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Trace Element Fingerprints of Gold for Traceability in the Yanomami Indigenous Territory, Brazil

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Gold traceability has become a critical forensic tool for addressing illegal mining and its associated environmental and public health impacts, particularly within the Yanomami Indigenous Territory (YIT) in the Brazilian Amazon. Despite legal protection prohibiting mineral extraction in the YIT, artisanal and small-scale mining remains active. In addition, the geochemical fingerprints of YIT gold remain poorly constrained, limiting the development of robust provenance tools for verification and regulatory enforcement. The YIT lies within the Amazon Craton and comprises Paleoproterozoic to Neoproterozoic rocks affected by major tectono-magmatic events. Primary gold mineralization is mainly associated with hydrothermal veins hosted by granitic and metasedimentary rocks and structurally controlled by regional fault and shear systems. This study presents the first trace-element (TE) characterization of gold grains from active mining areas across the northern and southeastern YIT, determined by LA-ICP-MS. Analytical quality was monitored using UQAC and CCu-1 sulfides, NIST 612 glass, and AuRM3 reference materials to ensure accuracy and reproducibility. The results reveal systematic geochemical contrasts between the two regions. Northern samples are relatively enriched in Fe, Pd, Ni, and As, whereas southern samples display higher Ag and Cu, with secondary enrichment in Co. Bismuth (Bi) exhibits subtle potential for internal discrimination between mining sites in the northern region. Multivariate and compositional analyses consistently resolve two coherent geochemical domains, indicating distinct geological controls on gold TE composition. These results demonstrate the strong potential of gold chemistry as a provenance discriminator within the YIT and establish a baseline geochemical framework for ongoing traceability efforts. Mercury isotope methodology is under active refinement to help distinguish geogenic from anthropogenic signatures in YIT gold, while Ag isotope analyses are expected to further strengthen source attribution and evaluate potential mixing. Together, these approaches provide the foundation for robust forensic tools and machine-learning–based provenance models to assist monitoring and enforcement against illegal mining in the Brazilian Amazon.