
Evidence from fluid and melt inclusions for synchronous sulfide melt oxidation and aqueous-carbonic fluid exsolution in intrusion-related gold deposits

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Granitic rocks within the giant intrusion-related Au-Bi-Te deposit at Fort Knox, Alaska, contain a well-preserved inclusion record of magmatic-hydrothermal transition and processes that were potentially critical for the development of the sheeted ore system. Early magmatic titanite grains contain (in their cores) inclusions of an iron sulfide melt that were trapped coevally with silicate melt inclusions at a minimum temperature of 780 °C (based on O₂ geobarometry). Textural and mineralogical evidence indicates that this sulfide melt phase was stable until a relatively late stage in the crystallization history of the granites, but was destabilized due to a progressive increase in oxygen fugacity. Laser ablation ICP-MS analyses of the sulfide melt inclusions show that they contain between 200 and 1800 ppm Cu, and concentrations of Ag, As, Bi, Sb, Te, W, Mo and Ni in the 10–100 ppm range. Notably, Au was detected in the sulfide melts at concentrations in the 1–3 ppm range. Analyses of the coeval silicate melt inclusions allow the calculation of sulfide-silicate melt partition coefficients. Values of $D(\text{sulfide/silicate})$ are between 10 and 100 indicating that the sulfide droplets would have contained the majority of the ore metals present in the system while they were stable. Remarkably, selected metal ratios in the sulfide melt droplets (e.g., Bi/Au) are identical to those in the sheeted ore veins at Fort Knox, suggesting that the sulfide melts. This would suggest that ore-forming processes that occurred after the destabilization of the sulfide droplets (i.e., silicate melt-fluid partitioning, and metal coprecipitation) did not fractionate the ore metals from one another. Textural evidence shows that during titanite growth, apatite saturation occurred. Apatite grains trapped coexisting primary inclusions containing silicate melt and a low salinity (~4–6 wt% eq. NaCl based on clathrate melting temperatures), aqueous-carbonic fluid (CO₂ ~21–39 vol%). These coeval melt and fluid inclusions in apatite provide unambiguous evidence for the saturation of the granitic magma in fluid phase. The fluid inclusions decrepitate at ~400 °C; however, apatite-biotite halogen exchange thermometry indicates that the inclusions were trapped at a minimum T of 560–680 °C.

The results show that ore-forming granitic magmas were saturated in a Au-Bi-Te-rich sulfide melt phase. Resorption of the sulfide melt appears to have coincided with saturation of the crystallizing magma in a low salinity aqueous-carbonic fluid. Sulfide melt that persists to a relatively late stage of magma crystallization may act as an important storage phase for ore metals, preventing the loss of ore metals to (i) fluids

that exsolve early on when the magma is insufficiently brittle to auto-generate mineralized sheeted veins, and (ii) crystallizing minerals in which metals such as Au are compatible (e.g., magnetite, biotite, titanite). Systematic identification and analysis of sulfide melt inclusions in granitic ore-forming settings significantly “inboard” of convergent plate margins may find application in locating highly mineralized granites and predicting the metal associations and metal ratios to be expected in the ores.