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Resolving sub-micrometer-scale zonation of trace elements in quartz using TOF-SIMS

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Abstract

Quartz is abundant in the Earth's continental crust and persistent throughout the geological record. Trace element signatures in silica minerals can be used to infer processes operating in magmatic and hydrothermal systems. Conventional analyses of trace elements in silica minerals are limited by either spatial or mass resolution [e.g., wavelength-dispersive X-ray spectroscopy, micro-X-ray fluorescence, laser ablation-inductively coupled plasma-mass spectrometry (LA-ICP-MS), and secondary ion mass spectrometry (SIMS)]. Time-of-flight SIMS (TOF-SIMS) is a relatively new technique for geological applications and provides both high spatial and mass resolution. This minimally destructive, in situ technique rapidly acquires a full suite of elements down to tens of nanometers depth. No previous study has utilized TOF-SIMS to analyze quartz or silica. Four samples of silica minerals representing distinct environments in a magmatic-hydrothermal system were characterized with optical microscopy and qualitative cathodoluminescence (CL), quantitatively analyzed for trace elements with a 157 nm LA-ICP-MS, and qualitatively mapped for trace elements using TOF-SIMS. The novel technique produced maps of trace element distribution in silica minerals to a maximum resolution of 65 nm and consistently resolved light elements (including Li) to 195 nm. That makes this study the highest resolution geochemical characterization of silica minerals and places it among the highest resolution analyses by TOF-SIMS, or any technique, for that matter. TOF-SIMS isotope maps differentiate trace elements hosted in nano- and micro-inclusions from lattice incorporation in quartz and cryptocrystalline silica—an impossibility for lower resolution techniques, allowing insights into cations substituting for Si^{4+} in the crystal lattice and their role in activating CL in low-temperature epithermal quartz. Further development of this technique could see TOF-SIMS become a routine tool for measuring diffusion profiles in a range of other geological materials. Quantification of TOF-SIMS would revolutionize mineral characterization, especially given its temporal efficiency and low-sampling volume.

Keywords: TOF-SIMS, quartz, trace element, in situ, silica