Some Models of Rainfall-triggered Collapse of Lava Domes in Potentially Gas-effusive Environments

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Abstract

Models are developed to examine rain triggering of lava dome collapses. A number of large dome collapses at the Soufrière Hills volcano were associated with heavy rainfalls, including the 3 July 1998 dome collapse during the period of 'residual volcanic activity', and the 20 March 2000 and 29 July 2001 events during periods of active dome growth. For example, the July 1998 collapse resulted in a series of large pyroclastic flows that discharged into the Tar River Valley, and lasted for about 2.5 hours. The c.20 x 10^6 m^3 collapse resulted in a deep canyon-like scar, and occurred 8 days after a local felt earthquake and 3 days after small-to-moderate pyroclastic flows were discharged from the dome. The failure followed directly after a period of heavy rain, was marked by the absence of pre- or post-collapse seismic activity, and was followed by anomalously high SO_2 emission rates. Likewise, 90% of the new lava dome collapsed in March 2000 (c.30 x 10^6 m^3), and an even larger collapse occurred in July 2001; these collapses were associated with rainfalls intense enough to generate large lahars in rivers around the volcano.

Three mechanistic models are applied to explain the collapses, including their deep-seated nature and abnormally large ratio of collapse volume to total dome volume, in the absence of obvious precursors, save the accumulation of rainwater in and around the carapace. Each considers the limit equilibrium of an idealized hemispherical dome, with the superposed collapse geometry, and subject to the loading of both rainwater-induced water pressures and trapped effusive gas pressures. The first model examines stability in the presence of rainwater infiltrating from a moat ponded around the toe of the dome. This model is incapable of developing deep-seated instability, and the rainwater moat exerts negligible influence on more shallow-seated failures. The second model considers the infiltration of rainwater into the spherical surface of the dome carapace, producing a saturated rind. Maximum water infiltration depth is controlled by the combined rainfall rate and capillary characteristics of the dome rocks comprising the rind, and infiltration rate is controlled by their permeability. At the peak infiltration depth, the role of water pressures alone is insufficient to result in all but minor spalling failure of the dome. The final model comprises the role of the saturated rind in occluding the fracture porosity, and enabling interior gas pressures to build by either of two mechanisms – the trapping of infiltrating rainwater, vaporized by the hot interior core of the dome, or by the trapping of pressurized volatiles effusing from the capped magma conduit. In either case, the maximum gas-overpressure, defined at the base of the saturated rind, is the same, and is limited by the supernatant water pressure. Where vaporization is the dominant pressurizing mechanism, the peak gas overpressure is uniform throughout the dome, and overpressures are sufficient to trigger failures consistent with the small-scale pyroclastic flows observed. Conversely, where the effusive flux of volatiles from the magma conduit dominates over vaporization of percolating water, trapping of gas by the water-saturated rind results in potentially larger gas overpressures in the dome core. These elevated gas overpressures appear necessary to produce potential failures consistent in volume, energetic release, and post-collapse gas emission to those observed.

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