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Volcanic debris avalanche and debris flow hazard assessment: contributions from geological and geotechnical characterization of the Cotopaxi Volcano deposits, (Ecuador)

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Sector collapse of a volcanic edifice and related debris avalanche and debris flow represent a catastrophic typology of volcanic hazard that affects several stratocones in densely populated regions. These events are frequently associated with volcanic explosive activity or involve poorly consolidated pyroclastic and volcaniclastic deposits mantling the volcano flanks. Useful tools to understand the transport and emplacement mechanisms of the volcanic debris avalanche and debris flow are the modelling analysis. A crucial aspect of the models validation is the appropriate knowledge and application of the physical parameters of the natural geologic bodies involved in the phenomena, and their geological representativity. At present, in the international literature, few quantitative data exist on direct physical and geotechnical measurements of volcanic material as pyroclastic and volcaniclastic deposits. Then, considering the peculiarities of volcanic environment and volcanic products, specific geotechnical characterization should be performed for every unique case. Cotopaxi Volcano is one of the highest (5900 m) active volcanoes in the world and its present symmetrical cone is covered by a summit glacier. Cotopaxi is located along the eastern border of the Interandean Depression, a narrow highly populated valley of the Ecuadorian Andes, that separates the Western Cordillera and the Cordillera Real. Cotopaxi was interested, about 5 ka ago, by a large sector collapse of the north-eastern flank that produced a debris avalanche and an immense debris flow that travelled as far as Pacific Ocean 326 km away. After the collapse, until 1878 AD, several explosive eruptions produced

glacier melting and generated destructive debris flows. The present research is focused on defining the main volcano-stratigraphic units involved in the debris avalanche and flow processes, and determining their geotechnical characters. The original field work included geological, lithostratigraphic, geomorphological and structural survey; in situ natural density and coarse fraction grain-size analysis. The volcaniclastic materials belong to the 5 ka debris avalanche deposit. The pyroclastic deposits constitute the poorly consolidated northern volcano flank cover. During future explosive eruptions, at the occurrence of the glacier melting, these pyroclasts may represent a potentially unstable mass easily involved in a debris flow. The Cotopaxi debris avalanche deposit covers the north-eastern foothill of the volcano and ramps on the slopes of surrounding volcanoes for several hundred of metres. The minimum estimation of the covered area is 25 km^2 and the volume is 2 km^3. The deposit is a mega breccia with a variable amount of coarse matrix. Surface morphology is a typical well preserved hummocky topography. Field mapping confirms that the debris avalanche was accompanied by explosive volcanic activity and pumice flow and lahar emplacement. The investigated pyroclastic deposits constitute a 5-12 m thick sequence of poorly consolidated pyroclastic materials that overlay the lavas flows of the post-5 ka activity. The sequence is mainly constituted by interlayered ash beds, agglutinated scoriae, pumiceous and scoriaceous lapillistones of fall-out origin, dune-bedded ash deposit of pyroclastic surge origin and lahar deposits constituted of matrix-supported lithic breccia. The lithological discontinuity between lavas and younger pyroclastic deposits represents the most probable detachment surface that can lead to the formation of a gravity driven instability phenomenon like a granular flow or a debris flow. Description and sampling of 8 sites was carried out. The loose volcaniclastic materials were subsequently characterized by standardised laboratory tests in terms of grain size particle distribution, physical properties, X-ray diffractometry on fine fraction, Consolidated -drained triaxial compression tests are in progress. These directly measured parameters will be the basic data for back analysis simulation of the debris avalanche phenomenon and for stability analysis of the Cotopaxi flank cover via numerical modelling.