The effects of granular dynamics on the triboelectric charging of volcanic ash: Experiments and numerical simulations

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***Abstract* — Volcanic plumes, like many other turbulent and collisional granular systems in nature, have the tendency to become electrostatically charged [Hatakeyama, 1943; Hatakeyama and Uchikawa, 1951; Hatakeyama, 1958; Anderson et al.1965; Lane and Gilbert, 1992; Miura et al. 1996, 2002; James et al.1998, 2008; McNutt and Davis, 2000; Mather and Harrison, 2006; Aizawa et al. 2010; Harrison et al. 2010; McNutt and Williams, 2010; Nicora et al. 2013]. Perhaps the most dramatic and evident consequence of this electrification are the impressive lightning displays often observed during vigorous eruptions. While volcanic lightning has been reported for millennia [Letters of Pliny, 2001 translation], the physics that generate and separate charge in plumes still require clarification. Investigated mechanisms for electrification include fractocharging or charging resulting from the break-up of magma in the conduit [James et al, 2000], triboelectric charging arising from particle-particle collisions [Forward et al. 2009c; Lacks and Sankaran, 2011], inductive charging of dry materials [Pähtz et al. 2010], and charging mechanisms similar to those found in thunderstorms related to the interaction of hydrometeors [Herzog et al.1998; McNutt and Williams, 2004; Mansell et al. 2005]. The observed variability in electrical behavior between eruptions and between volcanoes suggests that the generation of charge is modulated by specific eruption parameters such as fragmentation behavior, the properties of the ejected materials (both ash and volatiles), environmental conditions, as well as the dynamics of the plume itself. Therefore, understanding the coupling between eruption parameters and electrical activity, much of which can be studied remotely, may yield information about the internal dynamics of an eruption which would otherwise be opaque to observation [James et al.1998]. Indeed, Behnke and Bruning [2015] have recently shown that lightning (and by association, charging processes) could be used to infer changes in eruption kinematics. Here, we present the results of a set experiments and numerical simulations specifically designed to link the dynamics of a flow of ash to its electrification behavior. Based on the devices described by Forward et al. [2009a] and Bilici et al. [2014], we constructed a spouted-bed instrument capable of characterizing the triboelectric charging of ash due to solely particle-particle collisions. The apparatus is capable of measuring the transient electrification behavior of the fountain as well as measure the absolute charges on individual grains in the flow with a resolution of 1 fC. While the systems works well to quantify the electrostatic behavior of the fountain, extracting fountain dynamics, specifically grain collisions rates and energies, remains difficult. To address these shortcomings, the internal fountain kinematics were characterized using a large-scale, full 3-D discrete element model (DEM) using 10 million particles run on the NCSA Blue Waters supercomputer. Our results provide a microphysical framework to interpret recent observations of lightning and field changes at active volcanoes such as Redoubt and Sakurajima.**