Metallogenetic evolution of the Aquiri Hub: geochemical and isotopic contrasts between the AQW1-AQW2 and AQW7 Cu-Au deposits, Carajás Province

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The copper-gold deposits of the Aquiri Hub, located in the western portion of the Carajás Province, represent an underexplored area despite its significant importance to the mineral industry. This study aims to reveal the metallogenetic evolution of the hydrothermal system associated with the AQW1, AQW2, and AQW7 copper-gold deposits. The hydrothermal alteration fronts and mineralization in these deposits are structurally controlled and coeval with the development and/or reactivation of regional shear zones. The host rocks of AQW1, AQW2, and AQW7 belong to the Neoarchean Itacaiúnas Supergroup and intrusive gabbro, with subordinate occurrences of non-mineralized granites, pegmatite, and undifferentiated mafic dikes. The hydrothermal alteration patterns, mineralization control, and mineral association are similar in the AQW1-AQW2 deposits and distinct at AQW7. The IOCG (Iron Oxide-Copper-Gold) mineralization in the AQW1-AQW2 deposits is temporally and spatially associated with the Fe-Ca (magnetite-hastingsite-apatite) followed by Fe (grunerite-almandine-tourmaline) alteration stages. In addition to copper-gold mineralization (chalcopyrite±bornite), these mineral deposits exhibit significant Co, U, P, Fe, and LREE contents. Changes in V and Cr contents in zoned tourmaline in the AQW2 deposit indicate sufficiently oxidizing conditions of the parental fluid in the early IOCG stages. In the AQW1 deposit, negative Eu and slightly positive Ce anomalies in apatite from the initial Fe-Ca alteration also suggest oxidized conditions. The significant variation in LREE content suggests that metasomatic apatite underwent significant dissolution-reprecipitation due to interaction with retrograde fluids. The approximately concentric garnet zoning in the AQW1 and AQW2 deposits reflects the higher REE concentrations in the garnet cores. In the AQW7, however, the copper mineralization with chalcopyrite-(pyrrhotite) is related to a skarn stage developed close to the gabbro contact with siliciclastic units. The skarn paragenesis evolved from a progressive stage with diopside, later replaced by retrograde hornblende-albite and actinolite-epidote-clinozoisite. Highly reduced and saline conditions are suggested in the progressive skarn stage, evidenced by hydrothermal graphite in the gabbro and three-phase (liquid-vapor-halite?) primary fluid inclusions hosted in diopside, bearing CH_4, as evidenced by Raman analysis. A late hydrothermal event at AQW7 is represented by fault-controlled quartz-chalcopyrite-pyrite veins enveloped by chlorite halos. Magmatic sulfur sources are suggested for the AQW1 and AQW2 deposits, while thermochemical reduction of marine sulfates was likely associated with the sulfur source in the AQW7 deposit. Magmatic carbon, similar to that of carbonatites, is also indicated by the isotopic C and O signatures in late-stage calcite of the AQW2 and AQW7 deposits. In situ U-Pb (apatite) and Lu-Hf (garnet) geochronological analyses reveal overprinting ages related to hydrothermal-metallogenetic events in the AQW1-AQW2 deposits, with

the onset of copper mineralization around 2.7 Ga and mineralization synchronous with a significant tectonic-thermal event at 2.5 Ga, coinciding with the reactivation of the Cinzento Shear Zone. Collectively, the data point to a long-term evolution in the Aquiri Hub, with hydrothermal events overlapping in contrasting physicochemical conditions.