Origin and provenance of Emeralds

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Emerald is the highly-valued green gemstone variety of the beryl group ($Be_3Al_2Si_6O_{18}$), where the color is caused by impurities (chromophores) of Cr, V ± Fe. The unsual association of compatible elements Cr and V with incompatible Be make emeralds a scarce resource. Emeralds occur in collisional tectonic environments, in association with sediments (e.g., Colombia), magmatism, and regional metamorphism (e.g., Neo-Proterozoic Mozambique Metamorphic belt [NMB]). While formation of Colombian emeralds is well-constrained [1], the petrogenesis of other global emerald deposits are less well understood. Here we demonstrate that the origin of emeralds can be evaluated using trace element geochemistry. A solution inductively coupled plasma mass spectrometry (ICP-MS) technique has been utilized to examine >50 emeralds from classic localities in Colombia, South Africa, Madagascar, Zambia, Egypt, Australia, Austria and Brazil. Normalized to continental crust (CC) composition, global emeralds show consistent enrichments in Cs, Li, Cr, and Sc (>1 to >1000 × CC), variable enrichments in V, and low (<0.1 × CC) normalized abundances in Ba, Sr, U, high field strength elements, and the rare earth elements (REE). Colombian emeralds have nearly-flat CC normalized REE patterns (La/Yb_{CC} = ~2), consistent with a shale-like source.

NMB emeralds formed during the Pan-African Orogeny. Our results show that NMB emeralds have pronounced upturns in the heavy REE (Er, Tm and Yb; La/Yb_{CC} = ~0.3) that we interpret to result from anatectic melting and exhaustion of garnet in protoliths associated with orogeny. Interaction of incompatible element-rich fluids, evident from the REE signatures of emeralds, with Cr- and V-rich protoliths, led to formation of emerald-bearing amphibolites in the NMB. Our assessment of >50 elements in emeralds shows that diagnostic elements for provenancing using microbeam techniques (e.g., laser-ablation ICP-MS, secondary ionization mass spectrometry) should include Cs, Li, Cr, Sc, V, Ga, Zn and Rb, which are all relatively compatible elements within the emerald mineral structure.

[1] Ottaway, T., 1994. *Nature,* 369, 552-554.