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AGES AND SOURCES OF THE GOLD MINERALIZATIONS FROM MARMATO MINING DISTRICT, NW COLOMBIA, BASED ON RADIOGENIC ISOTOPIC EVIDENCES

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INTRODUCTION

The Andean Cordillera, in Colombia, is composed of three ridges, with N-S trends, named Oriental, Central and Occidental. Geologically, the Colombian Andes, is divided in two different domains by the Cauca-Romeral Shear Zone; the first one, which includes the oriental and central ridges at the eastern side, is composed of precambrian and paleozoic continental basement, intruded by several mesozoic and cenozoic granitic plutons, and covered by sedimentary sequences. The second domain, that includes the occidental ridge, was formed by successive accretions of allochthonous terranes, which show oceanic affinities (Etayo et. al. 1986 and Toussaint & Restrepo 1989). These terranes were intruded by several sub-volcanic intrusions, which form the Combia Formation, and one of them, is the Miocene Marmato Stock, that is the host - rock of the epithermal Au-Ag Marmato mineralizations (Restrepo et. al. 1981).

The Marmato Mining District is located at the Setentrional Andes of Colombia, in the Caldas State, at 50 km from N-NW of Manizales capital city. The mineralizations are divided in three different levels: the first one near the surface is named Echandia, the intermediary is the Cien Pesos Sector and the deepest is the Marmato Bajo Sector.

In order to characterize the age and sources of the mineralizations of Marmato Minig District, Sr-Sr, Pb-Pb, Sm-Nd and K-Ar isotopic analyses were carried out on ore and gangue minerals at the Geochronological Research Center of University of São Paulo. The sample selection, for isotopic analyses, was made based on petrographic and mineralogical characteristics, that included analyses using thin sections and polished sections, beyond analized sections on the back scatter electron microscope.

GEOLOGICAL SETTING

The Marmato Mining District is located within the Calima Terrain (Toussaint & Restrepo, 1991), which is bounded by the Cauca and Romeral Faults. The oldest exposed rocks in the area belong to metasedimentary Arquia Complex, with Cretaceous metamorphic ages, and are represented by graphite-schists metamorphosed within low amphibolite facies and by chlorite-schists metamorphosed within greenschist metamorphic conditions (Rosseti et al., 1999). The Miocene sedimentary rocks of the Amagá Formation overly the metamorphic basement. and are composed of sandstones, shales and conglomerates. The youngest stratigraphic unit in the Marmato area is the Combia Formation, which is characterized by volcanoclastic unit. Pyroclastic rocks include clasts of basalt and andesites. Mafic lavas with subordinate tuffaceous intercalations also occur. Associate with the Combia Formation appear some sub-volcanic bodies, with andesitic and dacitic compositions, with ages ranging from 9 Ma to 6 Ma (Restrepo et. al., 1981).

One of these bodies is the Marmato Stock, which is the host-rock of the Marmato Au-Ag mineralizations. This stock is composed of porphyritic volcanic rocks with dacitic and andesitic compositions. The porphyritic andesites outcrop in the border of the stock, while the porphyritic dacites appear in the central part of the body. The andesite, which occur at Echandia sector (Plata Fria Mine), is composed of plagioclase phenocrystals (andesine) hydrothermaly alterated to sericite and carbonate, hornblende, and partially chloritized biotite, within a fine matrix composed of plagioclase, chlorite, magnetite, apatite and epidote. The porphyry-dacite, which is the host-rock of the most of the auriferous quartz veins in the area, presents a mineralogical composition with plagioclase phenocrystals hydrothermaly alterated to sericite, carbonate and epidot e, quartz, hornblende and chloritized biotite, calcite and oxides. All these phenocrystals are immerse in a fine matrix composed of plagioclase, quartz, sericite and carbonates.

Within the Marmato Mining District the main structural features are related to sub-vertical faults, like Obispo Fault, with N25E trend, and distentional veins with N, NE and NW trends.

The porphyritic dacites contain abundant ore veins. The epithermal with low-sulphidation epithermal mineralization styles occur as distentional veins, stockwork structures and narrow brecciated zones with quartz veinlets. In general the ore veins are (no longer than 250 m) in length and 2 m thick. These veins present lateral zonation with pyrite in the border and sphalerite in the central zone. In the Echandia sector the ore consists of variable amount of pyrite, sphalerite and galena. Accessory and trace minerals include chalcopyrite, arsenopyrite, pyrrotite, argentite and gold electrum. In the Marmato Bajo the ore minerals are: pyrite, pyrrotite, sphalerite, arsenopyrite, chalcopyrite, gold, galena and marcassite (López-Rendon, 1991; Bedoya, 1998).

The volcanic unit is extensively affected by hydrothermal alteration, and two main alteration styles are depicted (sericitization and propylitization), silicification, argillization and albitization are also observed in some places.

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Fluid inclusions study, in Marmato Mining District, were documented by Bedoya (1998) and Rossetti & Colombo (1999). In general, the fluid inclusion microthermometric results indicate homogenization temperature values, of the primary fluid inclusions in quartz, around 300°C and the salinity values are low to moderate, varying from 1,6 to 8,1 wt.% NaCl eq.

RESULTS AND DISCUSSION

Fifty five samples of ore, gangue and host rocks of the Marmato Mining District were investigated for their Pb, Sr and Nd isotopic compositions. In addition, one sample of hydrothermal altered plagioclase was analyzed by K-Ar method in order to determine the age of the mineralization episode. All isotopic analyses were carried out at the Geochronological Research Center of University of São Paulo.

AGE OF THE ORE DEPOSITION

A sample of sericitized plagioclase from altered host rock was dated by K-Ar method and yielded an precise age of 5.6 ± 0.6 Ma, which is interpreted as the time of ore deposition. This age is in close agreement with the Cauca-Romeral Fault System reactivation, which occurred at 5.6 ± 0.4 Ma and it is slightly younger than the cooling age of 6.7 ± 0.06 Ma, both ages were obtained by Ar-Ar technique on biotite from the Marmato Stock (Vinasco, 2001). In this way, we can consider that the mineralization is related to distensional tectonic regime, that allows the left reactivation of the Cauca - Romeral shear zone, and the formation of pull-apart basins in the Cauca - Patia depression, related with the accretion of the Panama magmatic arc into NW margin of South America.

SOURCES OF THE MINERALIZING FLUIDS

The host porphyry andesitic-dacitic rocks, dated at 6.7 ± 0.1 Ma (Vinasco, 2001), have $^{87}Sr/^{86}Sr$ initial ratios between 0.70440 and 0.70460 and ε_{Nd} values from from + 2.2 and + 3.2. These results allow us to consider a subduction-related mantle magma as their main magmatic source, produced during the subduction of the Nazca Plate beneath South American Continent.

The $^{87}Sr/^{86}Sr$ and the ε_{Nd} values obtained on sulphides from the gold quartz veins, which occur at the shallow and intermediary levels of Echandia and Cien Pesos sectors, range from 0.70500 to 0.71210 and from - 1.11 to + 2.40 respectively, while for the deepest mineralizations, which appear in the Marmato Bajo sector, the ε_{Nd} values of the sulphides are between + 1.25 and + 3.28 and the $^{87}Sr/^{86}Sr$ ratios of calcite and pyrite fall between 0.70444 and 0.70930. The highest $^{87}Sr/^{86}Sr$ ratio was from the pyrite from Mina La Mona in Cien Pesos sector. Concerning Sr isotopic compositions, all analyzed sulphides are more radiogenic than the carbonates, which are less radiogenic and very homogeneous, and have $^{87}Sr/^{86}Sr$ ratios around 0.70445. These values overlap the Sr isotopic compositions measured on samples from the host porphyritic dacite. Based on Sr isotopic data we can interprete that the carbonatic fluids have been subjected to a restrict ed hydrothermal circulation, within the host igneous body, without important admixture from the regional metassedimentary units. On the other hand, the more radiogenic sulphide-bearing fluids, seem to have circulated not only within the Marmato Stock, but also through some other older crustal rocks.

The present-day $^{87}Sr/^{86}Sr$ ratios and ε_{Nd} values of the metasediments of the Arquia Group are variable, ranging from 0.70431 to 0.73511 and from -12,91 to +10 respectively. The less radiogenic Sr isotopic compositions and the positive ε_{Nd} values are related to the amphibolitic schists, and the more radiogenic Sr isotopic compositions and the strong negative ε_{Nd} values are related to the quartz-biotite schists and graphite schists. The Sr and Nd isotopic compositions of the mafic and ultramafic rocks are close to Sr and Nd isotopic compositions obtained for amphibolitic schists, yi elding, 0.70396 – 0.7068 for $^{87}Sr/^{86}Sr$ ratios and + 4.45 to + 10.32 for ε_{Nd} values.

The comparison of the Sr and Nd isotopic compositions from are mineral phases, gangue minerals, and of the whole-rocks from the metaedimentary sequences, indicates that the shallow level mineralizations from Echandia and Cien Pesos sectors were characterized by a more radiogenic meteoric fluids with significant crustal contributions derived mainly from the different kinds of metassediments of the Arquia Complex. In contrast the porphyritic rocks are more important sources for the deeper mineralizations of the Marmato Bajo sector, where the hydrothermal fluids seem to be a mix of meteoric and magmatic waters.

The $^{206}Pb/^{204}Pb$, $^{207}Pb/^{204}Pb$ and $^{208}Pb/^{204}Pb$ ratios of sulphides from all mineralizations fall between 18.970 - 19.258; 15.605 - 15.726 and 38.813 - 39208 respectively. The Pb isotopic compositions show that sulphides have radiogenic values, which is typical of crustal sources for Pb. The dacitic and andesitic porphyry rocks of the Marmato Stock display Pb isotopic compositions for $^{206}Pb/^{204}Pb$; $^{207}Pb/^{204}Pb$ and $^{208}Pb/^{204}Pb$, between 18.964 - 19.028; 15.561 - 15.570 and 38.640 - 38.745 respectively. The metassediments of the Arquia Group yielded Pb isotopic ratios of 18.948 - 19.652; 15.564 - 15.702 and 38.640 - 38.885 for $^{206}Pb/^{204}Pb$; $^{207}Pb/^{204}Pb$ and $^{208}Pb/^{204}Pb$. The average Pb isotopic composition for ore-minerals is more radiogenic than the Marmato Stock and a little less radiogenic than the metasediments. In the uranogenic diagram of the Plumbotectonic model of Zartman and Doe (1981), the analytical points related to sulphides plot above the orogenic growth curve and, some samples form a cluster between the Marmato Stock and the graphite schists, and others sulphides are more radiogenic, suggesting that the ores include Pb from upper crustal rocks, more radiogenic than the graphite schists and amphibolitic schists of the Arquia Complex fields (Fig. 1). The only compositions that could be more radiogenic than the part of ore fluids (superficial veins of Echandia sector and intermediary level veins of the Cien Pesos sector), in the area, are the biotite-quartz schists. So we can consider that Pb data indicate derivation of the ore fluids from country rocks, mainly from the Marmato

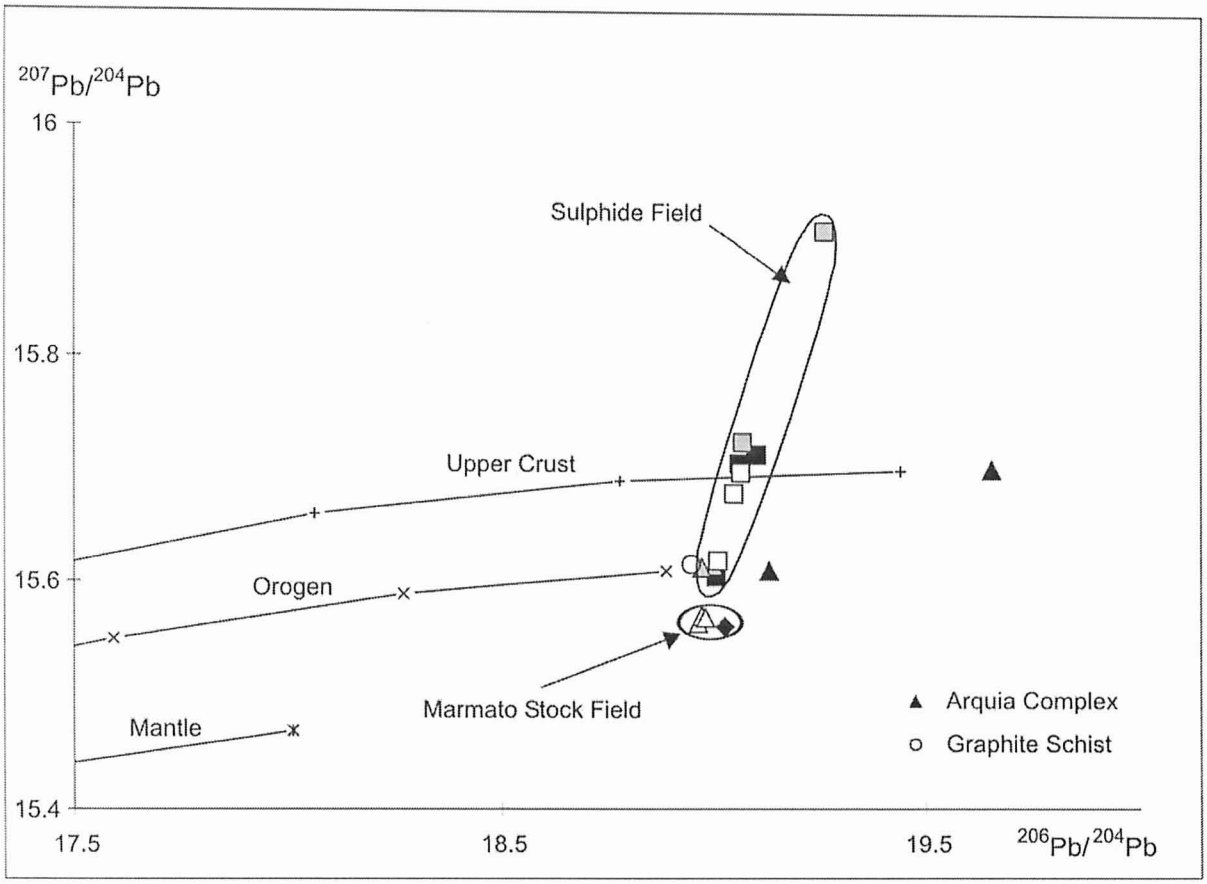

Figure 1. Figure 6. Uranogenic diagram with sulphide field and regional rocks in relation to Plumbotectonic curves (Zartman e Doe, 1981).

Uranogenic Diagram with the sulphide field and regional rocks in relation to Plumbotectonic curves (Zartman & Doe, 1981).

Stock with a minor contribution from the graphite schists and biotite-quartz-schists of the Arquia metamorphic Complex.

Based on previous geochronological data (Ordoñez, 2001, Vinasco, 2001, Sierra et. al., 2000, Restrepo et. al. 1981), and on our new isotopic results, the geological and metallogenetic evolution of the Marmato Mining District area, can be summarized as follows:

- 33 - 25 Ma: Magmatic activities of the Piedrancha-Farallones Arc.
- 22 Ma: Development of the back-arc basin, related to Piedrancha-Farallones Arc and beggining of Amagá Formation sedimentation.
- 12 Ma: Collision of the Panamá-Choco Arc against Sout America Continent. Reactivation of the Cauca-Romeral Shear Zone (CRSZ) and development of the pull apart basins.
- 11 Ma: Calc-alkaline and tholeiitic magmatism related to Combia formation, related to pull apart basins.
- 6,3 Ma: Marmato Stock magmatic crystallization, associated with Combia Formation. Beggining of the hydrothermal activities, related to CRSZ reactivation and fracturation of the Marmato Stock.
- 5,6 Ma: Last reactivation of the CRSZ, last magmatic activities of the Marmato Stock and main mineralization episode.
- 5.0 Ma: End of Combia Formation, magmatic activities.
- 3.1 - 3.7 Ma: Closure of the link between Pacific and Caribean Oceans through the collision of the Panamá-Choco Arc against South America.

The results of our study have implications in the mineral exploration programs in the area, because it was demonstrated that the igneous rocks of the Marmato stock are not exclusive sources for the Marmato ores, and that the sulphide deposition involved also ore-forming solutions from the graphite schists of the Arquia Complex, becoming these metasediments as potential target for gold mineralizations.

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