

Reconstructing volatile exsolution in a porphyry ore-forming magma chamber: Perspectives from apatite inclusions

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ABSTRACT

Porphyry-type deposits in the shallow crust (3–5 km) are formed from metal-rich fluids exsolved from underlying magma chambers (5–15 km). However, a direct volatile record of the fluid exsolution in the magma chamber is commonly lacking. Here, we analyze the compositions of apatite inclusions (in biotite and plagioclase phenocrysts and fully/partly included in zircon microphenocrysts) and the apatite in groundmass from the largest Cretaceous Luoboling porphyry Cu-Mo deposit in South China. In combination with thermodynamic models, we reconstructed the volatile behavior in the ore-forming magma. The analyzed apatites are magmatic in origin, without hydrothermal overprint, as indicated by their homogeneous cathodoluminescence (CL) and higher Cl and REE contents than typical hydrothermal apatite. Apatite inclusions fully enclosed in zircon show decreasing $X_{\text{Cl}}^{\text{Ap}}/X_{\text{OH}}^{\text{Ap}}$ (1.5–0.1) with increasing $X_{\text{F}}^{\text{Ap}}/X_{\text{OH}}^{\text{Ap}}$ (0.4–3.3) and $X_{\text{F}}^{\text{Ap}}/X_{\text{Cl}}^{\text{Ap}}$ (0.5–21), and display a steep drop in $X_{\text{Cl}}^{\text{Ap}}$ at approximately constant $X_{\text{OH}}^{\text{Ap}}$ in the ternary F-Cl-OH plot. These trends follow the modeled compositional trajectories of isobaric, H₂O-saturated crystallization, indicating volatile exsolution during or before zircon crystallization in the magma chamber. Groundmass apatite crystals, phenocryst-hosted apatite inclusions, and apatite inclusions that are partially enclosed by zircon microphenocrysts have comparable volatile compositions, with much higher $X_{\text{F}}^{\text{Ap}}/X_{\text{OH}}^{\text{Ap}}$ (1.7–78.8) and $X_{\text{F}}^{\text{Ap}}/X_{\text{Cl}}^{\text{Ap}}$ (2.3–37.5) but lower $X_{\text{OH}}^{\text{Ap}}$ and $X_{\text{Cl}}^{\text{Ap}}$ than those fully enclosed in zircon. Compositional similarities between these crystals in different textural associations indicate that the phenocryst-hosted apatite inclusions do not preserve their original volatile records at the time of entrapment, and the volatile compositions were overprinted by later re-equilibration with the residual melt and the exsolved magmatic fluids. Given the porphyry magma is highly oxidized, and sulfides phases would be unstable in such circumstance, we suggest that volatile exsolution in the magma chamber is essential for Cl and Cu-Mo extraction from the melts and therefore the porphyry mineralization. In this study, only zircon-hosted apatite inclusions appear to best record the magmatic volatile compositions in a porphyry system. Therefore, using apatite hosted in other minerals or groundmass compositions to unravel magma volatile contents in porphyry Cu systems should be conducted with caution.

Keywords: Porphyry deposit, apatite inclusions, volatile exsolution, diffusional re-equilibration