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# 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 $X_{Mg}$-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 $TiO_2$ 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+$TiO_2$-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 $f_{O_2}$ 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 $O_2$-conserving conditions, whereas the presence of both $TiO_2$-polymorphs displaying variable order-disorder phenomena is evidence for subtly $f_{O_2}$-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, K, 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