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Are magma chamber boundaries brittle or ductile? Rheological insights from thermal stressing experiments

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Rheological conditions at magma chamber boundaries remain poorly understood. Many field observations of deeply-eroded and well-exposed plutons, for example Slaufrudalur and Geitafell in SE Iceland, exhibit a sharp transition between what may have been a partially or fully molten magma chamber and its surrounding brittle host rock. Some studies have suggested a more gradual change in the rheological properties of chamber boundaries, marked by a ductile halo, which is likely to exert a significant impact on their rheological response. Understanding the state and rheological conditions of magma-rock interface and interaction is essential for constraining chamber-boundary failure conditions leading to dyke propagation, onset of volcanic eruption as well as caldera fault formation.

We present results from a series of thermal stressing experiments in which we attempt to recreate the likely conditions at magma-chamber boundaries. Cores of volcanic material (25 mm diameter x 65 mm long) were heated to magmatic temperatures under controlled conditions in a horizontal tube furnace (at atmospheric pressure) and then held at those temperatures over variable dwell times. At the maximum temperatures reached, the inner part of the samples undergoes partial melting whilst the outer part remains solid. After cooling the brittle shells commonly exhibit axial, fissure-like fractures with protruded blobs of solidified melt. This phenomenon is interpreted as being the result of volume expansion during partial melting. The internal melt overpressure generates fluid-driven fractures analogous to filter-pressing textures or on a large scale, dykes. We complement our observations with acoustic emission and seismic velocity data obtained from measurements throughout the experiments. These complementary data are used to infer the style and timescale of fracture formation. Our results pinpoint the temperature ranges over which brittle fractures form as a result of internal melt overpressure in several different rock types. Application of these observations and experiments will be useful for 1) determining the influence of volume increase due to melting on rock behaviour and melt migration 2) constraining the rheological conditions at magma chamber boundaries.