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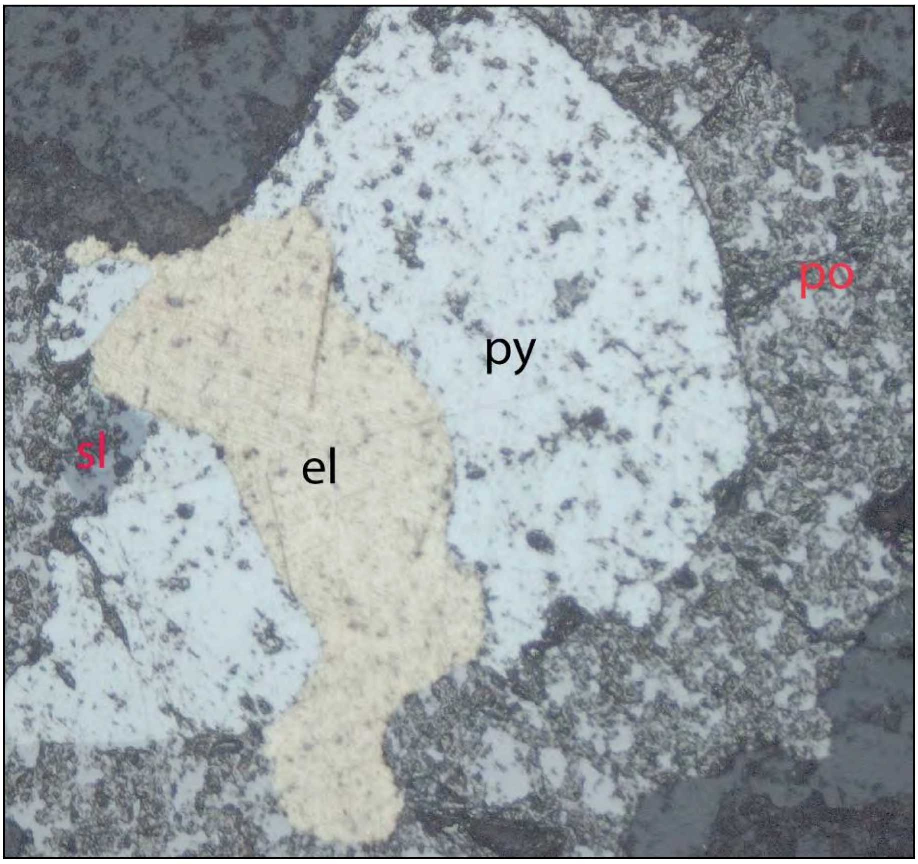
The low-sulfidation Au-Ag deposit of Rio Blanco (Ecuador): Geology, mineralogy, geochronology (U-Pb and Ar-Ar) and isotope (S, Pb, Sr) geochemistry



Master Thesis of Geology, option: Petrology, Geochemistry and Ore deposits

By Thierry BINELI BETSI

Supervisor: Dr. Massimo CHIARADIA

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ABSTRACT

The Rio Blanco Au-Ag prospect (Western Cordillera of southwestern Ecuador), is one of the most important precious metal deposits in Ecuador. Ore reserves of the Alejandra Vein (the principal vein of the prospect) exceed 2 Mt at average grades of 8.9 g/t Au and 68 g/t Ag, respectively, with bonanza grades up to 800 g/t Au (Appleyard 2003). The Au-Ag mineralization at Rio Blanco is hosted by the Tertiary Rio Blanco Formation consisting of volcaniclastics rocks, andesitic lavas, felsic ignimbrites, and dacitic tuffs, intruded by diorite intrusions and porphyry andesitic dykes (Appleyard, 2003).
Volcanic rocks of the Rio Blanco Formation and associated intrusions are mainly andesitic in composition, with few dacitic rocks, have calc-alkaline to transitional affinity, and in tectonomagtic discrimination diagrams, fall in the field of volcanic arc rocks. U-Pb single zircon ID-TIMS dating of two dioritic intrusions cutting the Rio Blanco Formation yielded $^{206}Pb/^{238}U$ weighted ages of 35.77 ± 0.06 Ma and 15.70 ± 0.08 Ma respectively, suggesting multiphase magmatism in the area.
Volcanic rocks have undergone pervasive biotite-quartz and propylitic alteration, followed by phyllic alteration and local silicification as well as argillic alteration, whereas intrusive rocks are overprinted by a calc-silicate alteration (silication).

Lead isotope compositions of the volcanic rocks of the Rio Blanco Formation and of the intrusions show variably elevated $^{207}Pb/^{204}Pb$ values (15.62-15.70) indicating mixing between crustal and mantle sources, with a dominant crustal contribution. $^{87}Sr/^{86}Sr$ values range from 0.704 to 0.707, also indicating crustal contribution to the magmas that formed the volcanic and intrusive of the area. Correlations of Sr and Pb isotopes with various fractionation indices suggest that magmatic rocks in the Rio Blanco area have acquired their radiogenic Pb and Sr isotope compositions, while fractionating, through assimilation of crustal rocks, likely represented by black shales of the crystalline basement, which have suitable Pb and Sr isotopic compositions (Chiaradia et al., 2004).

The Au-Ag mineralization occurs along several hundred meters within ENE-trending extensional veins dipping at angles >45° towards the SE. The extensional veins were formed during dextral strike-slip movements along NNE-SSW trending faults, likely induced by oblique subduction of the Nazca plate under the continental crust of Ecuador during the Tertiary. The veins show different filling textures including crustiform quartz and bladed carbonates replaced by quartz, as well as a variety of breccia types (monomictic, polymictic, matrix-supported, clast-supported and jig-saw). Breccias are mainly formed by clasts of hydrothermal milky quartz, crustiform white and black quartz bands, quartz pseudomorphs after bladed carbonates, adularia and lithic fragments. The matrix consists of fine-grained black quartz, sericite, carbonates, and accessory chlorite and actinolite-tremolite. Mineralization occurring in the breccia matrix comprises pyrite, pyrrhotite, pyrargyrite (65-58 wt. % Ag), tetrahedrite (34-22% Ag), As-bearing (up to 2 wt. %) tetrahedrite (20-6 wt. % Ag), arsenopyrite and accessory amounts of Fe-rich (10 wt. %) sphalerite, galena, chalcopyrite, dyscrasite (Ag_3Sb) and electrum (60-44% Au). The total amount of sulfides is <2 vol. %. Electrum is concentrated in volumes of few cm^3 within breccias and silicified zones where it is mainly associated with pyrrhotite, but also with pyrite and pyrargyrite, and occasionally with sphalerite. Gold-rich electrum occurs towards greater depths, whereas the highest Ag grades are encountered at shallow levels in the deposit.
Sericite associated with the mineralization yielded a weighted Ar-Ar plateau age of 18.9±0.5 Ma. This has to be considered as a maximum age because sericite is usually affected by ^{39}Ar loss by recoil during irradiation due to its small size. Whereas this maximum age indicates

that the Au-Ag deposit of Rio Blanco is unrelated to the older Eocene intrusion (~35.7 Ma), it does not exclude the possibility of a genetic association of the mineralization with the younger, Miocene intrusion (~15.7 Ma). In fact, the younger intrusion is overprinted in places by hydrothermal alteration (such as silicification, silication, propylitic alteration), brecciated and in places hosts ore minerals (galena, chalcopyrite and tetrahedrite), thus possibly indicating a pre- to syn-mineralization emplacement of this intrusion.

Lead isotope compositions of four pyrite samples (three from silicified wall rock and one from a stockwork vein hosted by altered lava), two galena samples from mineralized veins, and a pyrrhotite sample from disseminated ore hosted by altered lava are identical within error. They are characterized by high $^{206}Pb/^{204}Pb$ (19.040-19.139) and $^{207}Pb/^{204}Pb$ (15.664-15.689) values. Whereas ore minerals are more radiogenic (in terms of $^{207}Pb/^{204}Pb$) than Miocene intrusion, ore minerals and the Miocene intrusions however display nearly similar values of $^{206}Pb/^{204}Pb$. In the uranogenic diagram the Pb isotopic composition of ore minerals plot just above the Miocene intrusion and overlap the most radiogenic end of the host Rio Blanco volcanic rocks, possibly suggesting Pb ore mineral input from either fluid leaching of the most volcanic host or from mixing between magmatic fluid and black shales
The $\delta^{34}S$ values of pyrite and galena (of the same samples as used for Pb isotope analyses) range from -3 to +4 ‰, consistent with a magmatic source of S. The pyrrhotite occurring as disseminated ore in altered lava yielded a $\delta^{34}S$ value of -23.2 ‰ indicating a contribution of sedimentary S, probably related to black shales of the underlying basement, which are also found as clasts in the breccias.

Textures, gangue and sulfide mineralogy of Rio Blanco as well as the elevated Fe content of sphalerite and the volcanotectonic setting are typical of an epithermal low sulfidation deposit. In low- sulfidation systems Au is transported as a bisulfide complex and its precipitation usually occurs by boiling (Hedenquist 1991). The presence of bladed carbonate testifies the occurrence of boiling in the mineralized veins at Rio Blanco. However, the Au-Ag mineralization always postdates the formation of bladed carbonate, which occurs as clasts within the Au-bearing breccia matrix. Therefore, an alternative process of Au precipitation might have to be envisaged at Rio Blanco, such as sulfidation reaction of the hydrothermal Au-bearing fluid with Fe-bearing clasts within the breccia. Such a process could be supported by the frequent occurrence of pyrite around clasts, and of pyrite, pyrrhotite and Au within relict, now completely silicified clasts of the breccias. Sulfur and Pb isotope data for vein sulfides are consistent with a magmatic origin of these elements in the main ore, but it remains to establish whether these elements are from volcanic rocks or intrusive rocks. While our dating results seem to rule out a genetic relationships between the diorite bodies and the mineralization, in agreement with the model proposed by Hedenquist et al. (2000), further results (based on isotopic constraints and field relationships, e.g. hydrothermal alteration, brecciation and mineralization in the diorites) do not completely support this scenario and do not exclude the possibility of a genetic association of the mineralization with the younger, Miocene intrusion (~15.7 Ma). The discussed uncertainty of the Ar-Ar (maximum) age of the mineralization-related sericite might account for these differences. Further dating of mineralization-related adularia or biotite could help in clarifying this issue.