American Mineralogist, Volume 105, pages 194–226, 2020

Quartz crystals in Toba rhyolites show textures symptomatic of rapid crystallization

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Abstract

Textural and chemical heterogeneities in igneous quartz crystals preserve unique records of silicic magma evolution, yet their origins and applications are controversial. To improve our understanding of quartz textures and their formation, we examine those in crystal-laden rhyolites produced by the 74 ka Toba supereruption (>2800 km^3) and its post-caldera extrusions. Quartz crystals in these deposits can reach unusually large sizes (10–20 mm) and are rife with imperfections and disequilibrium features, including embayments, melt inclusions, titanomagnetite and apatite inclusions, spongy morphologies, hollow faces, subgrain boundaries, multiple growth centers, and Ti-enriched arborescent zoning. Using a combination of qualitative and quantitative analyses (petrography, CL, EBSD, X-ray CT, LA-ICP-MS), we determine that those textures commonly thought to signify crystal resorption, crystal deformation, synneusis, or fluctuating *P–T* conditions are here a consequence of rapid disequilibrium crystal growth. Most importantly, we discover that an overarching process of disequilibrium crystallization is manifested among these crystal features. We propose a model whereby early skeletal to dendritic quartz growth creates a causal sequence of textures derived from lattice mistakes that then proliferate during subsequent stages of slower polyhedral growth. In a reversed sequence, the same structural instabilities and defects form when slow polyhedral growth transitions late to fast skeletal-dendritic growth. Such morphological transitions result in texture interdependencies that become recorded in the textural-chemical stratigraphy of quartz, which may be unique to each crystal. Similar findings in petrologic experimental studies allow us to trace the textural network back to strong degrees of undercooling and supersaturation in the host melt, conditions likely introduced by dynamic magmatic processes acting on short geologic timescales. Because the textural network can manifest in single crystals, the overall morphology and chemistry of erupted quartz can reflect not only its last but its earliest growth behavior in the melt. Thus, our findings imply that thermodynamic disequilibrium crystallization can account for primary textural and chemical heterogeneities preserved in igneous quartz and may impact the application of quartz as a petrologic tool.

Keywords: Cathodoluminescence, EBSD, skeletal morphology, embayment, growth twinning, megacryst, supereruption, Youngest Toba Tuff