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The role of crystals on vesiculation and outgassing during volcanic eruptions: Insights from 4D synchrotron experiments

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Volcanic eruption style is controlled dominantly by the efficiency with which exsolved volatiles can outgas from the magma and therefore depends on the development and longevity of magma permeability. The explosive potential, driven by the pressurizing gas phase, can be reduced if a permeable network is quickly established and remains efficient leading possibly to shifts in the activity from explosive to effusive. The percolation threshold is the critical porosity at which the transition from impermeable to permeable magma occurs and therefore exerts a primary control on the eruptive style. This threshold is dependent on porosity changing processes (vesiculation, cracking or densification) and on several additional parameters such as the bubble size distribution, the presence or absence of shear deformation, brittle fracturing and crystallinity of the magma.

To explore the influence of crystals on the percolation threshold, we performed in situ vesiculation and densification experiments of a range of crystal-bearing samples at a synchrotron x-ray computed tomography beamline (TOMCAT). For the vesiculation experiments, we sintered mixtures of spherical glass beads with different volume fractions of quartz (both 63-90 μm in diameter) at high pressure (50 bars) and high temperature (850°C). After complete sintering, the samples had a low porosity ($\sim$4 vol%) and contained only isolated bubbles preserving the experimental pressure. Samples were then loaded into alumina sleeves and were heated at pressures lower than the synthesis pressure and at temperatures above the glass transition interval using the TOMCAT laser heating system. These conditions resulted in expansion of the pressurized isolated bubbles, bubble-bubble interactions and coalescence. In complementary experiments we sintered mixtures of glass particles and quartz crystals, tracking the reduction of porosity until complete sintering. Datasets were acquired using high temporal and spatial resolution ($\sim$1 s per scan, 1.6 μm per pixel) GIGAFrost camera. Image visualization and analysis was performed using Avizo. For each experimental run the 4D data set were used to quantify the bulk vesicularity, bubble connectivity, bubble number density and permeability allowing quantification of the percolation threshold for the melts with different crystal content.

During vesiculation experiments, the presence of crystals lowers the percolation threshold Φc1 relative to crystal-free samples as the crystal network forces coalescence through chains of interconnected pore pathways. Expansion was followed by densification induced by surface tension driven contraction of a connected network. This proceeded until isolation of the porous network at a second low percolation threshold Φc2. Sintering experiments also caused densification of the porous network until a still lower percolation threshold Φc3.

The systematically low percolation thresholds found for crystal-bearing samples in these experiments are consistent with the high pore connectivity and permeability of low porosity, high crystallinity andesitic and dacitic dome rocks. Our results imply that these rocks might have formed by several cycles of expansion and densification of the porous network, pointing to a complex outgassing history. The observed role of crystals on the percolation threshold might force porous networks to remain permeable for longer than previously expected, favoring explosive-effusive transitions in crystal-bearing magma.