With time and distance downstream, lahars lose solid material causing a progressive decrease in their load capacity, therefore changing their behavior.

Finally, deposition occurs in zones where lahars lose their energy, when they reach a relatively lower slope (plains) or less confined areas like alluvial fans or canyon mouths (Vallance, 2005).

AFFECTATION

It is very difficult to anticipate the occurrence and magnitude of a lahar, make them very dangerous. Due to their high density, they can be very erosive, transporting big blocks in suspension (metric size). In addition because of their high velocities and the energy they have, the probability of sirviving the direct impact of a lahar is minimal.

Moreover, their impact on structures is almost always devastating. Lahars can destroy everything on their path, causing important damage even in very distal areas away from the source where often their effects are not anticipated (fig 4). During the occurrence of a lahar, traveling in river valley bottoms, low relief areas and roads that cross the valleys must be avoided.

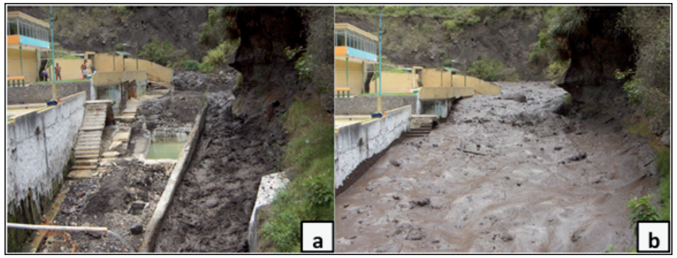

Figure 4: Pictures from El Salado thermal recreational zone, located on the Vazcún river margin on February 12, 2005. a) Minutes before lahar's arrival (13h30) b) lahar's transit, minutes after the alert and fast evacuation (13h42). Photography by: Civil Defense of Baños.

HAZARD MONITORING

Instrumental Monitoring is an important tool which can reduce risk from lahars. It has two principal uses: 1) early warning in case of lahar occurrence 2) flux parameters quantification (Andrade et al, 2006; Pierson et al, 2014).

Lahar monitoring its performed using specialized seismic sensors, mainly Broad Band (BB) and Acoustic Flow monitors (AFM). These sensors can detect the noise generated during the flow transit through the drainage where they are installed (in real time) and use an acquisition software which automatically emits alerts (Fig. 5).

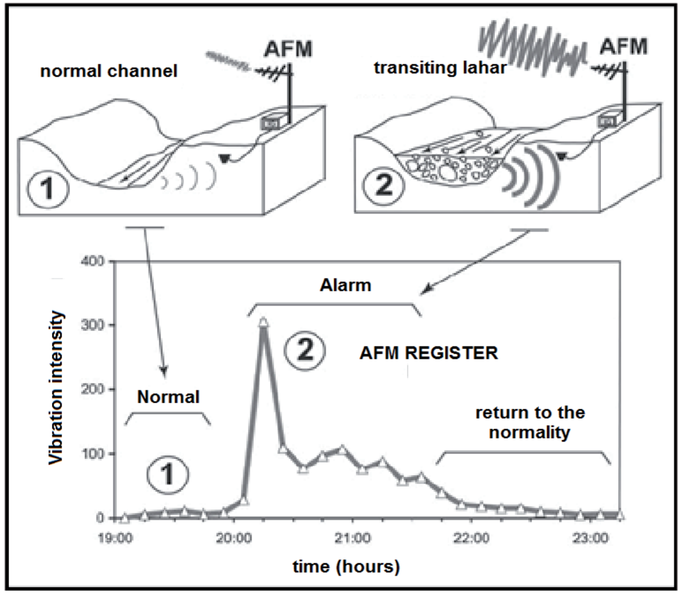

Figure 5: AFM lahar's detector function scheme during a lahar flow descending a river channel (taken from Andrade et al., 2005).

Soil vibration produced by lahar transit generates seismic noise in a specific predominant range of frequencies. This is useful to discriminate the signals produced by this flows from other signals or noises generated from other sources.

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LAHARS
(MUD FLOWS)

Mount Saint Helens. Marzo 19th, 1982. USGS webpage.

DEFINITION, PRIMARY AND SECONDARY LAHARS, FLOW TYPES, BEHAVIOR, AFECTATION AND HAZARD MONITORING.

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WHAT IS A LAHAR?

Lahars are mixtures of water and high concentrations of sediment and volcanic debris which can travel downstream from volcanoes by the influence of gravity (Waitt, 2013; Vallance & Iverson, 2015).

Due to their nature, lahars are very erosive, generally they travel in river channels at high speed (even higher than 70km/h), and they can reach long distances (even hundreds of km) from the source.

LAHAR'S ORIGIN

Lahars can be generated in several ways, nevertheless each case requires:

An adequate source of water: stored underground water, fast melted ice and snow, subglacial water, crater lakes or adjacent lakes, rainwater and even water from the hydrothermal or phreatic volcanic system.

Abundant unconsolidated material: fragments of volcanic rocks generally from explosive eruptions. Pyroclastic flow or ashfall deposits are abundant in material that can be easily removed.

High slope angles: very common on volcanic edifices they favor the descent of these flows by the influence of gravity.

A trigger mechanism: Eruptions, earthquakes, volcanic edifice instability and/or heavy rains. Sectorial colapses can also evolve into lahars.

PRIMARY AND SECONDARY LAHARS

Lahars can be catalogued as primary or secondary, based on their origin is directly or indirectly related to a volcanic eruption.

Primary Lahars (Syn-eruptive)

These flows are generated as a direct consequence of a volcanic eruption. During eruptive events incandescent materials produce the fast melting of big volumes of ice and snow on the volcano's summit (Fig. 1)

These lahars can also be generated by the rupture or expulsion of water from crater lakes during an ongoing eruption. Water and eruptive products mixture form lahars which can flow downstream (Vallance, 2005; Vallance & Iverson, 2015).

Primary lahars tend to be very voluminous (10^7 - 10^9 m^3) and to have high speeds (> 20 m / s) and discharges. Commonly their maximum flows are between 10^3 - 10^5 m^3/s (Mothes and Vallance, 2015).

These characteristics give them the capacity to flow great distances, up to hundreds of kilometers downstream.

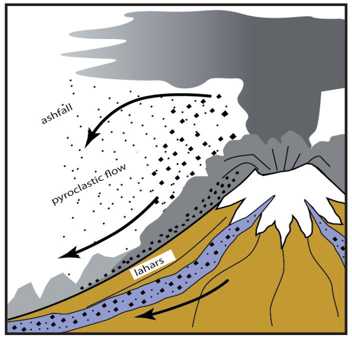

Figure 1.- Schematic model of primary lahar generation during an explosive eruption produced by the partial melting of a glacier.

Secondary lahars (Post-eruptive)

This category mainly includes rain generated lahars. Pyroclastic unconsolidated material, deposited by previous eruptions, can be easily removed by rains (Fig. 2). Generally their magnitude is smaller than those of primary lahars, nevertheless, their frequency is higher, especially during rainy periods.

These lahars can grow in magnitude and reoccur even weeks or months after the main eruption, making their hazzard level very difficult to anticipate (Vallance & Iverson, 2015).

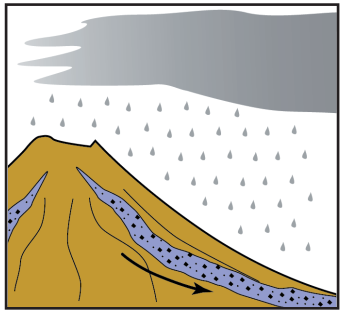

Figure 2.- Secondary lahar generation model caused by heavy rains which remove previously deposited pyroclastic material

Rain generated lahars are relatively small. Its volume and discharge get limited by the rain intensity and duration, in addition to the ammount of available material to be incorporated. Its volume is in the range of 10^4-10^6 m^3 and its discharges in the order of 10^2-10^3 m^3/s, with distances less than 10 km (Mothes and Vallance, 2015).

Secondary lahars can also occur, less frequently, due to lakes or dams rupture causing the removal of volcanic material that is concentrated on the volcano's slopes and drainages. These lahars tend to be larger in volume than those induced by rainfall.

FLOW TYPES

A lahar behavior may vary with time and distance downstream. Depending on the incorporated sediment percentage they can transform into debris flows if their sediment content exceeds 60% in volume or into hyper-concentrated flows with a volume of 20-60% sediments (Vallance & Iverson, 2015).

Lahar behavior not only depends on sediment concentration, but also on other factors such as: sediment grain size distribution and flow energy (agitation stage).

Debris flows: very poor sorting, with particle sizes from clay to blocks (meter size), characterized by being uniform in the solid and liquid phases. Their consistency is very similar to that of wet concrete and their viscosity is very high.

Hyperconcentrated flows: poor sorting, their main characteristic is the presence of sand (0.0625 - 2mm) to gravel sized clasts (2-64mm). They are distinguished by a non-uniform mixture of water and sediments, the water content is higher than that in the debris flow. Their consistence is very similar to that of dirty motor oil. These lahars don't have the same capacity of carrying big blocks on suspension as the debris flows do. In addition, they are more turbulent (Vallance, 2005).

FLOW BEHAVIOR

Lahars can include one or more flow types during a single event, evolving from debris flow phases to hyperconcentrated flows and even more aqueous phases as a sequence.
Their movement is mainly controlled by gravity, the topography and their volume. Lahars are normally confined to valleys, river channels and ravines, but when they surpass their capacity can overflow and flood adjacent plains (Fig. 3) (Vallance, 2005).

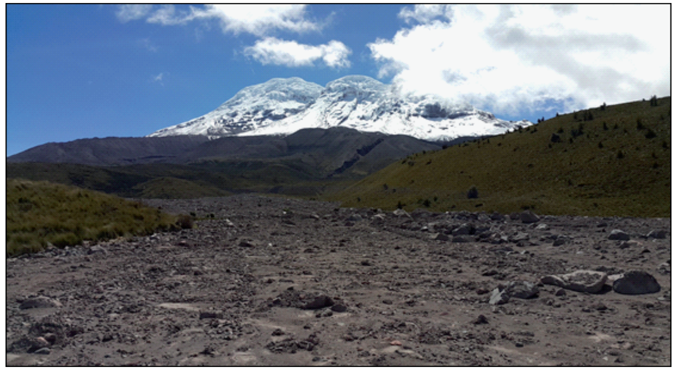

Figure 3: lahar depositional zone at Yambo Rumi ravine, SE flank of Chimborazo Volcano

Lahars can erode and incorporate sediments; principally undercutting step slopes, lateral terrace scarps and scouring riverbeds. Erosion is more intense on steep zones, areas with unconsolidated material or saturated deposits; which can increase the volume of the lahar (Vallance & Iverson, 2015).

In general, phases with higher water content are typically more erosive because they are more turbulent and agitated than those of sediment-rich debris flows. However, local erosion may occur during any flow phase.