Nanomineralogy of hydrothermal magnetite from Acropolis, South Australia: Genetic implications for iron-oxide copper gold mineralization

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Abstract

Magnetite is the dominant Fe-oxide at the Acropolis IOCG prospect, Olympic Dam district, South Australia. Complementary microbeam techniques, including scanning transmission electron microscopy (STEM), are used to characterize titanomagnetite from veins in volcanic rocks and Ti-poor magnetite from a granite body with uplifted position in the volcanic sequence. A temperature of 670 ± 50 °C is estimated for Ti-poor magnetite using XMg-in-magnetite thermometry. Titanomagnetite, typified by Ti-rich trellis lamellae of ilmenite in magnetite, also displays sub-micrometer inclusions forming densely mottled and orbicular subtypes of titanomagnetite with increasing degree of overprinting. STEM analysis shows nanoparticles (NPs) of spinels and TiO2 polymorphs, anatase, and rutile. These vary as dense, finest-scale, monophase-NPs of spinel sensu stricto in Ti-poor magnetite; two-phase, ulvöspinel-hercynite NPs in primary titanomagnetite; and coarser clusters of NPs (hercynite±gahnite±TiO2-polymorphs), in mottled and orbicular subtypes. Nano-thermobarometry using ilmenite-magnetite pairs gives temperatures in the range ~510–570 (±50) °C, with mineral-pair re-equilibration from primary to orbicular titanomagnetite constrained by changes in fO2 from ilmenite-stable to magnetite+hematite-stable conditions. Epitaxial relationships between spinel and Fe-Ti-oxides along trellis lamellae and among phases forming the NPs support exsolution from magnetite ss, followed by replacement via mineral-buffered reactions. Lattice-scale intergrowths between ulvöspinel and ilmenite within NPs are interpreted as exsolution recording cooling under O2-conserving conditions, whereas the presence of both TiO2-polymorphs displaying variable order-disorder phenomena is evidence for subtly fO2-buffered reactions from anatase (reducing) to rutile (more oxidizing) stabilities. Transient formation of O-deficient phases is retained during replacement of ilmenite by anatase displaying crystallographic-shear planes. Development of dense inclusion mottling and orbicular textures are associated with NP coarsening and clustering during vein re-opening. Fluid-assisted replacement locally recycles trace elements, forming gahnite NPs or discrete Sc-Ti-phases. Hydrothermal titanomagnetite from Acropolis is comparable with magmatic magnetite in granites across the district and typifies early, alkali-calcic alteration. Open-fracture circulation, inhibiting additional supply of Si, Ca, and so on during magnetite precipitation, prohibits formation of silician magnetite hosting calc-silicate NPs, as known from IOCG systems characterized by rock-buffered alteration of host lithologies. Obliteration of trellis textures during subsequent overprinting could explain the scarcity of this type of hydrothermal magnetite in other IOCG systems.

Keywords: Titanomagnetite, HAADF STEM, nanoparticles, spinels, Fe-Ti-oxides, IOCG, Acropolis

Introduction

Magnetite and related spinel group minerals are common accessories in igneous rocks, forming during magmatic crystallization, often before the rock-forming silicates (Bowles et al. 2011). The ubiquitous presence of Ti in igneous magnetite and the occurrence of ilmenite lamellae along crystallographic directions (trellis titanomagnetite) has prompted development of thermobarometric models based upon magnetite-ilmenite pairs with equilibrium T-fO2 conditions constrained from experimental studies (e.g., Buddington and Lindsay 1964). Such models have been widely applied to magnetite-ilmenite pairs at the micrometer-scale, and recently also at the nanoscale (Righter et al. 2014). Titanomagnetite formed from Fe-rich melts display the greatest Ti concentrations and most varied textures. These represent the main ore component of large Fe-Ti-V-deposits hosted by layered intrusions (e.g., Zhou et al. 2005). Sizable accumulations of Ti-bearing magnetite are known from several deposits and are subject to an ongoing debate in recent literature in terms of magmatic vs. hydrothermal origins. The Los Colorados deposit (Chile) is one example where nanoscale characterization of magnetite has been used to support a hydrothermal origin (Deditius et al. 2018).