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Physical constraints for effective magma-water interaction along volcanic conduits during silicic explosive eruptions

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We thank Houghton and Carey (2019) for their insightful Comment on our paper (Aravena et al., 2018), where they discuss new data for addressing the role of external water in explosive volcanism. Their comment gives us the opportunity to discuss in depth our conclusions and to present new results which detail the conditions needed to produce magma-groundwater interaction during explosive events. In our paper, we showed that the access of groundwater to ascending magma in large silicic explosive eruptions is only feasible above the primary fragmentation level, and that the pressure gradient–driven inlet of significant volume fractions of groundwater is not possible for high mass discharge rate (MDR) events. A corollary of this result is that high-intensity phases of volcanic events with evidence of magma-water interaction are mainly associated with the involvement of surface water, whereas a significant influence of groundwater can only occur during specific eruptive phases. The data presented by Houghton and Carey support our results; in particular, that significant involvement of external water is only feasible above the primary fragmentation level. In fact, as suggested by the vesicularity features of the products of the two case studies described by Houghton and Carey, external water would have entered the conduit above the fragmentation level, and the presence of plausible surface-water sources can be suggested for both eruptions. However, this is not the general case for hydro-volcanic events, as observed in the A.D. 79 Vesuvius eruption, where strong evidence suggests the involvement of external water (e.g., Sigurdsson et al., 1985) but a source of surface water is not feasible. For clarity, we use the term "hydro-volcanic" for referring to volcanic events characterized by the interaction between external water (no matter if from surface or subsurface origin) and the ascending material. Here we focus on those special conditions that may prompt groundwater access to the conduit during explosive eruptions, presenting new results related to the A.D. 79 Vesuvius eruption.

The onset of this eruption was characterized by a small hydro-volcanic explosion (EU1; Cioni et al., 1992) that marked the opening of the conduit, followed by the main Plinian phase (EU2 and EU3) and the "phreatomagmatic phase" (EU4–EU8). We performed a set of simulations of the entry of groundwater into the conduit during two phases of the A.D. 79 Vesuvius eruption that present evidence of hydro-volcanic interaction (EU1 and EU4). The deposits of EU1 are related to a low-height plume possibly associated with Vulcanian-like activity characterized by low MDR (on the order of 10^6 kg s^{-1}). Despite the low MDR, results suggest that a significant amount of groundwater could have had access to the conduit only in the presence of a highly permeable, geopressured aquifer (Fig. 1). Geologic data support the occurrence of dominant processes of conduit erosion during this phase, with fractions of lithic fragments higher than 50 vol% (Barberi et al., 1989). We suggest that the erosion and entrainment of water-saturated host rocks was responsible for the hydro-volcanic interaction that occurred during EU1, along with the presence of a still-narrow conduit (radius less than 10 m). On the other hand, for EU4, the high MDR of this phase prevented the entry of a significant proportion of groundwater driven by any feasible pressure gradient (Fig. 1). Considering the absence of surface water, we hypothesize that the injection of external water was controlled by significant conduit collapse processes. Shea et al. (2012) described an increasing incorporation of dense pyroclasts from conduit margins during the transition from the Plinian phase to the "phreatomagmatic phase", and Barberi et al. (1989) indicated the occurrence of an important increase in the wall-rock/juvenile ratio. This evidence is in agreement with the presence of a collapsing conduit able to engulf large volumes of water-saturated rocks (Aravena et al., 2017), preceding the well-documented caldera collapse (Cioni et al., 1999). For phases EU1 and EU4, the vesicularity of pyroclasts is ~70 ± 10 vol% (Shea et al., 2012), which can be interpreted as evidence of a dry fragmentation process, suggesting that groundwater entry occurred above the primary fragmentation level.

Our results suggest that effective interaction with external water during high-MDR events is feasible only during certain eruptive phases (e.g., conduit opening and caldera-forming processes) and/or by the entry of surface water. In both cases, because collapse conditions are primarily observed above the fragmentation level (Aravena et al., 2017), external water would tend to interact with a fragmented magma, with no major effects in the resulting vesicularity. Accordingly, the term "phreatomagmatic" seems, in fact, inappropriate for most volcanic events that involve interaction with external water, both because they are frequently related to surface water instead of groundwater, and because the interaction commonly occurs with a gas-pyroclast mixture instead of a magma in the true meaning of the word. These observations suggest that the role of fragmentation processes related to magma-water interaction in driving the dynamics of hydro-magmatic eruptions should be deeply re-thought.

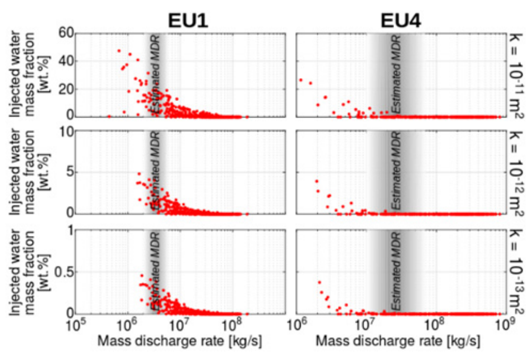

Figure 1. Injected water mass fraction versus MDR as a function of aquifer permeability (k). Detailed information is presented in our GSA Data Repository item 2018319.

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