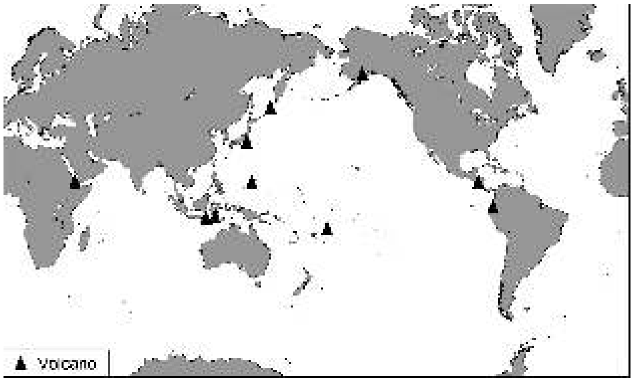
# Bulletin of the Global Volcanism Network

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# Sarychev Peak

Kuril Islands, Russia
48.092°N, 153.20°E; summit elev. 1,496 m
All times are local (= UTC + 11 hours)

On 11 June 2009 one of the largest historical eruptions in the Kuril Islands began–from Sarychev Peak (figure 1). A report from the Sakhalin Volcanic Eruption Response Team (SVERT) covered events through June, and included both remote-sensing and on-the-scene observations by Russian scientists. Other contributors include astronauts and remote-sensing specialists. Synonyms for the volcano include Fue-san, Matsuwa-jima, Matua-jima, and Sarnicheff.

***Monitoring.*** Volcano monitoring is conducted by SVERT in the southern and central Kurils, and by KVERT in the northern Kurils (figure 1). The region is well known for severe weather, including summertime cloudy and foggy conditions; volcano monitoring has depended heavily on remote-sensing methods.

With respect to civil aviation, the Kuril Islands are the responsibility of the Tokyo Volcanic Ash Advisory Center (VAAC). A zone without designated VAAC jurisdiction over N-central Russia is ~ 1,400 km N. The substantial plumes caused concern about that zone's ambiguous status and the whereabouts of Sarychev's ash.

This part of the North Pacific is sparsely populated but is one of the world's most heavily traveled air corridors, crossed by flights linking Europe and North America to northern Asia (including Japan, parts of China, Hong Kong, and Korea). Injecting ash into these flight routes, Sarychev's eruption triggered diversions or delays to an unknown number of flights. Reliable sources indicated that some aircraft diversions over Russia, and other unexpected factors, cost as much as $100,000 USD per flight.

***Precursors and initial eruption, 11 June 2009.*** Before the June 2009 eruption the volcano was dormant with substantial fumarolic activity. Visitors looking into the crater in August 2008 encountered thick fog, but did heard noises. On 6 June 2009 specialists came to the island to service an autonomous GPS station. Photographs documented increased gas emissions.

SVERT's report stated that the first signs of eruption came as a result of satellite observations acquired on 11 June 2009. Distinct then were both a thermal anomaly and weak ash emissions. During the eruption, ashfalls were widespread and noted at sites including Raikoke, Rasshua, Ushishir, Ketoi, the Simushir islands, the northern part of Urup Island, and widespread on Sakhalin Island.

On the night of 11-12 June, the scientific research ship *George Steller* passed near the island without anyone noticing an eruption, according to an oral report from the expedition chief Vladimir Burkanov.

***Space Station photograph, 12 June 2009.*** A stunning photo of the plume taken on 12 June 2009 (figure 2) from the International Space Station (ISS) shows not only a highly complex ash cloud, but at least two or three distinct (different colored) volcanic clouds hugging the ground surface and traveling radially out from the vent. One is an unmistakable, light-colored pyroclastic flow, narrowing as it progresses out over the island until ultimately hidden by the edge of the weather clouds. Another set are broader, dark-colored clouds, presumably other pyroclastic flows.

The vertical plume looks dense and well confined; absent is the strongly spreading upper region common in many eruptive plumes (an umbrella cloud). The top of this cloud is bulbous, and trailing below it is a narrower, columnar lower segment colored in shades of brown and cream. At the time of this writing no clear analysis of the plume height has come to our attention. Older dispersed plumes are also apparent at distance (some at the left edge of

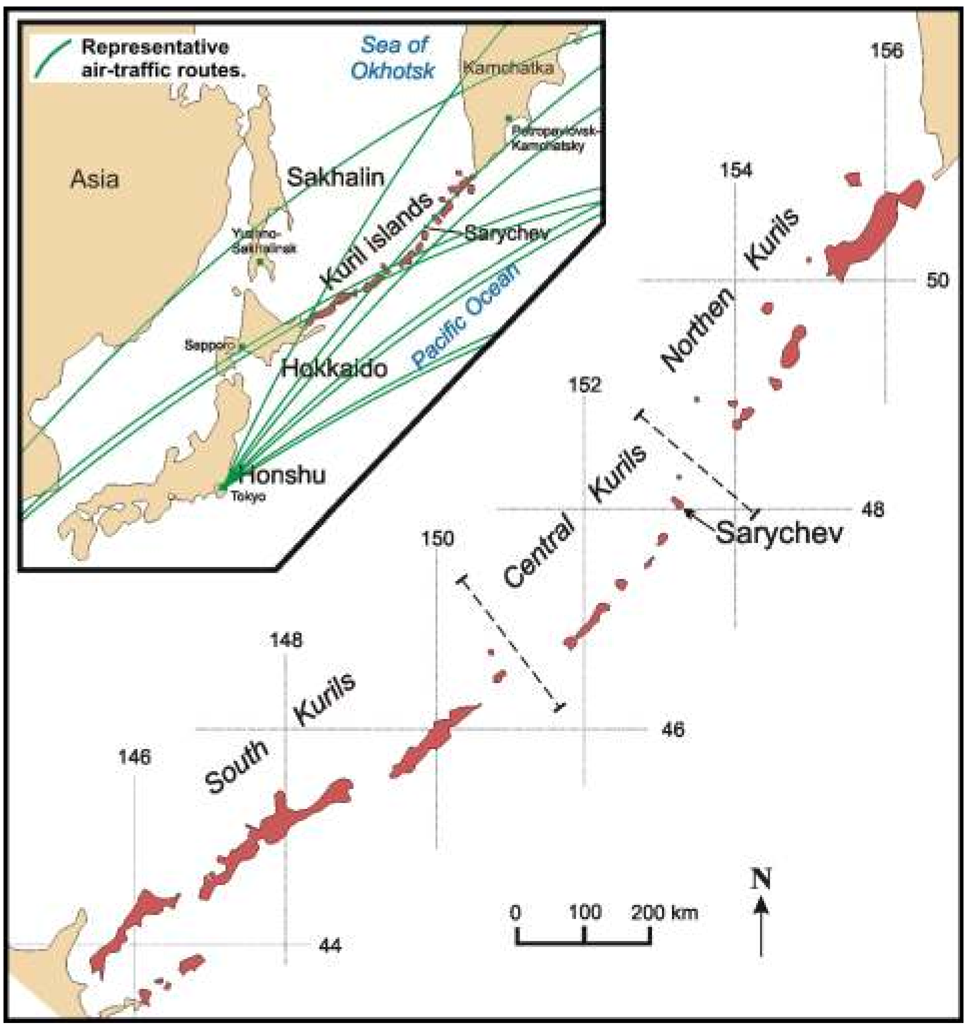


Figure 1. Broad-scale maps of the Kuril Islands showing regional geography and the location of Sarychev Peak. Base maps are courtesy of the Sakhalin Volcanic Eruption Response Team (SVERT). Representative aviation routes on the inset map are from Casadevall and Thompson (1995).

this photo) and on satellite imagery from 12 June, with airborne ash covering a considerable area and extending in more than one direction.

Capping the ash cloud's bulbous top and in a ring just below it, lies a strikingly smooth, white portion of the plume, a feature called a pileus cloud (figure 2). It results from a slab of uncontaminated air pushed upward ahead of the rapidly rising darker zone. Pileus clouds sometimes form above mountain tops and convectively rising weather clouds. For the pileus cloud to form, the lifted air layer must have sufficient moisture (relative humidity). The underlying clouds often punch through the pileus clouds, a process that seems to have started here. The lower clouds that result are sometimes described as cloud skirts (the ring in this case).

Figure 2. A digital photograph of a Sarychev Peak's eruption plume taken by astronauts on 12 June 2009 from the International Space Station. N is to the upper right. [Astronaut photograph ISS020-E-9048; acquired 12 June at 22:16 UTC with a Nikon D2XS digital camera fitted with a 400 mm lens; Nadir point 48.8°N, 157.5°E]. Courtesy of NASA Earth Observatory.

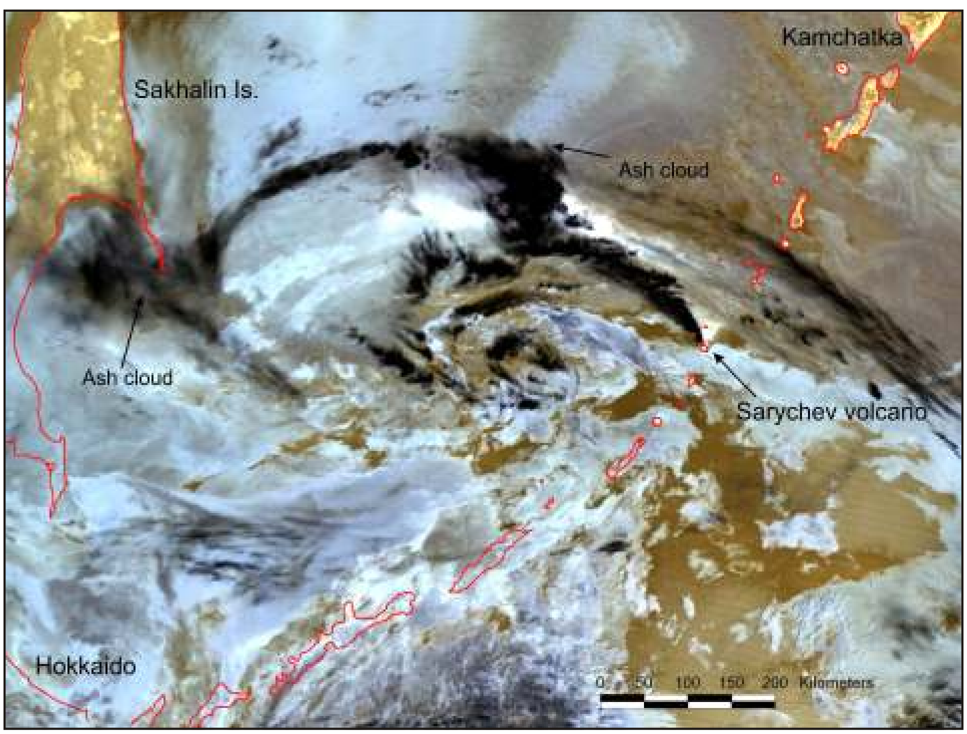


Figure 3. A MODIS satellite image of the Sarychev Peak eruption plume from 16 June 2009. In colored versions the plume is black. As it spread W, part of the plume took the form of a large spiral, portions of which extended at least as far W as Sakhalin Island. The plume also appears in thinner strands to the NE of the source. Courtesy of SVERT and MODIS.

The hole in the weather clouds centered above the volcano is likely in part due to meteorological conditions; such holes often occur similarly centered over islands in the Kuril chain. This may result, for example, from an island's landmass warming moist air or forcing it upwards to mix with dryer air, resulting in a local loss of cloud cover; such an effect might combine with downwind eddies. A broader 12 June ISS image shows a series of holes in regional weather clouds in a pattern aligned broadly over the Kuriles. Another explanation, with many adherants, is that the hole may have been caused or influenced by effects associated with dynamics of the eruption and plume propagation (Wilkinson, 2009).

The opportune ISS flyover resulted in 29 still images of the eruption taken over a 1-minute interval. NASA used the photos to create a series of animations, also available on the NASA Earth Observatory website. The ISS orbits at ~ 400 km altitude and ~ 27,500 km/hour. Patrick Vantuyne created a red-blue stereo image of the 12 June plume, posted by NASA as a "Picture of the Day."

***Satellite-based observations.*** SVERT reported that the energetic phase of the eruption, during 11-16 June, encompassed more than ten large explosions (figures 3 and 4). Resulting ash clouds rose up to altitudes of 8-16 km and, according to some estimates, up to 21 km. Ash plumes stretched N to W for 1,500 km, and E for more than 3,000 km. Comparative analysis of ASTER-Terra satellite images indicated newly formed territory amounted to 1.4 $km^2$. The area of island covered by June 2009 pyroclastic flows was more than 8 $km^2$. The preliminary estimated minimum volume of eruptive rock was 0.4 $km^3$.

Broader imagery of the region also indicated more diffuse high-altitude ash clouds. Starting on 12 June, the ash spread hundreds of kilometers both E and W and to lesser extent N, a large elongate mass high in the atmosphere that closed off a huge critical area to commercial air carriers and created new problems not seen before by aviation authorities.

According to Simon Carn, the Ozone Monitoring Instrument (OMI) on NASA's Aura satellite tracked a sulfur dioxide plume across the northern Pacific from Sakhalin Island and mainland Russia and E as far as Alaska (figure 5). Carn's tentative conclusion was that the eruption was also the largest sulfur dioxide event so far in 2009.

Figure 6. Photo of steam rising from Sarychev Peak as seen from the N at some time during 26-28 June. Rugged fringing older rocks can be seen protecting a beach front and tephra-covered landscape. Courtesy of SVERT.

By early July both atmospheric lidar instruments and the CALIPSO limb-sounding satellite had documented extended aerosol layers at 10-20 km altitude over the Northern Hemisphere. There were two potential sources for these aerosols, fires and the Sarychev Peak eruption. Fires due to biomass burning were seen around this time in both the Yukon and Alaska. Fire-generated aerosols are now known to reach 20 km altitudes (Mike Fromm, personal communication, and Fromm and others, 2004). According to Fromm, the Sarychev Peak eruptions must have at least contributed to high-altitude aerosols. As recent as mid-August, the atmospheric limb-sounding satellite CALYPSO had detected pronounced aerosol layers at 22-23 km altitude, layers also seen on MODIS visible-wavelength imagery. Fromm concluded the aerosol burden was larger than the substantial August-September 2008 eruption at Kasatochi (Alaska).


Figure 4. False-color ASTER images from 27 May 2007 and 30 June 2009 showing before-and-after scenes of Sarychev Peak's eruption. The 2007 photo shows remnant seasonal snow on the island and some cloud over the summit. N is towards the top and the long-axis of Matua (large island) is ~ 12 km and the diameter of Toporkovyi (small island) is ~ 1 km. The eruption's effects were strong to the NW, around the volcano, but fieldwork confirmed that they left both the SE end of Matua Island and all of the flat Toporkovyi Island comparatively untouched. Comparison of images shows that pyroclastic flows extended the shoreline of the island, particularly NE and SW of the volcano. Courtesy of ASTER and SVERT.

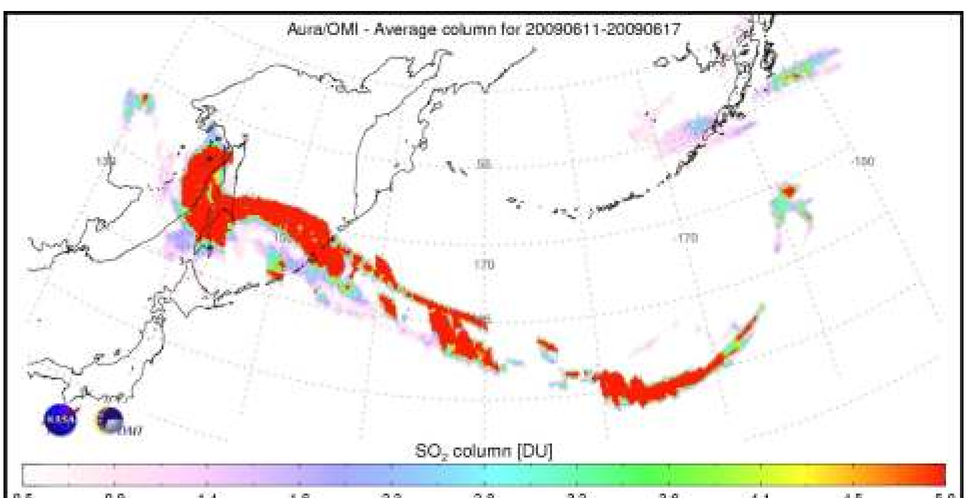


Figure 5. $SO_2$ emissions from Sarychev Peak during 10-17 June 2009 led to this composite picture of gas plumes. The emissions were measured by the OMI satellite and its support team. Note concentration-pathlength scale at bottom, in Dobson Units (DU). Courtesy of Simon Carn.

The microwave limb-sounding (MLS) satellite Aura can detect multiple gases. According to a NASA website, in mid-June 2009 it detected clear signals of both $SO_2$ and HCl across a large span of the North Pacific.

***Continuing activity during 16-28 June 2009.*** After 16 June, the eruptions entered a less energetic stage. Weak explosions continued and contained small amounts of tephra. The SVERT team visited the island during 26-28 June. Intense gas emissions came from still-hot deposits. Satellite data confirmed these gas emissions, which continued through at least 20 July. Field work and satellite observations led the team to consider the eruption to be VEI 4.

Good views of the island were obtained from the sea during the 26-28 June visit by SVERT (figures 7 and 8). One component of fieldwork involved the

GPS-aided mapping of pyroclastic deposits seen along the seashore. The team used an inflatable boat to access the shoreline (figure 9). The bulk of pyroclastic flows reached the sea (figures 10 and 11), and although wave action had substantially eroded the deposits along the coastline, the deposits clearly continued out into the sea. Weakly eroded underwater pyroclastic flows sometimes returned distinctive reflections on echo soundings. The soundings and other observations also revealed submerged deposits emitting gases and still-stirring hydrothermal exchanges.

The field inspection revealed three pyroclastic flows from the eruption. The team also recognized other pyroclastic material, including volcanic bombs, scoria flows, and ash. Compositionally, the field analysis suggested the eruptions were basaltic andesite. In accord with the density of the fresh blocky deposits along the sea cliff, and the clasts within them (figure 11), the team saw no floating pumice.

Figure 9. The field crew on a beach to inspect Sarychev Peak's recent pyroclastic flows. By the time of their 26-28 June visit, waves had eroded the fresh deposits that must have once covered this beach face. Massive, jointed rocks in the cliff backing the beach are older rocks; new deposits drape the upper cliff. Note steaming peak in the background. SVERT volcanologists (from left): Dmitrii Kozlov, Igor Koroteev, Artyom Degterev, Rafael Zharkov (far right), and Alexander Rybin (front right). Courtesy of SVERT.

Figure 7. Photos of steam rising from the pyroclastic flows as seen from the N at some time during 26-28 June. The steaming peak is faintly visible in the background. Courtesy of SVERT.

The intense fumarolic discharges escaping the pyroclastic flows reached ~ 500°C. Fumaroles were seen most frequently associated with impacts from large volcanic bombs, and from fissures. Areas of fumarolic exhalation included sublimated minerals such as native sulfur (figure 12). The team also encountered a pond with hot water (figure 13).

***Biological impacts.*** Prior to the eruption, the island was teeming with life and the SVERT team photographically documented many biological impacts (eg., surviving birds congregated at damaged or destroyed rookeries). The eruptions of June 2009 divided Matua Island into two sectors with a sharp and nearly linear boundary between them (eg., figure 5). On the NW side, nearest Sarychev Peak, its eruption left a dead zone. Many plants were buried by hot tephra, leaving a landscape devoid of vegetation on the current ground surface. This dead zone was bounded to the S by a deep ravine where a large mudflow had occurred, destroying ferns, thick growths of alder, and grass cover.

To the SE, ashfall damaged small plants, including rhododendron, crowberry, cassiopea, and phylodoce. Perhaps 10-15% of sites visited there had ash over 10 cm thick. Especially near the dead zone, many small plants suffered burial, yet they continued to blossom. Blossoming cowberry was buried in areas with thick ashfall.

Figure 8. Photos of Sarychev Peak seen from the S, the side of the island least impacted by the eruption, where the landscape remained green and vegetated. The support vessel seen here brought scientists to the Island and gave them safe lodging during the expedition. Courtesy of SVERT.

Figure 10. Rubbly surface of a 2009 pyroclastic flow (“pumice flow”) on Sarychev Peak’s W flanks. Field gear at flow front provides scale. Note the lobate form and comparatively large and consistent grain size. Courtesy of SVERT.

Figure 11. Exposed tephra stratigraphy from the Sarychev Peak eruption. The scientist is standing before fresh tephra deposits along the seashore with his feet on the beach. To his side lies a well-exposed ~ 2-m-thick pyroclastic flow deposit capped by fine-grained tephra of probable air-fall origin. The fine air-fall unit covers the surface in the distance, coloring it a uniform gray. Courtesy of SVERT.

Among high brush in the S part of the island, alder generally suffered little, but in some areas of ashfall (between Kruglaya mountain and the slopes of the volcano) it showed some leaf damage. The leaves of mountain ash displayed yellow rims and discolored spots. High-grasses located in the SE sector were little affected by ashfall.

In the dead zone, some bird colonies remained on the old lava flows supporting the island’s capes. It was difficult to estimate how many birds had died or lost nests. Many seagulls sat on the warm surfaces of the steaming pyroclastic flows. Wounded and dead seagulls found on the surfaces of pyroclastic flows were probably killed by burns after the eruption. Near the NW part of Matua Island, the team saw large flocks of sea birds aloft.

On the 28th, SVERT visited seal habitats on the S portion of the island where they counted 20 eared seals and 10 fur seals. On a cape along Matua’s W coast they encountered another seven eared seals. The team found no living land animals on the NW sector. On the SE sector, they found dead mice and three dead foxes.

***Additional geological background from SVERT.*** The modern edifice of Sarychev Peak occupies the bulk of Matua Island but is centered towards the NW (figure 5).

Figure 12. Two examples of sublimated mineral zones seen on the pyroclastic-flow surfaces from the Sarychev Peak eruption. Many such mineralized areas appeared related to bomb impacts (top). Other areas were elongate, some several meters long (bottom). Courtesy of SVERT.

Figure 13. Small pond encountered on Sarychev’s flanks. Cliffs and talus slopes behind the pond are tephra-draped older rocks. The green-hued water had been heated and mineralized by contact with recent eruptive products. The scientist standing in the pond estimated that the temperature was ~ 21°C. Courtesy of SVERT.

The island's SE side is flat, with average elevations of 30-40 m. The island's S and E sides are covered with brush and grass.

Before 25 August 1945, Matua Island supported a Japanese army base with as many as 4,000 residents. After 1945, the Soviet army occupied the island and maintained meteorological and seismic stations until a sharp decline in inhabitants at the end of the 1990's. The island still contains runways and structures. In recent years, the only people on the island were occasional visitors.

The geologic literature discusses Pliocene basaltic andesite volcanoes in this region (including Toporkovyi Island and the SE part of Matua). It is probable that these are part of an ancient shield volcano. In the SE part of Matua Island is a somma of an ancient caldera (Gorshkov 1967; Markhinin 1964; Andreev and others, 1978), making Sarychev Peak an intracaldera stratovolcano. It is formed by alternating lava and tephra of mainly basalt to andesite composition (Gorshkov 1967; Andreev et.al 1978).

According to Gorshkov (1967), after the major 1946 eruption the crater had both a diameter and depth of ~ 250 m, with steep, sometimes overhanging crater walls and a floor of solid lava. Modern lava flows consisted of two-pyroxene basalts and basaltic andesites vented from the central cone, forming small tongues near the crater.

After the 1960 eruption, field observers encountered dense fog and were thus unable to describe the crater (Shilov, 1962). According to eye-witnesses, the crater's N walls may have collapsed.

The 1976 eruption included strong emissions. Lava flows extended the W, SW, and NW slopes (Andreev and others, 1978). This eruption left the crater with a diameter of ~ 200 m and a flat bottom at a depth 50-70 m below the rim.

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Wilkinson, M.J., 2009, Sarychev Peak Eruption, Kurile Islands (caption): NASA Earth Observatory, posted 22 June 2009 (URL: http://earthobservatory.nasa.gov/IOTD/view.php?id=38985).

***Geologic Summary.*** Sarychev Peak, one of the most active volcanoes of the Kuril Islands, occupies the NW end of Matua Island in the central Kuriles. The central cone was constructed within a 3-3.5 km wide caldera, whose rim is exposed only on the SW side. A dramatic 250-m-wide, very-steep-walled crater with a jagged rim caps the volcano. The substantially higher SE rim forms the 1,496 m high point of the island. Fresh-looking lava flows descend all sides of Sarychev Peak and often form capes along the coast. Much of the lower-angle outer flanks of the volcano are overlain by pyroclastic-flow deposits. Eruptions have been recorded since the 1760's and include both quiet lava effusion and violent explosions. One of the largest historical eruptions of Sarychev Peak, in 1946, produced pyroclastic flows that reached the sea.

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# Miyake-jima

Izu Islands, Japan
34.079°N, 139.529°E; summit elev. 815 m

Miyake-jima has had a recent history of periodic minor eruptions and gas emissions containing relatively high concentrations of sulfur dioxide ($SO_2$). $SO_2$ emissions in January 2006 averaged about 2,000-5,000 tons per day, and there was a minor eruption on 17 February 2006 (*BGVN* 31:03).

The Tokyo Volcanic Ash Advisory Center (VAAC) described an eruption on 23 August 2006 that generated plumes which rose to an altitude of about 1.5 km and drifted SE. Ash was not identified on satellite imagery. No additional eruption reports were received until January 2008. Based on information from the Japan Meteorological Agency (JMA), the Tokyo VAAC reported that an eruption plume on 7 January rose to an altitude of 1.2 km and drifted SE. The JMA also reported an eruption on 8 May 2008. Another eruption reported by JMA produced an ash plume that rose 600 m above the crater and drifted E on 1 April 2009.

***Geologic Summary.*** The circular, 8-km-wide island of Miyake-jima forms a low-angle stratovolcano that rises about 1100 m from the sea floor in the northern Izu Islands about 200 km SSW of Tokyo. The basaltic volcano is truncated by small summit calderas, one of which, 3.5 km wide, was formed during a major eruption about 2500 years ago. Parasitic craters and vents, including maars near the coast and radially oriented fissure vents, dot the flanks of the volcano. Frequent historical eruptions have occurred since 1085 AD at vents ranging from the summit to below sea level, causing much damage on this small populated island. After a three-century-long hiatus ending in 1469, activity has been dominated by flank fissure eruptions sometimes accompanied by minor summit eruptions. A 1.6-km-wide summit caldera was slowly formed by subsidence during an eruption in 2000; by October of that year the crater floor had dropped to only 230 m above sea level.

***Information Contacts:*** *Tokyo Volcanic Ash Advisory Center* (VAAC), Tokyo, Japan (URL: http://ds.data.jma.go.jp/svd/vaac/data/); *Japan Meteorological Agency* (JMA), Otemachi, 1-3-4, Chiyoda-ku Tokyo 100-8122, Japan (URL: http://www.jma.go.jp/jma/indexe.html).

## NW Rota-1

Mariana Islands
14.601°N, 144.775°E; summit elev. -517 m

An oceanographic research expedition during 3-17 April 2009 visited NW Rota-1 submarine volcano, located about 100 km N of Guam in the Mariana arc. Scientists visited the volcano with Research Vessel (R/V) *Thomas G. Thompson*, making dives with the *Jason* remotely operated vehicle (ROV). The volcano was erupting almost all of the time with varying amplitude. This volcano was previously observed erupting during ROV dives in March 2004 (*BGVN 29:03*) and April 2006 (*BGVN 31:05*) on National Oceanographic and Atmospheric Agency (NOAA) Ocean Exploration expeditions, and by the Japanese in October 2005 and February 2008 (*BGVN 32:02*).

A hydrophone deployed from February 2008 until February 2009, operated under the direction of Robert Dziak, measured almost continuous signals from the volcano during the 1-year period. This hydrophone will record data for another year, but it lacks telemetry, so NOAA intends to retrieve its data in 6-12 months. Prior to the deployment of the hydrophone activity was observed using a ROV only during brief visits.

On the expedition blog, William Chadwick noted that with NW Rota-1 apparently nearly continuously active since at least 2003, the volcano can provide a natural laboratory for learning about underwater eruptions, how submarine volcanoes grow, and how they affect the ocean environment. Scientists are able to get close to the eruptive vent because the pressure of the ocean above keeps the energy of the eruptions subdued, allowing them to gain a view of what is happening in the vent. For example, scientists watched lava slowly being pushed up and out of the eruptive vent while the sea floor shuddered and quaked and huge blocks were bulldozed out of the way to make room for new lava emerging from the vent.

The volcano had grown considerably since 2006, producing a new cone ~ 40 m high and ~ 300 m wide. Despite the ongoing eruption, with ash and rocks falling everywhere and an extreme chemical environment, a thriving ecosystem was present. The population of animals and microbes had both increased relative to 2006 and become more diverse, including new species not yet found elsewhere.

At the end of the 2009 cruise, an array of instruments (hydrophone and chemical sensors) was left to monitor events over the next year. Moorings on the flanks will look for landslides and debris flows. Chadwick's group plans to return in 2010 to continue investigations. On his blog site are some video highlights from the 2009 expedition showing activity at the Brimstone eruptive vent at the top of the new cone.

***Geologic Summary.*** A submarine volcano detected during a 2003 NOAA bathymetric survey of the Mariana Island arc was found to be hydrothermally active and named NW Rota-1. The basaltic to basaltic-andesite seamount rises to within 517 m of the sea surface SW of Esmeralda Bank and lies 64 km NW of Rota Island and about 100 km N of Guam. When NW Rota-1 was revisited in 2004, a minor submarine eruption from a vent named Brimstone Pit on the upper S flank about 40 m below the summit intermittently ejected a plume several hundred meters high containing ash, rock particles, and molten sulfur droplets that adhered to the surface of the remotely operated submersible vehicle. The active vent was funnel-shaped, about 20 m wide and 12 m deep. NW Rota-1 is a large submarine volcano with prominent structural lineaments about a kilometer apart cutting across the summit of the edifice and down the NE and SW flanks.

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## Paluweh

Lesser Sunda Islands, Indonesia
8.32°S, 121.708°E; summit elev. 875 m

During 1-17 April 2009, seismicity increased at Paluweh (table 1), prompting the Center of Volcanology and Geological Hazard Mitigation (CVGHM) to raise the Alert Level from 1 to 2 (Waspada) on 18 April. CVGHM staff in the observation post did not see any gas or ash emissions. Visitors were requested to stay away from the active crater adjacent to the peak.

Explosive activity had most recently been observed in May 1984 and previously during November 1980-September 1981 (*SEAN* 06:01, 06:02, 06:08, and 06:09), October 1973, and October 1972-January 1973. Activity in December 1963-March 1966 included lava flows, pyroclastic flows, and fatalities.

An unconfirmed news report of activity in January 2005, not reported in the *Bulletin*, was later found to be false. The CVGHM staff found no activity at the volcano.

| Date | Deep volcanic earthquakes (daily average) | Shallow volcanic earthquakes (daily average) |
|---|---|---|
| 01-03 Apr 2009 | 2 | 2 |
| 04-05 Apr 2009 | 17 | 18 |
| 06-10 Apr 2009 | 6 | 11 |
| 11-13 Apr 2009 | 6 | 10 |
| 14-15 Apr 2009 | 22 | 10 |
| 16 Apr 2009 | 23 | 15 |

Table 1. Average number of daily seismic events recorded from Paluweh, April 2009. Courtesy of CVGHM.

As background on hazard considerations, the mouth of the principal crater opens to the S, where there is plantation agriculture almost to the volcano's peak. In the advent of a future crisis, evacuation would be complicated because a safer area is about two hours journey by motor vessel, and leaving the island might not be possible during storms or rough seas. CVGHM is in continuous contact with the provincial and regional governments, some monitor of Paluweh occurs from the hamlet of Ropa on the N-central coast of the big island of Flores, to Paluweh's S. Regional civil-defense agencies (such as SATKORLAK-PB, the Provincial Coordinating Unit for Disaster Management) and district government agencies of Sikka and Ende (such as SATLAK-PB, the Local Coordinating Body for Disaster Relief) are continually apprised of the activity level.

***Geologic Summary.*** Paluweh volcano, also known as Rokatenda, forms the 8-km-wide island of Paluweh (Palan-Palue) and sits N of the volcanic arc that cuts across Flores Island. Although the volcano rises about 3,000 m above the sea floor, its summit reaches only 875 m above sea level. The broad irregular summit region contains overlapping craters up to 900 m wide and several lava domes. Several flank vents occur along a NW-trending fissure. The largest historical eruption of Paluweh occurred in 1928, when a strong explosive eruption was accompanied by landslide-induced tsunamis and lava dome emplacement.

***Information Contacts:*** *Center of Volcanology and Geological Hazard Mitigation (CVGHM)*, Jalan Diponegoro 57, Bandung 40122, Indonesia (URL: http://portal.vsi.esdm.go.id/joomla/).

# Rinjani

Lesser Sunda Islands, Indonesia
8.42°S, 116.47°E; summit elev. 3,726 m
All times are local (= UTC + 7 hours)

Eruptions at Rinjani (figures 14 and 15) between October 2004 and January 2005 (*BVGN* 30:02) was the first activity noted since September 1995. On 29 April 2009, the Center of Volcanology and Geological Hazard Mitigation (CVGHM) again detected an increase in earthquakes and tremor, with eruptions from Barujari's cone beginning 2 May 2009 and continuing through 21 June 2009.

According to a 4 May news article in the *Jakarta Post*, the first 2 May eruption consisted of four tectonic earthquakes, each lasting between 70 and 120 seconds. Heriyadi Rachmat, head of the East Nusa Tenggara province's mining, energy and mineral resources agency, stated in the article that "the peak of the activity was on Saturday 2 May with four tremors and the eruption of thick ash." This activity prompted CVGHM to raise the Alert Level from 1 to 2 (on a scale of 1 to 4). The head of the Mt. Rinjani National Park confirmed that, as of 3 May, the park had been officially closed to hikers. At that time, around 50 hikers were asked to come down from the mountain. Rinjani, a popular tourist destination, attracts an average of 9,000 hikers per year, 4,000 of whom are foreigners.

During May and June 2009, seismic activity consisted of numerous eruption signals, while observers saw ash plumes, incandescent material, and lava flows (table 2). CVGHM recorded the largest numbers of seismic signals between 7 and 31 May. In detail, during that interval there were 1,897 eruptive earthquakes, 2,163 low-frequency earthquakes, 1,341 harmonic tremor episodes, 3,249 air blasts, 17 shallow volcanic earthquakes, 39 deep volcanic earthquakes, seven local tectonic earthquakes, and three

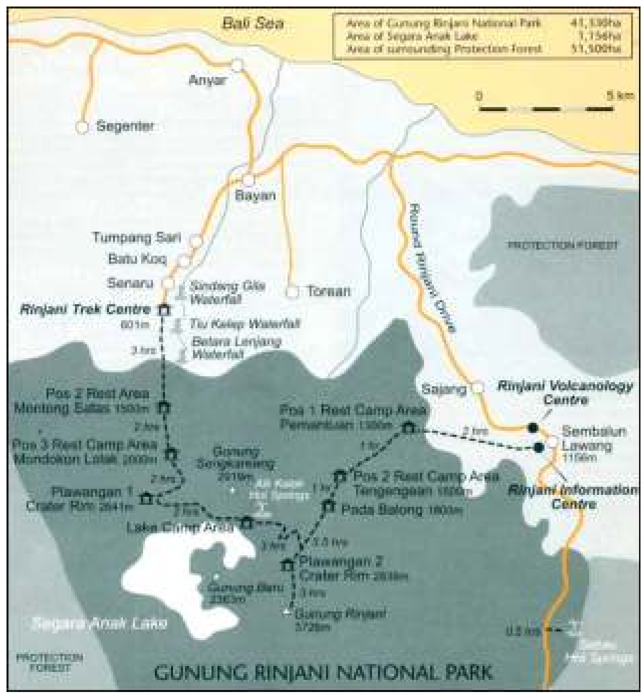


Figure 14. Map of Rinjani National Park's campsites and relative elevations. Courtesy of Rinjani Trek Centre (RTC).

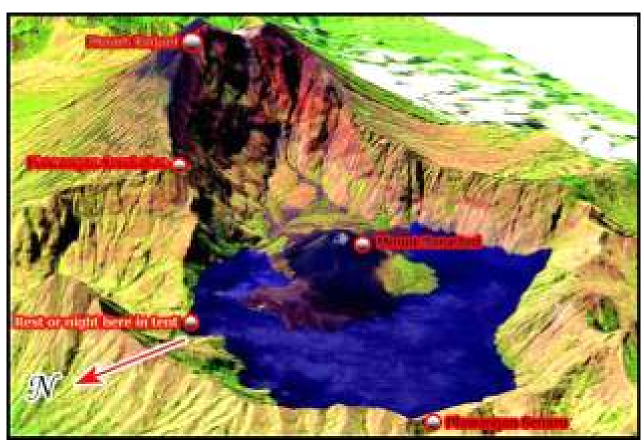

Figure 15. Diagram of Rinjani showing the Barujari volcanic cone surrounded by Lake Segara Anak. Courtesy of Bohari Adventures.

| Date (2009) | Eruptive earthquake | Low frequency Tremor | Harmonic tremor | Air blasts | Other earthquakes | Observations |
|---|---|---|---|---|---|---|
| 02 May | — | — | — | — | — | Dense brown ash plume to 4.7 km altitude; booming noise |
| 03 May | 21 | 13 | — | — | — | Recorded during 1800-2400 |
| 04 May | 85 | 12 | 1 | 7 | 1 LD | Ash eruption produced white to brown plume to 4.2-4.4 km altitude, drifting N |
| 05 May | 83 | | 2 | 45 | — | |
| 06 May | 83 | 22 | 30 | 53 | 3 volcanic | |
| 07 May | 92 | 43 | 29 | 88 | — | Recorded between 0000 and 1800; thick white plume |
| 07-31 May | 1,897 | 2,154 | 1,341 | 3,249 | 17 SV, 39 DV, 7 LT, 3 LD | 163 eruptions with dense white and gray plumes rising to 3.8-4.1 km altitude |
| 01-06 Jun | 240 | 569 | 493 | 316 | 5 SV,10 DV, 2 LT, 6 LD | |
| 07-15 Jun | — | Continuous | — | — | 3 DV | Dense white plumes to 1.3-2.7 km altitude |
| 16 Jun | — | Continuous | — | — | 1 LD | Dense white plumes to 1.3-1.5 km altitude |
| 21 June | — | — | — | — | — | Ash plumes to altitude of 3.0 km; drifted N |

Table 2. Earthquakes, tremor (both harmonic and non-harmonic with variable maximum amplitudes and durations), air blasts, and other observations between 2 May and 21 June 2009. Key: LD is long distance tectonic, SV is shallow volcanic, LT is local tectonic, DV is deep volcanic. Courtesy of CVGHM and the Darwin VAAC.

long-distance tectonic earthquakes. Although the volcano was frequently obscured by fog, people still saw impressive eruptions from the observation post at Sembalun Lawang. They noted continuous eruptions with ejected glowing material reaching 200 m in height above the vent, and thrown laterally out to a radius of 500 m from the summit. A great amount of ash, cinders, and incandescent material fell into the caldera, while smaller fragments were blown away.

Lava flowed into the caldera lake and then extended 100 m beyond the shoreline. CVGHM and Darwin Volcanic Ash Advisory Center (VAAC) reports also noted several ash plumes over the summit, including those of dense white and grayish color that rose 50-400 m above Sembalun Lawang observatory from 7 May through 29 May.

***Potential hazards.*** As of 16 June 2009, the status of Rinjani remained at Alert Level 2. CVGHM recommended remaining at least 4 km from the Barujari vent, noting potential risks from ashfall and incandescent rocks both within the caldera and in the surrounding areas (figure 16). In addition, CVGHM cautioned that landslides could enter Lake Segara Anak, causing an overflow that could form lahars.

***Geologic Summary.*** Rinjani volcano on the island of Lombok rises to 3726 m, second in height among Indonesian volcanoes only to Sumatra's Kerinci volcano. Rinjani has a steep-sided conical profile when viewed from the east, but the west side of the compound volcano is truncated by the 6 x 8.5 km, oval-shaped Segara Anak caldera. The western half of the caldera contains a 230-m-deep lake whose crescentic form results from growth of the post-caldera cone Barujari at the east end of the caldera. Historical eruptions at Rinjani dating back to 1847 have been restricted to Barujari cone and consist of moderate explosive activity and occasional lava flows that have entered Segara Anak lake.

***Information Contacts:*** *Center of Volcanology and Geological Hazard Mitigation (CVGHM)*, Jalan Diponegoro 57, Bandung 40122, Indonesia (URL: http://portal.vsi.esdm.go.id/joomla/); *Darwin Volcanic Ash Advisory Centre (VAAC)*, Bureau of Meteorology, Northern Territory Regional Office, PO Box 40050, Casuarina, NT 0811, Australia (URL: http://www.bom.gov.au/info/vaac/); *The Jakarta Post* (URL: http://www.thejakartapost.com/news/2009/05/04/mt-baru-jari-spews-ash.html); *Rinjani*

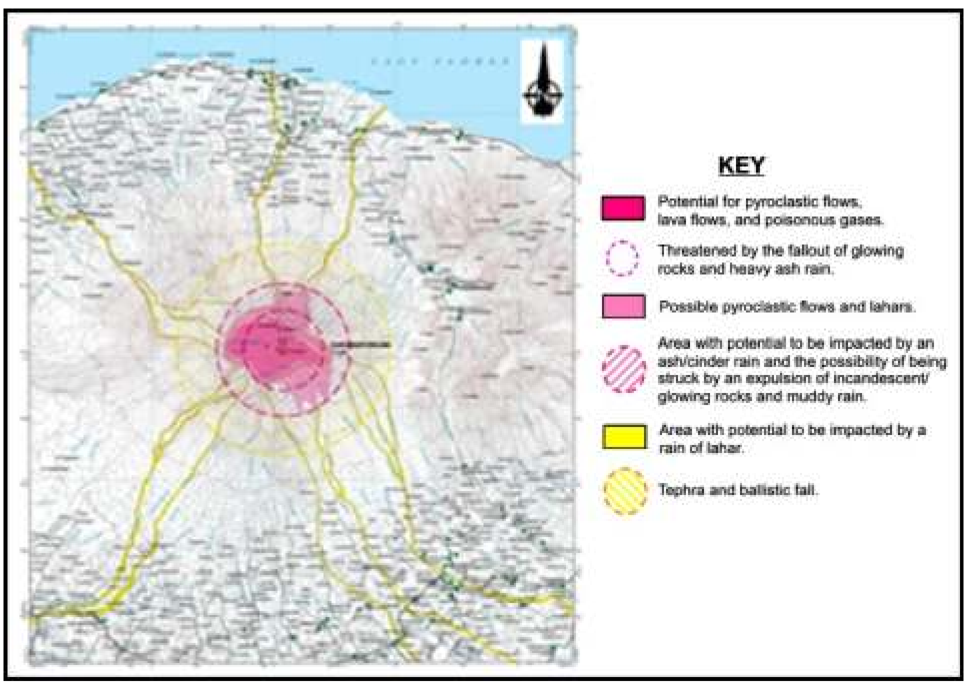


Figure 16. A hazard map showing risk areas at Rinjani. Note the lahars extend beyond the two concentric circular areas, reaching the sea on the N to NW outer flanks. Date of publication and exact details of authorship uncertain. Courtesy of CVGHM.

*Trekking Centre*, Jalan Barakuda 10, BTN Griya Batu Bolong Senggigi, Senggigi-West Lombok 83355, Lombok-NTB-Indonesia (URL: http://www.rinjanimountain.com/rinjani-information-center.htm); *Bohari Adventures*, Jalan Cendrawasih 8, Cakranegara Mataram 83231, Lombok-NTB-Indonesia (URL: http://www.trekkingrinjani.com/).

## Tafu-Maka

Tonga

15.37°S, 174.23°W; summit elev. -1,400 m

The following is the first *Bulletin* report about this submarine volcanic area in the S part of the Northeast Lau Spreading Center (NELSC) (figure 17). An informal paper by Resing and others (2009) reported that two recent eruption sites were discovered in the NE Lau Basin during a November 2008 scientific expedition aboard the *Research Vessel (R/V) Thompson*. The first eruption site discovered was within the NELSC and contained two active submarine volcanoes, Tafu and Maka (figure 18). During the expedition a conductivity/temperature/depth (CTD)/rosette package was used to measure the physical and chemical nature of hydrothermal systems, and the *Thompson's* multibeam sonar provided high resolution bathymetry and seafloor backscatter imagery. Another expedition in May 2009 revealed fresh lava flows near the Maka cone.

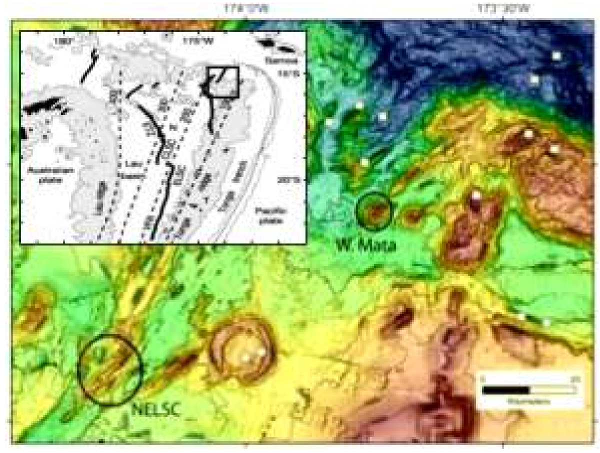


Figure 17. Bathymetric map of NE Lau area showing two eruption areas (circled) discovered during the 2009 expedition, West Mata and NELSC where volcanoes Tafu and Maka are located. Contour interval 500 m. Inset location map shows the Fiji Islands (~ 860 km WNW) and Samoa (~ 270 km NE), along with the East Lau Spreading Center (ELSC), Central Lau Spreading Center (CLSC), and Fonulalei Spreading Center (FSC). Courtesy of Resing and others (2009).

***Expedition during 13-28 November 2008.*** The Tafu-Maka eruption site was discovered on the neovolcanic zone of the southernmost segment of the NELSC at a depth of ~ 1,650 m depth (figure 17). Plumes characterized by high levels of turbidity, concentrations of volcanic glass shards, large temperature anomalies, pH anomalies, hydrogen, and methane were detected up to 800 m above the seafloor at several locations above this ridge between the Tafu and Maka features (figure 18). Volcanic glass and other clastic material were present in filtered particulate samples from the plume. Such high-rising plumes in this type of hydrographic setting have been reliable indicators of massive hydrothermal discharge associated with seafloor eruptions. The observed levels of hydrogen in plumes have only been associated with the interaction of molten rock and seawater. In addition, near-bottom tempera-

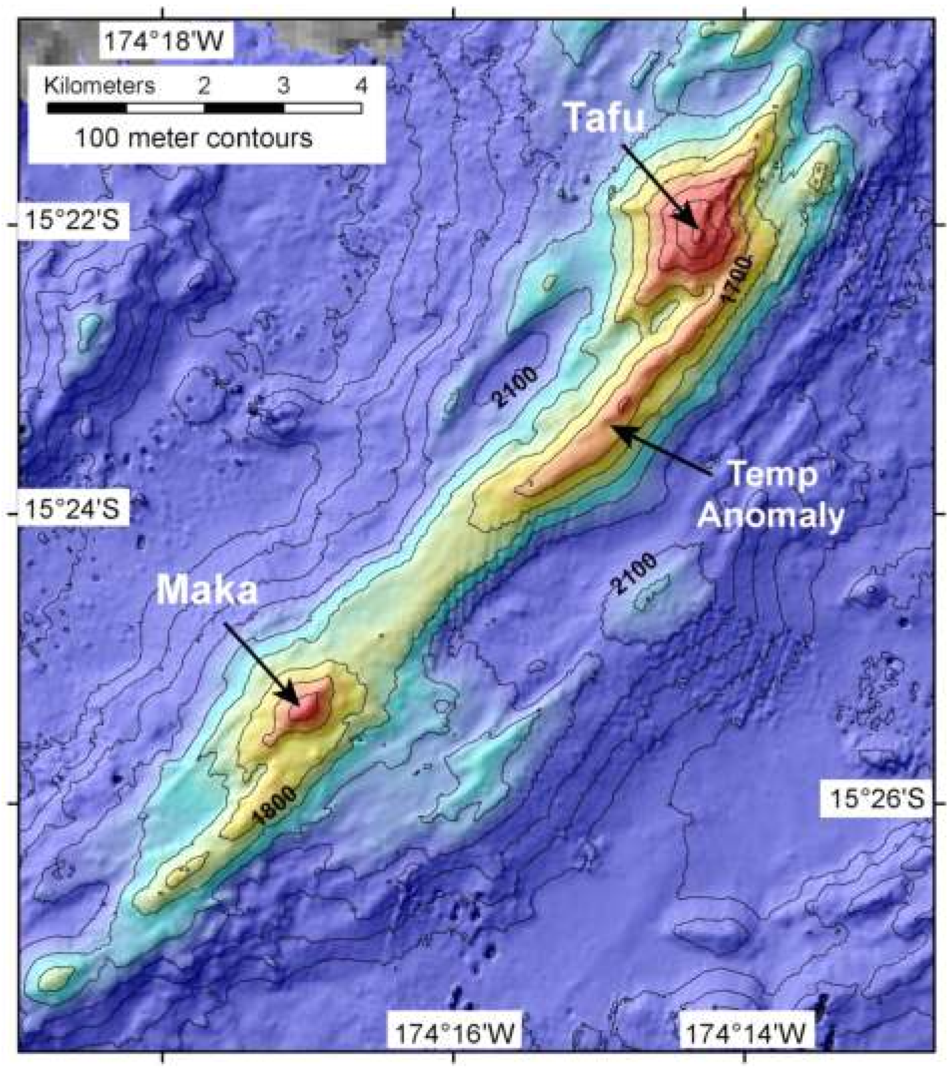


Figure 18. Multibeam bathymetry of the Tafu-Maka ridge eruption site along the southern segment of the Northeast Lau Spreading Center (NELSC). Contour interval 100 m. Courtesy of Resing and others (2009).

ture anomalies of ~ 0.5°C, measured with the CTDO (conductivity/temperature/depth/oxygen) package, coincided with high levels of $H_2$ and $CH_4$ on the neovolcanic ridge north of Maka.

Prior work in the area (German and others, 2006) had located an intense hydrothermal plume over Maka, and this plume was relocated and sampled in 2008. According to Resing, a survey in August 2008 using a commercial ROV funded by Nautilus Minerals, Inc., discovered a very active black smoker field underlying this plume. The vent was apparently at the boiling temperature, based on video observations. The 2008 dive found no hydrothermal activity during a traverse of the presumed eruption site on the ridge axis. There were also plumes at depths below the neovolcanic ridge. Many of these plumes were probably formed by fallout and/or bottom gravity flows of volcaniclastic material such as described from the erupting submarine volcano NW Rota-1 in the Mariana arc (*BGVN* 31:05 and 33:02).

Ed Baker, another scientist on the 2008 expedition, observed that many more plumes were found, and much higher above the seafloor, than expected. Instruments that were lowered above the summit of Tafu, the larger of the two (which rises some 500 m above the ridge, to a depth of ~ 1,400 m), found scant evidence of activity. Above Maka, with a summit 150 m deeper at, there was a plume found at a depth of 700 m. Instruments identified distinct layers, each chemical rich, some thick, some thin, until the instruments stopped at 1,560 m depth just above the summit.

***Expedition during 5-13 May 2009.*** Inspection with the *ROV Jason* during another cruise in May 2009 documented a lava flow along the NELSC, draped and folded over the seafloor near Maka, that scientists named “Puipui,” meaning “curtain” in Tongan. In a blog posting on the expedition website, Ken Rubin noted that the combination of steep topography, gas-rich fluid magma, and an apparently very fast lava effusion event, created a range of lava forms over a short spatial distance. The pre-eruption land surface strongly controlled where and how the young lava flowed. Ridges of old rock less than 2 m high dammed the flow in places, where it flowed in thin flat sheets between the high ground. Nearer the volcanic vents, which appear to be located along a narrow ridge, lava cascaded 10 m or more down steep rock faces, forming lava sheets. Rubin also reported that in other places the lava ponded, crusted over, and then drained out, leaving collapse pits and revealing chambers with lava shells held up by pillars of fresh rock.

***References:*** Falloon, T.J., Danyushevsky, L.V., Crawford, T.J., Maas, R.W., Eggins, S.M., Bloomer, S.H., Wright, D.J., Zlobin, S.K., and Stacey, A.R., 2007, Multiple mantle plume components involved in the petrogenesis of subduction-related lavas from the northern termination of the Tonga Arc and northern Lau Basin: Evidence from the geochemistry of arc and backarc submarine volcanics: Geochemistry, Geophysics, Geosystems, v. 8, Q09003, doi:10.1029/2007GC001619.

German, C.R., Baker, E.T., Connelly, D.P., Lupton, J.E. . Resing, J., Prien, R.D., Walker, S.L., Edmonds, H.N., and Langmuir, C.H., 2006, Hydrothermal exploration of the Fonualei Rift and spreading center and the North East Lau Spreading Center: Geochemistry, Geophysics, Geosystems, v. 7, Q11022, doi: 10.1029/2006GC001324.

Resing, J., Lupton, J., Embley, R., Baker, E., and Lilley, M. (compilers), 2009, Preliminary findings from the North Lau eruption sites, informal report, 2/5/09 (URL: http://www.ridge2000.org/science/downloads/email/Nlaupreliminaryfindings25.pdf).

***Geologic Summary.*** Two submarine volcanoes, Tafu and Maka, lie along a NE-SW-trending ridge segment on the southern part of the NE Lau Spreading Center (NELSC). The NELSC is a back-arc spreading center in the northeast part of the Lau Basin. Tafu (Tongan for “source of fire”) rises to about 1,400 m below sea level at the NE end of the ridge segment, and Maka (Tongan for “rock”) reaches 1,560 m below sea level at the SW end of the ridge segment. A November 2008 NOAA Vents Program expedition discovered submarine hydrothermal plumes consistent with very recent (days to weeks?) submarine lava effusion from Maka volcano. A return visit in May 2009 documented the freshly emplaced lava flow at Maka.

***Information Contacts:*** *2008 Expedition to Lau Basin (website)*, NOAA/PMEL VENTS Program, Hatfield Marine Science Center, 2115 S.E. OSU Dr., Newport, OR 97365, USA (URL: http://www.pmel.noaa.gov/vents/laubasin.html); *2009 Lau Basin Eruption Exploration Expedition (blog)*, NOAA/PMEL VENTS Program (URL: http://laueruptions.blogspot.com/).

# West Mata

Tonga

15.10°S, 173.75°W; summit elev. -1,174 m

This is the first *Bulletin* report on West Mata, a small seamount ~ 200 km SW of Samoa, the scene of inferred ongoing eruptions when visited during November 2008 and an unambiguous eruption at multiple vents when visited during May 2009. West Mata is located in the NE Lau basin ~ 35 km E of the closest portion of the Lau spreading center (figure 19) and ~ 70 km NE of a now-erupting portion of the NE Lau spreading center (NELSC). Investigations of this site were made on two research cruises conducted in the region by the Research Vessel (R/V) *Thompson* during November 2008 and May 2009.

***Expedition during 13-28 November 2008.*** During the 2008 expedition, water column measurements were made, including a conductivity, temperature, and depth (CTD) rosette package to characterize the physical and chemical nature of hydrothermal systems. The *R/V Thompson's* multibeam sonar provided high-resolution bathymetry and seafloor backscatter imagery. West Mata volcano (figure 20) was very likely erupting lava flows and/or pyroclastic material at this time. The intense plume rising ~ 175 m from the summit that was characterized by high values of turbidity, hydrogen, delta helium-3 ($\delta^3$He), oxidation-reduction potential (Eh), and pH. The acoustic backscatter over portions of the volcano was uniformly high, indicating geologically young seafloor.

Although the marine optical backscatter was dominated by elemental sulfur and particulate iron, there was also an abundance of large mineral and/or glass shards in the plume. The larger clastic materials were composed almost exclusively of Mg-silicates, with lesser Ca-Mg-silicates. These compositions were consistent with the eruption of boninites (glass olivine-bronzite andesite that contains little or no feldspar) that previously have only been observed at inactive volcanoes. These chemical and geological charac-

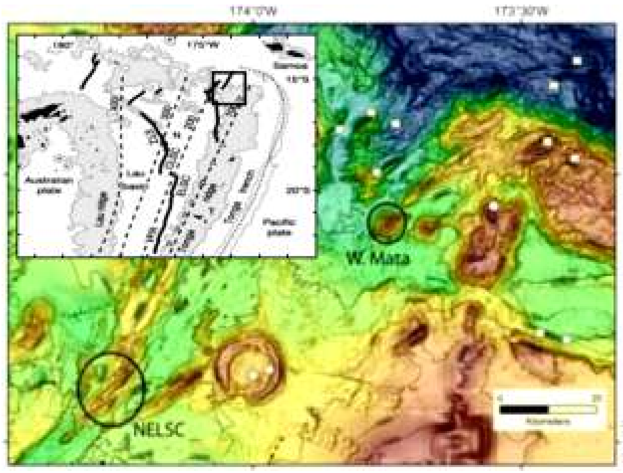


Figure 19. Bathymetric map of NE Lau area showing two eruption areas (circled) discovered during the 2009 expedition, West Mata and NELSC where volcanoes Tafu and Maka are located. Contour interval 500 m. Inset location map shows the Fiji Islands (~ 860 km WNW) and Samoa (~ 270 km NE), along with the East Lau Spreading Center (ELSC), Central Lau Spreading Center (CLSC), and Fonulalei Spreading Center (FSC). Courtesy of Resing and others (2009).

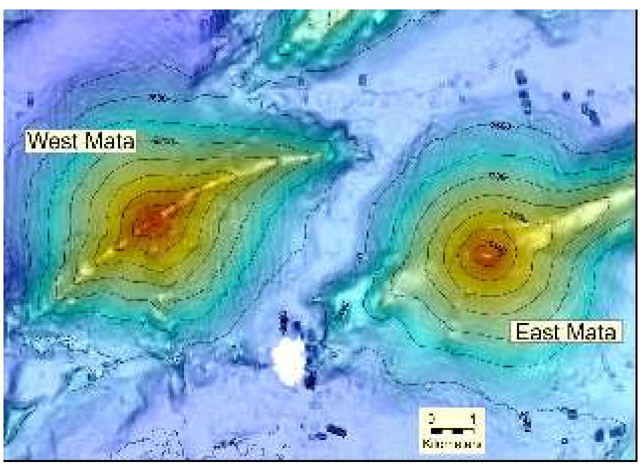


Figure 20. Multibeam bathymetry of West and East Mata volcanoes. Contour interval is 200 m. Taken from Resing and others (2009).

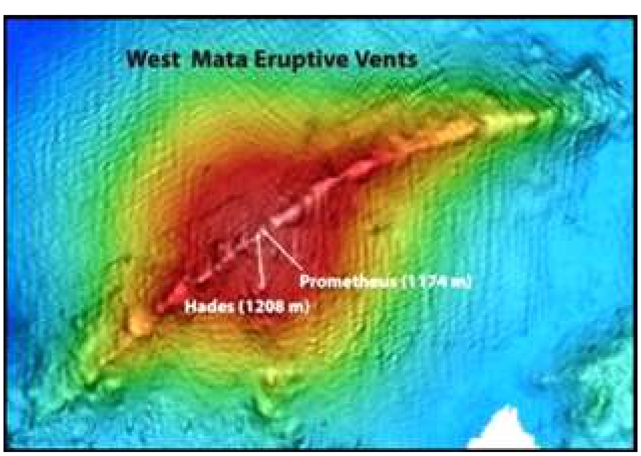


Figure 21. The two Jason ROV dives at West Mata volcano discovered not just one active volcanic vent, but two, Hades and Prometheus. Both vents were obscured much of the time by billowing sulfurous gas emissions, but bright orange lava was seen in both vents. The orange glowing lava was visible for minutes at a time. Text courtesy of Dave Clague (on expedition blog); bathymetric chart courtesy of NOAA Vents website.

teristics match well with those of NW Rota-1 in the southern Mariana arc, which has been undergoing submarine Strombolian eruptions for at least 4 years (*BGVN* 29:03, 31:05, and 33:02).

Resing and others (2009) reported that the acoustic backscatter appeared to show extensive deposits of clastic material draping the volcano and extending over a recent lava flow at its eastern end, suggesting a recent and continuous state of eruption. Finally, they note that East Mata (figure 21), a similar volcano ~ 10 km closer to the Tofua arc, is also hydrothermally active, albeit less intense than West Mata.

***Expedition during 5-13 May 2009.*** On 6-7 May, scientists onboard the *R/V Thompson* used the *Jason 2* ROV (remotely operated vehicle) to observe eruptions from two vents of West Mata (figure 21), Prometheus (at or near the summit) and Hades (slightly to the SW). According to Dave Clague, writing on the expedition blog, the deeper vent, Hades, sits on the SW rift. It was erupting both effusively and explosively at the same time on both days (6-7 May). Small bursts were occurring at one end of an erupting fissure ~ 5 m long at a depth of 1,208 m, while pillow lavas were being extruded from the other end. By the next night (7 May) the activity had become more vigorous, sometimes blowing glowing bubbles as much as a meter across from the fissure.

Clague noted that the second, shallower vent, Prometheus, was located very near the summit of the volcano and about 100 meters away from Hades, the first vent. The eruption here was entirely explosive with low-level, but nearly continuous fire fountains throwing ejecta into the water during both dives. Both vents were often obscured by sulfur gas emissions, but incandescence was visible for minutes at a time. According to an article on the *Discovery News* website, *Jason 2* approached the vent and was promptly buried in ~ 45 kg of debris. Huge gas bubbles, maybe 1 m in diameter, were observed coming out of West Mata.

***References:*** Resing, J., Lupton, J., Embley, R., Baker, E., and Lilley, M. (compilers), 2009, Preliminary findings from the North Lau eruption sites, informal report, 2/5/09 (URL: http://www.ridge2000.org/science/downloads/email/Nlaupreliminaryfindings25.pdf).

***Geologic Summary.*** West Mata, a submarine volcano rising to within 1174 m of the sea surface, is located in the northeastern Lau Basin at the northern end of the Tonga arc, about 200 km SW of Samoa. West Mata volcano lies about 7 km west of another submarine volcano, East Mata; both lie at the northern end of the Tonga arc, north of the historically active Curacoa submarine volcano. The two volcanoes were discovered during a November 2008 NOAA Vents Program expedition, and West Mata was found to be producing submarine hydrothermal plumes consistent with a recent or lava effusion. A return visit in May 2009 documented explosive and effusive activity from two closely spaced vents, one at the summit, and the other on the SW rift zone.

***Information Contacts:*** *2009 Lau Basin Eruption Exploration Expedition (blog)*, NOAA/PMEL VENTS Program (URL: http://laueruptions.blogspot.com/); *National Oceanographic and Atmospheric Agency (NOAA) Vents Program* (URL: http:/www.pmel.noaa.gov/vents/); *Discovery News* (URL: http://dsc.discovery.com/news/2009/06/05/undersea-eruption.html).

# Redoubt

southwestern Alaska, USA
60.485°N, 152.742°W; summit elev. 3,108 m
All times are local (= UTC - 9 hours)

Major eruptions took place at Redoubt between 15 March and 4 April 2009 (*BGVN* 34:04) (figure 22-24). Subsequent to those eruptions, through mid-May 2009, the lava dome continued to grow. That growth was often associated with occasional rockfalls, and small plumes, some of which contained ash and sulfur dioxide. The eruption had significant economic impacts including to the aviation industry (*BGVN* 34:04). The current report summarizes activity from mid-May to 30 June 2009.

Alaska Volcano Observatory (AVO) reported seismicity from Redoubt during 13 May to 23 June 2009 remained above background levels. Signals disclosed rock avalanches, discrete earthquakes. Minor volcanic tremor continued. Growth of the lava dome in the summit crater (figure 25) continued, and by 15 May the dome's volume was an estimated 30-60 million cubic meters. By 12 June, the dome was an estimated 1 km long, 460 m wide, and 200 m high. AVO warned that the unstable lava dome could fail with little or no warning, leading to significant ash emissions and possible lahars in the Drift River valley. Occasional rockfalls originating from unstable slopes of the lava dome produced minor ash clouds near the summit.

Vigorous steam emissions from the margins of the lava dome were seen on the web camera. At times, incandescence was observed in nighttime images. During an overflight on 16 May, scientists observed a turquoise lake along the S margin of the dome, and a hot, vigorous, persistent fumarole on the W wall of the upper gorge.

By late June 2009, AVO reported declining seismicity. The lower seismicity and gas emissions, along with occasional observations, suggested that dome growth had significantly slowed. On 30 June, AVO lowered the Alert Level to Advisory and the Aviation Color Code to Yellow.

***Aviation encounter on 26 March 2009.*** The Montreal VAAC received news that a plane for a Canadian carrier encountered a volcanic cloud over southern British Columbia, near Kelowna, at approximately 0000 UTC on 26 March 2009. At that time, to the best knowledge of the VAAC, the plume from the initial eruption of Redoubt (23 March) consisted of considerable amounts of $SO_2$, but no ash. A full inspection of the plane found no ash.

***Geologic Summary.*** Redoubt is a 3,108-m-high glacier-covered stratovolcano with a breached summit crater in Lake Clark National Park about 170 km SW of Anchorage. Next to Mount Spurr, Redoubt has been the most active Holocene volcano in the upper Cook Inlet. The volcano was constructed beginning about 890,000 years ago over Mesozoic granitic rocks of the Alaska-Aleutian Range batholith. Collapse of the summit of Redoubt 10,500-13,000 years ago produced a major debris avalanche that reached Cook Inlet. Holocene activity has included the emplacement of a large debris avalanche and clay-rich lahars that dammed Lake Crescent on the S side and reached Cook Inlet about 3,500 years ago. Eruptions during the past few centuries have affected only the Drift River drainage on the N. Historical eruptions have originated from a vent at the N end of the 1.8-km-wide breached summit crater. The 1989-90 eruption of Redoubt had severe economic impact on the Cook Inlet region and affected air traffic far beyond the volcano.


Figure 23. Redoubt fall deposit laid down on 23 March 2009. Taken at station RDW-C in July 2009. Courtesy of AVO/ADGGS and Kate Bull.

Figure 22. View of the face of Redoubt taken on 2 July 2009. Courtesy of AVO/USGS and Cyrus Read.

Figure 24. View looking towards Redoubt, 1 July 2009. Courtesy of the AVO/ADGGS and Kate Bull.

***Information Contacts:*** *Alaska Volcano Observatory (AVO)*, a cooperative program of a) U.S. Geological Survey, 4200 University Drive, Anchorage, AK 99508-4667 USA (URL: http://www.avo.alaska.edu/), b) Geophysical Institute, University of Alaska, P.O. Box 757320, Fairbanks, AK 99775-7320 USA, and c) Alaska Division of Geological & Geophysical Surveys, 794 University Ave., Suite 200, Fairbanks, AK 99709 USA; *Associated Press* (URL: http://www.ap.org/); *Dov Bensimon*, Montréal VAAC, 2121 North Service Road, Trans-Canada Highway, Dorval, Quebec H9P 1J3, Canada.

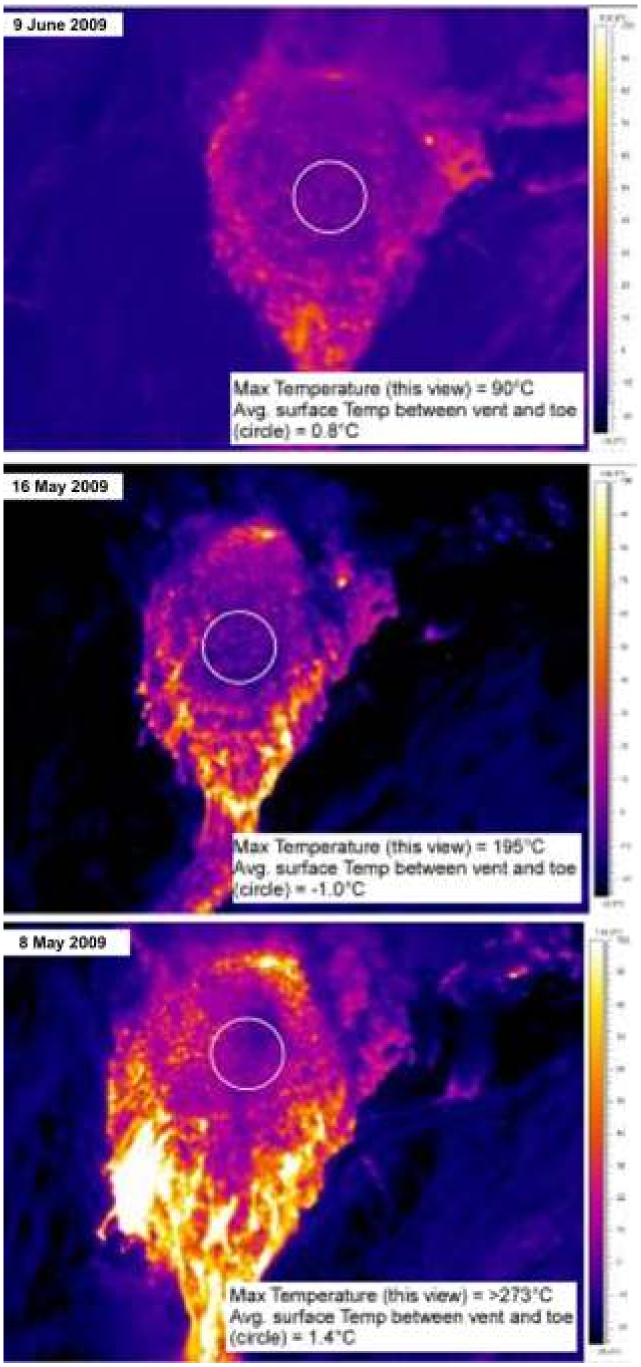


Figure 25. A series of Forward Looking InfraRed (FLIR) thermal images showing the Redoubt dome's gradual cooling. The new dome has been extruding since 4 April 2009. Temperature scales are at right. Note the average temperature of the rubbly area between the vent at the top of the dome and the block top at the N base of the dome (circle) varied between -1.0 to 1.4°C. Courtesy of AVO/USGS and Rick Wessles.

# Telica

Nicaragua
12.602°N, 86.845°W; summit elev. 1,061 m
All times are local (= UTC - 6 hours)

Intermittent ash explosions and crater incandescence were seen during 2000-2002, along with high levels of seismicity related to degassing and constant low tremor (*BGVN* 34:05). Strong gas emissions were typical in the first half of 2003, with incandescence often noted later in the year. Activity during 2004 included occasional ash explosions as well as incandescence. After small ash explosions in late January 2005 no volcanism was noted for the remainder of the year, with observers primarily noting crater wall collapses and degassing. The Nicaraguan Territorial Studies Institute (INETER) monitors activity; visits to the crater described below are by INETER staff (primarily Pedro Perez) unless otherwise noted, though scientists from other institutions may have also been present. Some observations were also made by a local resident who maintains the local seismic station.

***Activity during 2003.*** In January 2003 gas emissions at Telica fluctuated in their intensity. Dense gas prevented observations of incandescence. During a crater visit on 6 May an observer heard a pressurized sound, smelled sulfur, and saw blue gases. Eucalyptus trees 2 km E of the crater appeared to have been burned by the acidic gases. There was a bluish glow in the crater on 25 June and a strong smell of sulfur. To the W of the volcano several trees dropped the bulk of their leaves due to acid rain. Gas emissions remained almost constant at a moderate level.

On 31 July a high pressure noise was heard and incandescence was observed in the center of the crater. Pressurized gases emerging on 22 August from the vent at the bottom of the crater emitted a loud, jet-like sound. As in July, the vent also showed incandescence and emitted a sulfur odor. Satellite images on 24 September showed a column of gas. On 7 October incandescent was again observed, along with a strong odor of sulfur. There was a collapse of material in the SE sector.

***Activity during 2004.*** On 20 January 2004 a wavelike sound was heard, open fissures emitted little gas, and glow was observed in the crater (figure 26). A small ash explosion on 31 March at about 0856 was reported by the caretaker of the Tel3 seismic station. On 28 April an observer noted that internal collapses had covered almost half of the southern part of the crater floor with debris. As a result incandescence in the crater was difficult to detect.

A seismic swarm N of Telica lasted from 9 to 14 June. The earthquakes had magnitudes up to 2.4 and depths between 1 and 9 km, with some being felt by local residents in the Aguas Calientes area. On 28 June a seismic signal similar to that of an explosion was detected. INETER received no reports of ashfall in surrounding areas. Reports for July-September were not available. Ash explosions occurred from the crater on 5 and 11 November. On 10 December there was significant gas and ash output, with sounds of breaking rocks inside the crater. Unlike the previous months, no incandescence was seen.

***Activity during 2005.*** On 29 January 2005 the volcano produced small ash explosions with abundant gases. The next day when INETER technician Pedro Pérez visited he

Figure 26. Photograph of the crater at Telica, showing incandescence on 20 January 2004. Courtesy of P. Perez (INETER).


Figure 27. Photograph showing the Telica crater on 9 August 2005. Rockfall debris from crater wall collapses can be seen on the crater floor. Courtesy of P. Perez (INETER).

heard jet-like sounds and smelled strong gas emissions. Low gas emissions persisted during February-April. On 15 May a small earthquake swarm lasted about ten hours. Observers to the crater on 1 May noted small blue gas emissions and sulfur odor, but no incandescence. Collapses were also seen in the W and S portions of the crater.

On 30 June observers saw minor gas emissions and new material in the eruptive fissure from crater wall collapses. Activity was low on 9 August (figure 27), no sounds heard, but the crater walls had some precipitates from the gas emissions. On a 7 September visit additional collapses of the crater walls were observed along with significant gas emission. Small gas emissions were observed by a monitoring webcam for almost the entire month of December.

***Geologic Summary.*** Telica, one of Nicaragua's most active volcanoes, has erupted frequently since the beginning of the Spanish era. The Telica volcano group consists of several interlocking cones and vents with a general NW alignment. Sixteenth-century eruptions were reported at symmetrical Santa Clara volcano at the SW end of the Telica group. However, its eroded and breached crater has been covered by forests throughout historical time, and these eruptions may have originated from Telica, whose upper slopes in contrast are unvegetated. The steep-sided cone of 1,061-m-high Telica is truncated by a 700-m-wide double crater; the southern crater, the source of recent eruptions, is 120 m deep. El Liston, immediately SE of Telica, has several nested craters. The fumaroles and boiling mudpots of Hervideros de San Jacinto, SE of Telica, form a prominent geothermal area frequented by tourists, and geothermal exploration has occurred nearby.

***Information Contacts:*** *Wilfried Strauch*, Instituto Nicaragüense de Estudios Territoriales (INETER), Apartado Postal 2110, Managua, Nicaragua (URL: http://www.ineter.gob.ni/geofisica/geofisica.html).

# Sangay

Ecuador
2.002°S, 78.341°W; summit elev. 5230 m
All times are local (= UTC - 5 hours)

Our most recent reports on Sangay noted occasional steam and/or ash plumes between 11 October 2006 and 28 December 2007 (*BGVN* 33:03) and thermal anomalies between 27 March and 4 December 2008 (*BGVN* 34:01). The current report continues to tabulate this persistently erupting volcano's plumes from 28 December 2007 to 31 July 2009 (table 3), and thermal anomalies from 4 December 2008 to 10 August 2009 (table 4).

***Geologic Summary.*** The isolated Sangay volcano, located east of the Andean crest, is the southernmost of Ecuador's volcanoes, and its most active. The dominantly andesitic volcano has been in frequent eruption for the past several centuries. The steep-sided, 5,230-m-high, glacier-covered volcano grew within horseshoe-shaped calderas of two previous edifices, which were destroyed by collapse to the E, producing large debris avalanches that reached the Amazonian lowlands. The modern edifice dates back to at least 14,000 years ago. Sangay towers above the tropical jungle on the E side; on the other sides flat plains of ash from the volcano have been sculpted by heavy rains into steep-walled canyons up to 600 m deep. The earliest

| Date | Maximum Altitude | Bearing | Remarks |
|---|---|---|---|
| 05 Jan 2009 | 7 km | S | |
| 09 Feb 2009 | 7.9 | — | |
| 10 Mar 2009 | 5.5 | W | TA detected |
| 15 Jun 2009 | — | WNW | TA reported by VAAC |
| 26 Jun 2009 | 7.6 | W | |
| 23 Jul 2009 | 7.9 | — | |

Table 3. Sangay ash plume activity, reported for 29 December 2008 to July 2009. NR signifies not reported and no plumes were observed 29-31 December 2008. TA is thermal anomaly. Courtesy of the Washington Volcanic Ash Advisory Center.

| Date (UTC) | Time (UTC) | Pixels | Satellite |
|---|---|---|---|
| 10 Mar 2009 | 0645 | 1 | Aqua |
| 10 Aug 2009 | 0340 | 1 | Terra |

Table 4. Thermal anomalies at Sangay based on MODIS-MODVOLC data during 4 December 2008 to 10 August 2009 (continued from the list in *BGVN* 34:01). Courtesy HIGP Thermal Alerts System.

report of a historical eruption was in 1628. More or less continuous eruptions were reported from 1728 until 1916, and again from 1934 to the present. The more or less constant eruptive activity has caused frequent changes to the morphology of the summit crater complex.

***Information Contacts:*** *Washington Volcanic Ash Advisory Center*, Satellite Analysis Branch (SAB), NOAA/NESDIS E/SP23, NOAA Science Center Room 401, 5200 Auth Rd, Camp Springs, MD 20746, USA (URL: http://www.ssd.noaa.gov/VAAC/); *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/).

# Manda Hararo

Ethiopia
12.17°N, 40.82°E; summit elev. 600+ m
All times are local (= UTC + 3 hours)

A large $SO_2$ cloud in southern Afar, Ethiopia was detected by the OMI instrument aboard NASA's EOS-AURA satellite on 29 June 2009 (figure 28). The cloud appeared to originate from the Karbahi region of the Manda Hararo rift segment, a graben area with numerous active faults, fissures, and basalt flows. The cloud was similar in size to that observed during a basaltic fissure eruption in August 2007 (*BGVN* 32:07). As reported by Simon Carn, the 29 June 2009 cloud had a total mass of 3.864 kt, an area of 186,710 $km^2$, and an $SO_2$ max of 4.75 DU (Dobson Units). Other clouds were also seen, including a large one on 30 June.

MODIS satellite imagery from 2320 UTC on 28-29 June confirmed that the $SO_2$ cloud was associated with thermal anomalies appearing in the immediate vicinity of the August 2007 eruption. According to Charles Holliday, METEOSAT real time Active Fire Monitoring data derived from METEOSAT imagery suggests the eruption began within 15 minutes of 1715 UTC on 28 June 2009, about 7 hours after a magnitude 4.4 earthquake, identified by the Addis Ababa Geophysical Observatory and the European-Mediterranean Seismological Centre.

A field team of scientists, including Gezahegn Yirgu, Tesfaye Kidane, Elias Lewi, Tesfaye Chernet, Girma Wolde Tinsae, David Ferguson, Talfan Barnie, and Osman Mohammed, reached the site of the thermal anomalies by helicopter on 4 July 2009 and spent about two hours on the scene. They found the eruption had emitted predominantly a'a basalt flows, approximately 2-3 m thick that originated from fissures approximately 4-5 km long. The vent areas contained scoria ramparts approximately 30-50 m high. The field team collected rock and gas samples and surveyed the erupted material using visible and FLIR (Forward-Looking Infrared) cameras from both the air and the ground. Hand samples suggested the erupted lava was feldspar-bearing porphyritic basalt. No lava effusion was observed, although some steam was seen at the fissure (figure 29).

The fissure itself was inaccessible over land because it was surrounded by hot rock and could only be observed from a distance. Only a small part of the margins of the flow were visited on the ground due to limited time, rough terrain, and high temperature and humidity. The lava flows appeared to have cooled significantly, with the FLIR recording typical temperatures of between 30 and 120ºC for the flow surfaces, and a maximum temperature of 238ºC observed from the air (figure 30). The team made gas measurements at hot cracks in the flow front where they smelled volcanic gases and the FLIR registered temperatures over 100ºC. According to David Ferguson, the group used FLIR thermal images to determine a safe route for walking. While the front of the lava flow had a dark black crust, similar to that of much colder flows, the FLIR camera on land recorded temperatures of up to 162ºC around the cracks and fissures of the flow surface.

A 6 July ASTER (Advanced Spaceborne Thermal Emission and Reflection Radiometer) image from the eruption site shows a warm 6.3 x 1.4 km flow erupted from a NW-SE trending fissure (figure 31). The area of the flow field is 4.0 $km^2$. The coordinates of the center of the flow field are 40.655, 12.256. A 9 July EO-1 ALI panchromatic image shows the flow at a higher resolution (figure 32).

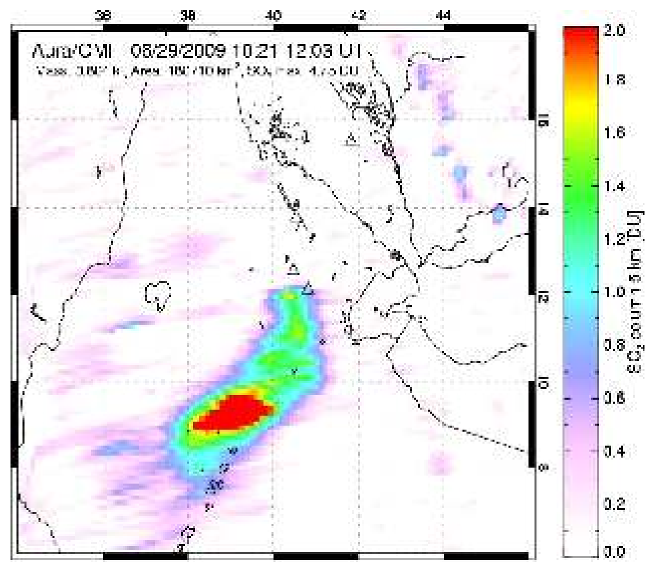


Figure 28. The eruptive $SO_2$ cloud from Manda hararo over southern Afar region detected by the OMI instrument. Image acquired during 1021-1203 UTC on 29 June 2009. Courtesy of Simon Carn, Michigan Technological University.

Figure 29. Oblique aerial photograph of Manda Hararo showing the eruptive fissure, scoria ramparts, and gas plume on 4 July 2009. Courtesy of Talfan Barnie, University of Cambridge.

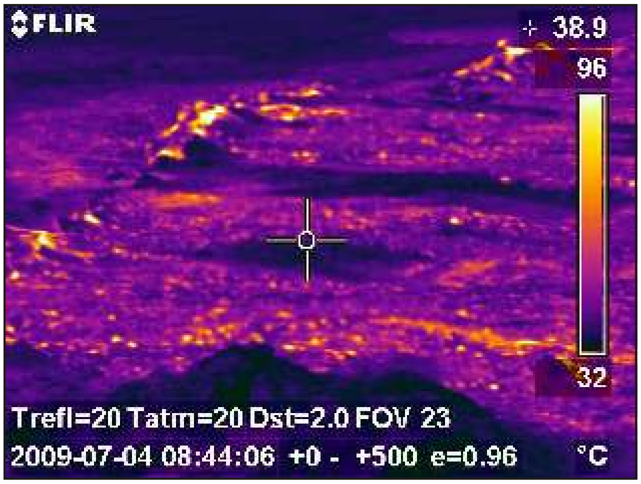


Figure 30. FLIR image of the 4 July 2009 eruption at Manda Hararo showing temperature distribution in and around the fissure. Courtesy of Talfan Barnie, University of Cambridge.

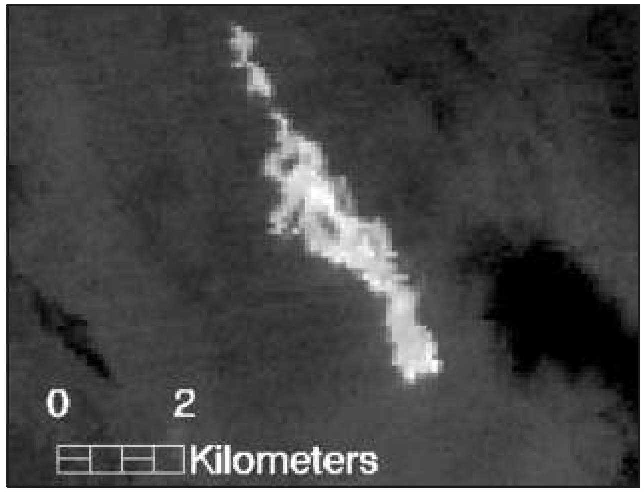


Figure 31. ASTER infrared image at Manda Hararo taken on 6 July 2009. The image shows a warm flow, 6.3 x 1.4 km, erupted from what looks like a NW-SE trending fissure. A clear pre-eruptive image from May 2009 shows nothing anomalous at this spot, indicating that the lava flow is new. The coordinates of the center of the flow field are 12.256°N, 40.655°E. Courtesy of Matt Patrick.

***Geologic Summary.*** The southernmost axial range of western Afar, the Manda Hararo complex is located in the Kalo plain, SSE of Dabbahu volcano. The massive complex is 105 km long and 20-30 km wide, and represents an uplifted segment of a mid-ocean ridge spreading center. A small basaltic shield volcano is located at the northern end of the complex, S of which is an area of abundant fissure-fed lava flows. Two basaltic shield volcanoes, the largest of which is Unda Hararo, occupy the center of the complex. The dominant part of the complex lies to the S, where the Gumatmali-Gablaytu fissure system is located. Voluminous fluid lava flows issued from these NNW-trending fissures, and solidified lava lakes occupy two large craters. The small Gablaytu shield volcano forms the SE-most end of the Manda Hararo complex. Lava flows from Gablaytu and from Manda overlie 8,000-year-old sediments. Hot springs and fumaroles occur around Daorre Lake. The first historical eruption of Manda Hararo produced fissure-fed lava flows in 2007.

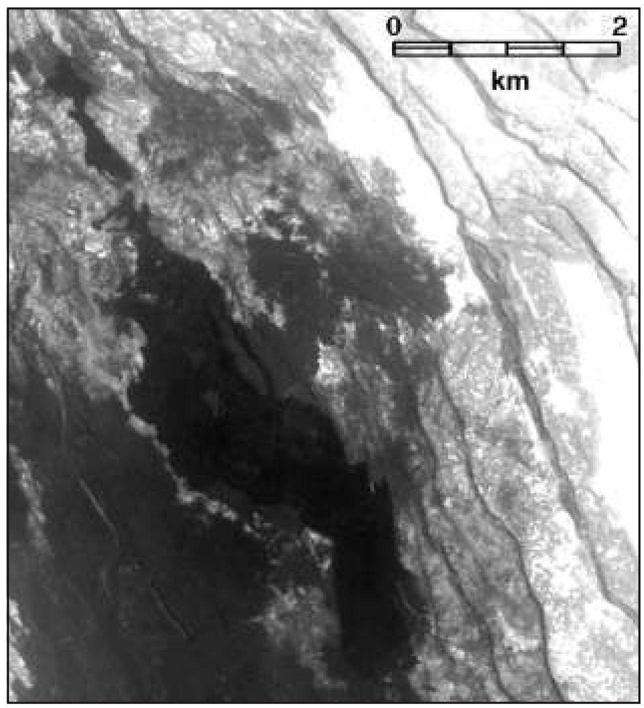


Figure 32. An EO-1 ALI panchromatic image (10-m pixel size) showing the flow at Manda Hararo on 9 July 2009. Courtesy of Matt Patrick.

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