Combined Fe-Mg chemical and isotopic zoning in olivine constraining magma mixing-to-eruption timescales for the continental arc volcano Irazú (Costa Rica) and Cr diffusion in olivine

Martin Oeser[1,*,†], Philipp Ruprecht[2,3], and Stefan Weyer[1]

[1]Institut für Mineralogie, Leibniz Universität Hannover, Callinstrasse 3, 30167 Hannover, Germany
[2]Department of Geological Sciences, University of Nevada, 1664 N. Virginia Street, Reno, Nevada 89557, U.S.A.
[3]Lamont-Doherty Earth Observatory, Columbia University, 61 Route 9W, Palisades, New York 10964, U.S.A.

Abstract

Arc magmas commonly are mixtures of newly arriving primitive melts, stored magmas at shallow levels, and xenolithic material added on ascent. Almost every eruption has a unique assembly of these components, which may record magmatic processes occurring in the plumbing system prior to an eruption. In this study, we focus on complexly zoned olivines (crustal xenocrysts) to obtain a better understanding of the magmatic processes and the assembly of the 1963−65 erupted magmas of Irazú volcano, one of the most voluminous active volcanoes in Costa Rica. We performed high-precision in situ Fe-Mg isotope analyses by femtosecond-LA-MC-ICP-MS on these olivines, to unravel the origin of their complex chemical zoning (growth, diffusion, or a combination of both processes). This information was used to establish a refined diffusion model to explore magma mixing-to-eruption timescales. Furthermore, trace element analyses using LA-ICP-MS were performed. Chromium displays a chemical zoning in the investigated olivine, which coincides spatially as well as in terms of length scale and geometry with Fe-Mg zoning and that was used to constrain Cr diffusivity in natural olivine.

Our findings show that Fe-Mg zoning in Irazú olivine mainly results from Fe-Mg inter-diffusion after two crystal growth episodes as indicated by strongly coupled chemical and isotopic zoning. Simulations of this diffusive process indicate that mixing of these crystals into ascending primitive melts occurred <600 days before their eruption, consistent with a previously reported diffusion study based on Ni zonation in Mg-rich olivines. Trace element characteristics of olivine suggest that the complex-zoned olivine crystals originate from a crystal mush/cumulate in the middle or lower crust and deeper than the shallow magma chamber and were mobilized by mantle-derived magma bearing Mg-rich olivines. Finally, modeling of the observed Cr zoning in the Irazú olivines indicates that the diffusion coefficient for Cr in olivine (D_{Cr}) is smaller than $D_{Fe\text{-}Mg}$ by a factor of 4.9 ± 2.9 at the conditions experienced by these crystals consistent with Cr diffusion experiments at high silica activity in the melt.

Our results show that by combining elemental and isotope zoning studies in individual minerals we can refine the timing/assembly of magmatic eruptions and provide independent constraints on element diffusivities. Last, it confirms that primitive arc magmas at Irazú are not aphyric during ascent, but carry primitive phenocrysts from lower crust or Moho depth to the surface.

Keywords: Olivine, Fe-Mg zoning, stable isotopes, laser ablation, diffusion modeling, Cr diffusivity, magma assembly; Rates and Depths of Magma Ascent on Earth