The debris avalanche of Chimborazo, Ecuador

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INTRODUCTION

Most Ecuadorian stratovolcanoes have been affected by at least one flank collapse during their evolution. Such an event generates a debris avalanche that represents an unfrequent but highly destructive volcanic hazard. In order to assess the magnitude and the frequency of this type of event, a thorough study of their deposits was undertaken in Ecuador since 2001 in the framework of a cooperation project IRD-IG-EPN, in association with the IGAL. Our main objective is to highlight factors influencing gravitational collapses and mechanisms of emplacement, using various Ecuadorian exemples, in a comparative analysis of different volcanic debris avalanche deposits. Most of the main characteristics are present in Ecaudor: various structural environments, diverse topographies, collapses triggered by seismicity, control of the surrounding topography on the longitudinal evolution of the gravitational debris flows (Alcaraz, 2002; Alcaraz *et al.*, 2002; 2003; Bernard, 2002; Cruz-Mermy, 2002). We only present here the main results obtained the debris avalanche deposit of the Chimborazo volcanic complex.

THE CHIMBORAZO STRATOVOLCANO

Among the studied volcanoes, Chimborazo volcanic complex is an upper Pleistocene stratovolcano of 6.268 m of altitude, which was edified in three phases (Barba *et al.*, 2005). Chimborazo II has been affected by a gravitational flank collapse that removed ~9 km^3 of materials during its late Quaternary history (Clapperton, 1990; Alcaraz *et al.*, 2002; 2003; Bernard, 2002; Barba *et al.*, 2005). This major collapse was previously correlated to a pyroclastic event dated at 35 ky BP (Clapperton, 1990). However, a new C^{14} date of a pyroclastic deposit emplaced just upon the debris avalanche deposit yielded an age of 42.6±0.5 ky BP (Barba *et al.*, 2005; analysed at the University of Groningen, Netherlands) implying an slightly older age for the debris avalanche deposit; ≥ 42.6 ky BP. However, this has some important implications in terms of hazard evaluation, especially in relation with the newly identified Holocene periods of activity of this large stratovolcano (Barba *et al*, 2005). Chimborazo is built on an heterogeneous substratum on the western edge of the graben of Riobamba, a sub-unit of the inter-andean valley (Monzier *et al.*, 1999). A N-S to NE-SW fault bundle, made of right lateral trans-tensional faults (McCourt *et al.*, 1997), strongly influenced the development of the present volcanic cone; all the edifice is asymmetric and steeper towards the basin of Riobamba with slopes of 40° in the upper part of the volcano. This configuration represents a very favourable context for gravitational destabilization and partial collapse in case of, *e.g.*, seismic activity. A lot of indices of neotectonic activity were identified, and we consider now that the collapse of the Chimborazo II stratovolcano towards the south-east in direction of the basin was triggered by seismic movements. This seismic activity is probably related with some magmatic activity as it is shown by the great amount of juvenile rocks found within the deposit and the presence of a pyroclastic flow deposit found directly on top of the avalanche deposit (Barba *et al.*, 2005).

THE DEBRIS AVALANCHE DEPOSIT

The Chimborazo debris avalanche has an estimated volume of ~10.4 km^3. The breccias were deposited from the north-west towards the south-east, covering a total area of 260 km^2 with an average thickness of ~40 m. Locally these breccias accumulate to a hundred meters in relation to the morphology of the depositional area and topographic obstacles that constrained the flow path. The avalanche was partially channelized, especially to the north-east by the Igualata volcano (Pleistocene extinct volcano of the inter-andean valley; Litherland *et al.*, 1993) and to the south by older pyroclastic breccias. Smaller reliefs, as the strombolian cinder cones near Calpi, also diverted the flow. All these obstacles induced various degrees of confinement, locally very high, in contrast with the main distribution path without constraint, towards the south-east of the Riobamba basin. There, the avalanche reaches its maximum distance (L) from the source of 33 km near the río Chambo. At present, the caldera scar is not well visible, as it is concealed by post-collapse magmatic activity of Chimborazo III edifice. But the avalanche surface morphology is extremely well-preserved in the form of ridges and hummocks. In this case, they correspond to superficial morphologies developed as a consequence of flow confinement induced by the pre-flow topography. The hummocks form small circular hills, 2 to 40 m high, and are mainly distributed in the south-east part of the deposit, in the area of lesser confinement. In contrast, transverse ridges (oriented NE-SW) and longitudinal ridges are 1 to 3 kilometres in length and 20 to 40 m high. Ridges of both kinds are especially concentrated in the area of compression where the avalanche has been more confined (Figure).

In general, the deposit lacks massive mega-blocks. Two facies are clearly individualised: a matrix-rich facies (80% in volume) and a basal facies (20%).

The matrix-rich facies is composed of a cataclasis of blocks and mega-blocks, juxtaposed side by side, that are increasingly deformed, fragmented and mixed towards the base and the margins of the deposit. This facies grades from the proximal to the distal zone with a concentration of the most clastic components in the upper part of the avalanche, reinforcing the features in relief, like hummocks and ridges. In few places, some hummocks are structured by a single large cataclazed mega-block, forming the hummock of type A according to the classification of Glicken (1991). More commonly, ridges and hummocks are clast-rich in their centre, whereas their borders consists of an evolved matrix facies (hummocks of Type C, for the biggest ones), that are increasingly mixed and heterogeneous and formed a majority of Type C hummocks in the most distal part of the deposit.

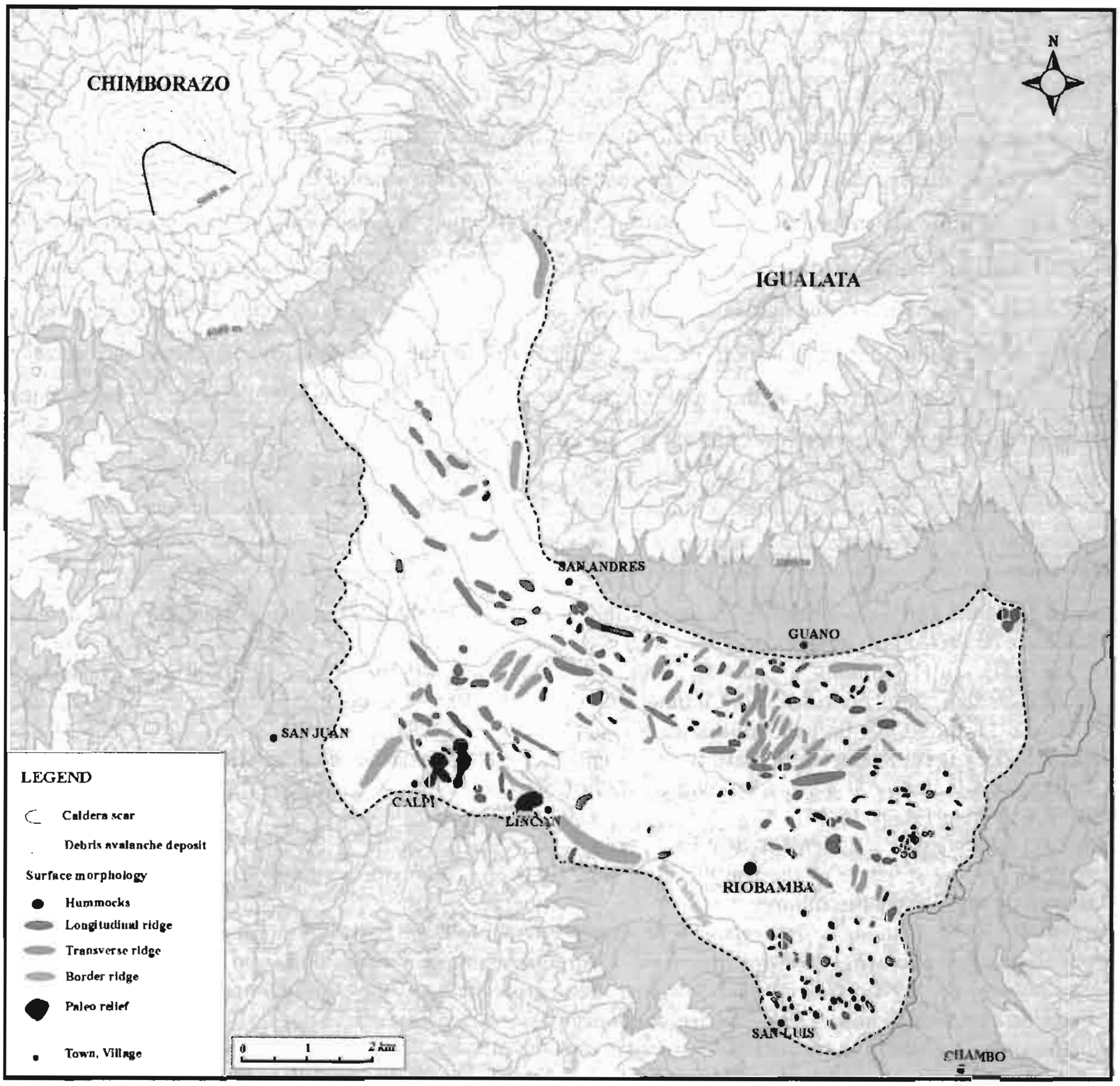

Figure: Map of the debris avalanche deposit of Chimborazo, showing its morphological features.

The basal facies, observed at 20 km from the source, is much more homogeneous. It is matrix-supported (70 vol% of particles <2 mm) and contains about 25 % of heterolithologic blocks, often rounded and sometimes incorporated. When it is a few meters thick, it evolves gradualy from the base to the summit of the deposit, and it tends to send injections upward into the matrix facies. The basal facies represents a higher volume proportion of the deposits in localities where the flow has been confined and presents different clast-deformation features such as abrasion, rotation and cataclasis. The basal contact presents a shear zone generated in the deposit as well as in the substratum. Some features suggest that the transport and emplacement processes vary within the avalanche. The homogeneity and the fine granulometry of the basal facies make it like to be considered as a fluidized layer that could have increased the mobility of the flow. However, the apparent coefficient of friction is $\mu = H / L = 3600 / 33000 = 0.11$, a value typical for large volume volcanic debris avalanches of this volume.

CONCLUSION

The good preservation of the breccias allowed us to describe the morphology and textural features of the Chimborazo debris avalanche deposit. The abundance of outcrops enabled us to analyse in details both the surface and the internal structures of the deposit. These observations revealed many informations regarding the transport and the emplacement mechanisms. The paleo-topography induced constraints on the flow path and controled the distribution of the hummocks and ridges according to the degree of confinement. The increase of shearing and friction during transport induced deformation of the materials, by cataclasis and abrasion, promoting progressive mixing with the sourrounding matrix. Thus, the shear zone developed at the basal contact is thought to dissipate most of the mechanical energy loss.

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