THE FORMATION OF THE EMERALD DEPOSITS OF COLOMBIA: AN EXAMPLE OF BASINAL FLUIDS MIGRATION WITHIN THE EASTERN CORDILLERA OF COLOMBIA

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The Cretaceous-Eocene sedimentary deposits of the Eastern Cordillera of Colombia were accumulated within a back-arc basin inverted during the Andean compressional episodes. The eastern and western borders of the Eastern Cordillera appear as major Late Miocene-Pliocene thrust faults, i.e., the Yopal and La Salina, respectively, which correspond roughly with the original limits of the Cretaceous basin. The emerald deposits are hosted within Lower Cretaceous black shale series at the proximity of these thrust zones. Major questions concerning their genesis can be addressed: 1) age of the mineralization and fluid circulation; 2) tectonic regime (compressive or distensive) and correlation with the Andean surrection; 3) nature, composition and origin of the mineralizing fluids; 4) channel-ways of the mineralizing fluids; 5) importance of the fluid-rock interactions on the leaching of chemical elements from the Lower Cretaceous series.

Several partial answers can be proposed:

1) Two emerald deposits of the western emerald zone have been dated [1], [2] by $^{40}Ar/^{39}Ar$ induction and laser-probe techniques on Cr-V-rich muscovites contemporaneous with emerald formation. Two distinct plateau and spot fusion ages of 38-35 Ma and 32.6-31.5 Ma were obtained for the Coscuez and Quipama mines, respectively. These Upper Eocene-Lower Oligocene ages are older than the Andean compressional episode (late Miocene-Pliocene time), and consequently older than the formation of the Yopal and La Salina thrust faults. These ages correspond to the acceleration of the convergence rate between Nazca and South American plates that provoked strong tectonic movements within the different segments of the Colombian Andes and particularly the Eastern Cordillera.

2) The mineralized vein system is constituted by a carbonate-pyrite-vein network whose geometry is constrained by shear zones and anticlines acting as traps for the mineralizing fluids. At a regional scale, the deposits are related to a compressive tectonic phase associated to thrusting, shearing, folding and evaporitic diapirism [3], [4].

3) Microthermometric, Raman-probe and SEM analysis demonstrate the presence of H_2O-NaCl-KCl-$CaCl_2$-CO_2-N_2 rich-brines trapped in emerald, carbonate and pyrite [5]. The fluid composition in these minerals is homogeneous and similar for the western and eastern emerald zones [6]. The chemistry of the fluids and the pressure-temperature trapping conditions (1kb, 320±30°C [2]) constitute strong evidence for an evaporitic origin of the parent brines. The source of the hydrothermal fluid has been approached by oxygen isotopic measurements [5]. Calculated $^{18}O(H_2O)$ for carbonates and quartz in equilibrium with the mineralization have a basinal formation waters signature. Sulfur isotopic data on pyrite cogenetic with emerald indicate a typical evaporitic sedimentary source for sulfur [7] and, calculated $^{34}H_2S$ of pyrites overlap the expected ^{34}S range of Lower Cretaceous-Jurassic marine sulfates.

4) The scale and the precise pathways of the hydrothermal fluids are not already elucidated. Nevertheless,

the basinal formation waters signature of the mineralizing fluids inclines to a fluid migration model within the Cretaceous sedimentary basin.

5) Petrographic observations and mass balance calculations in black shale hosting the emerald veins demonstrate that the hydrothermal fluid infiltration process is accompanied by a strong fluid-rock interaction leading to sodium and carbonate metasomatism [8]. The enclosing black shale is conversely leached in major (Si, Al, K, Ti, Mg, P), trace (Ba, Be, Cr, V, Rb, Sc, U, B, C) and REE elements. Therefore, these elements constituting a great part of the vein infilling minerals and particularly emerald, have a local sedimentary origin. The association beryl-parisite (LREE rich-carbonate) is exceptional in such a sedimentary environment.

All these data allow us to propose a new metallogenetic model for Colombian emerald deposits: they constitute mesothermal deposits (300°C) in a sedimentary environment, produced by the migration of fluids derived from basinal formation waters. This model is constrained by the geodynamic evolution of the Cretaceous-Focene sedimentary basin of the Eastern Cordillera.

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