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Lahar deposits on the eastern drainage of the Cotopaxi volcano: Sedimentology and implications for hazards

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INTRODUCTION

Located in the Eastern Cordillera of the Ecuadorian Andes, the Cotopaxi volcano (5890 m) is one of the most active Ecuadorian volcanoes. (Fig.1) During the last 2000 years, Cotopaxi was at least one eruption of VEI ≥ 3 per century (Barberi et al., 1995; Hall et al., 2000). Its summit reaches an elevation of 3000 m above a metamorphic basement, and its conical form has its origin in the alternance of pyroclastic deposits and lava flows of dominantly andesitic eruptions and few large rhyolitic eruptions (Mothes et al., 1998, Hall et al., 2000). The volcano is covered by a huge ice cap of about 13,97 km2 reaching a thickness of 30 to locally 115 m (Ramirez et al., 2004). In case of an eruption of the volcano, the melting of part of the glaciers can produce debris flows of great volume, as it has been observed during all of its recent eruptions with an important socio-economical impact (Mothes, et al., 1991; d'Ercole at al., 1991; Aguilera et al., 2004).

There are three main drainage systems at Cotopaxi volcano: the Pita-Esmeraldas rivers towards the North, the Cutuchi-Pastaza rivers towards the Southwest and the Tambo-Tamboyacu-Napo river system towards the East. Lahar deposits of the northern and southern flank of the volcano are well documented (Barberi et al.,1995; Mothes, et al., 1991; 1998). We present here a first and still preliminary study, which includes the sedimentological characterization of lahar deposits and attempt to evaluate the potential risk of debris flows and the risk perception by the population in the Eastern drainage of Cotopaxi.

METHODOLOGY

Field work was carried on in the proximal eastern zone of Cotopaxi volcano, along the drainage systems of the Tambo and Tamboyacu rivers and in the distal zone along the Jatunyacu river downwards to Puerto Napo in the Amazonian plain. In both areas, deposits of the most recent lahars were analysed according to their stratigraphy. Grain-size analyses were carried out in the field with a grid system. The diameter of clasts under each grid node has been measured, the size of the grid system varying within 1m x 1m and 50cm x 50cm (according to the layer's thickness). Then, the most representative layers of each deposit were sampled, one at the base and another at the top of the outcrop, and the samples were analyzed in laboratory using a sedigraph and nine sieves (from 128 mm to 0.038 mm).

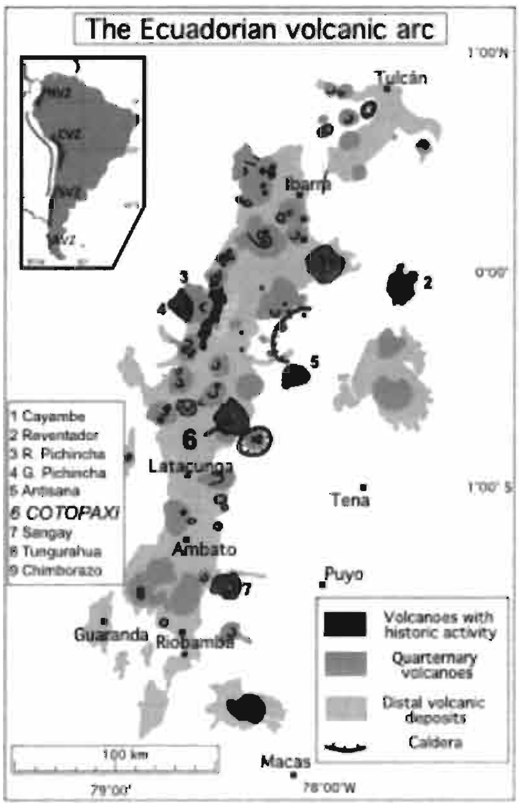
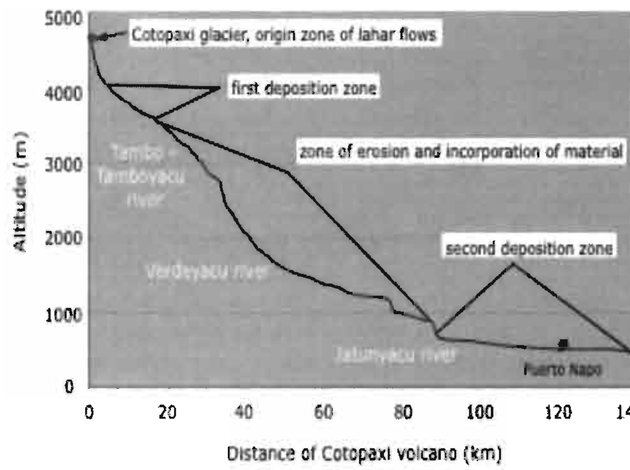


Fig. 1 (at the left side): Localisation of the Cotopaxi volcano in the Ecuadorian volcanic arc.

Fig. 2 (down): Longitudinal profile of the Tambo-Tamboyacu river system from its source at Cotopaxi's glaciers downwards to the Amazonian plain, with the succession of two deposition zones separated by an erosion zone.



Further on, interviews with native people living along the Jatunyacu river provided important information of the people's perception of potential debris flows impact and the extent of the zone at risk in case of a future eruption on the eastern flanks of Cotopaxi volcano. Over the next few months, further analyses of aerial photos, Studies of other remote sensing data, and the analysis of the deposits and risks by using GIS programs will improve our interpretation.

PRELIMINARY RESULTS

The lahars of the eastern flanks of the Cotopaxi volcano travelled distances of about 120 km, from the base of the volcano to Puerto Napo. The difference in altitude is about 4200 m, with a mean slope value of 9,06 % (Fig.2). Three quarters of their journey, lahars passed through the rain forest, which implies great possibility of erosion and incorporation of organic debris. The evolution of grain size distribution is from massive coarse-grained debris flow deposits in the Tambo-Tamboyacu area to fine-grained hyperconcentrated stream flow deposits in the Jatunyacu area. The Tambo-Tamboyacu lahar terraces are poorly sorted, mainly normally graded, with a weak fabric (Photo 1).

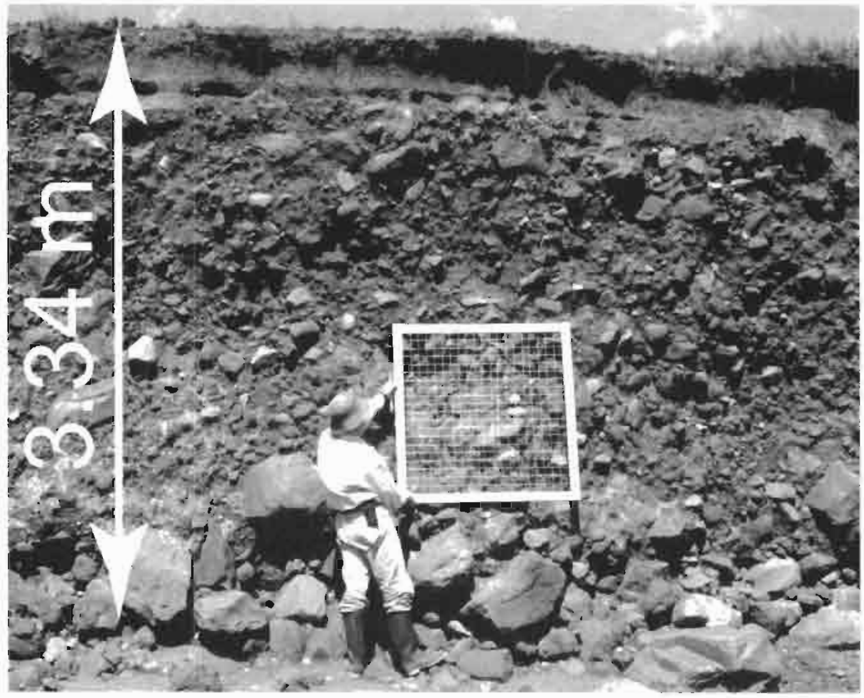


Photo 1: Lahar deposit section in the upper zone of river Tambo. This 3.34 m thick deposit is found over a horizontal distance of about 200 m. Note the 1 m grid and person for scale. The massive deposits are clast-supported debris flows, except for the upper finer grained layer, 40 cm thick (secondary hyperconcentrated flow deposit including scoria).

The deposits of debris flows in this study area can be found in two different environments:

(1) normal superposition of deposits with channel incision exposing pre-existing older lahar sequences ;

(2) inset terraces of progressively younger age accreted to walls of pre-existing channels.

The valley morphology plays an important role in accelerating flow velocity in narrow gullies or in restraining the flow velocity in wider areas. An approximate maximum peak discharge value of 12.920 m^3/s has been calculated for the Tambo-Tamboyacu river area. Terraces of older lahar deposits increase the possibility of bulking. The debris flows deposits observed on the eastern drainage of Cotopaxi volcano, along the Jatunyacu river, at 118 km from their source, are deposits of hyperconcentrated flow type at least at a 25 m distance from the riverbed inwards into the rainforest, maintaining a constant thickness of about 2 m. They represent the main debris flow deposit facies found in the distal part deposit zone. Their lithologic characteristics as well as the limited soil formation at their top and the lack of visible alteration argue in favour of very recent deposits, possibly historical (less than 500 years-old). No datable organic material was found during this study within the hyperconcentrated streamflow deposits in order to confirm this hypothesis by C^{14} dating. The hyperconcentrated stream flow (Jatunyacu facies) shows slight imbrication, stronger fabric, better bedding structures and a relatively good sorting. Grading is absent. Terraces of deposits along Jatunyacu river are nearly absent as a result of the river's strong erosive capacity during rainy periods.

CONCLUSIONS

The presence of these deposits testifies to the potential threat that these volcanic manifestations represent potentially for the native people living along the riverside of the Jatunyacu river. Many houses are constructed on lahar deposits and the majority of the population cultivate fruit and vegetable crops located all along the river or even sometimes on islands within the riverbed. A medium intensity lahar would primarily destroy the unique traffic path connecting the villages and the nearest houses as well as erode the plantations which represent an important base for their nourishment. These crops are often the only guarantee of the limited economic income of the local population.

This preliminary study of lahar deposits on the eastern flanks of the Cotopaxi volcano argue in favour of a warning system (Acoustic Flow Monitoring station for example) between the base of the volcano and the Amazonian basin, thus reducing the risk for the nearby living 4500 people.

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