Do Prince Ruperts Drops provide insight into phreatomagmatic fragmentation?

Katharine V Cashman, Alison C Rust, Emma J Nicholson

University of Bristol, UK

E-mail: glkvc@bristol.ac.uk

Prince Ruperts Drops (PRDs) are tadpole-shaped glass beads that are known for their unusual fracture properties: the head of the bead is very strong, but the entire bead will shatter explosively if the tail is broken. These properties result from residual stresses within the glass beads. Compressive stresses on the outer margin of the PRDs provide the strength. Tensile stresses inside the beads drive explosive fracture propagation when the outer compression zone is damaged. Fractures propagate at a rate determined by the terminal crack speed for the glass. Key to the residual stress geometry is the process by which PRDs are made, which involves dripping molten glass into water.

Water-quenching of silicate melts also occurs when rising magma encounters shallow water bodies in subglacial, submarine and sublacustrine environments. Such eruptions are known to generate more energetic eruptions, and finer particle sizes, than eruptions that do not involve an external water source. Most studies of explosive melt-water interaction are based on concepts of molten fuel-coolant interaction (MFCI), with experimental studies designed to study mechanisms of melt-water mixing. From this perspective, the energy release is determined by the efficiency of heat transfer and resulting volume expansion generated by the transformation of water to steam. Generation of fine ash particles is assumed to require brittle fragmentation, with the resulting grain size attributed to (1) the pore geometry, (2) a single episode of quench granulation, or (3) turbulent shedding of successive quenched layers.

To date, no examination of hydromagmatic volcanism has considered the role of residual stress on the fragmentation process. However, residual stress is common in air-quenched basaltic glass, as evidenced by the spontaneous ejection of glass flakes from pahoehoe flow surfaces. The blocky form of many hydromagmatic pyroclasts also suggests that fragmentation occurs in the brittle regime, although particles with the more fluidal shapes of Peles hair and Peles tears (i.e., tadpole-shaped glass beads) are not uncommon in phreatomagmatic deposits. Evidence of thermal contraction is also common as cracked outer surfaces of water-generated ash particles, as partially disaggregated surface skins on Peles tears, and as striations on the surface of blocky particles. Fragments generated by explosive disruption of PRDs show similar blocky to plately forms and surface striations. On the basis of these similarities, we suggest that residual stresses such as those that control explosive fragmentation of PRDs may contribute to fine ash production in hydrovolcanic eruptions. Spontaneous disruption of rapidly quenched glass provides a mechanism for the proposed model of fragmentation by turbulent shedding and suggests that studies of crack propagation in glasses and glass ceramics may contribute to our understanding of fragmentation processes.