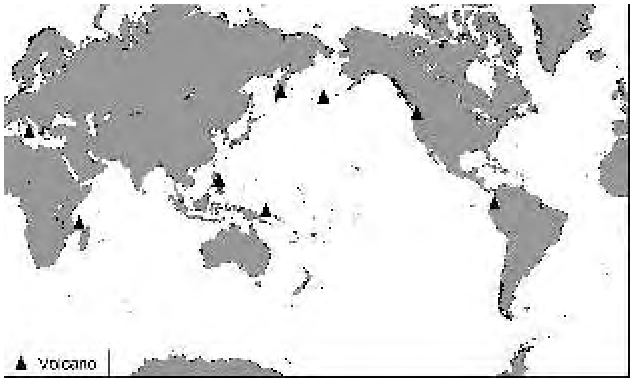
Bulletin of the Global Volcanism Network



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Tungurahua

Ecuador
1.467°S, 78.442°W; summit elev. 5,023 m
All times are local (= UTC - 5 hours)

This report discusses Tungurahua's behavior during August 2005 through the end of July 2006. Material presented here was chiefly gleaned from a series of special reports issued in Spanish by the Instituto Geofísico of the Escuela Politécnica Nacional (IGEPN, hereafter IG). Daily reports for mid-2005 through early 2006 were dominated by descriptions of small plumes and minor ashfall; the reports also noted occasional small rain-generated lahars. For the most part 2005 was the quietest year since eruptions began in 1999, leading residents and volcanologists to ponder if emissions were terminating. This report omits much discussion of evacuations and hazard-status postings. Large eruptions with a Volcanic Explosivity Index (VEI) of 3 that continued into at least late August 2006 will be the subject of the next *Bulletin* report.

During late December 2005 seismometers detected sudden clusters of tremor and earthquakes. Intervals of quiet were broken by the arrival of signals with energy over a broad frequency range (figures 1 and 2). These signals and later manifestations at the surface in late March-early April were thought to be related to a new injection of magma. As a consequence, IG began to produce a series of special reports (table 1). Beginning in February 2006 and particularly during May-June 2006, the volcano was the scene of particularly significant events, including the largest detonations heard and seen since eruptions renewed in 1999. Other observations included a shift in eruptive style, and generation of some pyroclastic flows during the 14 July (VEI 2) eruption. Notable also were constant "roars" and vibrations of such strength and duration that they keep residents awake at night and caused some to voluntarily evacuate.

A map and table of commonly referred-to locations appeared in a previous issue (*BGVN* 29:01). Our last report on Tungurahua covered February 2004 to July 2005 (*BGVN* 30:06), during which time volcanic and seismic activity varied, but included some intervals with comparatively low activity and seismicity such as February to mid-July 2005.

Activity during June to mid-December 2005. From June 2005 through mid-December 2005, volcanic and seismic activity at Tungurahua was at relatively low levels. Low-energy plumes composed of gas, steam, and occasionally small amounts of ash were emitted frequently. Some noteworthy events during this interval follow.

On 7 June 2005, fine ash fell in the Puela sector, ~ 8 km SW. On 24 June, about an hour after an ash eruption, a narrow plume was identified in multispectral satellite imagery. The ash plume was at an altitude of ~ 5.5 km and extended 35-45 km W from the summit.

Ash plumes rose to an altitude of 5.8 km on 4 July. On 21 and 22 August, ash fell in the town of Bilbao, 8 km W of the volcano. On 25 August, ash fell NW of the volcano in the towns of Bilbao and Cusúa. On 1 September, ash fell ~ 8 km SW of the summit in the Puela sector.

On 10 September, a lahar affected an area near the new Baños-Penipe highway. On 14 September, a steam column with little ash reached ~ 300 m above the crater and drifted W; small amounts of ash fell in Puela. A small amount of ash fell in the towns of Cusúa and Bilbao during the morning of 21 September. Fumaroles on the outer edge of the crater were visible from Runtún (6 km NNE of the summit) after not being seen for 6 months. Steam-and-gas plumes rose ~ 1 km and drifted W. A pilot reported an ash plume on 29 September at an altitude of ~ 6.1 km.

During October, and November heavy rain caused lahars to travel down some of the gorges on the volcano's flanks. On 3 and 13 November lahars caused the temporary closure of the Baños-Riobamba highway, and a highway in Pampas. On 15 November ash plumes rose to ~ 9.1 km; on 23 November plumes rose to ~ 6.7 km.

On 13 December, lahars were generated at Tungurahua that traveled down the Juive (NNW) and Achupashal (W) gorges. On 14 December a steam-and-ash cloud rose ~ 1 km above the volcano. On 17 December, lahars were generated in the NW and W zone of the volcano. There were reports of lahars to the W in the Chontapamba sector that blocked the Baños-Penipe highway, in the Salado sector where the volume of water in the Vazcún increased by 70 percent, and in the NW (La Pampa) sector.

Return, incidence, and significance of broadband seismicity. An important variation in behavior was noted during late December 2005, with the appear-

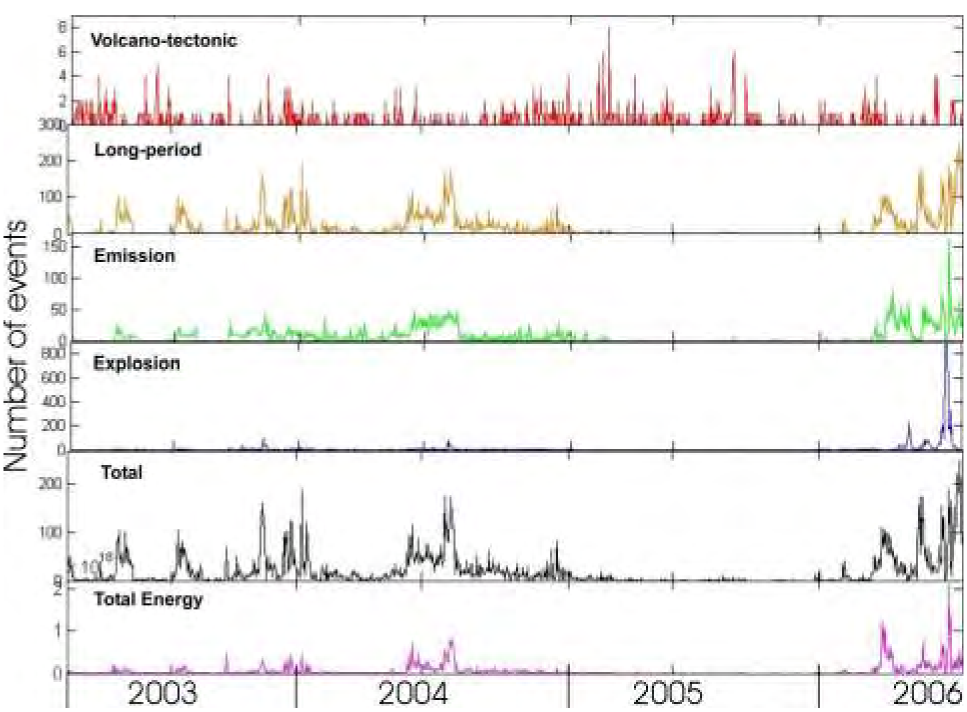

Figure 1. Plots showing daily tallies of Tungurahua's seismicity–volcano-tectonic, long-period, emission, explosion, total number of earthquakes, and total energy release–from 1 January 2003 to end of July 2006. Courtesy of IG.

ance of long-period-earthquake swarms. The swarms preceded emissions and explosions. Such swarms were associated with mid-February 2006 ash-bearing explosions discussed below. After 21 March 2006, the swarms became yet more common and stronger. They were joined by low-frequency harmonic tremor.

Interpreted as related to the motion of magma, the tremor and swarms also seemed closely associated with lava fountains seen in the crater on 25 March 2006. Along with long-period earthquakes there were two episodes of high-amplitude tremor during 4-5 April 2006. Such seismicity had been absent for about a year. Small lava fountains witnessed on the night of 17 April 2006 were again preceded by long-period earthquakes and banded tremor.

As a result, IG distributed two special reports (#2 & 3). The latter contained a spectrogram for late April 2006, illustrating intervals of relative quiet (up to ~ 5 hours long) punctuated by broad-band signals (i.e. coincident earthquakes and tremor) sometimes in tight clusters lasting ~ 90 minutes.

January-May 2006. At the beginning of January 2006, explosions generated moderate amounts of ash, but seismicity remained low. Though clouds obscured the volcano during much of 18-24 January 2006, steam clouds with minor ash content were seen on 20 and 22 January. A discharge of muddy, sediment-laden water along W-flank valleys on 23-24 January blocked the highway. On 25 January light rain caused lahars to flow in the NW sector. The lahars descended a NNW-flank gorge from the village of Juive, causing the closure of the Baños-Penipe highway. Around 28 January, ash fell in the village of Puela. On 31 January, a steam-and-ash plume rose ~ 1 km above the volcano and drifted W. A small lahar closed a road in Pampas for 2 hours.

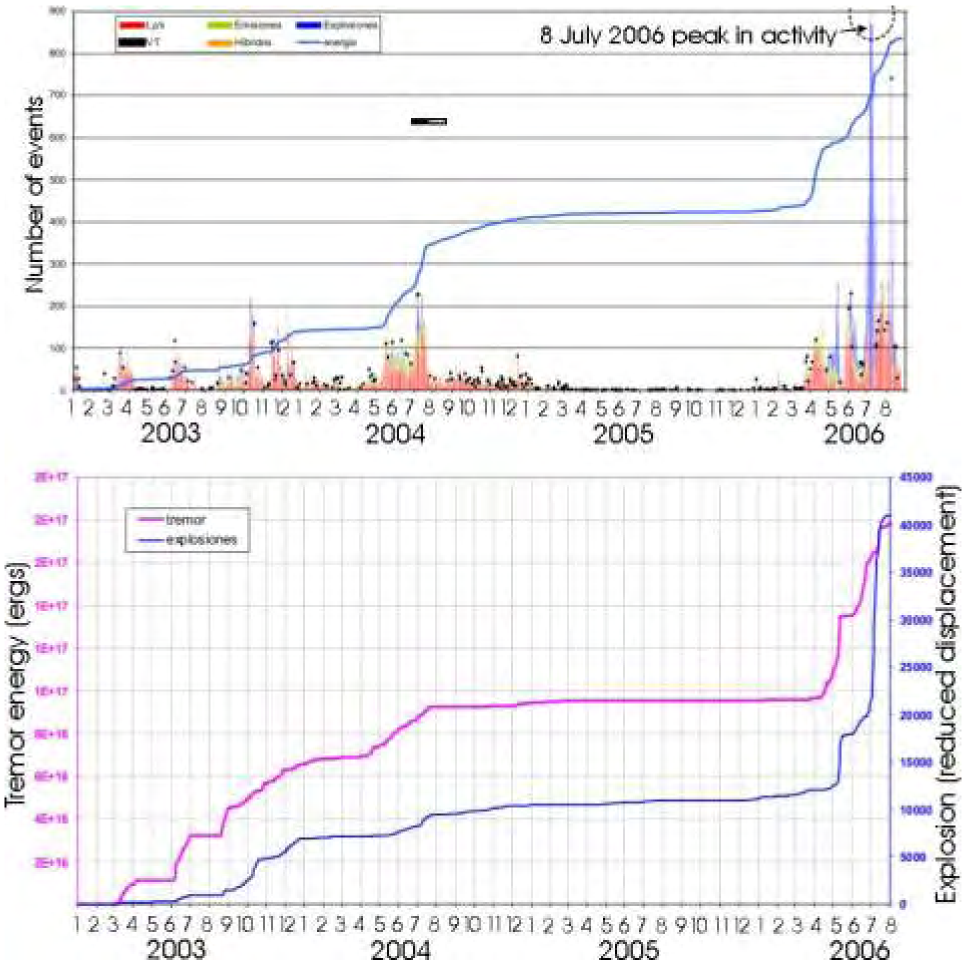

Figure 2. (Top) Summary of seismicity recorded at Tungurahua's station RETU during 1 January and into August 2006 (slightly different end points for two plots). Numbers of events appears on left-hand scale; RSAM (line), in appropriate units, on right-hand scale (peak value is ~ 9 x 10^{19}). (Bottom) Total energy liberated from volcanic tremor and explosions during January 2003 to 1 August 2006. The left-hand scale applies to tremor; the right-hand scale, explosions (reduced displacement). The sharp ascents formed by the "failed eruption" in mid May and the 14 July event are the largest increases since the activity's onset in 1999. Note the pronounced rise in reduced displacement from explosions in months 5-8 (May to August) 2006. Courtesy of IG.

Number	Date	Key observation(s)
1	18 Feb 2006	Moderate explosions and tephra falls in Puela (SW), Paillate (W), Ambato (NW) and Baños (N).
2	07 Apr 2006	Episodes of strong volcanic tremor and increase in number of long-period seismic events, indicating new magma injection.
3	25 Apr 2006	Notable banded tremor, the inferred product of new injected magma interacting with the hydrothermal system.
4	12 May 2006	10 May–start of major increase in number of explosions, long-period seismic events and tremor episodes. Very strong detonations (12 per hour). Peak of energy release on 14 May, then decline. Aborted eruption.
5	30 May 2006	Starting 16 May, significant decrease in activity and superficial manifestations. Explosions occur 2-3 times per day; columns of gases (water vapor mainly) with light ash content predominate.
6	14 Jul 2006	Advisory of intensified eruptive activity; notable increase in emissions and strong detonations (at 2210 & 2250 UTC). Incandescent lava flung from crater. Strong ground movements reported on W flank.
7	14 Jul 2006	Very strong detonations, period of calm, then ascent of 15-km-high, dark, ash-laden column. First pyroclastic flow (at 2250 UTC) and others to descend six valleys (quebradas) on the W-NW-N flanks. Intense lava fountaining; moderate ash and scoria fall to the W.
8	15 Jul 2006	Unusually large discharges with a detonation (at 0559 UTC), leading to the largest registered since 1999. Plume rose to ~ 15 km altitude. The eruptive style later shifted to periodic detonations with intervals of calm.

Table 1. A summary of special reports on Tungurahua issued by the IG during 2006 (reports numbered 1-8; See IG web page-*Informes Especiales-Volcanicos*).

On 5 February at 0600, a moderate explosion sent a steam plume, with a small amount of ash, to ~ 1 km above the volcano; the plume drifted SW. Light rainfall on 7 February generated a lahar in the La Pampa area NW of the volcano.

During 6-14 February, several moderate-sized emissions of gas and ash occurred at Tungurahua, with plumes rising to ~ 500 m above the volcano. Long-period earthquakes increased in number on the 6th. An explosion around midnight on 12 February expelled incandescent volcanic material that traveled down the N flank of the volcano. A small amount of ash fell in the town of Puela, SW of the volcano.

IG issued a report (#1; Boletín Especial Volcán Tungurahua) on 18 February 2006 noting slight increases in activity that week. Explosions were moderate; however, ashfall occurred in some settlements bordering the volcano. IG summarized the week with a table similar to one below, with multiple cases of ash fall on local towns (table 2).

Activity at Tungurahua during 28 February to 6 March consisted of low-level seismicity and emissions of steam and gas, with low ash content. An explosion on the 28th produced a plume composed of steam, gas, and some ash that reached ~ 3 km high.

In addition to the moderate explosions during 8-10 March, light drizzle produced muddy water in the gorges on the volcano's W flank. As a result the Baños-Penipe highway was closed for several hours. On 9 March, ash fell in the zone of Juive on the volcano's NW flank. On 10 March, ash fell in the towns of Pillate, Pondoa, Runtún, and Cusúa (on the W to NW to NNE flanks).

During 16-20 March, small-to-moderate explosions occurred at Tungurahua that consisted of gas, steam, and small amounts of ash. Plumes rose to ~ 3 km above the volcano. During 22-27 March, similar explosions consisted of gas, steam, and small amounts of ash. Plumes rose as high as ~ 1 km above the volcano on several days. An explosion on 26 March was accompanied by incandescent blocks that rolled down the volcano's NW flank.

On 18 February, small amounts of ashfall were reported at the observatory, Cotaló, Cusúa, and other settlements (table 2). On 19 February, rainfall generated a small mudflow SW of the volcano in the Quebrada Rea sector of Puela.

Table 3 summarizes observations associated with plumes and seismicity during 15 February to 8 May 2006. Many observations in that interval noted small-to-moderate explosions or other emissions. Ash plumes to 1-3 km above the volcano (6-8 km altitude) were typical.

During this 15 February to 8 May time interval ash affected localities as follows. During 29 March to 2 April, ash fell in the Bilbao, Choglontus, Puela, and Manzano sectors, and incandescent blocks rolled down the volcano's NW flank. Around 9 March, ash fell in the Baños, Guadalupe, Chogluntus, Bilbao, and Manzano sectors. Around 1500 on 9 March, several lahars traveled down W-flank gorges, disrupting traffic along the Baños-Penipe highway. An explosion on 26 March was accompanied by incandescent blocks that rolled down the NW flank. During 11-17 April, a small amount of ash fell in the Pondoa sector N of the volcano.

Increased activity starting 10 May 2006. Seismicity for mid-April 2006 to mid-August 2006 appears in figure 3. The figure shows the time sequence of hypocenters with various signal types given separate symbols. Between April and May there was a shallowing of event locations (indicated by the arrow on the left) from -4 km to +2 km. At that

Date	Number of explosions	Location and comment
13 Feb 2006	1	Puela (~ 8 km SW of the summit), ashfall during the day.
14 Feb 2006	4	Puela, ashfall during the afternoon.
15 Feb 2006	4	No ashfall reported.
16 Feb 2006	9	Runtún, ashfall at dawn; Observatory (OVT), Pelileo, Baños, and Garcia Moreno subjected to light ashfall in the morning; Bilbao, Cusúa, Puela, Humbaló, Bolívar, and Pillate subjected to strong ashfall in the morning.
17 Feb 2006	3	In Chacauco, Cusúa, and Juive ash fell at dawn and part of the morning. In Pillate, Cotaló, Cusúa, and Huambaló, ash in the morning. In Bilbao, ashfall all day; and Chogluntus, small ashfall during the afternoon.
18 Feb 2006 (until about 1200)	1	In Baños, OVT, Salasaca, Pondoa, Bilbao, San Juan, and Pelileo, ashfall at dawn. In Baños and Ambato, ashfall in both the morning and afternoon.

Table 2. A summary of Tungurahua's ash falls during an active interval, 13-18 February 2006, and the settlements affected. OVT stands for the Observatorio Volcán Tungurahua, a facility 13 km NW of the summit, down valley from the town of Patate. The report was issued at 1330 on the 18th, explaining why the entries only applied to the first half of that day. Courtesy of IG (special report #1).

Date range (2006)	Description of activity (plume heights in kilometers above the summit).
15 Feb-19 Feb	Ash plume as high as 3 km.
26 Feb-27 Feb	Steam and gas with low ash content; on the 26th, 1 plume to ~ 3 km; on the 27th, to 1 km. Both plumes drifted NW.
28 Feb-06 Mar	Steam and gas with low ash content; on the 28th, 1 plume to ~ 3 km. Low seismicity.
08 Mar-10 Mar	Several explosions with low ash content resulting in plumes under 2 km.
16 Mar-20 Mar	Small-to-moderate explosions consisting of gas, steam, and small amounts of ash. Plumes rose to ~ 3 km.
22 Mar-27 Mar	Small-to-moderate explosions consisting of gas, steam, and small amounts of ash. Plumes rose as high as ~ 1 km above the volcano on several days.
29 Mar-02 Apr	Small-to-moderate explosions consisting of gas, steam, and small amounts of ash.
04 Apr-10 Apr	Small-to-moderate explosions at Tungurahua consisting of gas, steam, and small amounts of ash. On the 9th, plumes rose to ~ 3 km.
11 Apr-17 Apr	Small-to-moderate explosions produced gas, steam, and small amounts of ash. On the 13th, plumes rose to ~ 2 km. High seismicity.
19 Apr-23 Apr	Small-to-moderate explosions produced gas, steam, and small amounts of ash. On the 19th, plumes rose to ~ 3 km. High seismicity.
28 Apr-01 May	Small-to-moderate explosions; gas, steam, and small amounts of ash. On the 28th, a plume rose to a maximum height of ~ 2 km. High seismicity.
04 May-08 May	Small-to-moderate explosions; gas, steam, and small amounts of ash. High seismicity, dominated by explosions and long-period earthquakes.

Table 3. A compilation of some daily and weekly observations from Tungurahua during 15 February to 8 May 2006. Courtesy of IG.

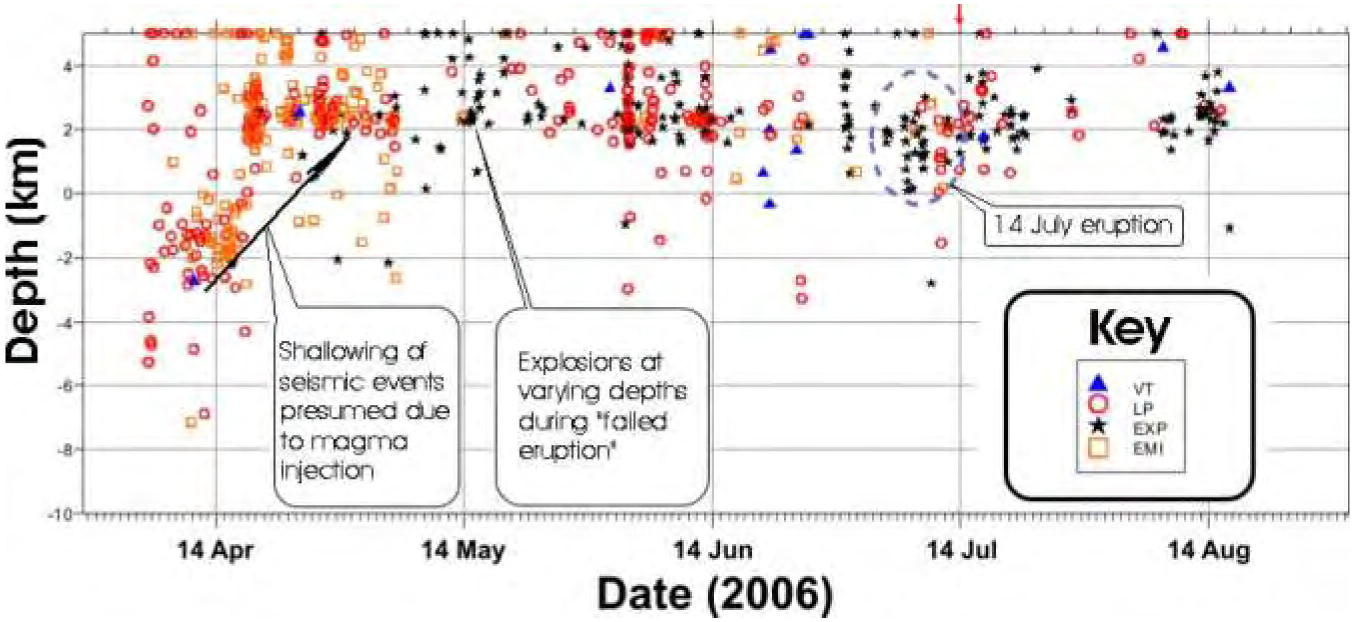

Figure 3. Temporal evolution of depth for various kinds of hypocenters recorded at Tungurahua between April and August 2006. Left-hand scale, depth, is fixed to sea level (i.e. 0 is at mean sea level.). The legend shows the symbols for the various signal types shown: VT (volcano-tectonic earthquakes), LP (long-period earthquakes), EXP (explosion signals), and EMI (emission signals). Courtesy of IG.

point, explosion signals suddenly began to dominate. Those explosion signals came from depths in the range from 0 to over +4 km depth. The 14 May seismic crisis seemingly ended without a large eruption. Explosion signals continued; however, they ceased dominating until around the time of the 14 July eruption when they again became the chief signal (circled area) just prior to the eruption breaking out at the surface.

IG put out special report #4 with a cautionary tone. In the 48 hours starting around 10 May, there was a very important increase in activity. IG judged the anomalous, high-activity conditions as severe as previous ones during this crisis (specifically, equivalent to those of October-December 1999, August 2001, September 2002, and October 2003). The summary that follows largely omits the discussion of plausible scenarios aimed at public safety; however, the IG noted that if rapid escalation were to occur during the current unstable situation, they might not have time to issue alerts. They also noted that the eruption might calm.

During the roughly two-day interval, seismometers registered over 130 explosion signals, averaging about three explosions per hour, but with a maximum of 12 per hour. The general tendency was towards yet more increases in the number of explosion signals. The activity was accompanied by continuous signals described as harmonic tremor and emission-related tremor, and after 10 May these tremor signals were also more intense and frequent. In spite of the increase in explosion and tremor signals, emissions of magmatic gases (SO_2) and ash stayed at relatively low levels.

First-hand observations during 10-12 May described extraordinarily loud explosions heard from 30-40 km away in Pillaro and from~ 31 km NW in Ambato, but absent 30 km SW in Riobamba. In settlements near the volcano, including Cusúa on the volcano's W foot, glass windows shattered. In some areas, roars were sufficiently intense that vibrations in windows and houses kept inhabitants awake at night. The intensities of eruptions from 10 May were reminiscent of the eruption's onset in 1999.

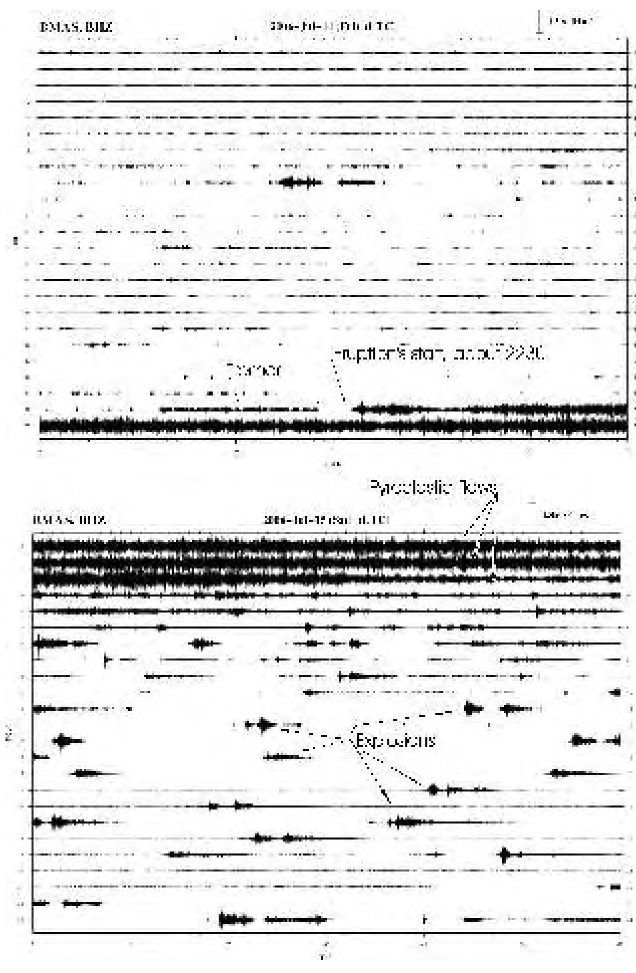

Figure 4. Consecutive records for 14-15 July 2006 (upper and lower panels, respectively) observed from the broadband seismic station Mson located on Tungurahua's SW flank at 3.2 km elevation. Time marks on the y-axis show hours (0 to 24) of the day, x-axis marks show minutes (0 to 60). Note the relative quiet on 14 July prior to eruption's onset at 1733. The latter was preceded by ~ 20 minutes of tremor. Courtesy of IG.

From the observatory in the Guadelupe sector (13 km NW of the cone) night observers saw the ejection and rolling descent of large glowing blocks of lava, and the crater gave off a permanent glow. However, ash emissions were considerably reduced; the chief component venting was steam with few other gases. The resulting outbursts were not continuous and they were too weak to form mushroom clouds. This was in contrast to other periods of high activity (e.g. August 2001, September 2002, and October 2003), when sustained ash-bearing eruption columns and ash falls were common.

IG special report #4 noted that the tremor signals during a 48-hour interval after 10 May were the strongest recorded since the eruptions renewed in 1999. The number of explosions and their seismic energy were the highest recorded since the end of 2003, but was less than registered during November 1999 and mid-2000.

On 30 May IG issued its next special report (#5), which noted elevated eruptive activity during 8-14 May, but a clear decrease thereafter. During 10-21 May, the following instruments detected the stated numbers of explosions: seismometers, 801; and infrasonic recorders, 682. The peak in these explosions occurred on 14 May, a day when the instrument counts were as follows: seismometers, 221; infrasonic, 204. As in the previous report, inhabitants close to the volcano heard loud roars, and in some cases were sleepless due to vibrations heard or felt in their homes at night. These conditions convinced residents in Cusúa to move during the night. But starting the 16th, the number and intensity of explosions per day decreased drastically, with only 17 explosions recorded on the 16th, dropping in later days to 2 or 3 daily explosions. According to a local mayor, given the lack of noises and relative calm, evacuees from Cusúa returned home.

The lull in explosions coincided with ongoing fluctuations in seismicity. The IG interpreted this as a sign of continued instability linked to the motion of fluids at depth. The lull in explosion signals accompanied increased gas emissions, which gradually came to contain more and more ash. Small, local ash fall again began to occur. Starting 17 May it became common to see ash columns extending to 4 km above the summit, frequently blown NW.

Reports for the week following 17 May by the Washington VAAC also discussed the increasing ash plumes. On 18 May, an ash plume reached an altitude of 5.2 km above the crater and extended NW. The Washington VAAC also noted that on 19 May, the Instituto Geofísico observed an ash plume that reached an altitude of 12 km. On satellite imagery, ash plumes were visible on 20 and 23 May and extended SW. Hotspots were visible on satellite imagery 19, 20 and 23 May. The ash plume and incandescence on 23 May were also observed on the scene by Instituto Geofísico

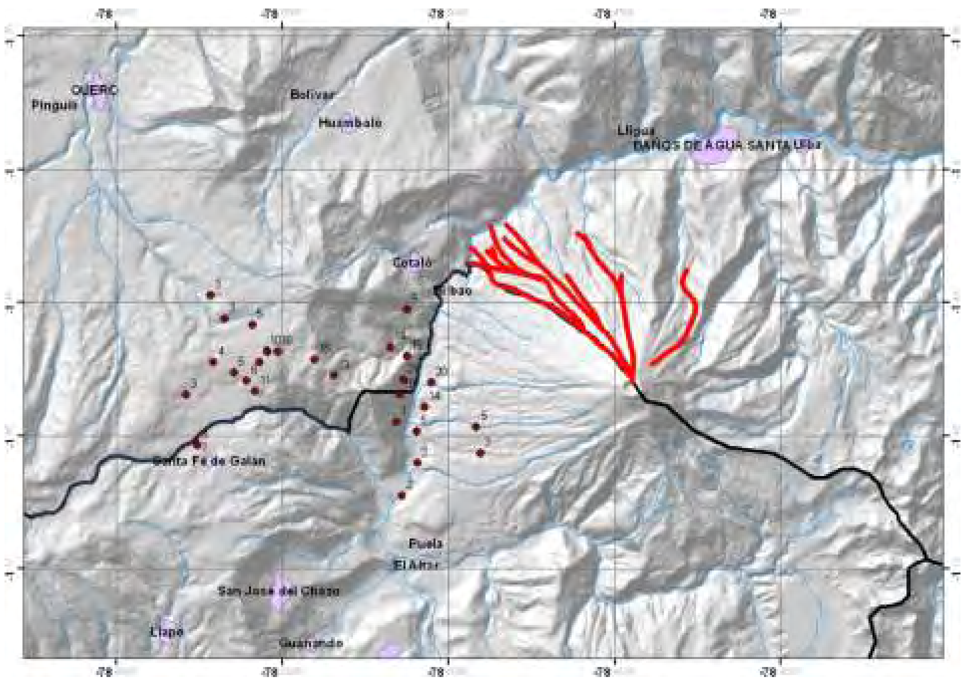

Figure 5. Paths where pyroclastic flows descended during Tungurahua's eruption of 14-15 July 2006. The associated ashfall deposits are identified at points W of the volcano's summit (thicknesses in mm). For scale, adjacent E-W grid lines are 4.44 km apart (and Cotalo, on the NW flank is ~8.5 km from the summit). Grid lines are latitude and longitude in degrees (heavy type) and decimal degrees (light type); lines are separated by 0.04 degrees N-S, and 0.05 degrees E-W. Courtesy of IG.

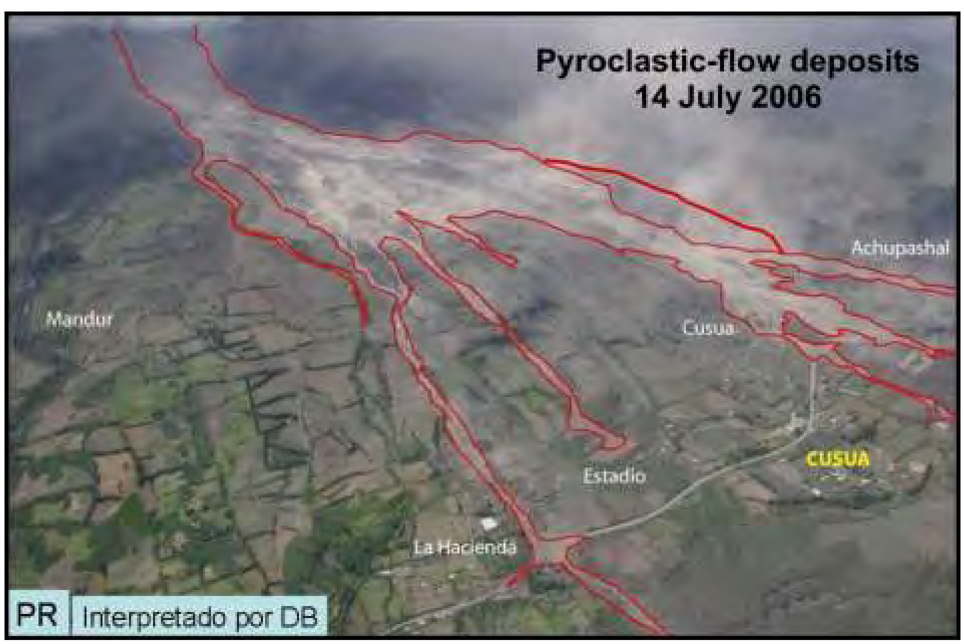

Figure 6. Pyroclastic flow routes and deposits on Tungurahua's lower W flank (near Cusúa). Photographed 14 July 2006 Courtesy of IG.

Figure 7. Three photos depicting the onset of strong pyroclastic flows on Tungurahua at about 1814 on 14 July 2006. This particular pyroclastic flow descended the Juive Grande river valley. Photo taken from Loma Grande, located about 9 km NNW of the crater. Photographed by L. Gomezjurado; courtesy of IG.

staff. On 25 May a significant meteorological advisory (SIGMET) indicated an ash plume to an altitude of 5 km. On 27 and 30 May, the VAAC reported that the Instituto Geofísico observed ash plumes at altitudes of 7.9 km and 5 km respectively. IG noted that behavior during the last few weeks of May seemed consistent with a gradual decrease from the state of elevated activity seen in mid-May.

Although satellite thermal data produced alerts during 8-14 May, these ceased later in the month. The reduced thermal flux was taken to suggest reduced manifestations in the crater during mid to late May. Coincident with that, deformation data suggested relative stability, particularly compared to the significant variations seen earlier in May.

During 28 June-4 July, small-to-moderate explosions at Tungurahua produced plumes composed of gas, steam, and small amounts of ash that reached 1.5 km above the summit. Light ashfall was reported in nearby localities during 29 June-2 July. On 29 June, reports of ground movement coincided with an explosive eruption that sent blocks of incandescent material as far as 1 km down the W flank.

During 5-11 July, seismic activity indicating explosions increased at Tungurahua. Incandescent blocks were ejected from the crater during 5 to 8 July, when blocks rolled approximately 1 km down the NW flank. Ash-and-steam plumes with moderate to no ash content were observed to reach maximum heights of 2.5 km above the summit and drifted to the W and NW.

Eruptive style changes after powerful discharges of mid-July 2006. On 14 and 15 July, IG issued its next special reports (#6, 7, and 8) documenting events surrounding the strongest eruption yet seen during the entire 1999-2006 eruptive process. The basis for the size assesment was made from the seismic record based on reduced displacement, sometimes called normalized or root-mean-square amplitude (a means to correct seismic data to a common reference point; McNutt, 2000) The largest discharge occurred at 0559 on 15 July.

On 14 July, seismicity was elevated above that seen in the previous several days. IG noted that at 1710 several large explosions were recorded on instruments, as well as heard by people. An eruption column formed, bearing moderate ash. It initially rose several kilometers but later was estimated to have attained ~ 15 km altitude. This was followed by 20 minutes of quiet. At 1733 a huge explosion presumably opened the conduit. Immediately local authorities were contacted and they evacuated people living on the lower NW-W flanks of the cone. Pyroclastic flows and explosion signals are notable in the seismic record (figure 4).

Figure 8. At Tungurahua, a pyroclastic flow descending the NW-trending Mandur valley at 0653 on 16 July 2006. Photo by P. Mothes, IG.

At 0050 on 14 July a pyroclastic flow poured down the NW flank (the Juive Grande drainage). An associated fine ashfall was noted 8 km SW in the town of Puela. Intense Strombolian activity ensued, including glowing blocks tossed 500 m above the crater that bounced downslope for considerable distances. Associated noises were particularly loud and heard widely, including in Ambato (30 km NW). Lookouts described these sounds as distinctive ("bramidos doble golpe;" roughly translated as 'double roars'), a new sound in the suite of those heard since 1999. In the Cusúa area, and up to 13 km NW in the sector of the Observatory of Guadelupe, residents felt intense ground movements.

At 1930 that day pumice fell on the W flank (the sector of Pillate) reaching a thickness of ~ 1 cm. About 10 minutes after the pumice fall, the IG issued the second special report (#7) on the 14 July events. It cautioned residents to remain away from the volcano's W side. The next special report (#8) noted that variations in activity prevailed through the end of 14 July, and that much of the first hour of 15 July brought decreased activity. Tremor continued on 15 July, often in episodes with durations of 4 to 5 minutes, separated by intervening calm intervals of similar duration.

After 0500 on 15 July the eruptive process changed, with the new regime characterized by sequences of abundant large explosions followed by intervals of calm lasting 30-40 minutes. A critical detonation occurred at 0559 on 15 July. On the basis of reduced displacement, it ranked as the largest since the eruption began in 1999. Other detonations with similar character followed the initial one. During 0500-0555 there were 20 large detonations. In assessing the 14-15 July eruptions, satellite analysis by both the Washington Volcanic Ash Advisory Center and the U.S. Air Force Weather Agency confirmed the highest ash-plume tops to altitudes of 15-16 km.

At sunup on 15 July observers found signs that a pyroclastic flow had descended a W-flank drainage (Achupashal valley, between Cusúa and Bilbao). The deposits filled the valley (to 5- to 10-m thickness). Small fires had ignited in the vegetation. A rockfall was also seen in the Bilbao area. Ash falls were reported, containing both ash and scoria fragments, affecting the cities of Penipe, Quero, Cevallo, Mocha, Riobamba, and Guaranda.

Additional fieldwork revealed that pyroclastic flows had traveled down at least six quebradas around the volcano, including Achupasal, Cusúa, Mandur, Hacienda, Juive Grande, and Vascún valleys (the latter, upslope from the western part of the touristic city of Baños).

Figures 5-8 depict the distribution of fresh deposits as well as some photos taken during the 14-15 July eruptions. Tilt and SO_2 monitored at Tungurahua appear on figures 9 and 10. Satellite photos from 25 June and 18 July appeared on the NASA Earth Observatory website.

Reference. McNutt, S., 2000, Seismic monitoring, in Encyclopedia of Volcanoes: Academic Press (editor-in-chief, Haraldur Sigurdsson), p. 1095-1119, ISBN 0–12-643140-X.

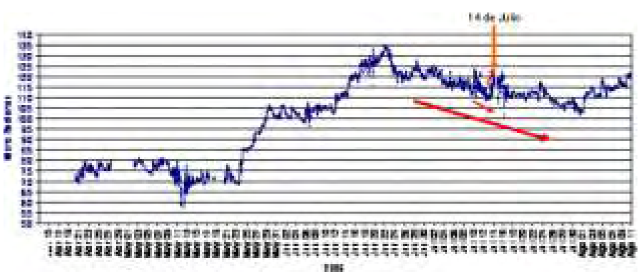

Figure 9. Plot showing radial tilt (at station RETU located at 4 km elevation on the N flank), 13 April-11 August 2006. During mid-May to mid-June 2006, tilt at the instrument had been in an inflationary trend. Around 22 June the tilt shifted to deflation, which became strong for a few day just prior to the eruption. The eruption occurred after several hours of sudden inflation. After the eruption, the broad deflationary trend continued until around the beginning of August.Courtesy of IG.

Geologic Summary. Tungurahua, a steep-sided andesitic-dacitic stratovolcano that towers more than 3 km above its northern base, is one of Ecuador's most active volcanoes. Three major volcanic edifices have been sequentially constructed since the mid-Pleistocene over a basement of metamorphic rocks. Tungurahua II was built within the past 14,000 years following the collapse of the initial edifice. Tungurahua II itself collapsed about 3000 years ago and produced a large debris-avalanche deposit and a horseshoe-shaped caldera open to the W, inside which the modern glacier-capped stratovolcano (Tungurahua III) was constructed. Historical eruptions have all originated from the summit crater. They have been accompanied by strong explosions and sometimes by pyroclastic flows and lava flows that reached populated areas at the volcano's base. Prior to a long-term eruption beginning in 1995 that caused the temporary evacuation of the city of Baños at the foot of the volcano, the last major eruption had occurred from 1916 to 1918, although minor activity continued until 1925.

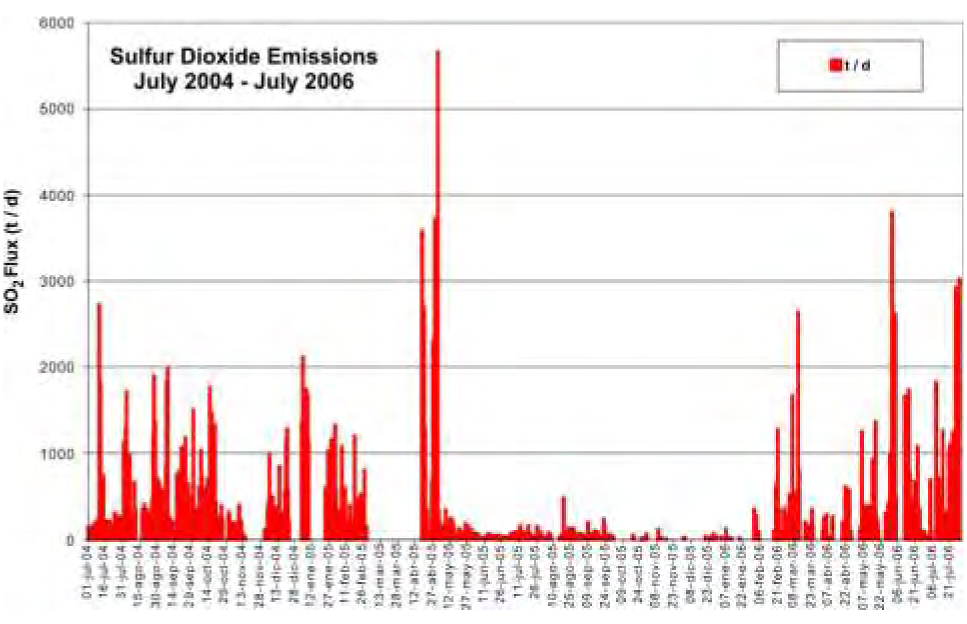

Figure 10. SO_2 flux at Tungurahua as measured by DOAS, July 2004-July 2006. Courtesy of IG.

Information Contacts: *Geophysical Institute (IG)*, Escuela Politécnica Nacional, Apartado 17-01-2759, Quito, Ecuador (URL: http://www.igepn.edu.ec/).

Galeras

Colombia
1.22°N, 77.37°W; summit elev. 4,276 m
All times are local (= UTC -5 hours)

On 24 November 2005 an eruption began at Galeras that resulted in local ash fall (*BGVN* 31:01and 31:03). This report discusses behavior through mid-August 2006.

Through December 2005 to the end of March 2006, the lava dome in the main crater continued to grow and seismicity remained elevated. Because of an increase in tremor at Galeras on 28 March 2006, Instituto Colombiano de Geología y Minería (INGEOMINAS) raised the Alert Level from 3 (changes in the behavior of volcanic activity have been noted) to 2 (likely eruption in days or weeks). Although the seismic activity apparently decreased on 29 March, Galeras remained at Alert Level 2.

INGEOMINAS reported that Galeras remained at a critical state during April and May 2006, with a partially solidified lava dome in the main crater. Seismicity, deformation, gas emissions, and temperatures all decreased. During 10-17 April, there were small gas emissions from the volcano. During 9-15 May, there were small gas and sporadic ash emissions. During 12-19 June, ash columns reached heights of 0.6-1.4 km above the summit.

According to Reuters and BBC reports, an increase in volcanic activity 12 July prompted the Colombian government to order the evacuation of ~ 10,000 people living near Galeras. INGEOMINAS reported an increase in seismic activity and at least two explosive eruptions. Ash accumulated in the towns of La Florida and Nariño, about 10 km N, and in the town of Genoy, 5 km NE. The Alert Level was increased from 2 (likely eruption in days to weeks) to 1 (eruption imminent or occurring). On 13 July, because of decreased activity, the Alert Level was lowered from 1 to 3. Approximately 2,000 people had been taken to shelters.

On 17 July, INGEOMINAS reported that after the 12 July eruption of Galeras, seismic activity decreased considerably. Observations of the dome and secondary craters in the W sector after 12 July showed minor physical changes. Weak gas plumes were observed without associated seismic activity. Through the first two weeks of August 2006, seismic activity remained at low levels. Gas and steam emissions from the main crater continued. Galeras remained at Alert Level 3 (changes in the behavior of volcanic activity have been noted).

Geologic Summary. Galeras, a stratovolcano with a large breached caldera located immediately W of the city of Pasto, is one of Colombia's most frequently active volcanoes. The dominantly andesitic Galeras volcanic complex has been active for more than 1 million years, and two major caldera collapse eruptions took place during the late Pleistocene. Long-term extensive hydrothermal alteration has affected the volcano. This has contributed to large-scale edifice collapse that has occurred on at least three occasions, producing debris avalanches that swept to the W and left a large horseshoe-shaped caldera inside which the modern cone has been constructed. Major explosive eruptions since the mid Holocene have produced widespread tephra deposits and pyroclastic flows that swept all but the southern flanks. A central cone slightly lower than the caldera rim has been the site of numerous small-to-moderate historical eruptions since the time of the Spanish conquistadors.

Information Contacts: *Diego Gomez Martinez*, Observatorio Vulcanológico y Sismológico de Pasto (OVSP), INGEOMINAS, Carrera 31, 1807 Parque Infantil, PO Box 1795, Pasto, Colombia (Email: dgomez@ingeomin.gov.co; URL: http://www.ingeomin.gov.co/pasto/; Email: ovp@ingeomin.gov.co); *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/); *El Pais* (URL: http://elpais-cali.terra.com.co/paisonline/); Reuters; British Broadcasting Company (BBC) (URL: http://www.bbc.co.uk/).

Karthala

Comoros
11.75°S, 43.38°E; summit elev. 2,361 m
All times are local (= UTC + 3 hours)

On 28 May 2006, a magmatic eruption occurred inside the Chahalé caldera of Karthala volcano. Information in the previous report (*BGVN* 31:06) was based on newspaper accounts. This report comes from Hamidou Nassor, Julie Morin, Christopher Gomez, Magali Smietana, François Sauvestre, and Christopher Gomez. They noted some key references relating to Karthala, including a 2001 dissertation (Bachèlery and others, 1995; Krafft, 1982; and Nassor, 2001).

The 28 May 2006 crisis began with a few hours of elevated seismic activity, beginning around 1230 (local time). Three hours later, seismic stations recorded a small crisis that lasted for 6 hours and produced both SP and LP signals. Around 2107 the magmatic eruption began. Seismographs recorded a tremor only a few seconds later.

From the coast of the island a red cloud was visible above the volcano. Scientists at the Karthala observatory met with government representatives and confirmed a magmatic eruption. It was not yet known if the eruption had occurred on the caldera floor or inside the main crater. A trip to the volcano was necessary in order to assess the volcanic activity and determine the exact location of the eruption. Two hypotheses were proposed: (1) If the eruption was located in the N part of the caldera, the lava could flow outside the caldera, towards populated areas; (2) If the eruption was located inside the main crater, to the S, lava would remain inside the crater. The Comorian authorities helped the scientific team to get assistance from the South African Army (AMISEC) to fly over the volcano.

On the morning of 29 May 2006, the scientific team and AMISEC personnel flew over the volcano. They saw that the eruption was contained inside the main (Chahalé) crater, where the past three eruptions had occurred. A lava fountain was observed in the middle of the lava lake (figure 11). No lava flow was observed outside the caldera. Seismic records showed a tremor caused by the lava fountain; the fountain was apparently spurting since the beginning of the eruption.

On the morning of 31 May, the scientific team returned to Karthala with AMISEC forces. Part of the lake was still mobile and bubbling, but part had solidified on the surface in the SE and a few blocks were floating on the side of the lake (figure 12). No projectiles overshot the caldera rim.

On 1 June 2006 seismic monitoring indicated the end of the tremor phase. On 2 June scientists returned to the summit with AMISEC forces. They observed that the surface of the lava lake was solidified, but the deeper portions of the lake remained hot (figure 13).

References: Bachèlery, P., Damir, B.A., Desgrolard, F., Toutain, J.P, Coudray, J.P., Cheminée, J-L., Delmond, J.C., and Klein, J.L. 1995, L'éruption phréatique du Karthala (Grande Comore) en juillet 1991: C.R Acad. Sci. Paris, 320, série Iia, p. 691-698.

Krafft, M., 1982, L'éruption volcanique du Karthala en avril 1977 (Grande Comore, Océan Indien): C.R. Acad. Sci. Paris, t 294, série II, p. 753-758.

Nassor, H., 2001, Contribution à l'étude du risque volcanique sur les grands volcans boucliers basaltiques: le Karthala et le Piton de la Fournaise: Ph.D. thesis, Univ. Reunion.

Geologic Summary. The southernmost and larger of the two shield volcanoes forming Grand Comore Island (also known as Ngazidja Island), Karthala contains a 3 x 4 km summit caldera generated by repeated collapse. Elongated rift zones extend to the NNW and SE from the summit of the Hawaiian-style basaltic shield, which has an asymmetrical profile that is steeper to the south. The lower SE rift zone forms the Massif du Badjini, a peninsula at the SE tip of the island. Historical eruptions have modified the morphology of the compound, irregular summit caldera. More than twenty eruptions have been recorded since the 19th century from both summit and flank vents. Many lava flows have reached the sea on both sides of the island, including during many 19th-century eruptions from the summit caldera and vents on the northern and southern flanks. An 1860 lava flow from the summit caldera traveled ~ 13 km to the NW, reaching the western coast north of the capital city of Moroni.

Figure 11. This lava lake was seen in the main crater, Chahalé, on 29 May. The lava fountain was in the N part of the lake. Some lava blocks larger than 1 m in diameter are visible. The gas and vapor plume reached an altitude of about 3 km. Photo courtesy of Julie Morin.

Figure 12. Karthala's lava lake on 31 May. In the lake's NW, a lava fountain was active, while the lake's S part had started to solidify. Photo courtesy of Magali Smietana.

Figure 13. The floor of Karthala's Chahalé crater remained filled by lava on 2 June, although a crust had formed covering much of the lava lake. Photo courtesy of Christopher Gomez.

Information Contacts: *Hamidou Nassor* (LSTUR) Université de la Réunion BP 7151, 15 Avenue, René Cassin, 97715 Saint-Denis (Email: hamidou.nassor@univ-reunion.fr; hamidounassor@hotmail.com; *Julie Morin*, Email: julieapi@yahoo.fr; *Christopher Gomez*, Laboratoire de géographie physique CNRS LGP, Email: kurisusing@hotmail.com; *Magali Smietana* , Email: magali.smietana@etudiant.univ-rennes1.fr; *François Sauvestre* (CNDRS), BP 169, Moroni (URL: http//volcano.ipgp.jussieu.fr:8080/Karthala/stationkar.html).

Etna

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

This report covers the new eruption from an E-flank fissure during mid July 2006. Previously, on 7 September 2004, an eruptive period began that lasted until March 2005 (*BGVN* 29:09, 30:01). From March 2005 until November quiet degassing took place at the summit craters; on 16 December 2005 an explosive sequence at the summit was accompanied by an ash emission from the Bocca Nuova crater (*BGVN* 30:12). This report is from Sonia Calvari of the Istituto Nazionale di Geofisica e Vulcanologia (INGV) and

Figure 14. Lava flows descending from vents near Etna's summit cone. Reuters photo.

Figure 15. On 21 July 2006, the Moderate Resolution Imaging Spectroradiometer (MODIS) flying onboard NASA's Terra satellite captured this image as Etna emitted a faint ash plume that blew SW. MODIS also detected a hotspot near the summit, where surface temperatures were much higher than in the surrounding area (red outline). Courtesy the MODIS Rapid Response Team, NASA GSFC.

covers the interval through 26 July. Brief mention is made at the end of the report about another episode starting on 31 August and going into at least mid-September.

On 14 July 2006 at 2330 a fissure opened on the E flank of the South-East Crater (SEC) summit cone. Two vents along the fissure produced a lava flow spreading E to the Valle del Bove (figure 14). A helicopter survey carried out on 16 July at 0730 showed a braided lava flow field up to 1. 7 km long. Based on the surface area and approximate volume of this lava flow field, workers estimated a mean output rate of ~ 2.6 m^3/s during the first 32 hours of eruption. During the opening phase of the eruptive fissure, moderate strombolian emissions occurred at a third upper vent, located at about 3,100 m on the E flank of the SEC, just below the wide depression that cuts its eastern flank. It produced minor ash fallout on Catania. The composition of the ash was 80% juvenile, with small amount of lithics probably due to the opening phase of the vents.

On 17 July, the lava flow field was situated on the W wall of the Valle del Bove, and the two main flow fronts reached about 2,100 m elevation, spreading N of the Serra Giannicola Piccola ridge. The lava discharge peaked on 20 July (figure 15), when an effusion rate of ~ 10 m^3/s drove the lava flow advance to a maximum distance of ~ 3 km within the Valle del Bove. The lava flow front widened at the base of Monte Centenari, at 1,800 m elevation, located at least 15 km from the closest villages. The effusion rate on 23 July decreased to ~ 3 m^3/s. At that time the lava channels had narrowed and levees had partially collapsed. The eruption appeared to end on 24 July.

On 26 July, observers on the rim of the NE Crater heard strong explosions, and saw lapilli fall. This crater, together with the south pit within Bocca Nuova, showed significant thermal anomalies during a helicopter survey carried out on 24 July.

In the early morning of 31 August, Strombolian activity resumed at SEC's summit. In the next two weeks SEC was the scene of a series of dramatic events. By 11 September, lava from the SE flank of the SEC had advanced to reach ~ 3 km ESE. The resulting ribbon of lava was in places over 200 m wide. More details will follow in a subsequent report.

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

Information Contact: *Sonia Calvari*, Istituto Nazionale di Geofisica e Vulcanologia Sezione di Catania, Piazza Roma 2, 95123 Catania, Italy (Email: calvari@ct.ingv.it, URL: http://www.ct.ingv.it/); *Reuters* (URL: http://today.reuters.com/).

St. Helens

Washington, USA
46.20°N, 122.18°W; summit elev. 2,549 m
All times are local (= UTC - 8 hours)

The current and ongoing eruption of the St. Helens started on 11 October 2004. Extrusion of the growing lava dome has continued in the same quiescent mode exhibited over the past year, and levels of seismicity remained generally low, with low emissions of steam and volcanic gases and minor production of ash. From 1830 hours on 26 Octo-

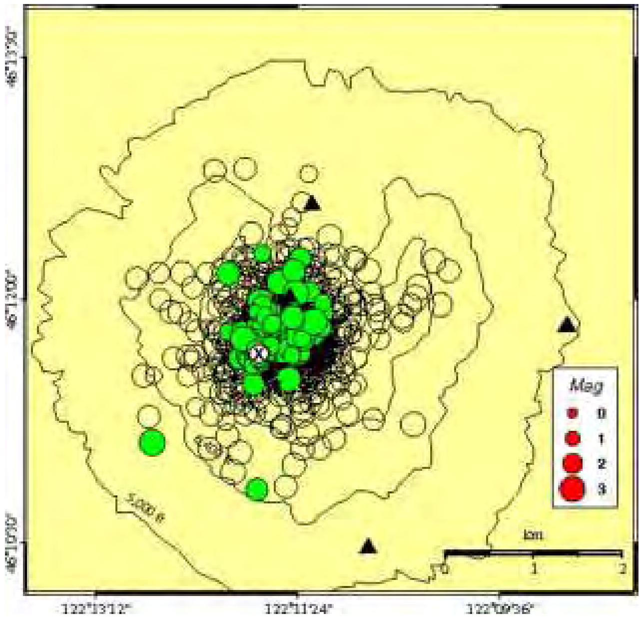

Figure 16. Epicenters of St. Helens earthquakes between 1 July 2005 and 15 August 2006, a total of 1,768 well-located earthquakes. The circle with an "x" represents events on 15 August 2006, and filled circles represent events since 15 July 2006; open circles represent older events in the past year. Black triangles locate Pacific Northwest Seismograph Network (PNSN) seismic stations. Courtesy of the PNSN.

ber 2004 to 15 August 2006, a total of 13,841 seismic triggers have occurred. Figures 16 and 17 summarize seismicity over the past year. A decade-long time-depth plot clearly shows the start of the current eruption (figure 18).

Pictures and movies taken in August 2006 with the Brutus camera (located on the E rim of the 1980 Mount St. Helens crater) showed continued extrusion of spine 7 on the growing lava dome (figure 19) (photos and movies are also available on the CVO website). Between 4-5 and 7-8 August a segment of the middle part of spine 7 temporarily stopped moving. At 1310 on 5 August a magnitude 3.6 earthquake occurred, and subsequent photographs showed that the "stuck" segment became unstuck. Motion again stopped sometime after 1310 on 7 August and much of 8 August, when a M 3.3 earthquake occurred at 2001 on 8 August. Clouds obscured the volcano from view on 9 August, but parted enough on 10 August to show that once again the segment became unstuck. One explanation by CVO scientists for these observations is that the large earthquakes were caused by parts of the spine sticking and then slipping.

Geologic Summary. Prior to 1980, Mount St. Helens formed a conical, youthful volcano sometimes known as the Fuji-san of America. During the 1980 eruption the upper 400 m of the summit was removed by slope failure, leaving a 2 x 3.5 km horseshoe-shaped crater now partially filled by a lava dome. Mount St. Helens was formed during nine eruptive periods beginning about 40-50,000 years ago and has been the most active volcano in the Cascade Range during the Holocene. Prior to 2200 years ago, tephra, lava domes, and pyroclastic flows were erupted, forming the older St. Helens edifice, but few lava flows extended beyond the base of the volcano. The modern edifice was constructed during the last 2200 years, when the volcano produced basaltic as well as andesitic and dacitic products from summit and flank vents. Historical eruptions in the 19th century originated from the Goat Rocks area on the north flank, and were witnessed by early settlers.

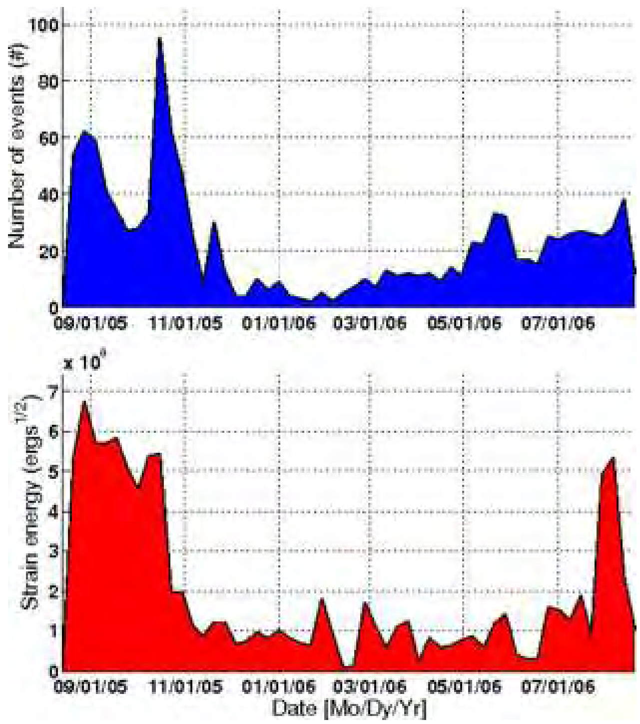

Figure 17. Plots of the number of well-located events and their main root of strain energy for St. Helens earthquakes between 1 July 2005 and 15 August 2006 describing a total of 1,768 earthquakes. Each point on the strain energy plot's curve represents the sum of energy released by all earthquakes in a 14-day period; energy is computed in 14-day time windows, every 7 days. Courtesy of the PNSN.

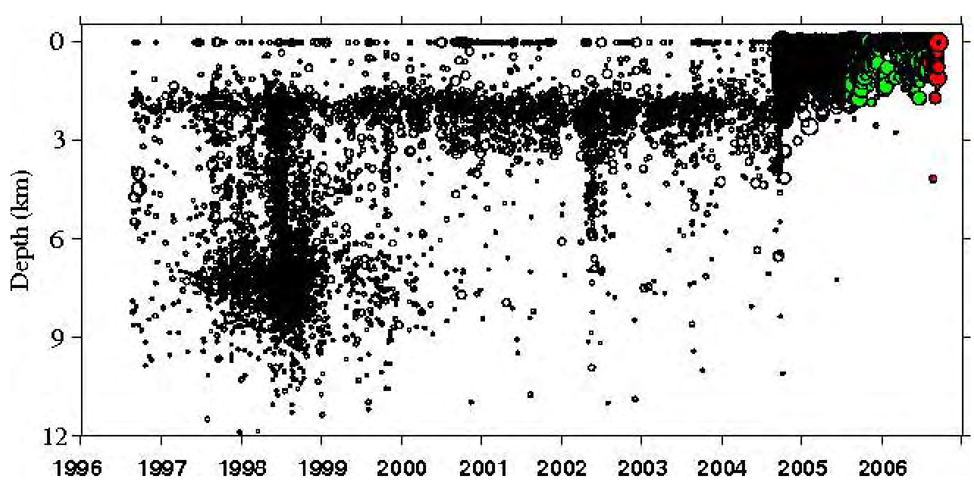

Figure 18. Time-depth plot of well-located earthquakes at St. Helens between 1996 and 14 September 2006, a total of 22,485 events. Courtesy of the PNSN.

Figure 19. Spine 7 of the growing lava dome of Mount St. Helens taken 3 August 2006. Courtesy of CVO.

Information Contacts: *U.S. Geological Survey Cascades Volcano Observatory*, Vancouver, WA (URL: http://vulcan.wr.usgs.gov/); *The Pacific Northwest Seismograph Network*, University of Washington Dept. of Earth and Space Sciences, Box 351310, Seattle, WA (URL: http://www.geophys.washington.edu/SEIS/PNSN/).

Cleveland

Aleutian Islands, USA
52.825°N, 169.944°W; summit elev. 1,790 m

On 23 May 2006, the Alaska Volcano Observatory (AVO) received a report from the International Space Station indicating that a plume was observed moving W from Cleveland volcano at 2300 UTC (*BGVN* 31:06). A photograph of the plume taken from the International Space Station was released by the National Aeronautics and Space Administration (NASA) (figure 20).

Starting at about 2300 UTC, just before this image was taken, Cleveland underwent a short eruption. The volcanic plume was seen in Advanced Very High Resolution Radiometer (AVHRR) polar-orbiting satellite data beginning from 2307 UTC. By 0100 UTC on 24 May the ash plume had detached from the vent and was approximately 130 kilometers SW of the volcano. Satellite data showed a cloud height of about 6.1 km asl (table 4). The plume was no longer detectable in satellite imagery by 0057 UTC on 25 May. In response to the event, AVO raised the Level of Concern Color Code to 'Yellow.'

The last eruption of Cleveland was 6 February 2006 (*BGVN* 31:01). Since 24 May 2006, no new information about ash emissions had been received, nor have indications of continuing activity been detected from satellite data for the volcano. This short-lived event was typical of recent Cleveland activity. On 7 August 2006, AVO downgraded the Level of Concern Color Code for Cleveland from 'Yellow' to 'Not Assigned." Because Cleveland is not monitored with real-time seismic instrumentation, during intervals of repose it does not receive an assignment of Color Code 'Green,' but instead is left 'Not Assigned.'

Geologic Summary. Beautifully symmetrical Mount Cleveland stratovolcano is situated at the western end of the uninhabited, dumbbell-shaped Chuginadak Island. It lies SE across Carlisle Pass strait from Carlisle volcano and NE across Chuginadak Pass strait from Herbert volcano. Cleveland is joined to the rest of Chuginadak Island by a low isthmus. The 1,730-m-high volcano is the highest of the Islands of the Four Mountains group and is one of the most active of the Aleutian Islands. The native name for Mount Cleveland, Chuginadak, refers to the Aleut goddess of fire, who was thought to reside on the volcano. Numerous large lava flows descend the steep-sided flanks of the volcano. It is possible that some 18th to 19th century eruptions attributed to Carlisle should be ascribed to Cleveland (Miller and others, 1998). In 1944 Cleveland produced the only known fatality from an Aleutian eruption. Recent eruptions from Mount Cleveland have been characterized by short-lived explosive ash emissions, at times accompanied by lava fountaining and lava flows down the flanks.

Information Contacts: *National Aeronautics and Space Administration (NASA) Earth Observatory* (URL: http://earthobservatory.nasa.gov/); Washington Volcanic Ash Advisory Center (VAAC) (URL: http://www.ssd.noaa.gov/VAAC/washington.html); *Jeffery Williams*, NASA, ISS Crew Earth Observations and the Image Science & Analysis Group, Johnson Space Center 2101 NASA Parkway, Houston, TX 77058, USA.

Date and Time (UTC)	Plume altitude	Direction and speed
24 May 2006 (0200)	8.2 km	SW at 55 km/hour
24 May 2006 (0800)	6.7 km	SW at 37-46 km/hour
24 May 2006 (1400)	6.1 km	W at 37-46 km/hour

Table 4. Satellite observations of ash plume from Cleveland volcano. Courtesy of the Washington Volcanic Ash Advisory Center (VAAC).

Figure 20. Eruption of Mount Cleveland on 23 May 2006 as photographed from the International Space Station at an orbital altitude of ~ 400 km. The photograph (N at the top; Carlisle Island to the NW) shows the ash plume moving SW from the summit. Banks of fog (arcuate clouds at upper right) are common features around the Aleutian Islands. The event proved to be short-lived; ~ 2 hours later, the plume had completely detached from the volcano. Courtesy of Jeffrey N. Williams, Flight Engineer and NASA Science Officer, International Space Station Expedition 13 Crew, NASA Earth Observatory web site.

Karymsky

Kamchatka Peninsula, Russia
54.05°N, 159.45°E; summit elev. 1,536 m

During April, May and June 2006, intermittent eruptive activity at Karymsky continued. Pilots had previously reported ash emissions from Karymsky rising to 3-5 km altitude during January to April 2006, during which time Karymsky remained at Concern Color Code Orange (*BGVN* 31:04). The same color code stayed in effect through August 2006.

Based on interpretations of April-June 2006 seismic data, ash plumes rose to altitudes of between 3 and 8 km. Satellite imagery showed a large thermal anomaly at the volcano's crater from January to August 2006, and numerous ash plumes and deposits extended 10-200 km SE and E of the volcano.

During 10-16 June 2006, 400-600 shallow earthquakes occurred daily. Ash plumes up to 5 km altitude traveling SE were observed by pilots. On 19 June, the Advanced Spaceborne Thermal Emission and Reflection Radiometer (ASTER) on NASA's Terra satellite captured a false-color image of an ash plume from Karymsky (figure 21). During 21-27 June 200-700 shallow earthquakes occurred daily; during 23-30 June, 100-350 shallow earthquakes occurred daily.

According to the Tokyo VAAC, the Kamchatkan Experimental and Methodical Seismological Department (KEMSD) reported that during July 2006 ash plumes reached altitudes between 3 and 7 km. Approximately 100-350 shallow earthquakes occurred daily during 29 June to 3 July, and increased to 1,000 per day during 4-5 July.

Activity at Karymsky continued during 8-14 July, with 250-1000 shallow earthquakes occurring daily. Based on interpretations of seismic data, ash plumes reached altitudes of 5 km.

During August 2006, 100-300 shallow earthquakes occurred daily. Based on interpretations of seismic data, ash plumes reached altitudes of 3-3.7 km.

Geologic Summary. Karymsky, the most active volcano of Kamchatka's eastern volcanic zone, is a symmetrical stratovolcano constructed within a 5-km-wide caldera that formed during the early Holocene. The caldera cuts the S side of the Pleistocene Dvor volcano and is located outside the N margin of the large mid-Pleistocene Polovinka caldera, which contains the smaller Akademia Nauk and Odnoboky calderas. Most seismicity preceding Karymsky eruptions originated beneath Akademia Nauk caldera, which is located immediately S of Karymsky volcano. The caldera enclosing Karymsky volcano formed about 7,600-7,700 radiocarbon years ago; construction of the Karymsky stratovolcano began about 2,000 years later. The latest eruptive period began about 500 years ago, following a 2,300-year quiescence. Much of the cone is mantled by lava flows less than 200 years old. Historical eruptions have

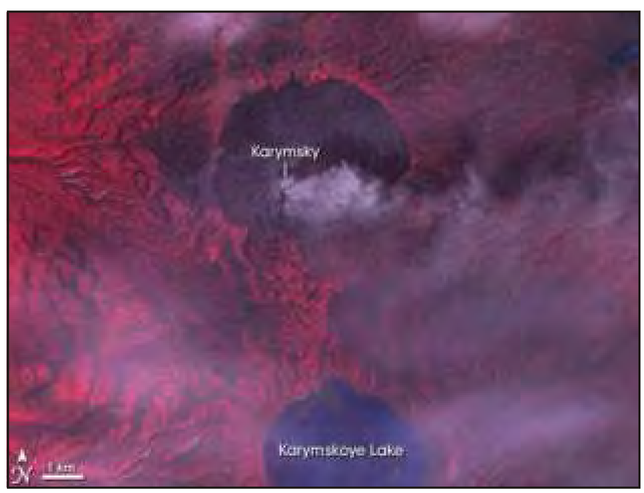

Figure 21. Karymsky had been erupting several times a day for about a week prior to emitting this ash plume on 19 June 2006. The ASTER instrument on NASA's Terra satellite captured this false-color image. Red indicates vegetation, which is lush around the volcano but very sparse on its slopes. The water of Karymskoye Lake appears in blue. The volcano's barren sides are dark gray, and the volcanic plume and nearby haze appear in white or gray. Image courtesy of NASA; created by Jesse Allen, Earth Observatory, using expedited ASTER data provided the NASA/GSFC/MITI/ERSDAC/JAROS and U.S./Japan ASTER Science Team.

been vulcanian or vulcanian-strombolian with moderate explosive activity and occasional lava flows from the summit crater.

Information Contacts: *Olga Girina*, Kamchatka Volcanic Eruptions Response Team (KVERT), a cooperative program of the Institute of Volcanic Geology and Geochemistry, Far East Division, Russian Academy of Sciences, Piip Ave. 9, Petropavlovsk-Kamchatskii 683006, Russia (Email: girina@kcs.iks.ru), the Kamchatka Experimental and Methodical Seismological Department (KEMSD), GS RAS (Russia), and the Alaska Volcano Observatory (USA); *Alaska Volcano Observatory* (AVO), a cooperative program of the U.S. Geological Survey, 4200 University Drive, Anchorage, AK 99508-4667, USA (URL: http://www.avo.alaska.edu/; Email: tlmurray@ usgs.gov), the Geophysical Institute, University of Alaska, P.O. Box 757320, Fairbanks, AK 99775-7320, USA (Email: eisch@dino.gi.alaska.edu), and the Alaska Division of Geological and Geophysical Surveys, 794 University Ave., Suite 200, Fairbanks, AK 99709, USA (Email: cnye@giseis.alaska.edu); *Tokyo Volcanic Ash Advisory Center* (VAAC) (URL: http://www.jma.go.jp/JMA_HP/jma/jma-eng/jma-center/vaac/; Email: vaac@eqvol.kishou.go.jp).

Mayon

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

Mayon was last reported on in March 2006 (*BGVN* 31:03), discussing an eruption in February 2006. Low-level activity and seismicity prevailed through early July. This report covers an eruptive pulse that began on 13 July 2006 and continued through August 2006. On 13 July there were phreatic eruptions that produced light ashfall in the areas of Calbayog and Malilipot. At 2200 on 14 July, authorities raised the Alert Level from 1 to 3 due to moderate white steam drifting NE and lava flows extending 0.7-1.0 km from the summit onto the SE slopes. On 15 July, the lava flow continued its SE progression towards Bonga gully.

On 16 July, the 6 km radius hazard zone known as the Permanent Danger Zone (PDZ) established around the SE area, was extended to 7 km and during the period covered by this report the radius of the danger zone around the southern sector was extended to 8 km. On 18 July, the Philippine Institute of Volcanology and Seismology (PHIVOLCS) reported that the lava flow had reached 1 km in length and incandescent boulders had rolled 3 km towards the Bonga gully. Seismicity, reported SO_2 fluxes, and posted alert levels appear in table 5.

Pyroclastic flows on the SE slopes prompted approximately 100 families to evacuate on 20 July. On 22 July, lava flows advanced NE towards the Mabinit channel. By 24 July, lava flows had traveled SSE, ~ 4 km from the summit toward Bonga gully, and branched off to the W and E. Incandescent blocks shed from the toe and margins of the flows traveled SE and were visible at night. Additionally, on 24 July seismographs recorded more than 324 tremor episodes and 11 volcanic earthquakes. SO_2 emissions from the summit crater reached 7,000 metric tons per day, several times larger than fluxes reported earlier.

PHIVOLCS reported lava flow advance in terms of straight-line distances, which progressed as follows: 26 July, 4.45 km; 27 July, 4.7 km; and 29 July, 5.4 km. During this time, SO_2 rates remained high (table 5), suggesting fresh magma at shallow levels in the volcano. The number of tremor episodes and earthquakes also remained high. Tremor was thought to indicate near-continuous lava blocks detaching from the lava flows. Volcanic earthquakes were thought to reflect ascending magma. Figure 22 shows the lava flow front on 29 July.

On 29 July, light ash accumulation was reported about 12 km S and SE, in Daraga municipality and Legazpi City and vicinity, respectively. Emissions of sulfur-dioxide reached ~ 12,500 tons per day on 31 July, a record high for this reporting interval. By 1 August, in the SE sector of the Bonga gully, lava flows had advanced ~ 1.35 km, and in the SSE sector they had advanced a maximum distance of 5.8 km from the summit.

According to a Philippine Information Agency (PIA) press report, military and police checkpoints were set up on 2 August around the 6-km-radius PDZ to prohibit entry. A large lava deposit had grown on the SE flanks. The lava which faced Legazpi and Daraga, had piled up during the initial two weeks of the eruption and threatened to cross the PDZ. PHIVOLCS had reported that the advancing incandescent front of the lava flow was ~ 20 m high and 50 m wide (figure 23). PHIVOLCS estimated that the lava front could breach the 6-km-radius PDZ within two to three days.

An overflight of Mayon on 6 August revealed that lavas discharging from the summit crater extended along the Mabinit channel and spilled into the Bonga gully, E of the Mabinit channel. Due to the decreased supply of lava to the Mabinit channel, the flow there was expected to cease a short distance beyond the 6-km-radius PDZ. Six ash explosions sent ash columns up to 800 m above the summit, prompting PHIVOLCS to raise the alert level from 3 to 4, indicating an eruption is imminent. According to the *Manila Bulletin Online*, as many as 50,00 people in the Albay province were evacuated.

On 7 August, an advancing lava flow crossed 100 m beyond the 6-km-radius PDZ. According to the *Manila Stan-*

Figure 22. Photograph taken on 29 July 2006 at Mayon showing the lava front as it continued to advance down the Mabinit channel. Courtesy of C. Sagution, PHIVOLCS.

Date	Volcanic earthquakes	Tremor episodes	SO_2 flux (t/d)	Alert Level
15 Jul 2006	—	111	2,211	3
17 Jul 2006	—	314	1,513	3
18 Jul 2006	—	—	—	3
19 Jul 2006	—	250	2,157	3
20 Jul 2006	—	—	—	—
21 Jul 2006	—	—	—	—
22 Jul 2006	—	—	—	—
23 Jul 2006	—	—	—	—
24 Jul 2006	11	324	7,020	3
25 Jul 2006	12	564	5,886	3
26 Jul 2006	7	316	9,275	3
27 Jul 2006	6	421	4,550	3
28 Jul 2006	8	423	8,724	3
29 Jul 2006	4	394	6,099	3
31 Jul 2006	—	388	12,548	3
01 Aug 2006	—	354	7,418	3
02 Aug 2006	16	450	7,050	3
03 Aug 2006	51	343	4,760	3
04 Aug 2006	18	354	2,965	3
05 Aug 2006	18	354	2,965	3
06 Aug 2006	12	371	1,919	3
07 Aug 2006	—	—	—	—
08 Aug 2006	109	344	12,745	4
09 Aug 2006	21	294	7,829	4
10 Aug 2006	3	501	6,573	4
11 Aug 2006	6	213	6,876	4
12 Aug 2006	6	191	3,423	4
13 Aug 2006	13	158	5,427	4
14 Aug 2006	16	152	3,493	4
16 Aug 2006	15	154	8,086	4
17 Aug 2006	5	130	2,937	4
18 Aug 2006	32	307	2,937	4
19 Aug 2006	22	240	2,712	4
20 Aug 2006	15	253	6,634	4
21 Aug 2006	15	274	5,390	4
22 Aug 2006	24	431	2,445	4
23 Aug 2006	10	316	5,215	4
24 Aug 2006	18	451	6,328	4

Table 5. Mayon's reported seismicity, SO_2 fluxes, and alert levels during 15 July 2006 to 24 August 2006. "—" indicates information not available. Courtesy of PHIVOLCS.

dard Today, authorities warned residents of more lava and fires as the lava flows crept along the Mabinit and Bonga gullies.

During 9-15 August, explosive activity continued at Mayon after a brief respite on 8 August. Based on interpretations of seismic data, minor explosions during 9-11 and 13-15 August were accompanied by lava extrusion and collapsing lava flow fronts that released blocks and small fragments. A drop in SO_2 emissions on 9 August worried volcanologists that something had blocked the flow of magma in Mayon's conduit and could therefore cause a build up in pressure resulting in a larger eruption. Visual observations were commonly obscured by clouds. On 11 August an ash plume was seen drifting ESE. On 12 August, four explosions occurred; one produced a pyroclastic flow that traveled over the SE and E slopes and generated a plume that rose to an altitude of 500 m and then drifted NE. On 15 August, a brief break in the clouds allowed for a view and confirmed the presence of fresh pyroclastic deposits from activity in the previous days. Approximately 40,000 people remained in evacuation centers and authorities maintained an Extended Danger Zone at 8 km from the summit in the SE sector.

PHIVOLCS reported that explosions from Mayon continued during 16-19 August. On 17 August, ash-and-steam plumes drifted at least 5.3 km NE and reached the town Calbayog, where light ashfall was reported. Lava extrusion continued and on the SE slopes lava-flow fronts shed blocks and small fragments. On 18 August, the Mibinit and Bonga gully lava flows reached ~ 6.8 km SE from the summit. PHIVOLCS estimated the volume of erupted materials at between 36 and 41 million cubic meters.

Geologic Summary. Beautifully symmetrical Mayon volcano, which rises to 2,462 m above the Albay Gulf, is the Philippines' most active volcano. The structurally simple volcano has steep upper slopes averaging 35-40 degrees that are capped by a small summit crater. The historical eruptions of this basaltic-andesitic volcano date back to 1616 and range from strombolian to basaltic plinian, with cyclical activity beginning with basaltic eruptions, followed by longer term andesitic lava flows. Eruptions occur predominately from the central conduit and have also produced lava flows that travel far down the flanks. Pyroclastic flows and

Figure 23. On the evening of 3 August 2006, lava advancing down the Mayon's Mabinit channel formed this impressive front. For scale, note tree at right. Although the government had issued an evacuation warning, many tourists flocked to the scene to watch the lava flows. Courtesy of Romeo Ranoco (Reuters).

mudflows have commonly swept down many of the approximately 40 ravines that radiate from the summit and have often devastated populated lowland areas. Mayon's most violent eruption, in 1814, killed more than 1,200 people and devastated several towns.

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Sulu Range

New Britain, SW Pacific
5.50°S, 150.942°E; summit elev. 610 m
All times are local (= UTC + 10 hours)

On 7 July 2006, observers reported the first historical indication of volcanic activity in the Sulu Range of New Britain (in the nation of Papua New Guinea (PNG)). As shown on figure 24, the Sulu Range lies near the N coast of New Britain Island. This spot sits in the Province of West New Britain but in terms of geometry, lies closer to the middle of the island ~100 km E of the prominent, N-trending Willaumez Peninsula and ~200 km SW of Rabaul at the island's E end.

Rabaul Volcano Observatory (RVO) noted that ground observations at the Sulu Range, confirmed by aerial inspection, indicated that the emissions were coming from an area initially incorrectly disclosed as Mount Karai. (Karai is reportedly equivalent to Mount Ruckenberg, mentioned below.) Later reports correcting the initial vent location, stated that the eruption took place 2 km SW of Mount Karai between Ubia and Ululu volcanoes.

Considerable light on the Sulu Range and other volcanoes in the vicinity is shed by an Australian Bureau of Mineral Resources report by Johnson (1971). The coordinates and summit elevation given in the header above apply to the highest point in the Sulu Range, Mount Malopu (synonyms include "Malutu" and "Malobu").

Changes in our nomenclature. We indicate Walo hot springs on the lower map of figure 24, the only feature in this vicinity previously identified in our database on active volcanoes. Walo was listed as a thermal feature in the Melanesian portion of the Catalog of Active Volcanoes of the World (Fisher, 1957) and in Simkin and Siebert (1994). Walo rests in a low swampy area ~ 3 km W of the edge of the Sulu Range, which we apply broadly to a ~ 10 km diameter mountainous area with multiple peaks of ~ 500-600 m elevation. The highland areas associated with the Sulu Range's NE end contains a cone near the coast, which is labeled "Mount Ruckenberg (extinct volcano)" on the Bangula Sheet (Papua New Guinea 1:100,000 Topographic Survey, 1975).

The Sulu Range eruption has spurred restructuring of our naming conventions. Walo is now listed as a thermal feature associated with the larger volcanic field called the Sulu Range (and it preserves the Volcano Number that used to apply only to Walo, 0502-09=).

2006 eruption and earthquakes. RVO reported that there were indications as early as February 2006 that something was changing at Sulu Range because vegetation there was dying off. RVO noted that earthquakes began on 6 July and most river systems near Mount Karai had turned muddy due to the continuous shaking. Seismic activity was followed by the emission of puffs of white vapor from the area and loud booming and rumbling noises accompanied strong tremors.

Eruptions started with forceful dark emissions late on 7 and 8 July and decreased to moderate emissions by 10 July. At the settlement Bialla, ~20 km NE of the Sulu Range, tremors were felt. These were also picked up by the seismic stations at Garbuna and Ulawun (~100 km W and ENE, respectively).

In a report discussing 10-11 July, RVO reported that three villages N of Mount Karai had been evacuated. For the 10th, RVO described the activity as weak-to-moderate emission of white vapor with no evidence of ashfall and with occasional weak-to-moderate roaring noises accompanying the emissions. On the 11th, associated with earthquakes, white puffs discharged. Similar observations of white emissions prevailed through the 12th.

Earthquakes increased both in size and frequency of occurrence, and on 11 July at Bialla they took place every 10-20 minutes. Near Ubia volcano, seismicity was very elevated, with earthquakes every few minutes. At 0820 on 12 July a large earthquake of Modified Mercalli (MM) intensity VII or more occurred in the region. It disturbed the shoreline, which discolored the seawater; shaking also caused the sea surface to become choppy.

The USGS epicenter for the above-cited 12 July (local time) earthquake was listed at very nearly the same time (in UTC, on 11 July at 2222) with epicenter at 5.48°S, 150.83°E, a depth of 37 km and a body magnitude (mb) of 4.90. That spot lies 12 km NE of Sulu Range (using the coordinates listed in the header above). On a table of earthquakes the same day (11 July, UTC), seven others, mb 3.9-4.7 occurred within several hundred kilometers of Sulu Range. All took place earlier, but a pattern of substantial ongoing earthquakes also prevailed later as well.

RVO noted that from 1600 on 12 July to 0900 on 13 July high-frequency earthquakes occurring at the rate of one every minute were recorded on the seismograph deployed at Bialla. The earthquakes recorded were of varying (though unstated) magnitudes and towards 0900 decreased slightly to one every 30 minutes. Shortly afterwards, from 1000 to 1400 on 13 July, the seismograph was deployed in Kaiamu village on the small point immediately NW of the uplands portions of the Sulu Range, where it recorded continuous strings of high frequency earthquakes. Although the instrument was out of service after 1400 on the 13th, recording resumed that afternoon and seismic activity continued at a high level through 0900 on 15 July. During this time, the occurrence of felt earthquakes with maximum MM intensity V increased from one every 40-60 minutes to one every 2-3 minutes. Details of a subsequent decline in seismicity are sketchy.

The last reported visible emissions from the Sulu Range were on 12 July. By early August 2006 seismic activity had decreased to earthquakes of MM intensity I to II occurring at increasing intervals.

Again referring to USGS seismicity tables, the previously mentioned pattern of ongoing earthquakes on 11 July, generally mb 3.9-4.9, continued. An exception, the largest magnitude event during 9-18 July struck 31 km from Sulu Range, listed in UTC on 13 July at 2248; mb 5.1. It was at 39 km depth with epicenter ~12 km away. About 5 hours later a mb 4.7 event was recorded directly at volcano. On the 19th two larger earthquakes struck. One an Ms 6.4 centered 28 km away; the second, an Mw 5.90, 33 km away. These were the largest earthquakes within 50 km during 1 July to 11 September 2006.

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Figure 24. Two maps indicating the context of the Sulu Range on New Britain Island. Volcanoes with currently listed Holocene activity are shown (solid triangles). (Top map) Covering all of New Britain and parts of neighboring islands New Guinea and New Ireland. Four volcanoes in this region have become active in the past few years: Garbuna, Pago, Sulu Range, and Bamus. In the cases of Garbuna and the Sulu Range, these were their first recorded historical eruptions. Beyond Bamus to the NE reside the better known Ulawun and Rabaul volcanoes. (Lower map) An enlargement of the area bounded to the W by the Willaumez Peninsula.

Geologic Summary. The Sulu Range consists of a group of partially overlapping small stratovolcanoes in north-central New Britain off Bangula Bay. The 610-m Mount Malopu forms the high point of the basaltic-to-rhyolitic complex at its SW end. Lava Point (also known as Lara Point) forms a peninsula of volcaniclastic-covered lava flows with a small lake extending about 1 km into Bangula Bay at the NW side of the Sulu Range. The Walo hydrothermal area, consisting of solfataras and mud pots, lies on the coastal plain about 3 km W of the SW base of the Sulu Range. Prior to 2006, no historical eruptions had occurred from the Sulu Range, although some of the cones display a relatively undissected morphology.

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