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Hydrothermal alteration in the Furnas iron oxide-copper-gold deposit, Carajás Province: evidences of a high-temperature magmatic-hydrothermal system.

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The Carajás Mineral Province, located in the southeastern portion of the Amazon Craton, hosts a variety of world-class iron oxide-copper-gold deposits (IOCG), which have been considered as formed in multiple events during the Neoarchean and/or Paleoproterozoic.
The Furnas copper-gold deposit (500 Mt @ 0.7% Cu) occurs along a 9 km-long WNW-ESE trend within the Cinzento Transcurrent Fault. The deposit is hosted by the Furnas granite and metavolcano-sedimentary units of the Neoarchean Grão Pará Group, Itacaiúnas Supergroup. The latter are intercepted at the eastern part of the Furnas deposit by the ca. 1.88 Ga Cigano Granite. The footwall zone of the Furnas deposit comprises andalusite-muscovite-biotite-rich rocks, whereas in the hanging wall zone (garnet)-biotite-actinolite-bearing rocks with expressive intercalations of garnet-biotite-rich rocks occur. Relicts of the Furnas granite are also recognized within extremely hydrothermally altered rocks.
All host rocks record intense hydrothermal alteration. The Furnas granite underwent an early stage of sodic alteration (albite) followed by silicification and potassic alteration (biotite), resulting in variably mylonitized quartz- or biotite-rich rocks. Silicification controlled by mylonitic foliation was previous to potassic alteration, as evidenced by biotite crosscutting quartz. However, silicification also overprinted zones with potassic alteration, obliterating the mylonitic foliation and reflecting recurrence of silicification stages.
Garnet-biotite-rich rocks have syn- to post-tectonic almandine porphyroblasts and layers composed of fine-grained euhedral garnet. In some zones, these rocks evolved to garnet-rich rocks made of coalescent garnet crystals, which may represent hydrothermal alteration fronts. Widespread grunerite formation in garnet-biotite-rich rocks and andalusite-muscovite-biotite-rich rocks results in conspicuous grunerite alteration zones with garnet and andalusite “ghost” crystals.
Hydrothermal magnetite formation was expressive, forming rocks composed of up to 50-60% of magnetite. Initially magnetite replaces almandine porphyroblasts and coalescent garnet crystals and also defines thin layers parallel to the mylonitic foliation. Magnetite alteration evolves to partial or total replacement of previous alteration zones with grunerite. Late silicification fronts controlled by brittle-ductile structures are accompanied by proximal coarse-grained hornblende-(actinolite) and distal chlorite halos.
The main copper-gold ore is composed of chalcopyrite and bornite, which occur in replacement fronts in garnet-grunerite-magnetite-rich rocks, veins and veinlets. In silicified zones, bornite and chalcopyrite infill network of fractures and represent the cement of hydraulic breccias within quartz fragments. Minor late mineralization is associated with quartz-(actinolite-chlorite) veins with open-space filling texture.
Alteration styles at Furnas deposit are associated with different deformational regimes and crustal levels, suggesting multiple stages of alteration and mineralization. The succession of almandine, grunerite and magnetite implies in high-temperatures during the early alteration stages controlled by ductile to ductile-brittle structures. Copper mineralization likely occurred at the brittle-ductile and brittle transition. This could point to an evolved hydrothermal system developed at relatively shallow