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A relationship between fragmentation energy and fragmentation speed: evidence for two mechanisms of magma failure?

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The investigation of volcanic eruptions and magmatic processes is becoming increasingly systematic, quantitative and rigorous. Nowadays models trying to explain volcanic phenomena are based on the results of numerical simulation, laboratory experiments as well as field observations. Thus the importance of a refined understanding of the underlying physical processes leading to volcanic grows.

Fragmentation is a decisive process to distinguish between explosive and effusive volcanic behavior. Various models have been proposed for fragmentation. In this study we solely focus on the fragmentation of magma due to rapid decompression. This process likely accounts for the eruption style of most silicic events, e.g. for dome collapse events and for the disintegration of (highly) viscous magma in Vulcanian eruptions. In most cases silicic, highly viscous magma will disrupt in a brittle manner, as the process occurs close to the glass transition.

To enhance our quantitative underpinning of mechanisms of magma failure, we performed rapid decompression experiments with an apparatus based on the shock tube principle. Samples from different volcanoes were investigated for this study. The open porosity ranges from 2.5 vol.% to 67 vol.%, resulting in a range of 2.5 - 30.0 MPa for the fragmentation threshold. These threshold values are in good agreement with the threshold curve of Spieler et al. (2004). Within the analyzed pressure range from 2 MPa to up to 40 MPa fragmentation speed values of up to 150 m/s could be obtained. The energy, which drives the fragmentation process, is largely provided by the expansion of the pressurized gas located in the pore space of the samples. In general, we observed a logarithmic increase of the fragmentation speed with the energy density (fragmentation energy standardized to a unit volume) as soon as a certain "energy threshold" is overcome. However, some highly porous samples with high permeability values deviate from the trend towards higher energy values. Whereas the densest samples of this study deviate clearly to lower energy values compared to the main trend. These observations lead us to the suggestion, that magma fragmentation is driven at least by two distinct physical mechanisms: (1) At moderate and high porosities gas expansion is the determining process, leading to a vesicle bursting, which is widely accepted as the common process. (2) At low porous samples the fracture process due to passing of the unloading wave appears to become increasingly important. We also infer a transition zone, in which both mechanisms occur jointly.