Visualizing trace element distribution in quartz using cathodoluminescence, electron microprobe, and laser ablation-inductively coupled plasma-mass spectrometry

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ABSTRACT

Cathodoluminescent (CL) textures in quartz reveal successive histories of the physical and chemical fluctuations that accompany crystal growth. Such CL textures reflect trace element concentration variations that can be mapped by electron microprobe or laser ablation-inductively coupled plasma-mass spectrometry (LA-ICP-MS). Trace element maps in hydrothermal quartz from four different ore deposit types (Carlin-type Au, epithermal Ag, porphyry-Cu, and MVT Pb-Zn) reveal correlations among trace elements and between trace element concentrations and CL textures. The distributions of trace elements reflect variations in the physical and chemical conditions of quartz precipitation. These maps show that Al is the most abundant trace element in hydrothermal quartz. In crystals grown at temperatures below 300 °C, Al concentrations may vary by up to two orders of magnitude between adjacent growth zones, with no evidence for diffusion. The monovalent cations Li, Na, and K, where detectable, always correlate with Al, with Li being the most abundant of the three. In most samples, Al is more abundant than the combined total of the monovalent cations; however, in the MVT sample, molar Al/Li ratios are ∼0.8. Antimony is present in concentrations up to ∼120 ppm in epithermal quartz (∼200–300 °C), but is not detectable in MVT, Carlin, or porphyry-Cu quartz. Concentrations of Sb do not correlate consistently with those of other trace elements or with CL textures. Titanium is only abundant enough to be mapped in quartz from porphyry-type ore deposits that precipitate at temperatures above ∼400 °C. In such quartz, Ti concentration correlates positively with CL intensity, suggesting a causative relationship. In contrast, in quartz from other deposit types, there is no consistent correlation between concentrations of any trace element and CL intensity fluctuations.

Keywords: Quartz, trace elements, cathodoluminescence, LA-ICP-MS, electron microprobe

INTRODUCTION

Quartz is the most abundant mineral in the Earth’s crust. It forms in a wide range of geologic environments and it is the most abundant gangue mineral in many hydrothermal ore deposits. Scanning electron microscope-cathodoluminescence (SEM-CL) reveals textures in quartz that are not visible by traditional petrographic methods. These textures provide a record of the sequence of quartz precipitation and dissolution in a sample. CL textures are caused by both intrinsic structural defects and extrinsic defects, such as those related to the substitution of trace elements into the crystal lattice (Götze et al. 2001, 2004).

Concentrations of trace elements in quartz reflect the physical and chemical environment of quartz precipitation such as pressure and temperature (Wark and Watson 2006; Thomas et al. 2010) or paleo-pH of hydrothermal fluids (Rusk et al. 2008). Thus, CL textures combined with trace element quantification illustrate fluctuations in quartz crystallization conditions through time in various geologic environments (Götze et al. 2005; Wark et al. 2007; Larsen et al. 2009; Lehmann et al. 2009). Typically, individual spot analyses are used to infer relationships among trace elements and between trace elements and CL intensity. Few studies clearly illustrate the distribution of trace elements in quartz via element mapping (Lehmann et al. 2009; Rusk et al. 2008) and those that do are limited to showing the distribution of Ti and Al (and rarely K) because most other elements in quartz are not present in high enough abundance to be mapped by electron microprobe (EMP) or secondary ion mass spectrometry (SIMS). Laser ablation-inductively coupled plasma-mass spectrometry (LA-ICP-MS), however, has far lower detection limits for most elements, and has the potential to reveal new insights into a wide range of geologic processes (Large et al. 2009; Koenig et al. 2009; Ulrich et al. 2009).

To illustrate the relationships between CL textures and trace elements, we used LA-ICP-MS and EMP wavelength-dispersive spectrometry (WDS) to map trace elements in quartz from hydrothermal ore deposits that formed between ∼150° and ∼750 °C. Using the two techniques together on the same sample combines the high spatial resolution of the EMP with lower detection limits and wider element range of the LA-ICP-MS. The trace element maps provide direct visual evidence for correlations...