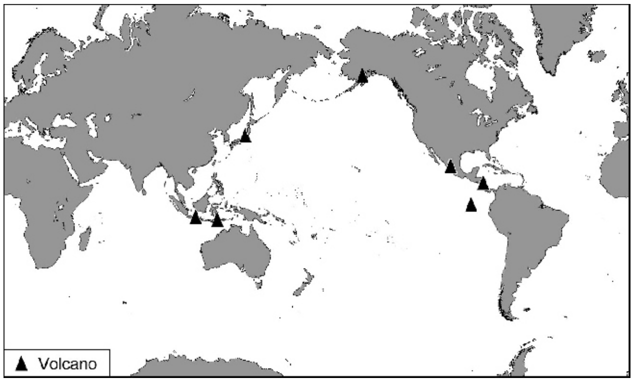
Bulletin of the Global Volcanism Network



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

Tom Simkin

Tom Simkin, who founded and for 28 years served as director of the Global Volcanism Program, died on 10 June at the age of 75 from complications after surgery for esophageal cancer, an ailment diagnosed ~ 6 months earlier. Tom saw our reporting on Earth's volcanism evolve from brief reports transmitted by postcard to its current formats in print and in various forms on the web. He began by incorporating previous databases, and enlisting volcano watchers to share their observations with the Smithsonian. This led to the most comprehensive database available on global volcanism during the past 10,000 years (the Holocene). This allowed Tom to write authoritative, pioneering papers describing the pace and character of active global volcanism. He authored two editions of the sought-after reference book, *Volcanoes of the World*, and had been collaborating in retirement on the third edition, an effort that will continue in his absence.

He received a bachelors degree from Swarthmore College and a Ph.D. from Princeton University and was known for his field studies on both North Skye in the U.K. and Fernandina and other Galápagos Islands volcanoes. He edited books commemorating the Krakatau 1883 eruption and the Parícutin 1943-52 eruption. He led efforts to create the popular wall map *This Dynamic Planet*, which plots earthquakes, volcanoes, meteorite impacts, and tectonic plate parameters; the map's latest (2006) edition features a companion website enabling users to prepare customized images. In recognition of his contributions to volcanology, Tom received the Krafft Medal (IAVCEI) in 2004 and was recently awarded the Jefferson Medal from the Virginia Museum of Natural History for 2010.

Redoubt

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

The previous eruption of Redoubt that began on 14 December 1989 (*SEAN* 14:11) lasted until June 1990. On 15 March 2009, an eruption again occurred, after changes in gas emissions, seismicity, and heat output were noted during the previous 8 months (*BGVN* 33:11).

As background, in late July 2008, Alaska Volcano Observatory (AVO) crews working near the summit smelled hydrogen sulfide (H_2S) gas. About a month later, a pilot reported a strong sulfur-dioxide (SO_2) odor, and nearby residents heard noises coming from the direction of Redoubt. Scientists also observed several fractures and circular openings in the upper Drift Glacier, and they found fumaroles atop the 1968 and 1990 lava domes more vigorous than when last observed in mid-August 2008. On 13 October 2008, satellite instruments detected warming at the summit, and on 2 November a slushy debris-flow originated near the 1966-68 vent. On 16 December 2008 a short-lived steam cloud rose no higher than the volcano's summit.

The rest of this report discusses unrest starting in late January 2009, and gives a brief overview of the eruption from the first ash-bearing explosions detected on 15 March, through those continuing during mid-May. Figure 1 shows a map of the area; the volcano sits along the Cook Inlet ~ 80 km WSW of Anchorage (see also figure 12 in *BGVN* 15:04; and Waythomas and others, 1998).

During 24-25 January 2009, Redoubt's seismicity increased markedly and steam and sulfurous gases were noted. On 25 January, tremor became sustained and amplitude increased notably. Steaming increased at previously identified vent areas in the snow and ice cover, which also emitted sulfurous gas. An overflight on 26 January revealed elevated SO_2 emissions from the summit and new outflows of muddy debris along the glacier that is downslope of the summit. Seismicity was variable during the last few days of January extending into early March, but it remained above background levels. Observations revealed increased fumarolic activity, enlarged melt features in the summit glacier, and increased runoff from along the margins of the Drift glacier, which feeds the river system of the same name down Redoubt's N-flank (figure 1). Steam plumes within the summit crater were seen on the web camera.

The 2009 eruption began with a minor ash-and-steam explosion just after 1300 on 15 March; major explosions began at about 2240. The emissions originated from a new vent, located just S of the 1990 lava dome and W of the prominent ice collapse feature near the N edge of the summit crater. A sediment-laden flow occurred from a small area in the ice on the upper part of Drift glacier (figure 2).

During 15 March-4 April, AVO recorded more than 19 separate explosions and reported that ash plumes exceeded

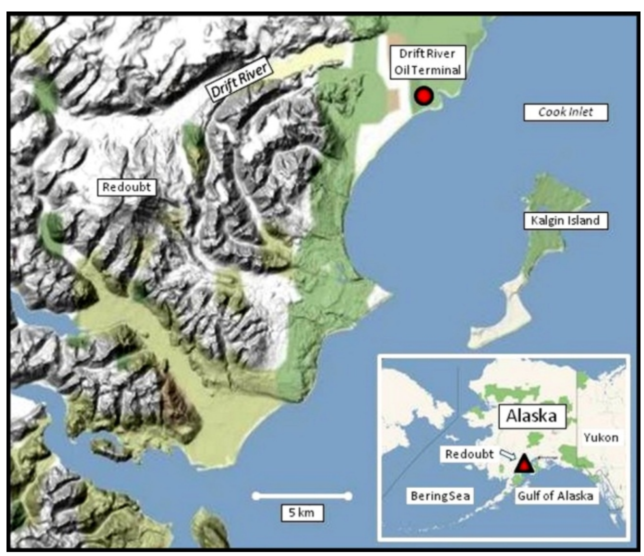

Figure 1. Shaded relief map of the Redoubt area, indicating both the Drift river and the oil terminal with the same name. A sketch map of the Drift river oil terminal. Base maps courtesy of Google Maps; feature locations courtesy of USGS-AVO.

Figure 2. Photograph of Redoubt's N face taken about 35 minutes after the ash burst of 15 March 2009 during a monitoring flight. A dark area of fresh ash deposits lies on top of the snow on the sloping crater floor. In front of that a gas plume escapes from a vent near the crater rim. The sinuous dark stripe in the foreground is a watery debris flow that emerged from beneath the ice about 20 minutes after the ash event. Photo by Heather Bleick; courtesy of USGS-AVO.

Figure 3. Image taken on 30 April 2009 showing several the large blocks of glacial ice deposited in the Drift River valley during the flood caused by the eruptive event on 4 April 2009. The N shoulder of the western end of Dumbbell Hills is on left side of image. The high-water mark near this site was nearly 10 m. Note the geologist standing to the left of the largest block for scale. Photo by Game McGimsey, courtesy of USGS-AVO.

altitudes of 15.2 km. The largest explosion occurred at 0555 on 4 April. This explosion lasted more than 30 minutes, and was comparable in size to the largest event of the 1989-1990 eruption. The explosion produced an ash plume that rose to an altitude of 15.2 km and drifted SE.

The eruptions caused melting of the Drift Glacier and greatly increased discharge, causing lahars in the Drift River that traveled more than 35 km, reaching the Cook Inlet. On 23 March, AVO staff saw large lahar and flood deposits in the Drift River valley. In the middle to upper Drift River valley, high-water marks reached 6-8 m above the valley floor. Some of these deposits were observed on 30 April (figure 3).

Several of the explosions resulted in ashfall in several populated areas, as far away as Delta Junction (~ 545 km NE). More significant ashfall occurred in more contiguous areas, including the Matanuska-Susitna Valley, the Kenai Peninsula and the Anchorage bowl. Satellite images showed a broad layer of volcanic haze that extended over these areas. On 22 March, ashfall was reported in areas 190-250 km NE. According to a 29 March Associated Press article, flights in and out of Anchorage and other local areas were canceled or diverted during 24-28 March. As many as 185 Alaska Airlines flights had been canceled since the beginning of the eruption; airports and other airlines also experienced service disruptions. The maximum thickness of ashfall measured in a populated area was about 1.5 mm near Seldovia, following the 4 April explosion. A measurement of about 3 mm, following the explosion on 26 March, was recorded near Silver Salmon Creek Lodge, about 48 km S. Trace ashfall was also observed between explosive events, during times when the volcano emitted continuous low-altitude (under 4.6 km) gas-and-ash plumes.

On 30 March a thermal anomaly at the vent seen on satellite imagery was caused by the extrusion of a lava dome in the summit crater (confirmed by AVO on 3 April). Observers also recognized that the dome had already began spilling occasional avalanches of hot blocks a short distance down the N flank. Observations on 9 April determined that the lava dome, which had grown in the same location as the previous one, was circular in shape, and 400 m in diameter. By 16 April, the lava dome was estimated to be about 500 x 700 m across and at least 50 m thick (figure 4). A volume estimate of the still-expanding dome made during 29 April-5 May suggested a volume of 25-30 million cubic meters.

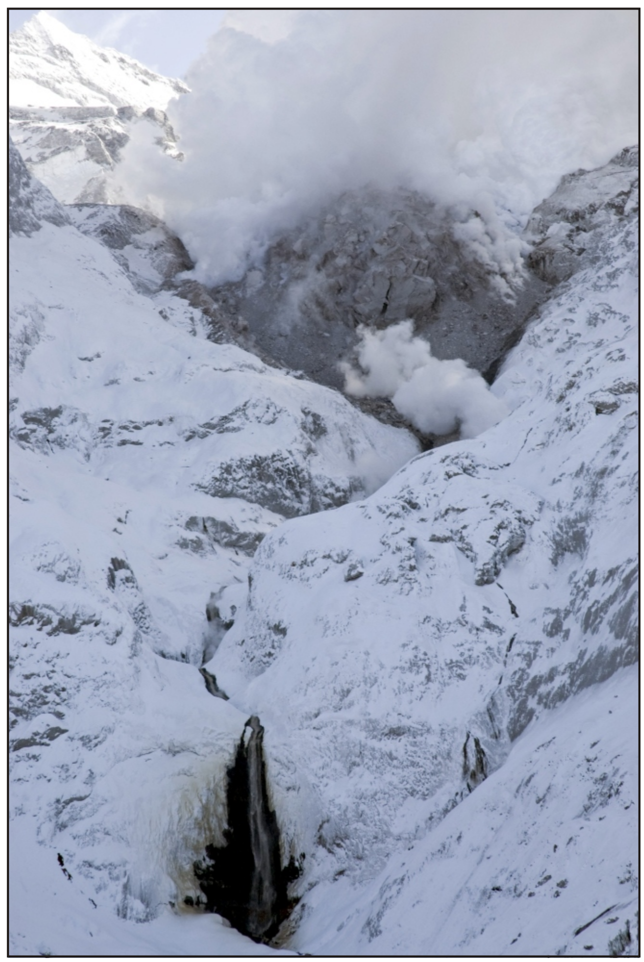

Figure 4. Image from 16 April 2009 of the active lava dome that grew in Redoubt's summit crater. The steam plume near the base of the dome comes from a pocket where abundant hot blocks shedding off the dome accumulated. The waterfall (dark area in lower part of photo) is ~ 75 m high. Photo by Game McGimsey, courtesy of USGS-AVO.

After the last explosion detected on 4 April and until mid-May, small steam-and-gas plumes occasionally containing some ash were seen on satellite imagery and on the web camera. Elevated seismicity and satellite imagery indicated that the lava dome continued to grow. SO_2 plumes were also detected by satellite imagery. Occasional rockfalls originating from the lava dome's flanks were observed on the web camera.

Reference: Waythomas, C.F., Dorava, J.M., Miller, T. M., Neal, C.A., and McGimsey, R.A., 1998, Preliminary volcano-hazard assessment for Redoubt volcano, Alaska: USGS Open File report 97-857, plate 1.

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.

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Asama

Honshu, Japan
36.403 N, 138.526 E; summit elev. 2,568 m
All times are local (= UTC + 9 hours)

As we previously reported (*BGVN* 33:12), Asama erupted in January and February 2009. As reported there, scientists noted that sulfur-dioxide fluxes suddenly rose during late 2008 from more than two years of very low values, that yellow sublimates subsequently appeared, and that thin ash fell on the rim of the summit crater by 21 January. Our statement that high seismicity began 1 January 2009 is clarified in this report, where we present long-baseline seismic data. A larger eruption followed on 2 February, reaching 2 km above the summit and dropping minor ash on parts of Tokyo (~ 140 km SE of the vent) and beyond.

This report begins with a brief mention of a satellite image from the 2004 eruption, and then continues with descriptions of the 2009 behavior chronicled in a previous report (*BGVN* 33:12). Much of this information has come from the Japan Meteorological Agency (JMA). Translations of those detailed and informative reports from the original Japanese were provided by Yukio Hayakawa.

Satellite image of 2004 activity. An annotated satellite image not included in *Bulletin* reports on the 2004 eruption (*BGVN* 29:08, 29:10; 30:01; 30:02) has come to light (figure 5). On 16 September 2004, a plume at ~ 3,700 m altitude (indicated on the figure in aviation parlance as "FL120," flight level 12,000 feet) traveled due S leaving a thin ash deposit.

Multi-year eruptions and seismicity. Seismicity recorded at Asama between June 2002 and February 2009 (figure 6) included a number of different types of signals (figure 7). Eruptions are indicated by arrows of variable length corresponding to very small to medium eruptions as they occurred during 2003, 2004, 2008, and 2009.

As brief background, seismic signals at volcanoes are often described using some common terms (Minakami, 1960; McNutt, 2000). Tremor consists of semi-continuous signal with durations of minutes to days or longer. Tremor's dominant frequencies are 1-5 Hz (often 2-3 Hz). Many investigators have concluded that tremor is akin to a series of low-frequency earthquakes occurring every few seconds. Explosion earthquakes accompany explosions and feature compressional, first P-wave arrivals. Some of the explosion energy enters the air where it travels much more slowly than through rocks, propagating as an acoustic wave that may be recorded by microphones or barographs. This air wave also couples back into the ground, allowing detection by a seismometer.

B-type earthquakes sometimes lack clear S waves, generally feature low frequency signals, but may include

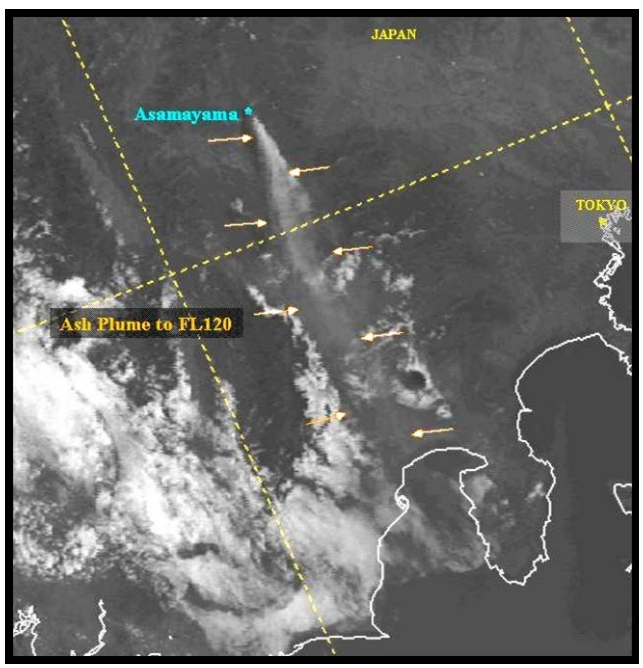

Figure 5. An annotated satellite image showing a 2004 Asama ash and steam plume at 0017 UTC on 16 September 2004. Enhanced Defense Meteorological Satellite Program (DMSP) visual imagery. Note dashed lines of latitude and longitude and the outlines of the coast of Honshu Island. This and at least seven other images were prepared by Charles Holliday and staff around that time. Image courtesy of US Air Force Weather Agency (AFWA).

high-frequency signals as well. The types BL and BH respectively stand for low- and high-frequency (but the two types may also grade from one to the other).

Type A earthquakes are also called tectonic and volcano-tectonic. Their signals display clear P- and S-wave arrivals and are often thought to represent processes such as slip on a fault or breaking rock associated with intrusions.

Prior to the 2009 eruptions, tremor had been somewhat elevated at times during the latter half of 2007 and more consistently during the latter half of 2008. BL-Explosion earthquakes became scarce during late 2006, and from then until about mid-2008 they fluctuated to occasionally somewhat higher daily numbers. After mid-2008, these BL-Explosion earthquakes grew dramatically in number, peaking with the 2009 eruption. This pattern was similar to seismicity associated with the September 2004 eruption.

BH earthquakes generally stood at background after mid-2006 until just before the 2008 eruption. In the middle to latter months of 2008 they again grew, often remaining elevated until the start of 2009, when they increased still further.

Type-A earthquakes remained consistently small in number through 2007 onwards until their numbers peaked suddenly 2 February 2009. They were, however, present on more days approaching the 2009 eruptions.

The 2004, 2008, and 2009 eruptions included conspicuous increases in tremor, BL-Explosion earthquakes, and to some extent, BH earthquakes. Least diagnostic were type-A earthquakes, though they were present on more days with approach to the point of the 2009 eruption.

The predicted 2 February 2009 eruption. Sufficient precursory data were available for JMA to confidently announce the elevation of the hazard status to Level 3 (on a scale where the highest level is 5) at 1300 on 1 February 2009. In discussing the situation at a meeting around that time, a JMA officer said that an eruption similar to that of 2004 would take place within 2 days. Accordingly, authorities closed a vulnerable, 7-km stretch of Oni-oshi highway. It reopened the day after the 2 February eruption.

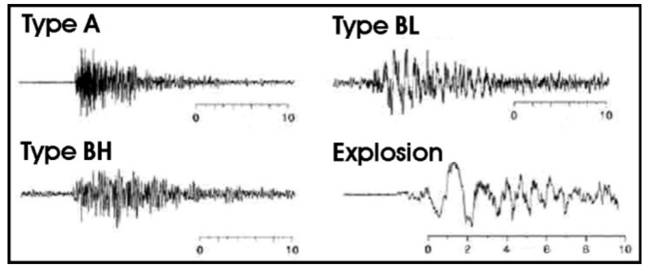

Figure 7. Typical seismic signals of four types of earthquakes seen at Asama during June 2002-February 2009. Scales show time in seconds. Courtesy of JMA.

The volcano is heavily instrumented, and those maintained by JMA's Asamayama observatory are shown on figure 8. Precursory data used as a basis for the forecast included seismicity (figure 6), sulfur-dioxide fluxes (*BGVN* 33:12), and tilt (e.g., figure 9).

In accord with JMA's precursory warnings, representatives of Komoro City decided to close the mountain hut 2 km W of the summit. The afternoon of 1 February, the resident and official observer there, Keisuke Kanda, readied the hut for closure. After that, he went to bed, planning to climb down the mountain the next morning. At the time of the eruption (0151) he neither felt nor heard any disturbance. At 0200 (about 9 minutes after the eruption began), he was awakened by his ringing cell phone.

The eruption that started at 0151 on 2 February generated a plume that rose to 2,000 m above the summit (to an altitude of ~ 4.6 km). Volcanic bombs were thrown to the N as far as 1 km. An air wave observed at Oiwake, 8 km SSE, had a pressure of 7 Pa. For comparison, the eruption of 1 September 2004 had a recorded air wave of 205 Pa. Cities recording ashfall included Karuizawa, Kamogawa, Tomioka, Chichibu, and in the broader Tokyo metropolitan area, Kawasaki, and Yokohama.

Aviation sources suggested that the 2 February eruption only lasted until 0800 (that is equivalent to 1 February during 1651-2300 UTC). Charles Holliday noted airport weather data. Downtown, at Tokyo International Airport (RJTT), meteorologists reported 'Volcanic Ash Cloud' during 0530-0636 on 2 February. Meteorologists at Narita International airport (RJAA) had one report interval where they noted volcanic cloud, at 1300 local time (~ 3 km altitude with ~ 9 km visibility), but this cloud did not cause local ashfall.

A US Air Force video clip noted that on 2 February ash fell on Yokota Air Base, 105 km SE of Asama. The video said that Yokota received 3-5 mm of ashfall but the features in the field of view appeared to show considerably less, perhaps suggesting

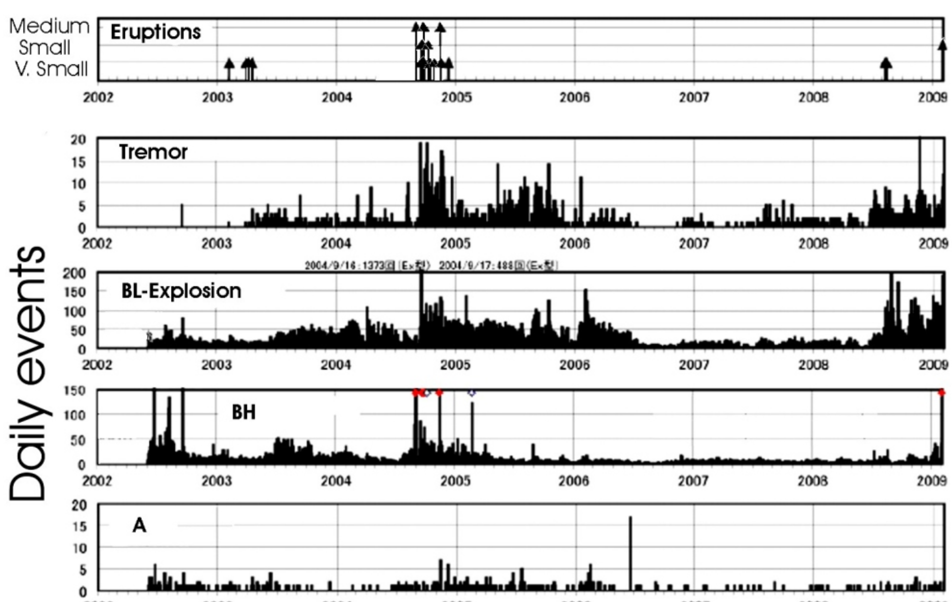

Figure 6. Asama eruptions and seismic data recorded from June 2002 through 2 February 2009 depicted in a series of five panels. The top panel shows eruptions (arrows) sorted into the size categories of very small, small, and medium (represented by respective arrow lengths). The second panel down shows the daily number of volcanic tremor events. The third through fifth panels show, respectively, daily numbers of earthquakes of types BL-Explosion, BH, and A. Courtesy of JMA.

some areas of thickened ash deposition. Holliday noted that ash fell at the Base hours after the eruption; although he was unable to establish the exact start time there, ashfall ended at 0800.

During the eruption, Masakatsu Umeda, working in a French restaurant 7 km N of the summit, felt small but continuous shaking and saw a red plume rising from the summit crater. He heard a far softer sound than he did on 1 September 2004 but then he was 4 km NE of the summit at Rokurigahara parking lot.

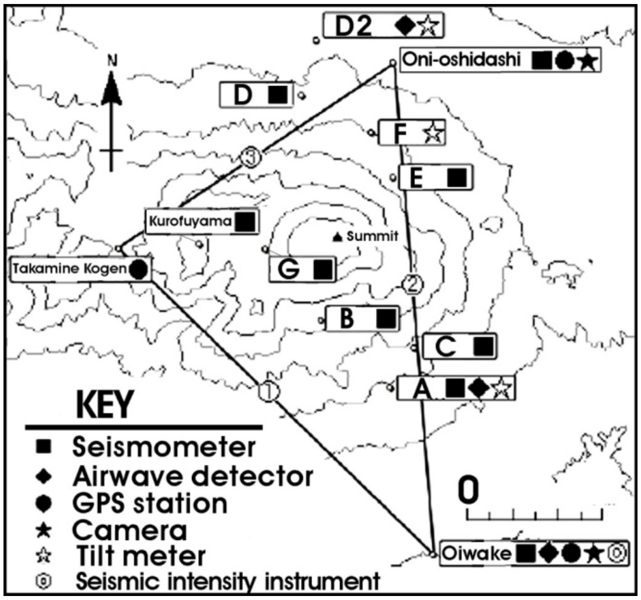

Figure 8. A sketch map showing Asama monitoring instrumentation discussed in 2009 JMA reports. Note the stations F, A, and D, points for collecting tilt data presented in the next figure. The contour interval is 200 m. The mountain hut is 0.7 km W of station G. The settlement Oiwake (near map's S edge) is now part of Karuizawa city. The station Oiwake is the site of JMA's Karuizawa weather station. (Oiwake is an ancient settlement located on the route between Kyoto and Edo (Tokyo), a path in use during the Edo period, 4,000-100 years ago). Courtesy of JMA.

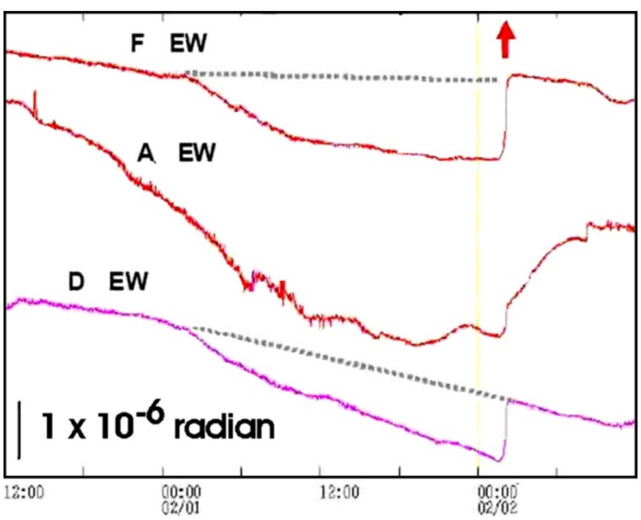

Figure 9. Tilt versus time at three Asama stations (F, A, and D) undergoing strong tilt excursions that helped scientists predict the 2 February eruption. The x-axis covers from 1200 on 31 January to 1200 on 2 February; the time of eruption (0151) indicated by heavy arrow at top. Clear tilt excursions (all in the EW direction) started roughly mid-day on 31 January at station A, and early on 1 February at stations F and D. At or shortly after the eruptions tilt excursions rebounded and made sudden shifts back towards their previous trends. Stations D and F returned most directly to their previous trends. With respect to time after the eruption, station A's excursions, though increasingly less extreme, continued for hours. Courtesy of JMA.

An 18 February JMA report presented a sequence of night photos capturing incandescent explosions on 2 February at 0200 and for the next 15 minutes (figure 10). These photos portray the eruptive stage often termed the jet- or gas-thrust phase (see diagrams and models on a website by Camp, 2009).

Waning eruptions during next few months. A series of small eruptions followed, including those on 9, 10, 11, 16, and 17 February, 15 and 23 March, and at least as late as 2 May. The hazard status, initially raised to 3 on 1 February, dropped to 2 on 7 April.

JMA said that on 9 February at 0746, a plume rose 400 m above the summit; at 1700, a plume was 1,000 m above the summit. A trace of ashfall blew NE, to Kitakaruizawa. As of 0200 on 10 February, the plume height was 600 m above the summit; at 0500, it was 1400 m. As of 2300 on 10 February the plume height was 300 m above the summit. Takayuki Nagai, a teacher at a middle school 12 km N of Asama's summit; said that few students arriving there appeared to recognize that the eruption continued. One had seen a gray ash plume.

As of 2100 on 11 February, the eruption apparently continued, but JMA could not see plumes, probably because of bad weather. The eruption determination was seemingly based on elevated seismicity. The Tokyo Volcanic Ash Advisory Center (VAAC) indicated plumes in the range of 3-3.7 km altitude during 11-12 and 16-17 February. JMA noted an eruption during 1310-1400 on 16 February. A colored plume rose to 400 m above the summit and moved E.

Asama again erupted at 1833 on 17 February. A plume bearing ash rose to 400 m above the summit, and moved to E. Web cameras disclosed crater glow.

Figure 10. Onset of an Asama explosion captured photographically on 2 February 2009, as viewed from ~ 8 km NW at 1400 m elevation. The sequence starts in the upper left and proceeds down the first column and then to the second column (numerical values in each photo's upper left-hand corner represent time stamps; e.g., 02 08 represents 0208 hours). Note the growth of a dark billowing plume in the last two frames (from 0212 and 0215). The camera belongs to Ministry of Land, Infrastructure, Transport, and Tourism.

The Tokyo VAAC noted a plume to 3 km altitude on 15 March. JMA reported incandescence from the crater on 23 March, and an observer 50 km E at Maebashi saw strong steam plumes on 30 March. Although authorities had lowered the alert level, similar eruptions continued (with plumes to 3.4 km altitude) as late as 2 May. This was the last eruption clearly noted in available reports through the end of May.

2 February eruption's minimum mass. Several detailed maps of the SE-trending, elongate (cigar-shaped) 2009 deposits were compiled in the days after the 2009 eruptions. Such detailed maps (figure 11) enabled scientists to estimate the mass of material that fell on Honshu Island.

For the map in the proximal region (inset), traverses were made across portions of the 2009 tephra deposits in early February at approximate distances of 5, 10, and 13 km from the crater. Besides showing points with measurable ash (solid circles), the maps disclose considerable points where the ash was absent or negligible (open circles). The investigators took many measurements at ~ 5 km near the axis of the deposit. Such deposits are often ephemeral, owing to post-depositional processes such as wind and particularly rainfall, which frequently strip the tephra away before detailed measurements.

For the map including the medial to more distal regions (figure 11), trace amounts of Asama tephra extended beyond Tokyo's large bay (Tokyo-wan) to the coastline of the Chiba Peninsula, ~ 220 km SE. Additional fine ash clearly blew beyond the coastline, settling over the adjacent Pacific Ocean. The GSJ estimated the erupted mass falling on Honshu Island at 20,000-30,000 metric tons (20-30 Gg).

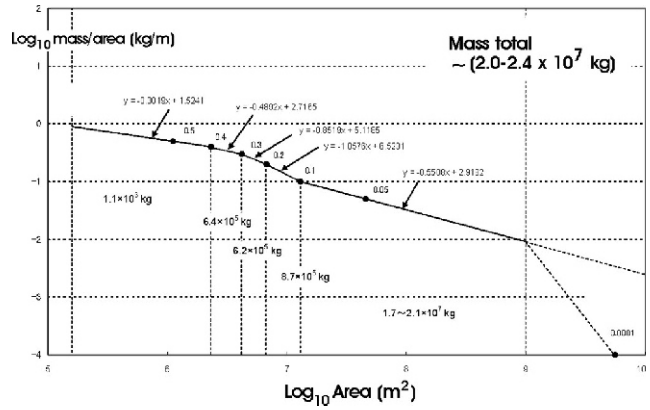

Figure 12. A plot summarizing mass data for the tephra blanket associated with the 2 February Asama eruption (the isomass map shown at right in the figure above). This is a plot of log10 [mass per unit area (kg/m^2)] versus log10 [area (m^2)]. The plot shows mass contributions along various segments. Courtesy of ERI, Univ. of Tokyo.

Figure 12 illustrates the near-source deposit's mass assessment (for figure 7 inset). This yielded an erupted-mass estimate of about 2.0-2.4 metric tons. Various other maps and solutions for contours exist.

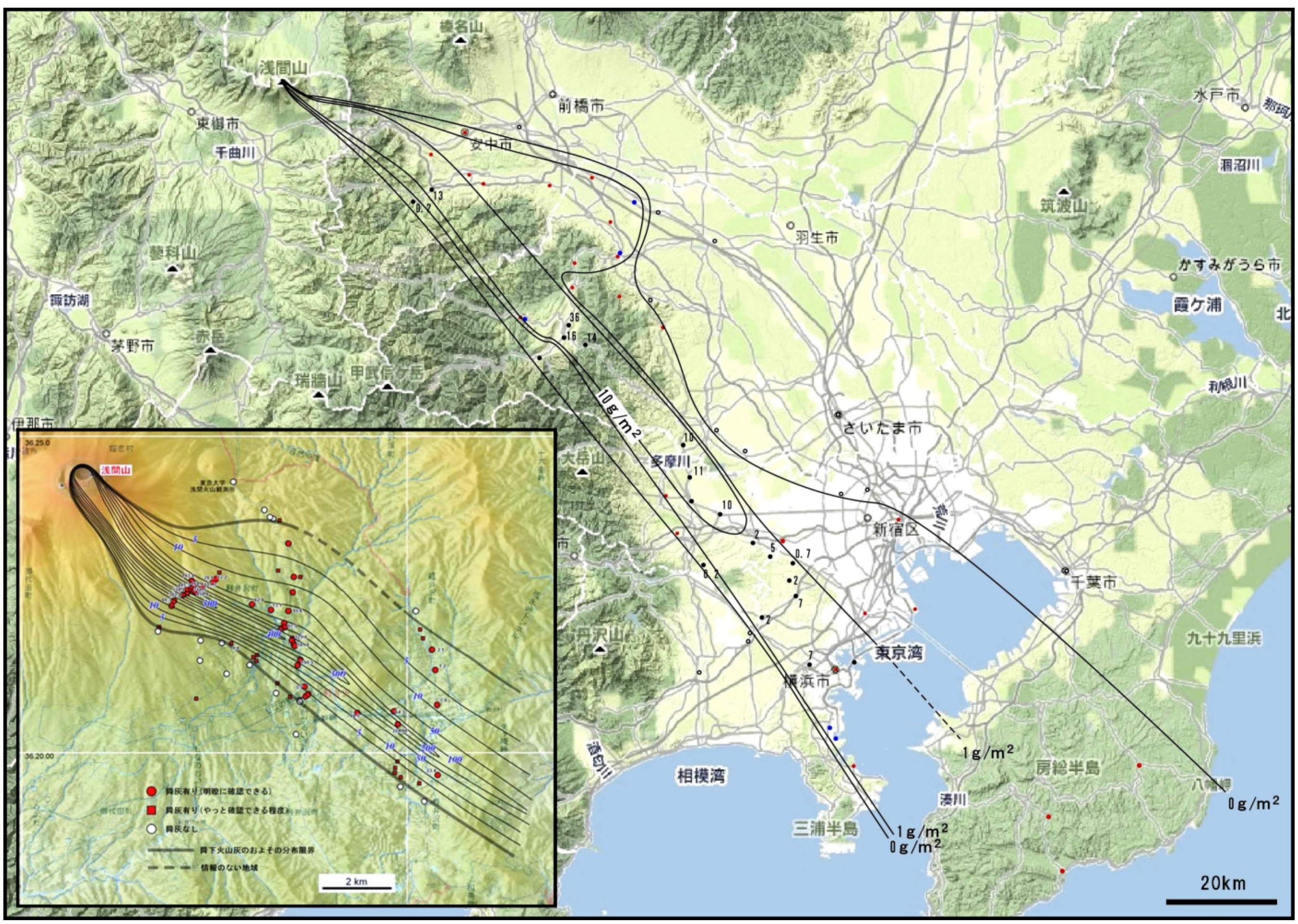

Figure 11. Isomass maps compiled from sampling tephra from Asama's 2 February 2009 eruption. Maps show data points and contours for the mass of ash found over S-central Honshu Island and (inset) in the 5-16 km distance range from Asama's summit vent. Data credits: (large map) Geological Survey of Japan (GSJ 18 February 2009 report); (inset) Earthquake Research Institute (ERI), University of Tokyo.

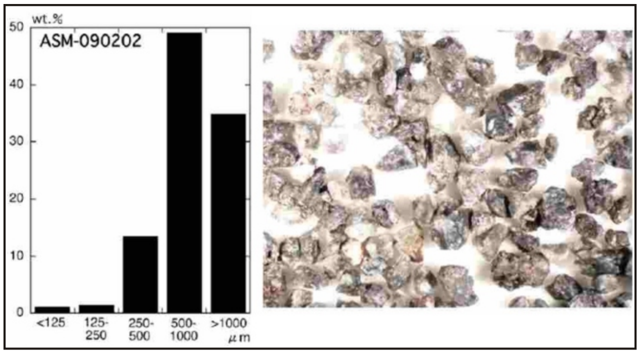

Figure 13. (Left). Grain size fractions for Asama ash from the 2 February eruption (collection site 8 km SE of Asama). (Right) Ash washed and sieved to capture particles above the 1 mm mesh size. The picture is 20 mm wide. Courtesy of ERI, Univ. of Tokyo.

Figure 13 presents basic grain-size information on the deposit. The photo shows some of the larger grains found at distance from the vent. The grains consisted largely of pre-existing rocks. Investigators found very few examples of juvenile glass grains (less than 1%). These juvenile grains were rhyolitic to dacitic.

Few thin ash blankets have been assessed in more detail than the one shown here. The relevance of these efforts include understanding the character and size of the eruption and calibrating ashfall with satellite observations. Volcanic Ash Advisory Centers (VAACs) regularly model eruptions such as this in order to forecast the transport of ash in the atmosphere. This is based in part on the height of ash plumes and on meteorological observations such as wind-velocity profiles. One goal of those ash transport models is to steer aircraft clear of ash in the atmosphere. Volcanic ash plumes can reach higher altitudes than commercial aircraft can fly, and encounters with ash may lead to severe engine damage.

Reference: Camp, V., 2009, Eruption model (online): Department of Geological Sciences, San Diego State University (URL: http://www.geology.sdsu.edu/how_volcanoes_work/).

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Geologic Summary. Asama, Honshu's most active volcano, overlooks the resort town of Karuizawa, 140 km NW of Tokyo. The volcano is located at the junction of the Izu-Marianas and NE Japan volcanic arcs. The modern cone of Maekake-yama forms the summit of the volcano and is situated E of the horseshoe-shaped remnant of an older andesitic volcano, Kurofu-yama, which was destroyed by a late-Pleistocene landslide about 20,000 years before present (BP). Growth of a dacitic shield volcano was accompanied by pumiceous pyroclastic flows, the largest of which occurred about 14,000-11,000 years BP, and by growth of the Ko-Asama-yama lava dome on the E flank. Maekake-yama, capped by the Kama-yama pyroclastic cone that forms the present summit of the volcano, is probably only a few thousand years old and has an historical record dating back at least to the 11th century AD. Maekake-yama has had several major plinian eruptions, the last two of which occurred in 1108 AD (Asama's largest Holocene eruption) and 1783 AD.

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Dieng Volcanic Complex

Java, Indonesia
7.20°S, 109.92°E; summit elev. 2,565 m
All times are local (= UTC + 7 hours)

This report discusses a small phreatic eruption at Dieng from Sibanteng crater in January 2009. The Dieng complex covers more than 80 km^2 in Central Java NW of Yogyakarta. The volcanic field trends E and contains two or more stratovolcanoes, more than 20 craters and cones, several crater lakes, a caldera, and active thermal features (van Bergen and others, 2000). Phreatic eruptions are those that eject both magmatic gasses and steam, and contain fragments of pre-existing solid rock from the volcanic conduit or vent, but without primary erupted magma. Many of these eruptions are attributed to subsurface interaction between magma and groundwater (Germanovich and Lowell, 1995). Some are precursors to phreatomagmatic and magmatic eruptions.

Recent reports discussed mud ejected from the active Sileri crater in July 2003 associated with a modest increase in seismicity and steam plumes during April-July 2002 and August 2003 (*BGVN* 27:05, 28:06, 28:07, and 28:09). A May 2005 pilot report of a steam plume turned out to be caused by pipe maintenance at Dieng's geothermal site.

January 2009 landslide and eruption. This event began when, after three days of heavy rain, one or more landslides broke loose in steep volcanic terrain at about the 1900- to 2000-m elevation at 0800 on 15 January 2009. Landslide debris covered the floor of Sibanteng crater, sealing the vent there. At 0830 a sudden and short-lived phreatic eruption took place. The alert level was raised to 2 (on a scale of 1 to 4).

Much of these and other details were learned by an emergency response team from the Center of Volcanology and Geological Hazard Mitigation (CVGHM), who conducted a field investigation between 16-21 January. The team's findings are discussed below (as extracted from the CVGHM report dated 22 January 2009 ("Tanggap Darurat G. Dieng Kab. Wonosobo, Prov. Jawa Tengah, tanggal 16-21 Januari 2009").

The eruption left an explosion crater about 50 m in diameter and deposited the bulk of the erupted material in a ~ 50 m radius. The erupted deposits consisted of material from the landslide and vent area. This relationship indicated that the landslide preceded the phreatic eruption. The landslides covered an area 100 × 200 m, with an estimated

40,000 m^3 of debris. In places, the landslide debris created temporary dams. One blocked the Kali Putih River, and downstream, the Kali Tulis River.

On 17 January, four additional seismic stations were installed. Three were in the vicinity of the Sibanteng and Sikidang craters and one was near the thermally active colored lake Telaga Warna. Earthquakes and tremor were both absent on the seismographic record at Timbang crater during 17-20 January following the phreatic eruption.

The team reported that witnesses in the field had heard two explosions. The first came from the landslide; the second, the phreatic eruption. During their visit, the eruption vent emitted a white plume 5 m high. The vent was largely covered by landslide debris from Sibanteng crater's upper wall. In Sibanteng and other craters temperature ranges were 93.2-93.6° C, values similar to previous data.

The concentrations of gases, including hydrogen sulfide (H_2S), sulfur dioxide (SO_2), methane (CH_4), carbon dioxide (CO_2), and carbon monoxide (CO) were reported for eight locations. The CO and CO_2 concentrations were below ~ 1 ppm. H_2S concentrations were under ~ 7 ppm, with the highest value seen near a thermal feature at Skikdang, but a 6 ppm value near a bulletin board in a tourist area. The eight SO_2 concentrations were under 18 ppm. CH_4 concentrations ranged between 5 and 17 ppm. (More detailed data are available in the 22 January CVGHM report.)

The investigation indicated that the phreatic eruption was preceded by one or more landslides that covered the floor of Sibanteng crater. The team suggested that the sealing action and pressure buildup due to the landslide caused the phreatic eruption. They concluded that the phreatic eruption posed no danger to the public because the Sibanteng crater is not close to an inhabited area. However, they noted that landslide debris was still unstable and could be easily dislodged and transported by rainwater.

Reference: Germanovich, L.N., and Lowell, R.P., 1995, The mechanism of phreatic eruptions: J. Geophys. Res., v. 100 (B5), p. 8417-8434.

van Bergen, M.J., Bernard, A., Sumarti, S., Sriwana, T., and Sitorus, K., 2000, Crater lakes of Java: Dieng, Kelud and Ijen, Excursion Guidebook, IAVCEI General Assembly, Bali 2000 (URL: www.ulb.ac.be/sciences/cvl/DKIPART1.pdf).

Geologic Summary. The Dieng plateau in the highlands of central Java is renowned both for the variety of its volcanic scenery and as a sacred area housing Java's oldest Hindu temples, dating back to the 9th century AD. The Dieng volcanic complex consists of two or more stratovolcanoes and more than 20 small craters and cones of Pleistocene-to-Holocene age over a 6 x 14 km area. Prahu stratovolcano was truncated by a large Pleistocene caldera, which was subsequently filled by a series of dissected to youthful cones, lava domes, and craters, many containing lakes. Lava flows cover much of the plateau, but have not occurred in historical time, when activity has been restricted to minor phreatic eruptions. Toxic volcanic gas emission has caused fatalities and is a hazard at several craters. The abundant thermal features that dot the plateau and high heat flow make Dieng a major geothermal prospect.

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

Lewotobi

Lesser Sunda Islands, Indonesia
8.542°S, 122.775°E; summit elev. 1,703 m
All times are local (= UTC + 8 hours)

Unrest caused authorities to elevate the alert level here to 2 in May 2008 (*BGVN* 34:01). No ash emissions were reported, as has been the case since 2003 (*BGVN* 28:06, 28:10, 34:01).

On 23 March 2009, the Center for Volcanology and the Mitigation of Geologic Disaster (CVGHM) lowered the alert level on Lewotobi from 2 to 1 (on a scale of 1-4). This shift was based on visual observations and decreased seismicity during March. Rarely seen diffuse white plumes rose 25 m above the crater and drifted E. Visitors and residents continued to be advised not to approach the crater.

Over the period 1-23 March 2009 a cluster of shallow volcanic earthquakes occurred. Their initial numbers, 5-25 daily, soon declined to 1-5 occurrences per day. The total number of deep volcanic earthquakes did not change, averaging 1-3 daily. No tremor had been recorded since 1 February 2009 and at least as late as mid-2009.

Geologic Summary. The Lewotobi "husband and wife" twin volcano (also known as Lewetobi) in eastern Flores Island is composed of the Lewotobi Lakilaki and Lewotobi Perempuan stratovolcanoes. Their summits are less than 2 km apart along a NW-SE line. The conical 1,584-m-high Lewotobi Lakilaki has been frequently active during the 19th and 20th centuries, while the taller and broader 1,703-m-high Lewotobi Perempuan has erupted only twice in historical time. Small lava domes have grown during the 20th century in the crescentic summit craters of both volcanoes, which are open to the north. A prominent flank cone, Iliwokar, occurs on the east flank of Lewotobi Perampuan.

Information Contacts: *Center of Volcanology and Geological Hazard Mitigation (CVGHM)*, Jalan Diponegoro 57, Bandung 40122, Indonesia (URL: http://portal.vsi.esdm.go.id/joomla/); *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/); *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/); *Agence France-Presse* (URL: http://www.afp.com/); *Jakarta Post* (URL: http://www.thejakartapost.com/).

Apoyeque

Nicaragua
12.242°N, 86.342°W; summit elev. 518 m

Seismic swarms took place during 2001 and 2007. The last overview of Apoyeque (*BGVN* 14:04) reported slight variations of the crater lake's surface temperature of between 25 and 30°C (which began to rise in 1988). Faint sulfurous odors were noted as well as some active fumaroles.

Swarms were reported by INETER (Instituto Nicaragüense de Estudios Territoriales) in a 23 September 2007 report. The first swarm, during January 2001, included earthquakes up to M_R 5.2. This swarm was felt strongly in the cities of Managua (~ 8 km away) and in Ciudad Sandino. No damage was reported. The second swarm began on 21 September 2007, becoming more intense on 23 September, by which time there had been 10 earthquakes up to M_R 2.8. Scores of smaller earthquakes were also detected at a seismometer in Apoyeque's crater.

INETER stated that, based on past cases at this volcano, such swarms can continue for days and might reach M 4-M 5 (as they had in January 2001). The typical pattern is for a series of smaller volcanic earthquakes to precede one or more larger ones. This is in contrast to earthquakes associated with the subduction of the Cocos plate, where larger earthquakes often precede substantially smaller ones.

Apoyeque remains in repose without documented historical eruptions. Tephrochronology (the study of ash layers, in this case including radiometric dating) indicates the most recent eruption here was large and took place about 50 BC (± 100 years) depositing the Chiltepe tephra. That tephra deposit has an estimated 4 km^3 on-land volume and a total volume (including the offshore component) of about 18 km^3 (Kutterolf and others, 2008).

Reference: Kutterolf, S., Freundt, A., and Perez, W., 2008, Pacific offshore record of Plinian arc volcanism in Central America: 2. Tephra Volumes and erupted masses: Geochemistry, Geophysics, Geosystems (G^3), v. 8, Q02S02, doi: 10.1029/2007GC001791.

Geologic Summary. The Apoyeque volcanic complex occupies the broad Chiltepe Peninsula, which extends into S-central Lake Managua. The peninsula is part of the Chiltepe pyroclastic shield volcano, one of three large ignimbrite shields on the Nicaraguan volcanic front. A 2.8-km wide, 400-m-deep, lake-filled caldera whose floor lies near sea level truncates the low Apoyeque volcano, which rises only about 500 m above the lake shore. The caldera was the source of a thick mantle of dacitic pumice that blankets the surrounding area. The 2.5 x 3 km wide lake-filled Xiloá (Jiloá) maar, is located immediately SE of Apoyeque. The Talpetatl lava dome was constructed between Laguna Xiloá and Lake Managua. Pumiceous pyroclastic flows from Laguna Xiloá were erupted about 6,100 years ago and overlie deposits of comparable age from the Masaya plinian eruption.

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Colima

México
19.514°N, 103.62°W; summit elev. 3,850 m
All times are local (= UTC - 6 hours)

Our most recent reports on Colima (*BGVN* 33:04 and 33:10) discussed new dome growth between February 2007 and November 2008. This report provides an update on the dome growth through May 2009.

According to a report from the Colima Observatory, the slow growth of Colima's new lava dome continued (figure

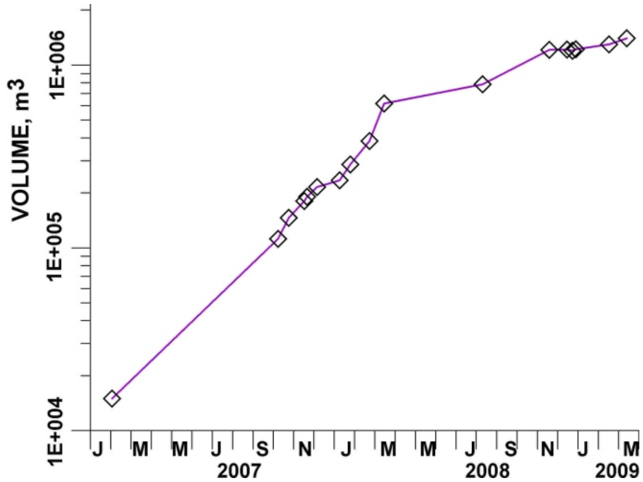

Figure 14. Dome volume versus time at Colima during January 2007 to March 2009. Courtesy of Colima Volcano Observatory.

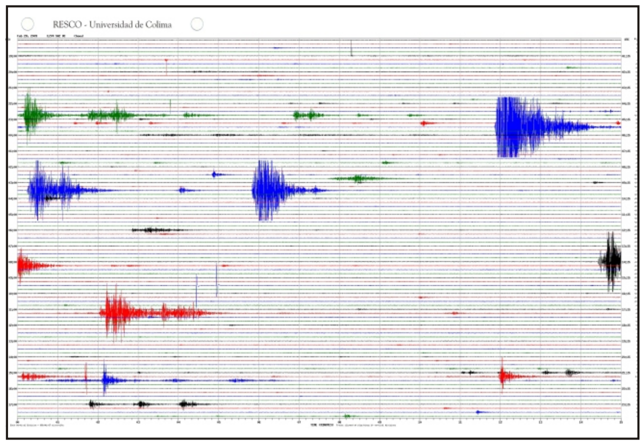

Figure 15. A typical daily seismogram at Colima, showing small explosions during 1800 hours on 28 February to 1800 hours on 29 February 2009. Recorded at station EZV4, located 1.7 km from the crater; vertical lines are 1-minute intervals. Courtesy of Colima Volcano Observatory.

Figure 16. Photos of Colima showing the edifice (top) and close-up of the crater (bottom). View is from the Nevado video station on 25 March 2009. Courtesy of Colima Volcano Observatory.

14). By March 2009, the volume was about 1,400,000 m^3, roughly 80% of the total crater volume. Since the beginning of October 2007 the mean effusion rate has been ~ 0.03 m^3/s. During the last two years, dome growth has been accompanied by 5-10 small explosions daily without significant variations (figure 15).

To improve monitoring of the dome growth and any lava flows, pyroclastic flows, and explosive columns, the video station Nevado has been upgraded with two additional video cameras. These cameras allow digital images of the crater and the whole volcanic edifice of Colima to be taken every 4 seconds (figure 16). The station is situated at ~ 4,000 m elevation, below the summit of Nevado de Colima and 5.8 km N of the Volcán de Colima crater.

Table 1 contains a condensation of reports on Colima ash plumes and selected eruptions during 4 January 2006 though 25 May 2009.

Geologic Summary. The Colima volcanic complex is the most prominent volcanic center of the western Mexican Volcanic Belt. It consists of two southward-younging volcanoes, Nevado de Colima (the 4320 m high point of the complex) on the N and the 3,850-m-high historically active Volcán de Colima at the south. A group of cinder cones of late-Pleistocene age is located on the floor of the Colima graben W and E of the Colima complex. Volcán de Colima (also known as Volcán Fuego) is a youthful stratovolcano constructed within a 5-km-wide caldera, breached to the S, that has been the source of large debris avalanches. Major slope failures have occurred repeatedly from both the Nevado and Colima cones, and have produced a thick apron of debris-avalanche deposits on three sides of the complex. Frequent historical eruptions date back to the 16th century. Occasional major explosive eruptions (most recently in 1913) have destroyed the summit and left a deep, steep-sided crater that was slowly refilled and then overtopped by lava dome growth.

Information Contacts: *Observatorio Vulcanológico de la Universidad de Colima*, Colima, Col., 28045, México (URL: http://www.ucol.mx/volcan); *Washington Volcanic Ash Advisory Center (VAAC)*, Satellite Analysis Branch (SAB), NOAA/NESDIS E/SP23, NOAA Science Center Room 401, 5200 Auth Rd, Camp Springs, MD 20746, USA (URL: http://www.ssd.noaa.gov/VAAC/); *Gobierno del Estado de Colima* (URL: http://www.colima-estado.gob.mx/2006/index.php).

Date	Max plume altitude (km)	Plume drift direction	Remarks
04 Jan-09 Jan 2006	6.7	NE, SW	—
11 Jan-15 Jan 2006	9.1	ENE	—
04 Feb-07 Feb 2006	8.5	—	—
22 Feb-26 Feb 2006	9.1	NE	—
26 Mar-27 Mar 2006	6.1	—	—
01 Apr-03 Apr 2006	7.9	—	—
08 Jul 2006	—	—	Ash emission to unknown height.
29 Oct 2006	6.1	S	—
06 Nov 2006	6.1	NE	—
19 Nov 2006	5.5	W, SW	—
30 Nov 2006	6.7	SE, NE	—
15 Dec 2006	—	SE, W	Continuous ash-and-steam emissions.
21 Mar-27 Mar 2007	5.2	NE	Incandescent material to 50-150 m.
11 Apr-16 Apr 2007	6.1	W	Multiple, sometimes continuous ash-and-steam emissions.
26 Apr 2007	—	NW	—
28 and 30 Apr 2007	—	—	Incandescent material to 100 m.
31 May 2007	—	S, SW	—
19 Sep-23 Sep 2007	4-4.9	Various	—
31 Oct-01 Nov 2007	4.5	N	—
26 Nov-29 Nov 2007	7.3	W, NNE	Multiple steam and steam-and-ash plumes to 3.9-4.6 km.
03 Dec-04 Dec 2007	—	—	Multiple steam and steam-and-ash plumes to 3.9-4.6 km.
12 Dec-18 Dec 2007	4-4.4	Various	Multiple plumes
20 Dec-25 Dec 2007	4.3-4.7	—	—
29 Dec-30 Dec 2007	4-4.3	Various	Incandescent material ejected.
14 Feb-19 Feb 2008	4.4	Various	—
12 Mar-18 Mar 2008	3.9-4.8	Various	—
01 Apr-07 Apr 2008	4.2-6.4	Various	Multiple plumes; incandescent material ejected 150 m; incandescent avalanches.
08 Apr-15 Apr 2008	4.5-4.9	Various	Multiple plumes; incandescent material ejected 50 m.
13 May 2008	—	NW	—
03 Jun-09 Jun 2008	4-4.8	Various	—
13 Aug-18 Aug 2008	4-4.7	Various	Multiple plumes
22 Oct-28 Oct 2008	3.9-4.5	Various	Multiple plumes
30 Oct-31 Oct 2008	4.1-4.3	—	White plumes
02 Nov 2008	4.6	SW, E	Gray plumes
03 Dec-08 Dec 2008	6.4	—	Gray plumes and white plumes.
09 Dec-16 Dec 2008	3.9-5.8	SE, N	—
02 Jan 2009	4.1	—	Incandescent material ejected 100 m.
03 Jan-05 Jan 2009	4-4.2	Various	Multiple gray and white plumes
03 Feb-10 Feb 2009	3.9-4.9	—	Multiple gray and white plumes; incandescent material ejected 50 m.
25 Feb-03 Mar 2009	3.9-4.5	—	Multiple gray and white plumes.
25 Mar-31 Mar 2009	3.9-4.6	Various	Multiple gray and white plumes
08 Apr-13 Apr 2009	3.9-5.2	Various	Multiple gray and white plumes
21 May-25 May 2009	3.9-4.2	E, SE, S	Multiple gray and white plumes

Table 1. Ash plumes from Colima seen between 4 January 2006 and May 2009. The plume altitudes (height above mean sea level) are approximate and indicate the highest plume during the specified period. Incandescent ejections are meters above the summit. Data from the Washington Volcanic Ash Advisory Center, Universidad de Colima, Gobierno del Estado de Colima, and news articles.

Fernandina

Galápagos Islands, Ecuador
0.37°S, 91.55°W; summit elev. 1,476 m
All times are local (= UTC - 6 hours)

In early April 2009, Fernandina (also known as La Cumbre volcano) erupted. According to the Ecuador Institute of Geophysics (IG), satellite data suggested that the eruption began sometime between 2200 on 10 April and 0030 on 11 April. The seismic station at Puerto Ayora, on the nearby island of Santa Cruz, recorded no earthquakes associated with this eruption. High numbers of thermal anomalies ended after 28 April. Although no report is available, photos posted by the IG show steam rising from the eruptive fissure, but no active lava emission, on 1 May.

On the morning of 11 April an eruptive column was seen by both a passing tourist boat and Galápagos National Park rangers located on Canal Bolívar. Authorities at the National Park reported both lava flows and ash plumes. A true-color MODIS image taken on the morning of 11 April showed an ash-and-steam plume rising from the area of active lava flows (figure 17).

Galápagos National Park Rangers conducted a flyover on 13 April 2009 (figure 18) and found the eruption's intensity undiminished. The eruption source was a fissure on the SW flank, in an area ~ 500 m from the summit crater near the site of the 2005 eruption. The fissure was ~ 200 m long and 10 m wide, and ejected lava fountains 15 m high. A gas-and-ash plume drifted SW. Lava traveled several kilometers in a single flow, then downslope it divided into three branches. Further downslope it merged into two flows, both of which reached the ocean. A large column of steam rose where lava poured into the ocean.

During an overflight on the morning of 15 April, personnel from the Galapagos National Park Service (GNPS) verified that the eruption continued, but with less intensity. Three vents at ~ 400 m elevation on the southwest flank along the radial fissure were active (figure 19), feeding a lava flow up to 10 m wide. The area was free of clouds, making it possible to observe a band of hot water along the coastline of the island, near the point at which the lava enters the ocean. According to a preliminary report from the research vessel sent by the GNPS to the eruption site, the lava has caused deaths among different species of fish and killed several fur seals. During 15-16 April gas-and-steam plumes from Fernandina drifted up to 555 km W.

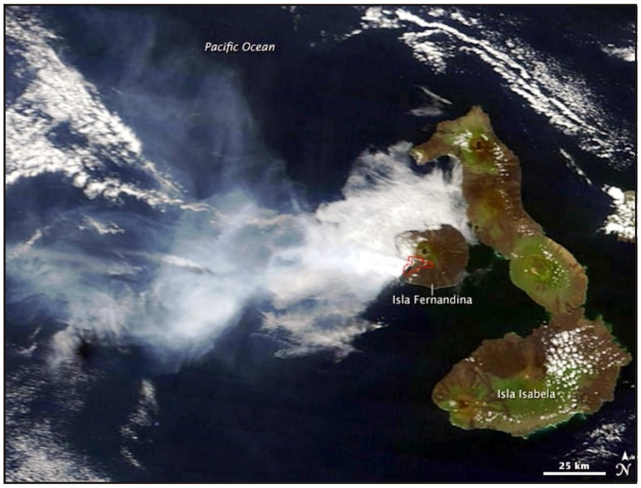

Figure 17. Terra MODIS satellite image of volcanic activity on Isla Fernandina, 11 April 2009 (1610 UTC). Its larger neighbor, Isla Isabela, encircles the island's E side. The plume extended over the ocean and diffuse portions remained visible at least 150 km W. The diffuse plume's contours partly cover denser zones of billowy weather clouds. The outline on the SW side of Isla Fernandina shows the margin of the hotspot detected on this date by MODIS. Courtesy of Jeff Schmaltz and Michon Scott, NASA MODIS Rapid Response Team and NASA Earth Observatory.

Figure 18. Aerial photo of Fernandina, 13 April 2009, showing fountaining lava along a fissure feeding lava flows downslope (left). Courtesy of the Office of Public Relations, Galápagos National Park Service.

Figure 19. Aerial photo of Fernandina, 15 April 2009, showing three active vents along the radial fissure. Courtesy of the Office of Public Relations, Galápagos National Park Service.

Satellite imagery. Satellite images posted by NASA Earth Observatory showed ash plumes on 11, 12, and 27 April in MODIS imagery. All of the plumes were moving W and interpreted as ash-bearing. Based on analysis of satellite imagery, the Washington VAAC reported that during 11-14 April, gas and possible ash plumes expanded laterally up to both 300 km W and 270 km N. The eruption also produced a substantial plume of sulfur dioxide (SO_2) seen in Ozone Monitoring Instrument (OMI) imagery that extended far W of the islands over the Pacific Ocean (figure 20). The Aura image indicated a tentative mass of 1.47 x 10^5 metric tons. NASA's Cloud-Aerosol Lidar and Infrared Pathfinder Satellite Observations (CALIPSO) also detected a substantial low-altitude sulfate aerosol plume at an altitude of ~ 3 km.

MODVOLC data. Thermal anomalies detected by the MODVOLC system were measured from 11 April to at least 12 May 2009 (figure 21). After the initial widespread pixels on 11 April, the thermal alerts were all located on the SW flank below the caldera, and extended down to the ocean. From 11-28 April, the number of the alerts during any satellite pass was rather large, ranging from 45 pixels at the onset of the eruption to 20 pixels after two weeks. Intermittent anomalies were detected through 21 May 2009.

Geologic Summary. Fernandina, the most active of Galápagos volcanoes and the one closest to the Galápagos mantle plume, is a basaltic shield volcano with a deep 5 x 6.5 km summit caldera. The volcano displays the classic "overturned soup bowl" profile of Galápagos shield volcanoes. Its caldera is elongated in a NW-SE direction and formed during several episodes of collapse. Circumferential fissures surround the caldera and were instrumental in growth of the volcano. Reporting has been poor in this uninhabited western end of the archipelago, and even a 1981 eruption was not witnessed at the time. In 1968 the caldera floor dropped 350 m following a major explosive eruption. Subsequent eruptions, mostly from vents located on or near the caldera boundary faults, have produced lava flows inside the caldera as well as those in 1995 that reached the coast from a SW-flank vent. Collapse of a nearly 1 cu km section of the E caldera wall during an eruption in 1988 produced a debris-avalanche deposit that covered much of the caldera floor and absorbed the caldera lake.

Information Contacts: *Geophysical Institute (IG)*, Escuela Politécnica Nacional, Apartado 17-01-2759, Quito, Ecuador (URL: http://www.igepn.edu.ec/); *Galápagos National Park Service*, Ministry of the Environment, Isla Santa Cruz, Galápagos, Ecuador (URL: http://www.galapagospark.org/); *Galapagos Conservancy*, 11150 Fairfax Blvd, Suite 408, Fairfax, VA 22030, USA (URL: http://www.galapagos.org/); *Washington Volcanic Ash Advisory Center (VAAC)*, Satellite Analysis Branch, NOAA/NESDIS E/SP23, NOAA Science Center Room 401, 5200 Auth Road, Camp Springs, MD 20746 USA (URL: http://www.ssd.noaa.gov/); *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/); *Simon Carn*, Dept of Geological and Mining Engineering and Sciences, Michigan Technological University, 1400 Townsend Dr., Houghton, MI 49931, USA (URL: http://www.volcarno.com/, http://so2.umbc.edu/omi/; Email: scarn@mtu.edu); *NASA Earth Observatory* (URL: http://earthobservatory.nasa.gov/).

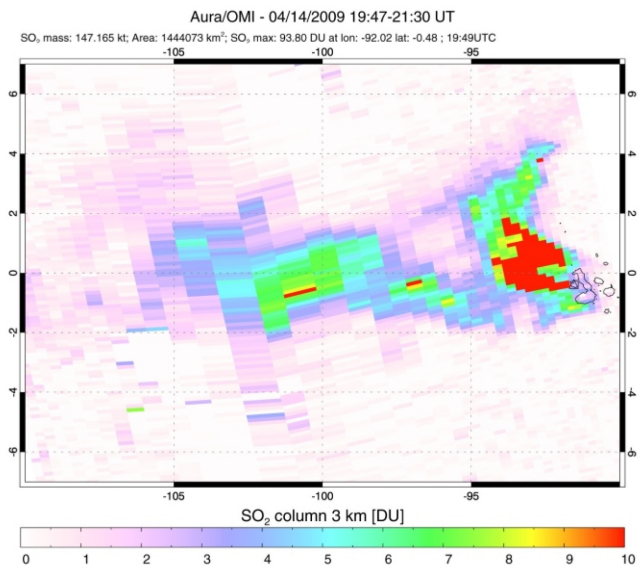

Figure 20. Plume of SO_2 that extended far W of Fernandina, over the Pacific Ocean, imaged by the Ozone Monitoring Instrument (OMI) on NASA's Aura satellite from 1947-2130 UTC on 14 April 2009. In this image, SO_2 is measured in Dobson Units. (See key to shading of colors along bottom edge.) NASA image courtesy Simon Carn.

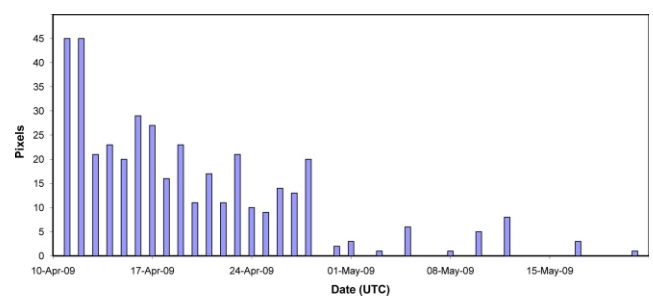

Figure 21. Graph showing the largest number of daily MODVOLC thermal alerts at Fernandina, 10 April-22 May 2009. For many of the days during this event, thermal alerts were measured in 3-4 satellite crossings; only the crossing with the highest number of pixels per day were selected for the graph. Data courtesy of Hawai'i Institute of Geophysics and Planetology (HIGP) Thermal Alerts System.