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Fragmentation phenomena in populations of magmatic crystals

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ABSTRACT

Fragmentation of crystals is an important mechanism, and a component of particle dynamics in igneous and metamorphic rocks that has received surprisingly little attention. Recent advances in textural analysis, extraction techniques, digital imaging, and computer-assisted measurements enable rapid accumulation of 3D data on particle shapes and size distributions. This paper reviews fragment size distributions (FSD) that result from fragmentation: lognormal, fractal, loggamma, and Weibull; discusses their genesis mechanisms; and presents relevant examples of fragmentation from experimental physics. Next, the paper considers FSDs of feldspars on digitized images of thin sections and on published images, and quartz extracted from vesicular pumice by acid from eight well-known large-volume eruptive units. The acid solution of pumice enables examination of volume abundance, 3D shapes, proportions of fragmented crystals, and measurements of their CSDs and FSDs. FSDs were also measured in samples of welded tuff and a granite disaggregated by electric pulse. Products of syneruptive shock wave fragmentation, and fragmentation by an electric pulse are found to be fractal with large breakage probabilities, branching ratios, and fractal dimensions of 2 to 3. In contrast, most quartz fragments in pumice obey a lognormal distribution and fragmentation is driven by a melt inclusion decrepitation mechanism, which results in low breakage probability and small number (2–3) of fragments per breakage cycle. These results are consistent with one atmosphere heating experiments of quartz phenocrysts that led to melt inclusion decrepitation and caused quartz to break up into several smaller pieces collectively having lognormal FSD. Measured melt inclusion size distributions suggest decrepitation of outermost melt inclusions, and low survival rate for large inclusions, and inclusions with large radius/crystal size ratio. The modeling of periodic fragmentation of crystals with melt inclusions due to overheating and/or decompression, which may occur many times during the lifetime of a long-lived magma body, may explain concave-down, lognormal CSDs abundant in igneous rocks. The genesis of lognormality can be explained by the fragmentation algorithm of Kolmogorov (1941). Other algorithms may generate lognormal-like loggamma distributions. Fragmentation serves as an important size limiting factor, a nucleation aid, and it facilitates isotopic and trace elemental exchange.