Copper and iron isotopic fractionation in the supergene evolution of the Alvo 118 deposit - Carajás Mineral Province, Brazil

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In the Carajás Mineral Province, IOCG deposits and their host rocks, mainly chloritites, have been transformed due to gossan formation and lateritization, leading to the formation of several supergene orebodies. The Alvo 118 deposit is characterized by hypogene massive and disseminated copper sulphides associated with supergene mineralization (gossans and saprolites). The hypogene reserves of the deposit comprise 170 Mt of 1% Cu and 0.3 ppm Au, while the supergene reserves consist of 55 Mt, which includes 30% gossan and 70% saprolite, with 0.92% Cu and 0.03 ppm Au. The study of iron and copper isotopic analyses, along with mineralogical and geochemical data, revealed that the gossan consists of goethite, malachite, cuprite, and libethenite zones. The $\delta^{65}Cu$ value in the goethite zone (+0.73‰) is higher than in the hypogene mineralization (+0.13 and +0.06‰), indicating that redox reactions have produced isotopically heavier solutions, which have been adsorbed by the iron oxyhydroxides. The depletion in δ65Cu in the malachite zone (−0.69 and −0.70‰) is consistent with previous reports, suggesting strong negative fractionation between the solution and malachite, resulting in an isotopic composition lighter than the precursor solution and parent sulphide. In saprolite, the main carrier of Cu released after chalcopyrite dissolution might be goethite, formed from isotopically heavier solutions compared with hypogene mineralization. However, exposure to leaching close to the surface leads to preferential loss of the heavy isotope, causing a reduction in δ65Cu values (+0.07, 0.08, and +0.09‰). The δ56Fe values reflect different degrees of Fe oxidation in chalcopyrite and goethite. As goethite is the only iron-bearing mineral in the malachite zone, the increase in the $\delta^{56}Fe$ values compared with the hypogene sulphides confirms that Fe(III)-bearing phases are usually enriched in heavy isotopes (+0, 57, and +1.00‰) compared with those carrying Fe(II), represented by chalcopyrite ($\delta^{56}Fe$ = +0,36, and +0.45‰). Conversely, the goethite zone is depleted in the heavy isotope compared to hypogene mineralization ($\delta^{56}Fe$ = −0.56‰), which may suggest some variation in the isotopic content of the precursor sulphide or additional contribution of chlorite. The slightly negative fractionation of the saprolite ($\delta^{56}Fe$ = +0.02, +0.14, and +0.22‰) compared with the hypogene mineralization indicates that chlorites from the host rocks exert more influence on the saprolite than the hypogene mineralization. Copper fractionation suggests that the Alvo 118 gossan was preserved from intense leaching. Conversely, near the surface, the host rocks were converted into a typical saprolite horizon. Additionally, iron fractionation indicates a restricted contribution of the hypogene mineralization to the Fe content of the saprolite, which is more related to chlorite weathering.