

Cristobalite in volcanic domes: crystallisation of a meta-stable mineral

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Cristobalite is a high-temperature, low-pressure (>1470 °C, 1 atm) crystalline silica polymorph that can persist in ambient conditions as a meta-stable mineral. It crystallises in volcanic domes through devitrification of groundmass glass and deposition from silica-saturated vapours. However, active dome environments are typically 800-900 °C, and within the stability field of the crystalline silica polymorph tridymite; this begs the question: why does cristobalite crystallise preferentially?

The nature and mode of formation of cristobalite in lava domes was investigated through analysis of 45 dome rock samples collected from 6 different dome-forming volcanoes worldwide (Colima, Merapi, Mount St Helens, Santiaguito, Soufrière Hills and Unzen). Textural (SEM imaging), compositional (EDS, WDS, CL) and structural (CL, Raman spectroscopy) analyses were combined to provide a detailed description of the physicochemical properties of cristobalite in dome rock and revealed no volcano-specific differences. Electron microprobe was used to quantify compositional purity (i.e., deviation from pure SiO₂), and showed that cristobalite contains up to 4 wt. % aluminium. In general, devitrification cristobalite contains more aluminium than vapour phase cristobalite, likely due to the local abundance of Al within glass and the high diffusivity of charge-balancing cations (e.g., Na). X-ray diffraction and differential scanning calorimetry analyses show that cation substitutions result in a disordered crystal with a low enthalpy of fusion.

We have determined experimentally that cristobalite can form below its stability field, and at dome-relevant temperatures (<1000 °C), from amorphous silica. In these experiments, doping with aluminium favours cristobalite formation, and low sintering temperatures result in poorly-ordered crystals. Although further experiments are required to set these results within the context of the complex dome environment, we rationalise the crystallisation of meta-stable cristobalite below its stability field in all domes studied through the structural incorporation of aluminium and sodium. We further suggest that the presence of these interstitial ions physically bolsters the crystal structure, preventing the immediate reconstructive phase transformation to quartz. Constraining the mechanism for cristobalite crystallisation allows us to define the origin and physicochemical properties of the crystalline silica hazard in volcanic ash to most effectively aid the risk mitigation work of disaster managers globally.