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Geomechanical characterization of the Miocene Cuitzeo ignimbrites, Michoacán, Central Mexico

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ABSTRACT

Volcanic rocks, especially ignimbrites, exhibit complex mechanical behaviours due to their large variation in welding, porosity, textural and granulometrical characteristics. Moreover, there is a lack of knowledge of how alteration processes affect their intrinsic properties. Main objective of this research is to characterize the physical, mechanical, and hydraulic behaviour of different lithofacies of the Cuitzeo ignimbrites (Mexico). These volcaniclastic mixtures of lithics and pumice supported by a fine-rich matrix are characterized by different textural and granulometric features. A general lithostratigraphic section and geological mapping of the study area were accomplished to attain the temporal and spatial distribution of the ignimbrites. Strength, deformation and the failure mode of selected lithofacies were directly related to micro-textural and granulometric characteristics by a series of uniaxial and pre- and post-failure non-destructive analyses (e.g. ultrasonic pulse velocity and X-ray image tomographies). Results for four different lithofacies were compared, allowing us to explore the variation in the mechanical properties associated with characteristics derived from diagenesis. Petrophysical properties show that there is a large dependence on the textural characteristics and particularly on the pumice fragments content. Results derived from laboratory observations and X-ray image reconstruction analysis, show that the main differences in the average values of porosity are associated to the geometry and morphology of the grains and pore network. These are closely related to the stress – strength relationship and the mode of failure of each specimen. In general, the strength for all lithofacies tends to increase linearly with several of the physical properties (e.g. ultrasonic pulse velocity, bulk density). Slake durability tests demonstrate that a large part of the mechanical degradation could be attributed to swelling during wetting-drying cycles. This decay is significant in lithofacies with groundmass rich in expansible clays.

1. Introduction

The physical and mechanical characterization of rocks is required to build both conceptual and numerical model of the natural phenomena (e.g. pyroclastic density currents; landslides, volcanic instabilities, groundwater flow and heat transport). Several insights into the behaviour of rocks have emerged from laboratory tests (e.g. uniaxial and triaxial compressive strength, total and effective porosity, P and S wave velocity measurements, e.g. Hudyma et al., 2004; Sousa et al., 2005; del Potro and Hürlimann, 2009; Marques et al., 2010; Pola et al., 2012, 2014). Empirical correlations among rock properties have been used to estimate other parameters (e.g. Vernik et al., 1993; Ulusay et al., 1994; Avar et al., 2003; Schöpfer et al., 2009; Baud et al., 2014). These correlations are based on the observation that some specific set of rock characteristics controls both mechanical (e.g. strength, elastic moduli) and physical properties (e.g. elastic wave velocity, Chang et al., 2006; Wong et al., 1996; Stanchits et al., 2003). On the contrary, there is an enormous lack of knowledge about how alteration affects the intrinsic properties of a rock. For example, alteration could drastically change the geometry and morphology of the grain framework and pore network influencing the mechanical and hydraulic behaviour of the altered material (e.g. Frolova et al., 2014; Thörn et al., 2014).

The main objective of this paper is to describe the physical and mechanical behaviour of the Cuitzeo ignimbrites (Mexico) and some of their lithofacies. These volcaniclastic mixtures of lithics and pumice supported by a fine-rich matrix are characterized by different textural and granulometric features. To attain the temporal and spatial distribution

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of these ignimbrites at a regional scale, both a lithostratigraphic section and geological mapping were carried out. The results cast new light on the reconstruction of conceptual models and scenarios of natural phenomena (e.g. landslides) occurring in the area.

1.1. Study area

The study area is located in the northern part of the State of Michoacán (west-central Mexico), and it covers approximately 250 km^2 close to the boundary with the State of Guanajuato (Fig. 1) and it is part of the Michoacán-Guanajuato Volcanic Field (MGVF, Gadow, 1930; Luhr and Carmichael, 1985; Hasenaka and Carmichael, 1987; Hasenaka et al., 1994; Newton et al., 2005; Pérez-López et al., 2011; Guilbaud et al., 2011; Pola et al., 2015). The area is bounded by the Cuitzeo lake to the north and the Quinceo-Tetillas volcanic complex (QTVC) to the south. The monogenetic MGVF is composed of more than one thousand volcanic edifices (Hasenaka and Carmichael, 1987) displaying a wide range of eruption styles, from magmatic events that produced cones and lavas to phreatomagmatic events that produced maars, tuff cones and rings (e.g. Ferrari et al., 2000; Ego and Ansan, 2002; Blatter and Hammersley, 2010; Pola et al., 2015). The hilly landscape is made of the Cuitzeo ignimbrites and lava flows and other

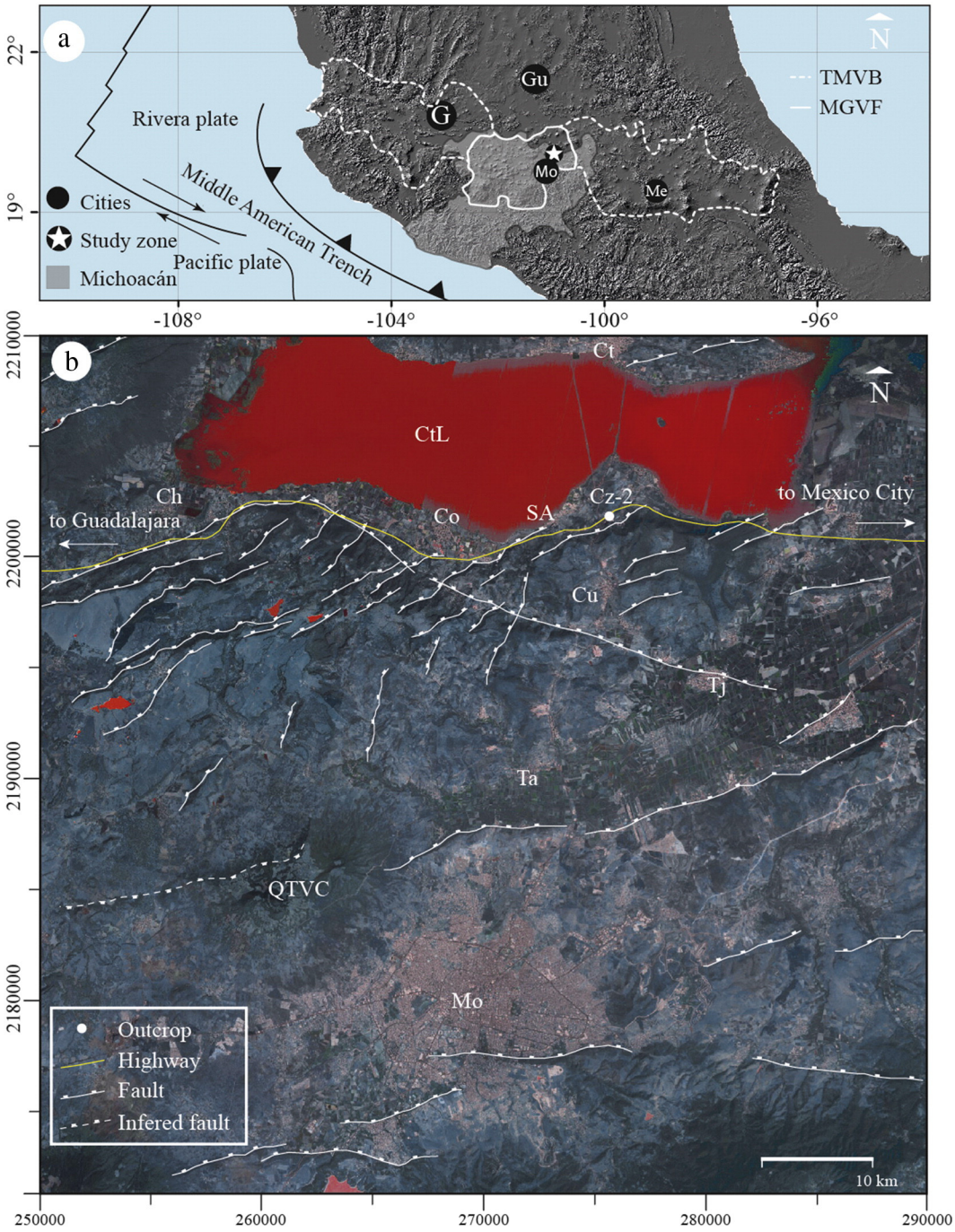

Fig. 1. a) Illustrative map of the central part of Mexico. The trace of Michoacán state, the TMVB, the MGVF, and the most representative cities, as well as studied outcrops are included; b) map of Cuitzeo volcanic zone. Images were obtained by merging of two SPOT images (multispectral and panchromatic with 10 and 2.5 m of resolution, respectively). Abbreviations are: Ct = Cuitzeo del Porvenir; CtL = Cuitzeo lake; SA = San Agustín del Maíz; Mo = Morelia; Ta = Tarímbaro; Cp = Copandaro de Galeana; Cu = Cuto; Tj = Téjaro; QTVC = Quinceo-Tetillas Volcanic Complex; Ch = Chucándiro.