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Timescales of magmatic evolution: Constraints from coupled Fe-Mg chemical and isotopic diffusion profiles

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Chemical zoning in minerals, such as Fe-Mg in olivine, is frequently used to constrain time information on the evolution of magma chambers, assuming that it was generated by chemical diffusion. However, Fe-Mg zoning in olivine may also develop during olivine growth in an evolving magma and, in this case, provides no time information. As recently observed, chemical diffusion generates Fe and Mg isotope fractionation in olivine (of $\sim$ 1‰ and 0.5‰ respectively) that exceeds potential equilibrium isotope fractionation at magmatic temperatures by an order of magnitude [1, 2]. Accordingly, diffusion-generated Fe-Mg zoning in olivine should be coupled with Fe-Mg isotopic zoning, allowing to distinguishing between growth- and diffusion zoning.

Here, we present Fe and Mg isotope profiles across olivine grains of basaltic rocks from different volcanic regions (Vogelsberg, Massif Central, Canary Islands) that were analyzed in situ using femtosecond laser ablation MC-ICP-MS. With this technique, we can analyse δ^{56}Fe and δ^{26}Mg with a precision of $\sim$ 0.1‰ (Oeser et al., this conference). We focused on olivine grains with strong zoning in Mg#. Several of the investigated olivines (including both xeno- and phenocrysts) show significant Fe-Mg isotopic zoning (of up to 1.1‰ for δ^{56}Fe and up to 0.8‰ for δ^{26}Mg), coupled to that of Mg# zoning and δ^{26}Mg and δ^{56}Fe are negatively correlated, i.e. show inverse zoning profiles. These findings strongly indicate that the zoning in Mg# for these olivine grains was generated by Fe-Mg inter-diffusion driven by a chemical gradient between crystals and melt that developed during magma differentiation. Simplified and independent modeling of Fe- and Mg- chemical [3, 4] and isotopic zoning [5, 6] of olivine grains from an ancient lava lake (Roche Sauterre, Massif Central) revealed a best fit for an initial cooling of 10-100 ˚C/year, assuming an initial temperature of 1200 ˚C. A second group of olivine grains exhibit flat Mg-Fe isotopic profiles implying that chemical zoning was generated during crystal growth in an evolving melt rather than by diffusion. A third group of olivines, including some pheno- and xenocrysts from the Canary Islands and the Vogelsberg, show non-correlated variations in δ^{26}Mg and δ^{56}Fe which may indicate a complex history of crystal growth and diffusive processes, driven by a chemical- and/or a thermal gradient.

These initial results of our study demonstrate that chemical zoning in olivine (and likely other phenocrysts as well) cannot straight forward be used to receive time information about the magma residence time of crystals. However, modeling of chemical combined with isotopic diffusion zoning with appropriate diffusion parameters may provide a powerful tool to estimate magma residence times and constrain the evolution of magma chambers.

References:

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