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Ferro-tschermakite with polysomatic chain-width disorder identified in silician magnetite from Wirrda Well, South Australia: A HAADF STEM study

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Abstract

Silician magnetite within ~1.85 Ga lithologies hosting the ~1.6 Ga Wirrda Well iron oxide copper gold (IOCG) prospect, South Australia, was examined at the nanoscale. The magnetite is oscillatory-zoned with respect to the density and orientation of nanometer-scale inclusions, among which Si-Fe-nanorods and Al-rich amphibole (as much as hundreds of nanometers long and tens of nanometers wide) form swarms along <111> directions in magnetite. The amphibole is identified as ferro-tschermakite (Ftsk) with the crystal-chemical formula: $^{A}(K_{0.06}Na_{0.01})_{0.07}{}^{B}(Ca_{1.65}Na_{0.35})_2{}^{C}(Fe^{2+}_{2.07}Al_{1.64}Mg_{1.15}Ti_{0.06}Fe^{3+}_{0.04}Mn_{0.04})_5{}^{T}(Si_{6.48}Al_{1.52})_8O_{22}{}^{W}(OH)_2$. This contains single and double rows of a triple-chain silicate attributed to clinojimthompsonite (Cjt) as coherently intergrown (010) zippers along the entire length of the grains. High-angle annular dark-field scanning transmission electron microscopy (HAADF STEM) imaging and simulation of Ftsk and Cjt on the [001] zone axis provide direct visualization of crystal structures. These are defined by the 7- and 10-atom octahedron strips (*B*+*C* sites) and flanked by double- and triple-pairs of Si atoms (*T* sites). Remarkably, the sites for light cations and/or vacancies are clearly imaged as single and double, darkest, diamond-shaped motifs separating the octahedron strips showing that *A* cavities known in amphibole are readily depicted in the wider-chain silicate. *I-beam* models show that nanoscale intergrowths among the two silicates are coherent along zigzag chains of cations at the edges of the octahedron strips, with single and double rows of the triple-chain silicate corresponding to 1 and 1.5 unit cells of Cjt (27 and 41 Å intervals along the *b* axis). This type of polysomatic chain-width disorder is widely reported in Mg-rich pyriboles but is shown here in an Al-Fe-rich amphibole. The lack of planar defects and/or reaction fronts at mutual contacts between three-chain zippers and host amphibole indicates primary co-crystallization growth, promoted by the formation of the Si-Fe-nanorods. Co-crystallizing plagioclase is also preserved in close vicinity to the amphibole hosted by magnetite (from a few nanometers to micrometers apart). In contrast, the replacement of amphibole by phyllosilicates is recognizable as irregular swells along the (010) zippers and results in extensive chloritization of the amphibole during an overprinting event. Pressures of ~11.5 kbar are estimated using Al-in-hornblende nano-geobarometry and calculated Al content in Ftsk (3.16 apfu). Assuming the amphibole-plagioclase association buffered by host magnetite fulfills the textural equilibration criteria required for application of this barometer, we interpret the Ftsk nanoinclusions in magnetite as preserved evidence for amphibolite facies metamorphism affecting host lithologies at Wirrda Well with subsequent retrograde alteration during the ~1.6 Ga IOCG mineralizing event. Magnetite records petrogenetic processes by accommodating variable ranges of nanomineral inclusions and preserving them over geological time scales. HAADF STEM imaging is ideally suited to the depiction of crystal-structural modularity and also provides insights into the evolution of geological terranes with protracted histories.

Keywords: Silician magnetite, ferro-tschermakite, clinojimthompsonite, polysomatic chain-width disorder, pyriboles, HAADF STEM