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Combined effects of gas entrapment and reduced entrainment on the collapse of explosive volcanic eruptions columns

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High-velocity turbulent jets produced by explosive volcanic eruptions can form either a buoyant Plinian plume or a collapsing fountain producing pyroclastic density currents (PDC) rushing down the volcano flanks. These two eruptive regimes, which may occur one after another and even alternate during the same eruption, can lead to various hazards. A better understanding and prediction of the source conditions leading to these extreme regimes is required to quantify the volcanic impacts associated with these eruptions. Previous studies show that the transition between the buoyant and the collapsing regimes is strongly controlled by the mass eruption rate and the effective gas content at the vent. The latter parameter can be significantly reduced due to gas entrapment in large pumice at fragmentation, which tends to promote column collapse. In addition, the high density of the volcanic jet due to the load in particles near the vent reduces the turbulent air entrainment, which also promotes column collapse. Both effects have a strong control on the regime transition but they were never combined together to investigate the dynamics of volcanic columns. To fill this gap, we use a 1D model of a volcanic plume accounting for the particle sedimentation rate calculated as a function of the particle size depending on the total grain-size distribution (TGSD). A power law exponent D generally close to 3 characterizes the TGSD. Our results show that for sub-Plinian and Vulcanian eruptions (i.e., eruption rates < 10^7 kg s^{-1}), the loss of particles by sedimentation during the plume rise is large enough to drain out the thermal reservoir available to heat the engulfed atmospheric air, hence favoring column collapse. In powerful Plinian eruptions (> 10^7 kg s^{-1}), the loss of particles is reduced and tends to decrease the column mass flux during the plume rise, which favors the formation of a stable column. In this case, we further obtain that coarse GSD promote the formation of stable plumes, a result at odds with the predictions of models considering gas entrapment in large pyroclastic fragments. We then compare our model predictions to the 79 AD Vesuvius and the 186 AD Taupo eruptions. In both cases, we find that our model have to consider not solely gas entrapment but also an open porosity of 70% to reproduce field data. This full model then allows us to predict the characteristics of the PDC produced by column collapse as a function of the GSD and MDR at the source. These results have thus important implications for volcanic hazard assessment related to explosive volcanic eruptions.