POTENTIAL VOLCANIC THREATS

Pyroclastic Flows: They are very hot mixtures (> 200 ° C) of gases, ash and rock fragments which descend from the crater trough the flanks of the volcano, moving at high speeds (50-100 km/h). They occur during large explosive eruptions. The worst consequence in the generation of a pyroclastic flow is the partial melting of the glacier and the generation of large volumes of water that can form lahars as happened on June 26, 1877.

Volcanic Gases: Direct contact with high concentrated volcanic gas could cause eye irritation and respiratory problems. In very high concentrations they can even cause decease. They can also destroy vegetation. Aditionally, some volcanic gases can react with the atmospheric water and produce acid compounds, which can cause highly corrosive acid rain.

Figure 6. Gas emission observed on October 17th, 2016 (Photo: P. Ramón)

Lava flows: spills of very hot molten rock originated in the crater or lateral fractures of the volcano that descend through the flanks and valleys of the cone traveling at low speeds (few km/h). Lava flows have been a common phenomenon in Cotopaxi's geological evolution.

Debris Avalanche: large landslides of a portion of the volcanic edifice, which can happen in a volcano as a result of the instability and later collapse of its flanks. They are very fast, mobile and destroy everything on their path. The Cotopaxi volcano experienced a collapse of this type about 4500 years ago. These events are very rare.

Lahars (Mud and debris flows): Lahars are mixtures of rocky material from volcanic origin with water from heavy rains or melting from the glacier cap. They are the most dangerous phenomena in case of a large eruption of the Cotopaxi volcano. Due to their high speed they can move and drag weight and great size objects such as bridges, vehicles, trees, etc

The lahars can be classified according to their origin as: primary (synerupive) and secondary (posterupive) according to whether or not they are directly related to eruptions.

- Primary lahars: occur when large volumes of ice and snow melt during explosive eruptions, generating a mixture of rocks, fine material and water. These lahars can reach long distances and flow at high speeds (50-70 km/h).

- Lahares secundarios: generally originated by torrential and/or continuous rains that occur on the flanks of the volcano saturating the pyroclastic deposits (Figure 7). These deposits can be regularly remobilized and can produce lahars very frequently, but smaller in magnitude than the primary ones

Figure 7. *Secondary lahar deposit at Cutzualo ravine - Cotopaxi Volcano, caused by heavy rainfalls, recorded on January 13th, 2016, and the scouring of volcanic material (Photo: D. Andrade - IGEPN)*

Ash falls: During volcanic eruptions, pulverized rock fragments get ejected from the crater. This phenomenon is quite common in all the eruptions of Cotopaxi and has caused great losses in agriculture and livestock farming, as well as the collapse of some infrastructures in past eruptions. Due to the predominant direction the wind towards the west, the areas located in that direction are the most affected in case of ash fall (Figure 8).

Figure 8. *Ash fall on the western side of the Cotopaxi volcano (Photos: J. Bernard - IRD and S. Almeida - IGEPN*

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COTOPAXI VOLCANO

BRIEF SUMMARY OF ITS HISTORY, ERUPTIVE ACTIVITY AND POTENTIAL HAZARD

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COTOPAXI VOLCANO

Cotopaxi is an active stratovolcano located at Ecuadorian Andes western Cordillera, 50 km Sureast from Quito, 35 km North from Latacunga and 75 km Northeast from Tena. It's covered by a glacier with an area of 11.56 km^2.

Ravines located at its flanks feed tree main fluvial systems: Cutuchi (south), Tambo (East) and Pita (North).

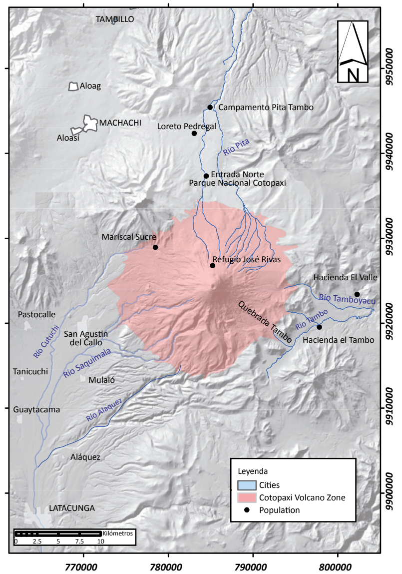

***Figure1.-** Cotopaxi Volcano location, principal drainages at Northern, Southern and Eastern zone.*

Its edifice is a symmetrical cone with slopes up to 35 ° (Figure 2) and a basal diameter of ~ 20 km. The diameter of the crater is 800 m in the N-S direction and 650 m in the E-O direction.

***Figure 2.-** Cotopaxi Volcano seen from Tambopaxi area (photo: P. Ramón-IGEPN)*

ERUPTIVE HISTORY

Geological studies show that Cotopaxi's formation started ~500,000 years ago with a very explosive eruptive activity, characterized by rhyolitic composition magmas which deposits can be observed in the southern part of the volcano (Hall and Mothes, 2008). Subsequently, the volcano experienced a resting period ~ 400 thousand years.

During the period between 13 200 AP and 4 500 AP, Cotopaxi resumed its activity and produced six large rhyolitic eruptions. At the end of this stage, a big proportion landslide occurred (debris avalanche) which affected a major portion of northeast building flank generating a huge lahar called "Los Chillos Valley lahar ". Their deposits have been found in regions as far away from the volcano as the province of Esmeraldas, suggesting that this enormous flow reached the Pacific Ocean (Mothes et al., 1998; Hall and Mothes, 2008).

During historical times, Cotopaxi has presented 14 important eruptions, standing out 1532, 1742, 1744, 1768 and 1877. These eruptions severely affected areas close and distant to the volcano, causing human and animal losses, damage to properties, as well as regional economic crisis (Wolf, 1878). Cotopaxi volcano initiated a new eruptive phase on August 14, 2015, which concluded at the end of November of the same year (Bernard et al., 2016).

COTOPAXI'S AWAKENING, 2015

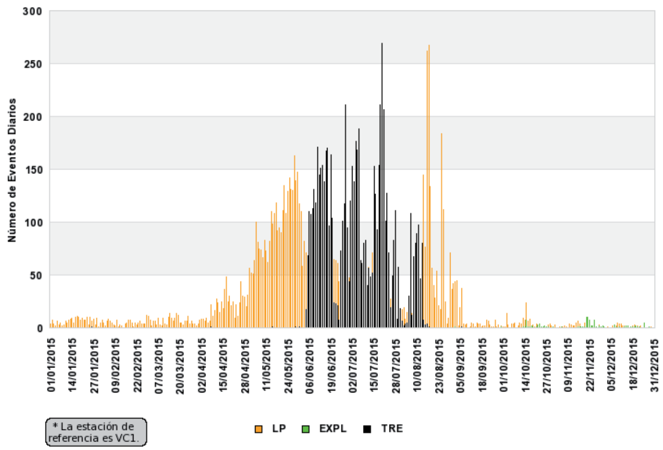

***Figure 3.** Daily number of seismic events from January to December, 2015. The IG-EPN keeps the Cotopaxi Volcano under seismic monitoring since 1986.*

The seismic activity of the Cotopaxi volcano showed a variation on middle April 2015, and increased on May, when it reached a total of 3000 volcanic earthquakes per day (Figure 3). This increase is considerably high compared to the background level (~ 300 earthquakes / month) and to the increase during 2001-2002 seismic crisis (the most important one recorded before 2015).

Sulfur dioxide (SO2) emission also increased and fumarolic activity was observed from places as far away as Quito and Latacunga since June of the same year. On the other hand the geodesy network used to measure the deformation of the volcano detected small changes at the eastern flank and others more accentuated in the western flank.

These premonitory signs preceded the hydromagmatic explosions (Gaunt et al., 2016) of August 14, 2015 at 04:02 and 04:07 TL, the beginning of the eruptive activity.

During the following months the superficial activity was catalogued as moderate and was characterized by strong gases and ash emission that mainly affected the zones located to the west of the volcano and that concluded at late November, 2015.

COTOPAXI VOLCANO MONITORING NETWORK

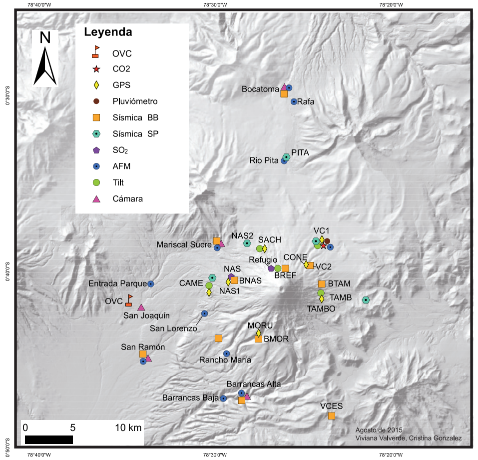

Figure 5. Cotopaxi Volcano Monitoring Network.

Volcanic monitoring network (Figure 5) made possible to observe the mentioned premonitory signs and to alert the authorities and citizens of a possible reactivation, months before the first explosions of August 14, 2015. Thanks to the support of SGR, MICS, USGS and CHALMERS, the existing monitoring network was improved with the installation of new instruments, which strengthened the monitoring system. Nowadays the monitoring network consists of: 16 seismic stations; 5 infrasound and 13 lahares detectors; 7 cameras, 1 thermal camera, 12 deformation control lines, 5 inclinometers, 7 GPS stations and 4 SO2 measurement devices. The network transmits on real time, 365 days per year. The data is processed in the Center of processing, information and early seismic and volcanic alerts, TERRAS (IG-Quito). TERRAS center continuously sends information about the volcanic condition to the authorities and response agencies. This is intended to communicate in a timely manner the possibility of an eruption, as well as the detection of secondary phenomena associated with it (lahars).

ASHMETER NETWORK

Figure 6. Ashmeter located at cotopaxi Volcano (photo: M. Córdova-IGEPN)

In order to quantify the amount of ash emitted by the volcano, a network of ashmeters was installed since July 2015 (Figure 6). By the end of the same year, the network reached a total of 37 stations. Data obtained through this network enables a periodic control of the volume and dispersion of volcanic emitted ash (Bernard, 2013). In addition it allows to collect unaltered samples which can be analyzed in the laboratory, among other things, to analyze its composition and evaluate the associated eruptive dynamisms. From this analysis it is known that during the eruptive period August-November 2015 the Cotopaxi emitted 860 thousand m3 of ash (Bernard et al., 2016).