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Polysomatic intergrowths between amphiboles and non-classical pyriboles in magnetite: Smallest-scale features recording a protracted geological history

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Abstract

Non-classical pyriboles (NCPs) have tetrahedral silicate chains (I_{beam}) of multiplicity higher than single (pyroxene) or double (amphibole) I_{beams} and are known from amphiboles in altered mafic-ultramafic complexes. NCPs, their polysomatic sequences, and inherent chain-width disorder are petrogenetic tools for interpreting igneous and metamorphic processes. Magnetite, a refractory mineral that can trap and preserve NCPs is a major constituent of iron oxide-copper-gold (IOCG) deposits. We undertook a nanoscale study to show that NCPs and amphiboles are hosted within magnetite cores from the Jatobá Ni-bearing IOCG deposit, Carajás Mineral Province, Brazil. Monoclinic amphiboles and NCPs form polysomatic intergrowths or occur as sparse inclusions along $\{111\}_{magnetite}$. There are two chemical populations of amphiboles: Mg-Fe- and Ca-(Al)-amphiboles, the latter including Ce-bearing Mg-hornblende and (ferro)tschermakite. The occurrence contains one of the widest ranges of chain silicates ever recorded, from simple intergrowths of single to triple I_{beam} zippers, including pyroxene slabs, to longer NCP polysomes up to 15-I_{beam} chains. Clinojimthompsonite (Cjim) is observed for the first time within magnetite. Although no discrete polysomes could be defined, the NCP-amphibole intergrowths have compositions between Mg-Fe amphiboles and Cjim based on I_{beam} averages of 2.5–2.7. Relationships between increase in the number of C and A cations from amphibole (2-I_{beam}) to n chain silicates (nI_{beam}) are formulated as $nI_{beam} = T(2 + n) = C(5 + 3n) = A(1 + n)$, n = integer. Empirical models of crystal structures, validated by STEM simulation, are shown for 4- and 5-I_{beam} chain silicates. Co-crystallization of double- and triple-chain silicate structures with rhythmic intergrowths as larger blocks along *b* is often accompanied by rhythmic Ca-Fe zonation along *a*, supporting primary NCP crystallization via self-patterning during amphibole growth within magnetite in a close-to-equilibrium system. Chain-width disorder is documented from defects including planar faults, derailments, jogs, and swells.

Violations of zipper termination rules indicate primary growth rather than replacement. Amphibole-NCPs inclusions support a multi-stage evolution for Jatobá magnetite. They formed during the first cycle of magnetite overprinting within a mafic/ultramafic lithology that records syn-shearing events. Subsequent formation of calcic-amphiboles, including Ce-bearing species, indicate IOCG-related fluids at the onset of mineralization. (Ferro) tschermakite formed at ~7.5 kbar during high-pressure shearing is preserved during main ore deposition. The multi-stage amphibole-NCPs generations in magnetite revealed by our nanoscale study emphasize the interpretive value of magnetite for overprinting events in terranes with protracted geological histories. Analogous NCPs are likely to be abundant in magnetite from magmatic-hydrothermal deposits hosted by greenstone belts and altered mafic/ultramafic complexes. Likewise, discovery of Ce-rich hornblende provides new avenues to understand the early, alkali-calcic alteration stages of IOCG systems and models for REE incorporation into, and subsequent release from chain silicates.

Keywords: Non-classical pyriboles, (Ce-bearing) amphiboles, magnetite, polysomatic sequences, chain-width disorder, Jatobá Ni-IOCG deposit