Textural, fluid inclusion, and in-situ oxygen isotope studies of quartz: Constraints on vein formation, disequilibrium fractionation, and gold precipitation at the Bilihe gold deposit, Inner Mongolia, China

XUEYUAN QIAO¹, WENBO LI¹*, LEJUN ZHANG²†, FANGHUA ZHANG¹, XUEFENG ZHU³, AND XIAOPING XIA⁴‡

¹Key Laboratory of Orogenic Belt and Crustal Evolution, School of Earth and Space Sciences, Peking University, Beijing 100871, China
²Centre for Ore Deposit and Earth Sciences (CODES) University of Tasmania, Private Bag 79, Hobart 7001, Australia
³School of Mining and Coal, Inner Mongolia University of Science and Technology, Baotou 014010, China
⁴State Key Laboratory of Isotope Geochemistry, Guangzhou Institute of Geochemistry, Chinese Academy of Sciences, Wushan, Guangzhou 510640, China

ABSTRACT

Bilihe is a porphyry gold deposit located in the northern margin of the North China Craton (NCC), Inner Mongolia, China. Different stages of quartz are well developed at this deposit. To document the history of quartz deposition, the fluid evolution and gold precipitation events of the deposit and the detailed oxygen isotope signatures of quartz from Bilihe were studied using high-resolution secondary ion mass spectroscopy (SIMS), then integrated with scanning electron microscope-cathodoluminescence (SEM-CL) and fluid inclusion microthermometry. The SEM-CL features show that the hydrothermal veins at Bilihe have a complex growth history, with multiple generations of quartz developed in each set of veins. Fluid inclusions in different quartz stages yield variable homogenization temperatures, ranging from 178 °C to above 600 °C. These quartz stages exhibit variable δ18O values of 3.5–15.4‰, corresponding to δ18Ofluid ranging from –8.7 to 12.0‰. There are two abnormal peaks of δ18Oquartz and δ18Ofluid values occurring in a sub-generation of A type veins and auriferous-banded quartz veins, suggesting that the vein quartz may have experienced sporadic disequilibrium oxygen fractionation with water when crystallizing, thus resulting in local 18O-enrichment. The overall δ18Ofluid Values, which show a gradual decrease from early to late stages, suggest a progressive decrease in the proportion of magmatic hydrothermal fluids. The relationship between quartz textures and gold occurrence shows that gold precipitated twice at Bilihe. The first precipitation in the UST quartz may have resulted from rapid cooling and indicates that the addition of meteoric water was not necessary for gold precipitation, whereas the progressive incursion of meteoric water probably had a significant effect on the second gold precipitation event.

Keywords: Porphyry gold deposit, quartz, cathodoluminescence, in situ oxygen isotopes, magmatic-hydrothermal evolution, disequilibrium fractionation

INTRODUCTION

Porphyry ore deposits are an important source of copper, molybdenum and gold (Sillitoe 2010). The magmatic-hydrothermal evolution of porphyry ore-forming systems has been extensively studied using bulk sample isotopic analysis. Quartz veins are a characteristic feature of porphyry deposits (Sillitoe 2010; Richards 2011), and quartz crystals can be valuable indicators of fluid origin, as their oxygen isotopic composition is derived from the parental fluid, with the fluid-quartz fractionation factor controlled by temperature at isotopic equilibrium conditions (Matsuhisa et al. 1979). Oxygen isotopes, combined with hydrogen isotopes, have been widely used to constrain the source and evolution of ore-forming fluids (Taylor 1974). An important factor for oxygen isotope calculations is the requirement that isotopic equilibrium fractionation was achieved between quartz and the aqueous fluid. However, very complex zoning in porphyry-related quartz is commonly observed in cathodoluminescence (CL) images (Rusk et al. 2008), and extreme δ18Oquartz heterogeneity is commonly observed in individual quartz grains (Allan and Yardley 2007; Tanner et al. 2013). These suggest that isotopic fractionation during quartz growth may not have been achieved under equilibrium, which would greatly affect the calculation of δ18Ofluid. In most studies, the variations of oxygen isotope compositions or isotopic dynamic disequilibrium fractionation during quartz growth are difficult to identify and overlooked, especially when using bulk sample isotopic analysis. Consequently, the final calculated δ18Ofluid may be not representative.

The texture of quartz is also a useful monitor of fluid characteristics (e.g., composition and temperature) in hydrothermal processes (Rusk and Reed 2002). Crystal size, zones, generations, and fluid inclusion properties are valuable indicators of growth history. Variations in CL intensity are generally considered to be in response to structural defects or differences in chemical composition (Allan and Yardley 2007; Rusk and Reed 2002). Variations of δ18Oquartz and calculated δ18Ofluid in different CL...