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Quantifying water entrainment in volcanic jets

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Magma-water interaction affects magma fragmentation and the resultant production of volcanic ash is of importance for hazard mitigation both on a local and on a regional scale. The relative proportion of water that interacts with magma, quantified as the water-to-melt ratio, is thought to determine the fragmentation efficiency. Here, we quantify the water-to-melt ratio for a well-characterized explosive eruption with pyroclastic deposits associated with and without external water interaction. We use jet entrainment theory in conjunction with fragmentation energetics, based on pyroclastic grain size distributions to estimate the water-to-melt ratio. Our case study is the 10th century Eldgjá fissure eruption in Iceland, where some of the magma passed through a water column formed by glacial melt water, whereas other vents of the eruption were subaerial. The pyroclastic deposits that were associated with subglacial vents have a distinctly finer grain-size distribution than the subaerial deposits. We attribute this difference to magma-water interaction. Based on the additional fragmentation (surface) energy required to produce these finer grained subglacial deposits, and assuming that this energy difference is due to the conversion of thermal to mechanical energy during the vaporization of all external water entrained into the subaqueous volcanic jet, we estimate a water-to-melt ratio of approximately 0.5 to 4. Then, using jet entrainment theory, we independently estimate the mass of water entrained into the pyroclastic jet as a function of eruption parameters (e.g. vent radius, mass eruption rate) and the environmental factors (e.g. water column thickness, density ratio); this obtains water-to-melt ratios in good agreement with those estimated from fragmentation energetics. More broadly, our results show that subglacial eruptions are capable of having water-to-melt ratios of 0.1 to 10; the range thought to cover the spectrum between highly inefficient and optimal conversion of thermal to mechanical energy. We propose that, using our jet entrainment model, the degree of hydromagmatic behaviour during an subglacial eruption can be estimated.