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Radiogenic Lead Signatures in Au-Rich Volcanic-Hosted Massive Sulfide Ores and Associated Volcanic Rocks of the Early Tertiary Macuchi Island Arc (Western Cordillera of Ecuador)

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Abstract

An early Tertiary ensimatic island arc, whose remnants are known as the Macuchi unit, is exposed in the occidental portion of the Western Cordillera of Ecuador. The Macuchi unit consists of two volcaniclastic and volcanic sequences: the Basal Macuchi, of Paleocene age, which is the lower part of the arc pile, and the Main Macuchi, of Eocene age, which is stratigraphically higher. The Main Macuchi hosts the Macuchi, La Plata, and El Patiño Au-rich volcanic-hosted massive sulfide (VHMS) deposits. Despite higher contents of SiO_2 and lower contents of MgO than rocks of the Basal Macuchi, the least evolved rocks of the Main Macuchi have lower or similar concentrations of incompatible elements and higher Sc/Y, V/Ti, and Ti/Zr ratios. This suggests derivation of the Main Macuchi rocks from a depleted source compared to the Basal Macuchi sequence. The VHMS orebodies are characterized by a mineral assemblage including chalcopyrite, pyrite, low Fe sphalerite, bornite, covellite, digenite, tennantite, and by quartz-sericite and quartz-chlorite alteration. Lead isotope compositions of the volcanic rocks of the two sequences ($^{206}Pb/^{204}Pb$ = 18.65–19.10, $^{207}Pb/^{204}Pb$ = 15.53–15.67, and $^{208}Pb/^{204}Pb$ = 38.20–39.00) define mixing trends between a MORB-type reservoir and an upper crustal source. Volcanic rocks of both sequences display positive correlations of $^{207}Pb/^{204}Pb$ with MgO, which are compatible with fractional crystallization and assimilation of oceanic crust by a parent magma enriched at its source by radiogenic lead of pelagic sediments. The isotopic compositions of the orebodies overlap largely the compositional field of the Main Macuchi rocks, suggesting derivation of the majority of ore lead from leaching of the Main Macuchi sequence, even though small contributions from the Basal Macuchi cannot be ruled out. Lead isotope compositions are internally homogeneous within each of the three orebodies but vary beyond analytical uncertainties among the deposits ($^{206}Pb/^{204}Pb$ = 18.835 ± 0.009, $^{207}Pb/^{204}Pb$ = 15.613 ± 0.005, $^{208}Pb/^{204}Pb$ = 38.535 ± 0.018 for Macuchi; $^{206}Pb/^{204}Pb$ = 18.859 ± 0.007, $^{207}Pb/^{204}Pb$ = 15.638 ± 0.005, $^{208}Pb/^{204}Pb$ = 38.643 ± 0.028 for El Patiño; $^{206}Pb/^{204}Pb$ = 19.023 ± 0.008, $^{207}Pb/^{204}Pb$ = 15.660 ± 0.003, $^{208}Pb/^{204}Pb$ = 38.786 ± 0.015 for La Plata). The isotopic difference between Macuchi ($^{207}Pb/^{204}Pb$ = 15.613 ± 0.005) and El Patiño ($^{207}Pb/^{204}Pb$=15.638 ± 0.005), separated by a few hundreds of meters, suggests fluid homogenization only at a local scale, a possible result of high-level emplacement of magmatic chambers, and consequent reduced size of the convective cells. Consistent covariations between metal ratios and isotopic compositions of the orebodies suggest also that leaching by hydrothermal fluids of different portions of the Main (and Basal?) Macuchi resulted in a distinct metal geochemistry of the orebodies. The highest $^{207}Pb/^{204}Pb$ value measured in the Eocene Main Macuchi volcanic rocks and associated ores is among the most radiogenic recorded in ensimatic island-arc systems and would require assimilation of unrealistic amounts of pelagic sediments (up to 36 wt %). In agreement with whole-rock geochemistry, it is more likely that this signature results from mixing of radiogenic lead equivalent to assimilation of commonly accepted pelagic sediment amounts (i.e., <10 wt %) with a residual mantle, depleted in incompatible elements such as low radiogenic, MORB-type lead. Melts extracted from a residual source are candidates to be enriched in Au and other chalcophile elements. The stratigraphic association and isotopic affinity of the Au-rich VHMS ore minerals with the rocks of the Main Macuchi sequence suggests, therefore, a possible petrogenetic control on the formation of the VHMS deposits of the Macuchi arc.