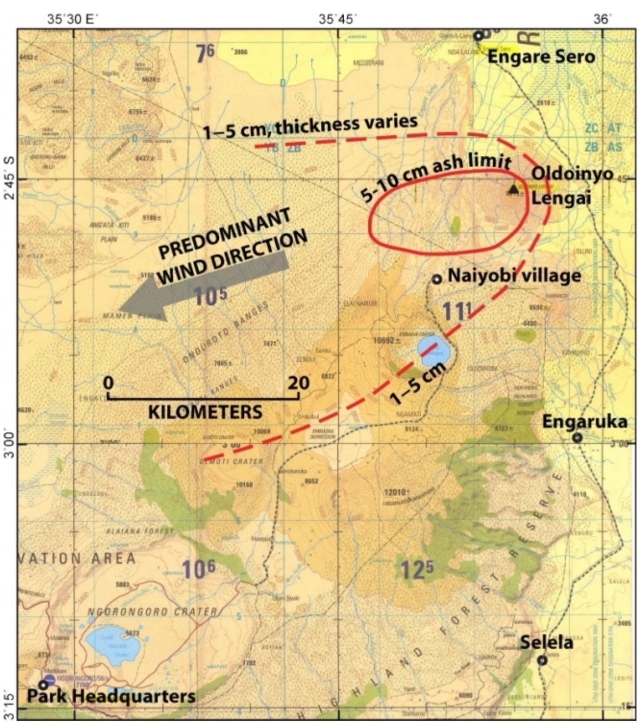

Figure 15. Map showing the distribution of ash from 2007 and 2008 eruptions of Ol Doinyo Lengai. Courtesy of the US-Tanzanian team.

The September 2007-March 2008 tephra falls covered an area predominantly to the W (figure 15). A few ash-thickness measurements were collected there across the trend of the September 2007-March 2008 tephra falls. Thicknesses as great as 17 cm were found 4 km from the vent (figure 16).

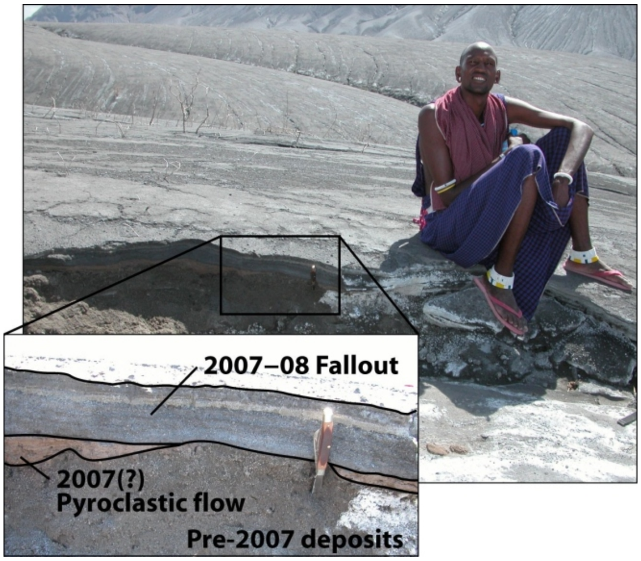

Figure 16. Photograph and annotated enlargement illustrating an exposed section of W-flank deposits from 2007-2008 Ol Doinyo Lengai eruptions. Fallout in this area completely buried vegetation. The photograph was taken 19 January 2009. Courtesy of David Sherrod (USGS).

Figure 17. A'a flow deposited during a 2006 eruptive episode on Ol Doinyo Lengai's NW flank. Note the hat for scale (in foreground). USGS photo taken by Gari Mayberry on 19 January 2009.

Lava flows deposited on the W flank in 2006 reached 200 m wide at the point of greatest breadth and extended 4. 4 km downslope from the summit, terminating at ~ 1,230 m elevation. Where visited, the flows' surface textures were mostly pahoehoe with patches of a'a 3-5 m thick (figure 17). Trees caught in the lava flows remained standing and largely uncharred (figure 18), providing evidence that the lava flows were at or below the ignition temperature for vegetation.

A guide who ascended Lengai the morning of 20 January 2009 saw active lava flows on the NE portion of the N crater's floor.

On 22 January team members traveled to the village of Naiyobi, in the Ngorogoro Conservation Area ~ 12 km SW of the summit. Naiyobi, and the neighboring village of Kapenjiro (15 km S of the volcano). Residents were evacuated from these villages during the height of activity. According to the area coordinator, by January 2009 thousands of people had returned to both villages. Ash thicknesses measured on 22 January at a location 5.6 km NW of Naiyobi village were 5-6 cm (figure 19).

The US team had an interview that was featured on the web (Ransom, 2009). They noted the comparative repose seen during 2008 and that fewer than 10,000 people live within 10 km of the volcano. The rainy season (May-October), had passed by the time the US-Tanzanian team had arrived, and grass had begun to grow on previously ash-covered surfaces. Despite the emergence of these grasses, the

Figure 18. A tree remains standing in the 2006 lava flow from Ol Doinyo Lengai on the W flank. The lava flow was not hot enough to ignite the tree, an observation consistent with the lava chemistry. Photographed on 19 January 2009 by Gari Mayberry.

Figure 19. With Ol Doinyo Lengai in the background (6.5 km NE), USGS and GST scientists assess ash thickness at a location 5.6 km NNW of Naiyobi village. Taken 22 January 2009 by Gari Mayberry.

team expected that next rainy season(s) will probably trigger mudflows and flash floods. This would impose periods of days when vehicles would be unable to reach the small communities around the volcano.

Gari Mayberry noted "The International Volcano Health Hazard Network has produced some pamphlets that discuss how to deal with ashfall. We are going to work with our colleagues from the University of Dar es Salaam in Tanzania who have offered to translate these pamphlets into Swahili so that local people ... can learn more about how they can deal with this hazard. It may go on to be translated into Maa, the local Masai language."

In discussing the lack of monitoring they noted that circumstances, "... forced us to look at the situation in a new way and to determine that disaster risk reduction education may be the most feasible way to reduce the hazard because it will be quite difficult due to the lack of infrastructure ... to install monitoring equipment."

They also commented that the unique carbonatite lavas are "so low on the temperature scale that it almost doesn't glow red. It has a hard time igniting trees or grasses as it flows over it because it's right at the point of ignition temperature from any of the things that grow on the surface ...."

References: D'Oreye, N., Fernandez, J, Gonzalez, P, Kervyn, F, Wauthier, C, Frischknecht, C, Calais, E, Heleno, S, Cayol, V, Oyen, A, Marinkovic, P, 2008, Systematic InSAR monitoring of African active volcanic zones: What we have learned in three years, or an harvest beyond our expectations: Dept. of Geophys./Astrophys., Nat. Museum of Natural History, Walferdange, *in* Second workshop on use of remote sensing techniques for monitoring volcanoes and seismogenic areas, 11-14 November 2008, p. 1-6, ISBN: 978-1-4244-2546-4

Ransom, C. N., 2009, Tanzanian Villagers Encouraged to Learn Hazards of Living Near Erupting Volcano, US Geological Survey; Audio interview taken 5 March 2009 (with transcript): USGS Interviews Collection (URL: http://gallery.usgs.gov/audios/244).

Geologic Summary. The symmetrical Ol Doinyo Lengai stratovolcano is the only volcano known to have erupted carbonatite tephras and lavas in historical time. The prominent volcano, known to the Maasai as "The Mountain of God," rises abruptly above the broad plain south of Lake Natron in the Gregory Rift Valley. The cone-building stage of the volcano ended about 15,000 years ago and was followed by periodic ejection of natrocarbonatitic and nephelinite tephra during the Holocene. Historical eruptions have consisted of smaller tephra eruptions and emission of numerous natrocarbonatitic lava flows on the floor of the summit crater and occasionally down the upper flanks. The depth and morphology of the northern crater have changed dramatically during the course of historical eruptions, ranging from steep crater walls about 200 m deep in the mid-20th century to shallow platforms mostly filling the crater. Long-term lava effusion in the summit crater beginning in 1983 had by the turn of the century mostly filled the northern crater; by late 1998 lava had begun overflowing the crater rim.

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