Correlations between cathodoluminescence intensity and aluminum concentration in low-temperature hydrothermal quartz

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ABSTRACT

Quartz cathodoluminescence (CL) images are commonly combined with trace element concentrations to decipher complex histories of hydrothermal systems. However, the correlations between aluminum content and CL zoning of low-temperature hydrothermal quartz and their genesis remain controversial. In this contribution, a multiparametric study was carried out on CL-aluminum zoning of low-temperature hydrothermal quartz (≤350 °C) from the Shihu and Rushan quartz-vein type Au deposits in the North China Craton. The results show that aluminum concentration correlates negatively with CL intensity in quartz from the Shihu Au deposit. CL-dark quartz zoning has significant Al concentrations as well as detectable Al-H bonds. However, in the Rushan Au deposit, the correlation is positive, and aluminum is enriched in the CL-bright quartz zoning. The Al content is positively correlated with K content with \( r^2 = 0.769 \). Combined with the electron backscatter diffraction (EBSD), X-ray single crystal diffraction (XRD), and transmission electron microscope (TEM) data, we infer that the genesis of CL zoning in the low-temperature hydrothermal quartz is closely related to \( Al^{3+}-H^+ \) and \( Al^{3+}-K^+ \) concentrations. The \( Al^{3+}-K^+ \) may act as the CL-activator, while the \( Al^{3+}-H^+ \) may act as the CL-dampener. Where \( Al^{3+}-Si^4+ \) substitution is charge balanced by hydrogen, the intensity of CL response decreases; where \( Al^{3+}-Si^4+ \) substitution is charge balanced by potassium, the intensity of CL response increases. The correlations between CL intensity and aluminum concentration in the low-temperature hydrothermal quartz reflect pH fluctuations of hydrothermal system.

Keywords: Shihu and Rushan Au deposits, low-temperature hydrothermal quartz, cathodoluminescence, \( Al^{3+}-H^+ \) and \( Al^{3+}-K^+ \) concentrations, pH

INTRODUCTION

Cathodoluminescence (CL) images can effectively visualize the micro-textures that record complex histories of quartz precipitation and dissolution (Rusk and Reed 2002; Götte et al. 2001, 2005; Barbee et al. 2020). Concentrations of trace elements reflect the growth processes and physio-chemical conditions during quartz growth, such as pressure, temperature, and pH (Wark and Watson 2006; Thomas et al. 2010; Acosta et al. 2020). Therefore, CL images combined with trace element concentrations in quartz are extensively used to obtain insight into quartz vein formation processes, especially in magmatic systems (Watt et al. 1997; Penniston-Dorland 2001; Monecke et al. 2002; Redmond et al. 2004). Müller et al. (2005) used CL zones of quartz to reveal multiple magma-mixing processes in the eastern Erzgebirge volcano-plutonic complex (Germany, Czech Republic). Allan and Yardley (2007) used scanned CL and trace elements of quartz to track the meteoric water infiltration into a magmatic-hydrothermal system in the Mt. Leyshon, porphyry deposit, Australia. Takashi et al. (2020) evaluated the cooling processes of the Toki granitic pluton by using (CL) oscillatory-zoned quartz. Such studies have helped to better understand the magmatic processes, the origin of granites, and the genesis of porphyry deposits (Watt et al. 1997; Müller et al. 2005; Takashi et al. 2020). However, there is a lack of application of CL to low-temperature hydrothermal deposits due to the controversy concerning the genesis of CL zoning.

Several studies have explored the coupling relationships between CL intensity and trace element concentrations in quartz crystals (Müller et al. 2000, 2002; Penniston-Dorland 2001; Rusk et al. 2011). The formation process of CL-trace element zoning in high-temperature quartz (>350 °C; Rusk et al. 2008) shows that CL intensity variations in the high-temperature quartz are positively correlated with trace element concentrations, such as Ti, Al, K, Na, H, Li, and P (Götte et al. 2004; Landtwing and Pettke 2005; Wang et al. 2022). The genesis of CL zoning of low-temperature hydrothermal quartz (<350 °C; Rusk et al. 2008; Qiu et al. 2021) is different from that of the high-temperature quartz and demonstrably more complex. Correlations between CL intensity and trace elements in low-temperature hydrothermal quartz are varied. For example, in most low-temperature hydrothermal quartz [such as quartz in the Magmont, Comstock Lode, and Butte Main Stage deposits (Rusk et al. 2008)], aluminum concentration correlates positively with CL intensity, but in some low-temperature hydro-