VOLCANIC MONITORING

Cayambe Volcano monitoring network is composed of four seismic stations, two differential GPS an one DOAS (SO_2 monitoring station). All the data are transmitted in real time to the Terras Monitoring Center (Quito) where it is collected and proccesed.

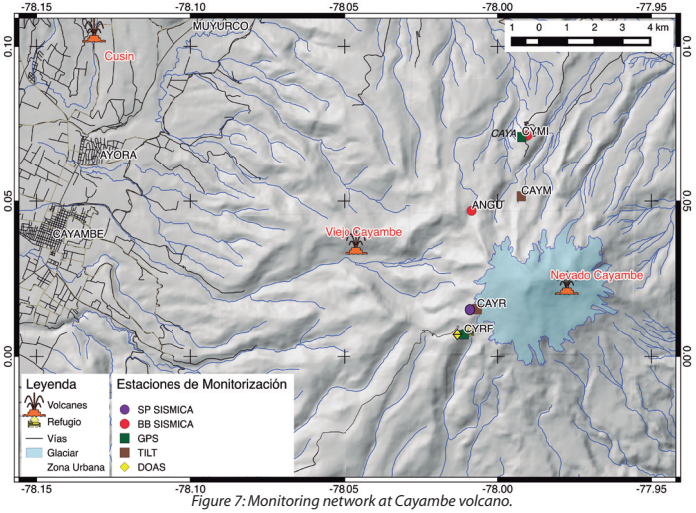

Figure 7: Monitoring network at Cayambe volcano.

POTENTIAL VOLCANIC HAZARDS

LAVA FLOWS AND DOMES: are partially or totally molten, hot and viscuos rocks. They erupt from vents or craks on the flanks of the volcanoes when almost all their gases have scaped. These flows go down the slopes and ravines of the volcanoes due to gravity. They are very slow with velocities <100 m/h. Usually, they form acumulations called lava domes because of their high viscosity. These phenomena are not the most dangerous volcanic hazard because they move very slowly. However, they can destroy all the infrastructure and farmland on their way. During the last thousand years, Cayambe volcano has generated few lava flows including ***Cono de la Virgen***, located on its eastern flank. In early time, however, Cayambe extruded several lava domes that nowadays make up the three summits of the volcano, without a crater. In case of a new eruption the northern and eastern flanks could produce lava domes. The lava domes could then collapse and form pyroclastic flows which are more dangerous.

PYROCLASTIC FLOWS: are very hot mixtures (>200°C) of gases, ash and rock fragments which can go down the flanks of the volcano with velocities between 50-200 km/h during explosive eruptions. Pyroclastic flows can be generated by: column collapse, boiling over or gravitational collapse of a sector of a lava dome/flow. In the past eruptions of the Cayambe volcano all of these phenomena have occured at least one time each century over the last 4000 years. There are evidences on the northern and northeastern flanks of the volcano. For that reason, we have to take into account that these kind of phenomenon could occur in the near future in case of a reactivation.

LAHARS: This word is used to describe debris and mud flows. They are water saturated mixtures with high concentrations of sediments and debris (sand, pumice, pebbels, blocks, etc). They are generated on the high flanks of a volcano and travel downslope with velocities between 10-70 km/h due to gravity. This phenomenon can occur: 1) during an ongoing eruption due to the partial glaciar melting or the destruction of a crater lake (This type of lahar is called "primary lahar").

2) During heavy rainfall, thaws caused due to wheater conditions or seismic activity (Carihuarizaro 1698) which can remove the deposits of past eruptions or water saturated soils generating what is called "secondary lahars". These ones are more common and smaller than primary lahars.

Due to their high density and velocity, lahars can pull and drag big objects like: bridges, cars, trees, etc. Primary lahars habe been a common and recurring volcanic phenomenon in the past eruptios of Cayambe. The most affected drainages, the Azuela and Huataringo rivers, are located in the North and East. They disembogue in the Salado and Quijos rivers and then in Coca fluvial system. In case of a new eruption of Cayambe volcano in the current summit we have to take into account that the potentailly more dangerous drainage would be Blanco river system (which passes through Cayambe city) to the West, the Monjas and Guachala rivers to the southwestern flank and la Chimba river to the northwestern flank of the volcano.

ASH CLOUDS AND FALLOUT: During an ongoing eruption, gases and pyroclastic material like: ash, pumice and rock fragments are erupted from the crater or vent forming an eruptive column. These columns could reach heights of several kilometers above the crater level and stay there for several minutes or hours, bouyant in the atmosphere. The biggest rock fragments follow ballistic trajectories and fall close to the crater. Meanwhile, the fine particles (ash) are transported by the wind and could fall out far away from the vent, covering large areas with differents thicknesses from few milimeters (far from the volcano) to meters (close to the volcano). During the past eruptions of Cayambe the fallout deposits have had limited distribution around the volcano and low thicknesses. However, taking into account that the wind direction in Ecuador is usually East to West, we can expect ash fallout in the cities of Cayambe, Tabacundo, Ayora and Tupigachi.

DEBRIS AVALANCHES: These are huge landslides which partially destroy the volcanic edifices. They are very fast >200 km/h. This kind of phenomenon can occur due to: 1) shallow magmatic intrusions close to the flank of the volcano 2) a large earthquake close to the volcano 3) weakening of the volcanic edifice due to hydrothermal activity. Debris avalanches destroy everything on their path. However, is reccurence is very sparsely in time (<1 event each 50.000 years). This phenomenon occured at Cayambe volcano at least two times partially destroying the northern and western flanks.

VOLCANIC GASES: The magma has gases dissolved on it. They are the motor for volcanic eruptions. The most abundant volcanic gas is water steam (H_2O), however, there are other gases like: carbon dioxide (CO_2), sulfur dioxide (SO_2), hydrogen sulfide (H_2S), and hydrogen halides. These gases can be emitted before, during and after and eruption. Depending of the concentration of each component they could be dangerous.

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NEVADO CAYAMBE

VOLCANIC HISTORY, CURRENT ACTIVITY, MONITORING AND VOLCANIC HAZARDS

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INTRODUCTION

Cayambe volcano is located at the North of the Ecuadorian Eastern Cordillera, 60 km Northeast of Quito (Capital of Ecuador) and 15 km East of Cayambe city, which has aprox. 86.000 inhabitants (INEC, 2010).

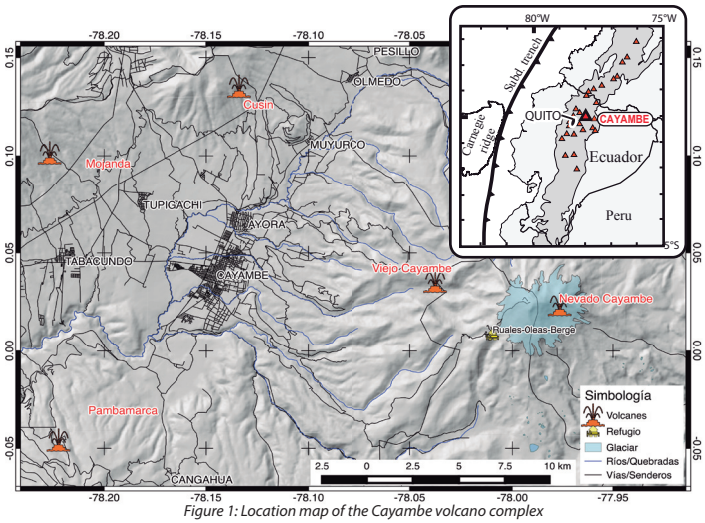


Figure 1: Location map of the Cayambe volcano complex

Cayambe is a very complex-volcano. Three lava domes form its summit. The hightest one is located on the western flank of the volcano reaching 5790 asl. Above 4800 asl the volcano is covered by a big glacier cap of 22 km^2, with a thickness between 30 to 50 meters at the summit. Its glacier feeds several main fluvial systems: Chimba and Granobles rivers to the North and Northwest, Guachalá river to the South, Blanco river to the West and Azuela and Quijos rivers to the East.

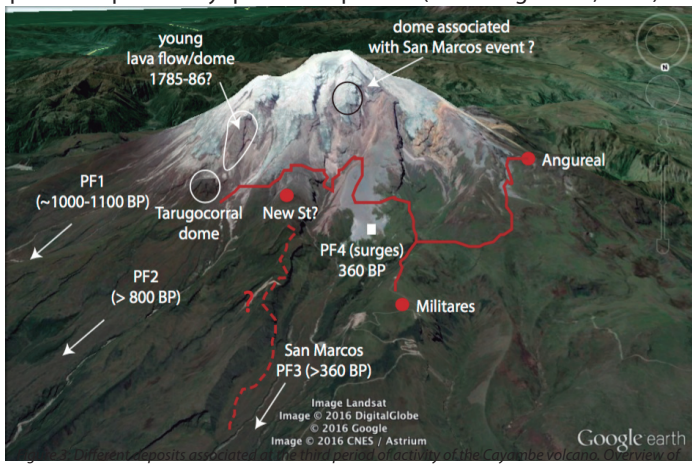
With an area of 432 km^2, Cayambe is one of the biggest volcanoes in Ecuador. The Eastern zone has steep slopes which correpond to the youngest edifice (Nevado Cayambe). On the other hand, the western zone has gentle slopes that correspond to the oldest edifice called "Viejo Cayambe" (Old Cayambe).

Figure 2: Overview of Cayambe volcano from Southwestern flank

Photo: Patricio Ramón IGEPN, 9.12.2003

GEOLOGICAL FEATURES

The "Nevado Cayambe" is considered an active volcano because its last eruptions ocurred in historical times (post-1532). The main volcanic phenomena related with those eruptions were lava domes and flows, pyroclastic flows, lahars and ash cloud formation and fallout (Samaniego et al., 2004). The recent activity consists of 18 to 20 eruptions over the last 4000 years, all of them distributed in three periods separated by quiessence periods (Samaniego et al., 1998)



the North flak over the base of Google Earth. Samaniego, 2016 unpublished.

The first stage ranges from 3800 to 3500 years BP (Before the Present). The second one from 2500 to 1700 yBP and the thrird period began in 1100 yBP and is still going on. The last one was characterized by lava dome growth forming at the top of the northern and northeastern flanks of the Nevado Cayambe, generating pyroclastic flows due to the partial collapse of the domes. Aditionally, primary lahars were formed because of the partial melting of the glacier-cap and ash clouds whose distribution was limitated and fallout deposits were found close to the volcano. During this period occured the largests eruptions in the recent times. The last eruption occured in 1785-1786 (Ascásubi in Alexander von Humboldt, 1802), and produced ash fall in Cayambe city and ended whit a lava flow or lahar in 1786.

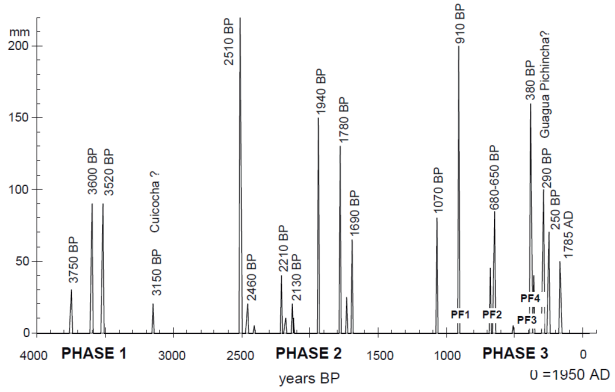


Figure 4: Chronodiagram of the three eruptive periods of the Nevado Cayambe . SAmaniego et al., 1998

CURRENT ACTIVITY

Most of the volcanoes in the world have a background seismic activity even in quiessence periods. Usually, they present few daily seismic events, which are detected by a sensitive seismic network installed around the volcano. Before and during an ongoing eruption the number and magnitude of the seismic events increase due to a rising magma body. In some occasions this increased seismic activity is even felt by the people living in the vicinity of the volcano.

The seismic activity in the Cayambe volcano is characterized by Low Frecuency (LP) events which are interpreted as fluid transit (orange bars in Fig. 5), very common in active volcanoes. From 2001 to 2003 another kind of seismic waves known as Volcano-tectonic (VT, red bars) appeared. They are related to rock fracturing caused by the rising of a magma body. In 2005 there was a period of unrest, when the seismic activity incresed, after which the seismic activity went back to its background level (Fig. 5)

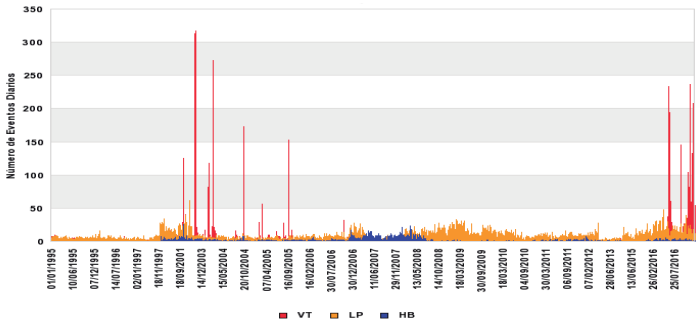


Figure 5: Seismic activity of the Cayambe volcano record since January 1995 until December 2016

In 2016 a new increse in the seismic activity was reported, regarding the number and magnitude of VT events (red bars, Fig. 6). The unrest period got worst between June and October. Moreover, mountain climbers ("andinistas")reported a smell of rotten eggs (H_2S) on the path to the highest summit and the formation of new crevasses at the top.

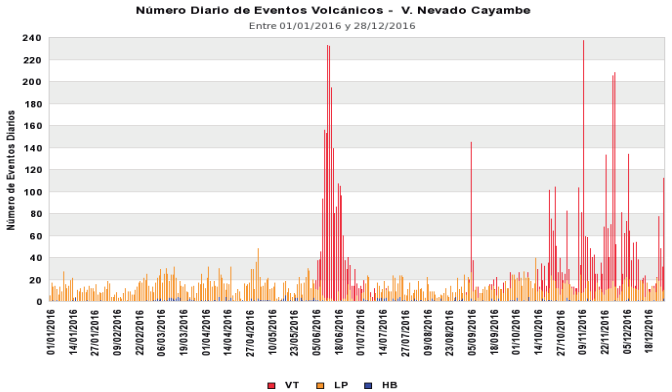


Figure 6: Seismic activity of the Cayambe volcano record since January until December 2016. The red bars (VT) show the increase in the seismic activity of the volcano in June and October