

The May 17-19 1994 Llaima volcano eruption, southern Andes (38°42'S -71°44'W)

INTRODUCTION

On May 17, at about 6:00 a.m., the Llaima volcano began a strombolian eruption, 10 years since the last short phreatomagmatic eruption (April 1984). The Llaima volcano is a complex composite-shield volcano, with a buried caldera and 40 parasitic scoria cones. It is one of the largest volcanoes in the Southern Andes, covering an area of ca. 500 km² and with a volume of ca. 400 m³ (Naranjo and Moreno, 1991). Together with Villarrica (Chile) and Sangay (Ecuador) volcanoes, Llaima is one of the most active in the Andes and shows a permanent fumarole in its open summit crater. It is mainly composed of basaltic to andesitic lava flows (51-59% SiO₂), although early postglacial deposits include a voluminous andesitic pyroclastic flow (the Curacautín ignimbrite ~24 km³; 13,200 yr. B.P.), surges and a remarkable dacitic plinian pumice fall (~4 km³; 8,800 yr. B.P.), the latter being the most silicic product of the volcano (Moreno and Naranjo, 1991). Since 1640, about 47 eruptions have been reported, 1957 being the year of the last big lava eruption. Most of the eruptive events have generated lahars, and the most hazardous river valleys have been Captrén (north) and Trifultruful (southeast) during the 20th century. Though the western slope is covered by the largest glacier, the Lanlán and Calbuco river valleys have also been affected by lahars in recent times (Moreno and Naranjo, 1991). This note aims at describing the most recent eruption of the Llaima volcano that took place on May 17-19, 1994.

OBSERVATIONS IN THE YEAR PRIOR TO THE ERUPTION

July 1993. After a long rainstorm, the Conguillío Lake, located at the NE foot of the Llaima volcano, reached its maximum level ever since 1957. A res-

taurant called 'La Concesión' was covered by over 1 m of water. That means that the lake rose up to about 10 m over its usual seasonal level.

November. Rangers of the Conguillío National Park reported underground rumbling at Captrén, on the north foot of the volcano.

Late December. All the camping sites, roads and bridges were still under water; something unusual for the last 36 years.

December 25. An overflight above the main crater of the Llaima volcano was made, as no fumarolic activity had been reported for nearly a month (most unusual). For the first time since 1975, the bottom of the crater (350 m wide and ~300 m deep) was completely covered by ice, and only a very weak fumarole was seen on its SW rim. On the other hand, the southern summit (Pichillaima), that also erupted in 1957, had no snow and showed many small fumaroles, which had progressively increased since 1984.

February 14 to 17, 1994. A seismic survey at Lago Verde (east of the Llaima volcano) showed that the average frequency of the recorded events was about 1.0 Hz, *i.e.* within the usual seismic behavior recorded during the last three years. On February 16 and 17 a remarkable increase in the daily number of events was recorded (ca. 90-180). These events were interpreted as magma degassing.

February 24 to March 1. Still no signs of fumaroles were seen on the main crater, except the weak fume on the SW rim. Nevertheless, the southern summit Pichillaima showed many small fumaroles.

March 8 to 10. A new seismic survey at Lago Verde showed that the daily 150 to 160 recorded events, had an average frequency of 1.0-2.4 Hz.

March 22. A portable seismic station located at the western slope of the volcano (Los Paraguas), recorded an average frequency of 1.6-3.0 Hz. This progressive increase of the frequency since February 16, was interpreted as a slow magma ascent within the main conduit of the volcano.

SITE OF THE MAY 17-19 ERUPTION

According to the Police Station at Melipeuco, 20 km S of the volcano, on May 17 between 5:00 and 6:00 a.m. (local time), eruptions could be seen on the main crater of the volcano. At about 6:00 a.m. a dense column of ash, gases and steam was being dispersed toward the ESE by strong WNW winds.

Between 9:00 and 10:00 a.m., three local flights of LAN Chile reported a 24,000 ft high eruptive column (4,000-5,000 m above the summit). Between 11:00 a.m. and 3:30 p.m. air observations of the western and northern sides of the volcano were made from a Chilean Air Force (FACH) helicopter.

A N10°E fissure about 500 m long opened in the main crater toward the SSW, from where at least, 4 lava fountains could be seen. Minor explosion vents generated small 3-second interval 'mushroom columns' along the fissure. Lava was thrown up to ca. 200 m high and flowed from the southern end of the fissure under the western glacier toward the SSW (Fig. 1) followed by numerous explosions.

The eruption was typically strombolian VEI 2, with a strong phreatic component. The column height reached ca. 4,000 m above the summit (7,000 m a.s.l.), and had a rich water-vapor phase with a minor ash plume oriented toward the ESE at a lower level (~5,000 m a.s.l.). The ash plume could be seen for at least 80 km E of the volcano, toward the NE edge of Aluminé lake in Argentina at Lonco Luan (Fig. 2).

The lava-glacier interaction led to violent melting and strong vaporization. Rough estimations suggest that at least ca. 3-4 million m³ of ice were melted by the lava flows. Considering that the volume of the debris flows was only ca. 2.5 millions m³, most of the released water equivalent (2.4-3.2 million m³) would have been evaporated.

After the eruption, the volcano remained completely covered until May 21. That day, the main crater rim showed a small notch on the SSW, from where a 50 m wide and ca. 500 m long 'ice channel' could be clearly seen downslope. It turned 110° toward the west and its width increased to ca. 150 m for the next 1.5 km (Fig. 1).

Climatic conditions worsened again since May 22, but in the night of 29, a councilman from

Cherquenco reported a strong rumbling and a red glow on the main crater of Llaima. This could indicate that magma ascent was taking place in the volcanic conduit. On the other hand, on June 1 at 3:20 a.m. a thunder-like noise probably due to the north wind, was heard in Melipeuco, and was eventually associated with a volcanic explosion.

Lahars and floods

The western and largest glacier (A~17.2 km²; V~367x10⁶ water equivalent), showed numerous crevasses with strong steaming and explosions downslope the eruption site, which indicated that lava was flowing beneath the ice and turning toward the west, heading toward the Lanlán and/or Calbuco rivers.

At about 12:15 p.m., a lahar was generated and flowed down along the Calbuco river (Figs. 1, 3).

At the localities of El Danubio, La Selva and Santa Juana, 16 km WSW from the volcano, the lahar was seen at 12:45 p.m. for 15 minutes, carrying trees, sediments, ice blocks and large boulders up to 9 m in diameter down a gully 35 m wide and 19 m deep (Fig. 3). The 'peak' volume was estimated here in ca. 2.5x10⁶m³.

Five bridges and numerous roads were cut by the debris flow, 59 people rescued and 7 rangers were evacuated at the Conguillío National Park. The cemetery in Cherquenco, a village ca. 25 km W from the volcano, was mostly covered by the deposits.

From the helicopter the authors could follow, film and photograph the dilute head of the lahar, merged with Río Quepe in a reddish brown flood that carried hundreds of trees and ice blocks. The inhabitants of the Río Quepe riverside were warned before the flood arrived and it was possible to land and wait for it near a small bridge next to Vilcún village, 43 km W of the volcano. The flow arrived at 3:15 p.m. (Fig. 3), at a 13-14 km/h speed, reached a 61 m width (the river width is only 32 m), and a maximum height of 4.3 m above the previous river level.

Thousands of fishes were killed and left lying on the flooded lands.

At 4:00 p.m., at El Danubio, La Selva and Santa Juana, another flood occurred and lasted 30 minutes.

Tephra fall

The main eruption lasted a minimum of 8 hours. The area affected by the tephra fall was located ESE (Fig. 3); detailed data reported are as follows:

CONAF at Trifultruful	Ash traces (Th <1 mm).
Laguna Verde, 3.5 km S	Lapilli (Ms=35 mm; Th=25 mm).
Laguna Verde, 3 km S	Lapilli and small bombs (Ms=80 mm; Th=43 mm).
Laguna Verde	Ash traces (Th<1 mm).
Coyamento Grande	Ash traces (Th=1 mm).
Icalma Customs	Ash layer (Th=1 mm).
Cruzaco houses	Coarse ash-fine lapilli (Ms=4 mm; Th~10 mm).
Zapala (Argentina)	Fine ash layer (Th>1 mm)

Ms=maximum size; Th=thickness

The Trifultruful-Laguna Verde area was affected from 8:00 a.m.- 12:30 p.m., while the Icalma-Cruzaco area, had an increasing ash fall from 10:00 a.m. to 1:00 p.m. In the latter locality, the ash-fall peak took place between 1:00-1:30 p.m.

As shown in Fig. 3, the plume was quite narrow: ca. 8 km in Trifultruful and 9 km in Icalma, 40 km ESE from the volcano.

Samples collected in Cruzaco on May 19, showed particles between 0.1 and 4 mm (fine ash to fine lapilli), that consisted of black and reddish glassy scoria, plus fragments of plagioclase, olivine and magnetite. Scoria fragments had very sharp edges, and also some shards were observed, hence it was very abrasive.

On May 18 at 8:00 p.m., there was a new though finer-grained ash-fall for several minutes and small explosions were heard.

On May 19 at 12:00 a.m., again a very fine ash-fall took place for the last time in Cruzaco.

In this area ash and grass samples ('coirón') were taken for sulphide, chloride and fluorine analyses. 'Coirón' is a widespread andean grass that feeds cattle, horses and sheep. The water from Trifultruful river was sampled for the same purpose.

The analyses done at SERNAGEOMIN chemical laboratory gave the following fluorine content:

Water from Trifultruful river (Los Saltos)	0.16 mg/l
Coirón grass from Cruzaco	53 ppm
Ash from Cruzaco	38 ppm
Ash SiO ₂ content	53.0%

SEISMIC MONITORING DURING AND AFTER THE ERUPTION

On May 17 at 10:21 p.m. (local time) 2 portable seismic MEQ-800 stations were installed near Cherquenco village (El Trueno and Lanlán stations). The following day May 18 at 11:00 a.m., a third MEQ-800 station was located, 3.5 km north of Melipeuco village.

Between 10:21 p.m. May 17 and 10:42 a.m. May 18, about 22 seismic events were recorded. Later, from 12:32 p.m. onward swarms of LP (long period) events were observed.

The seismic information recorded on May 17 and 18 was interpreted as the result of strong explosions in the volcano crater.

On May 18 from 10:09 until to 11:39 a.m. of May 19, the behavior was stationary though a light increment on the number of events was recorded.

Since May 18 noon, the activity would have evolved mainly to degassing processes, followed by some explosive periods and small ash eruptions which were dispersed toward the ESE.

Since May 19 at 12:00 a.m., the seismicity had an aleatoric behavior, with long periods of seismic silence and smaller periods with 1-2 LP events, lasting two minutes each.

On May 20, only some B type earthquakes were recorded and weak harmonic tremors were observed in Melipeuco.

In addition, the seismic silence was interrupted only by small high frequency swarms, without tremor events.

Since May 28 only one MEQ-800 station remained on the western slopes of the volcano, at the Lanlán site.

As mentioned before, rumbling was heard and a red glow seen above the main crater on May 29 night, a fact that could mean magma rising within the conduit.

On the other hand, the June 1st 3:20 a.m. report on thunderstorm was eventually related to a volcanic explosion. In fact, at 3:21 a.m. a 20 second high frequency earthquake was clearly recorded by the Lanlán seismic station, followed by a degassification process that lasted more than 2 minutes and had a 2.3 Hz frequency.

On June 3, the seismic activity recorded at the Llaima volcano, still had an anomalous behavior, compared to the background activity recorded in the area in the last three years.

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