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Trace Element Compositions and Cathodoluminescence Textures of Apatite from Neoarchean and Paleoproterozoic Fe Oxide Cu-Au (IOCG) Deposits of the Carajás Province, Brazil

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Apatite is a common accessory mineral in either hydrothermally altered or mineralized zones of several iron oxide copper-gold deposits (IOCG) of the Carajás Province, northern Brazil. It mainly occurs as individual prismatic- to ovoid-shaped crystals of variable sizes (up to 10 cm wide), which are paragenetically related to sulfide-rich ore zones. Additionally, apatite may be associated with early sodic-calcic alteration, eventually accompanying the formation of massive magnetite-rich bodies. Based on in situ LA-ICP-MS data of apatite, combined with cathodoluminescence (CL) imaging, we investigate morphological and compositional variations among apatite from six IOCG deposits of Carajás formed during the Neoarchean (ca. 2.7 and 2.5 Ga) and the Paleoproterozoic (ca. 1.8 Ga). Apatite from all deposits contains low amounts of Na_2O (<0.05 wt %), Mn (<360 ppm), and Ba (<35 ppm), and low to moderate Fe (<8400 ppm), Mg (≤1400 ppm), and Sr (<635 ppm) contents. Ore-related apatite from the ca. 1.88 Ga Sossego orebody (Sossego deposit) displays brownish-yellow luminescence and has the most fractionated REE+Y (REY) distribution, with significant LREE enrichment (Ce/Yb_{CN} = 3.084–60.430) and moderate negative Eu anomalies (Eu/Eu* = 0.423–0.569). Similarly, apatite from the 2.7 Ga Sequeirinho orebody (Sossego deposit) is LREE-enriched (Ce/Yb_{CN} = 1.408–16.896) and shows orange-brown luminescence; it demonstrates lower total REY contents (206.043–1423.255 ppm) but larger negative Eu anomalies (Eu/Eu* = 0.311–0.436). In contrast, apatite from the ca. 2.57 Ga Igarapé Cinzento (GT-46) and ca. 1.88 Ga Alvo 118 deposits is characterized by a distinct HREE enrichment (Ce/Yb_{CN} = 0.323–1.351 and 0.316–0.765, respectively) and exhibits positive Y anomalies. Under CL light, apatite crystals at GT-46 are predominantly dull yellowish-green and may show sectorized darker blue zones, whereas apatite from the Alvo 118 deposit is generally bluish-grey. Within the main orebody of the ca. 2.57 Igarapé Bahia deposit, apatite displays bright greenish-yellow rims with darker cores and have overall higher Sr (318.244–631.401 ppm) contents. Chondrite-normalized fractionation trends indicate that these grains are mostly MREE-enriched and have weak to moderate positive Eu anomalies (Eu/Eu* = 1.151–1.803), which could collectively be an indication of alkaline, CO_2-rich fluid conditions. Lastly, apatite from the 2.5 Ga Grota Funda deposit is commonly patchy, zoned, and displays LREE-enriched domains (Ce/Yb_{CN} = 2.067–4.667) identified by a purplish luminescence, which are surrounded by relatively REY-depleted, yellowish-green zones. Such compositional variation in apatite could be attributable to coupled dissolution-reprecipitation mechanisms caused by later interaction with metasomatic fluids. Notably, Eu/Eu* and Ce/Ce* values suggest that apatite crystallized under relatively distinct oxidation states, from moderately reduced (Grota Funda and GT-46) to moderately oxidized (Sequeirinho, Sossego and Alvo 118) and predominantly oxidized conditions (Igarapé Bahia). The results from this study indicate that the processes that controlled the REY and trace element incorporation into apatite in these deposits do not seem to be linked to a specific metallogenic epoch recorded at Carajás. Thus, the observed compositional and morphological variations in apatite most likely reflect the history of fluid-rock interaction and hydrothermal evolution at a deposit scale, regardless of its age.

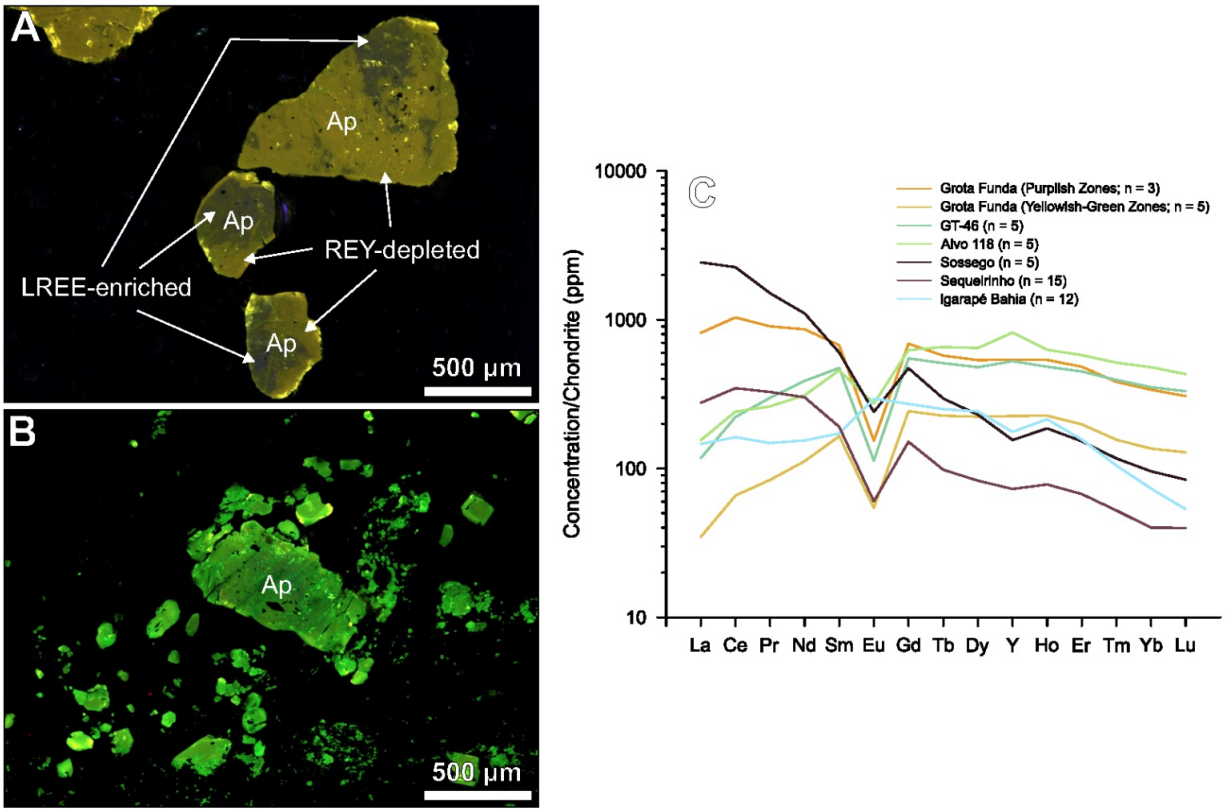

Figure 1. A and **B** Cathodoluminescence images of yellowish and greenish-yellow apatite crystals from ore zones of the Grota Funda and Igarapé Bahia deposits, respectively. Note that apatite from the Grota Funda deposit displays purplish LREE-enriched domains, which are surrounded by relatively REE + Y (REY)-depleted yellowish zones. **C** Average rare earth element (REE) distribution patterns of apatite from iron oxide copper-gold (IOCG) deposits of the Carajás Province. Chondrite values are from McDonough and Sun (1995)