VII SSAGI
South American Symposium on Isotope Geology
Brasília, 25th-28th July 2010

THE AGE AND ORIGIN OF THE EMERALD DEPOSITS FROM CORDILLERA ORIENTAL, COLOMBIA

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ABSTRACT

The emerald deposits in Colombian are located at Andean Cordillera Oriental, about 70 km to NE from Bogota, distributed in two zones on both sides of cordillera, the eastern and western mineralized zones. Emerald mineralizations occurs as hydrothermal veins, composed by albite, calcite, dolomite and pyrite, within lower cretaceous black shales. The deposits are associated with hydrothermal breccias filling by calcite, dolomite, pyrite, muscovite and albitite, which is the result of the Na metasomatism within black shales. Emerald samples from La Paz mine, western zone, give an Re-Os isochronic age of 12,4 ± 0,9 Ma with an initial $^{187}Os/^{188}Os$ of 0.148 ± 0.002 (MSWD =1.6). Sr, Nd and Pb isotopic compositions were measured on emerald samples and clearly indicate rocks from upper continental crust as the main sources of mineralizations. Part of the emeralds cluster in the same field than the black shales, indicating this rock as one of the sources for the fluids. Our isotopic data led us to consider an origin from sedimentary basin for the emerald mineralizing fluids.

INTRODUCTION

The emerald deposits in Colombian are located at Andean Cordillera Oriental, about 70 km to NE from Bogota, distributed in two zones on both sides of cordillera, the eastern and western mineralized zones. The mineralizations are hosted by the cretaceous sedimentary rocks from the Santa Rosa and Chivor Formations in the eastern zone and from Muzo and Rosablanca Formations in the western zone (Cheilletz and Giuliani, 1996). These emerald mineralizations are interesting because they are host in sedimentary rocks, what is in contrast with most of emerald deposits around world, which are igneous related.

There is no consensus about the age of the emeralds deposits. Based on Ar-Ar and K-Ar age determinations on green-micas, sometimes present on the edge of the some emerald-bearing veins, Cheilletz *et al.*, (1994) suggested an cretaceous-tertiary age (65 Ma) in the eastern zone and between 38 and 35 Ma for the time of the emerald crystallization in the western zone. On the other hand Romero *et. al.* (2000) indicate an age of about 67 Ma for the emeralds from western zone and about 61 Ma for the mineralizations from the eastern zone, based on Rb-Sr isochron, not very well defined.

In the past an igneous origin was considered for the hydrothermal fluids responsible for the emerald crystallization. Mafic igneous intrusions into cretaceous sedimentary rocks, or tertiary traquitic volcanism were characterized as the main sources of the mineralization fluids (Ulloa, 1980). Later on Cheilletz and Giuliani (1996) and Giuliani *et. al.* (1995), indicated that the emerald formed as a result of the hydrothermal circulation within a sedimentary basin. The fluids are composed by a mixing of meteoric water and sedimentary rocks derived brines.

Taking into account that the age and the source-rocks of the fluids is not fully characterized, the main purpose of the work are to define the age of the emerald

mineralization based on Re-Os isochronic method applied directly on emeralds and to characterize the nature of the emerald fluid sources, using Sr, Pb and Nd isotopic compositions. In addition the Rb-Sr isochronic age of the hosted black shales and the K-Ar age determination on mafic intrusion were reported.

GEOLOGICAL SETTING

The Emerald mineralizations of the Cordillera Oriental crops out in anticlinorium structures (Los Farallones, eastern zone and Villeta, western zone) and the tectonic is dominated by thrusts, faults and folds. On the eastern zone the emerald deposits formed during a thin-skinned extensional tectonic and on the western zone the mineralizations are related to tear faults and thrusts developed during a compressive regime (Branquet *et. al.* (1999). According these authors, in the eastern zone, the emerald mineralizations are conditioned by high angle reverse faults and the most important emerald deposits are located within shear zones, fractures or veins close the fault systems.

The host-rock lithologies are dominated by carbonaceous black shales with intercalated black mudstones and, in some places, with enriched pyrite layers. Normally these rocks are massive, but sometimes exhibit layers parallel to the bedding. Dolomitic limestones and quartz-feldspathic sandstone also occur (Alvarez and Roser, 2006).

Emerald mineralizations occurs as hydrothermal veins, mainly composed by albite, calcite, dolomite and pyrite, within lower cretaceous black shales of the Muzo, Rosablanca and Chivor, Santa Rosa Formations, from occidental and oriental zones respectively. The deposits are associated with hydrothermal breccias filling by calcite, dolomite, pyrite, muscovite and albitite, which is the result of the Na metasomatism within black shales.

RESULTS

Emerald samples from La Paz mine, western zone, were analyzed by Re – Os technique to directly dating ore deposition. These analyses yield Re and Os concentrations that range between 1.25 – 6.03 ppb and 0.06 – 0.43 ppb respectively. The calculated $^{187}Re/^{188}Os$ and $^{187}Os/^{188}Os$ ratios range between approximately 52.02 – 249.99 and 0.159 – 1.101, respectively.

When all analytic data are plotted on a Re-Os isochron diagram, the data form an isochron which give an age of 12,4 ± 0,9 Ma with an initial $^{187}Os/^{188}Os$ of 0.148 ± 0.002 (MSWD =1.6).

Ten analyses of the emerald samples were also performed by Sm-Nd technique on leachate and residue products from each sample. Most of the samples yield a different ε_{Nd} values for the leachate and residue from the same sample. This fact is due to the presence of solid inclusions within emeralds and there was no Nd isotopic homogenization between emerald fluids and previous mineral solid inclusions. Using only the sample with coincident ε_{Nd} values for both leachate and residue products (sample from eastern zone), the Sm-Nd isochronic age was calculate for the leachate – residue pair and it was obtained the age around 12 Ma.

The $^{87}Sr/^{86}Sr$ initial ratios and the ε_{Nd} values, both calculated to 12 Ma, for emerald samples range from 0.71190 to 0.72846 and – 2,68 to -9,7 (leachate), - 3.4 to – 66 (residue). The high values of the Sr initial composition combined with the negative ε_{Nd} values clearly indicate rocks from upper continental crust as the main sources of the hydrothermal fluid responsible for the emerald-forming process. The Pb isotopic

compositions for the emerald samples are very radiogenic, ranging from 20,187 to 24,001; 15,725 to 15,918 and 38,500 to 38,624 for $^{206}Pb/^{204}Pb$; $^{207}Pb/^{204}Pb$ and $^{208}Pb/^{204}Pb$, respectively. These values are in agreement with the Sr and Nd isotopic compositions that suggest a crustal source for the emeralds. Pb isotopic compositions for emeralds cluster above the upper crust Pb evolution curve of the plumbotectonic model.

In addition were performed Rb-Sr, Sm-Nd and Pb-Pb analyses on whole rock samples from the hosted black shales and mudstones of the Muzo, Rosablanca and Furatena Formations, as well as Sm-Nd and K-Ar radiometric determinations on samples from the gabbro intrusive onto lower cretaceous host sedimentary rocks, with the purpose of to characterize the role developed by these rocks within emerald metallogenetic process.

Nineteen whole-rock samples from the black shales were analyzed by the Rb-Sr method and the analytical points were plotted in the Rb-Sr isochronic diagram, where they define two parallels line. The best line yield an isochronic age of 159 ± 10 Ma with a $^{87}Sr/^{86}Sr$ initial ratio of 0,70751 ± 0,00024 (MSWD =2.4). These data suggest an upper Jurassic age for deposition of the sediments, which is a slightly older than the estimated age by paleontological evidences for these rocks, that point out an age related to lower cretaceous.

The $^{87}Sr/^{86}Sr$ ratios and the ε_{Nd} values, both calculated to 12 Ma, for the sedimentary rocks range from 0,70858 to 0,71881 and from -3,2 to -10,5, respectively. Pb isotopic compositions were measured for the same samples and yield values between 18,781 and 20,238 for $^{206}Pb/^{204}Pb$ and between 15,650 e 15,709 for $^{207}Pb/^{204}Pb$.

K-Ar age determination was carried out on plagioclase from the intrusive gabbro and gave an age of 112 ± 7 Ma. The ε_{Nd} value, calculated to 12 Ma for the whole-rock sample of the same gabbro was +4.8.

DISCUSSION

Based on our results we consider an age of 12 Ma for the emerald mineralizations of the Cordillera Oriental.

Sr, Pb and Nd isotopic compositions measured on the emerald samples clearly indicate that the sources of the hydrothermal fluids are derived from rocks of the upper continental crust. The comparison of the Pb, Sr and Nd isotopic compositions of the emeralds with the isotopic compositions of the host black shale show that part of the emeralds cluster in the same field, indicating the black shale as the main source for the mineralizing fluids, while other samples present ε_{Nd} values more negative and more radiogenic Pb isotopic compositions, compatible with other more radiogenic crustal rock, as another source component.

The hypothesis of the intrusive gabbro, with a positive ε_{Nd} value of +4.8, to be a source of the emerald mineralizations is completely discarded.

The pyrite, which occurs within hydrothermal breccias, present $^{87}Sr/^{86}Sr$ ratios and the ε_{Nd} values, both calculated to 12 Ma, ranging from 0.71099 to 0.71717 and from – 9.16 to -10.42. The pyrite presents $^{87}Sr/^{86}Sr$ ratios slightly less radiogenic than the emeralds and a ε_{Nd} values around the smaller values obtained for emeralds. The observed differences between the isotopic compositions could be related to different amounts of sea water and/or evaporite-derived brines involved in the fluids responsible for emerald and pyrite crystallization.

The conclusion of this work related to emerald deposits genetic model is in agreement with the previous model established by Cheilletz et al. (1994) and Cheilletz

and Giuliani (1996), that consider a sedimentary basin as geological environment to development of the emerald mineralizations. The fluids are composed by a mixing of meteoric water and sedimentary rocks derived water, mainly from the black shales and evaporites. The evaporitic origin for the fluids is supported by S isotopes and fluid inclusions sutdy as is reported by Cheilletz and Giuliani (1996). These sedimentary-derived fluids migrated, through the calcareous black shales and associated sedimentary rocks, by fractures and shear zones. The interaction between these fluids and the black shales produced albitization and carbonatation as well as provide the Be, Cr and V to the fluid, which are responsible for the emerald formation.

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