Phosphorus-in-olivine: Experimental constraints on partitioning and zoning

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Igneous olivine phenocrysts generally fail to retain their original compositions and zoning patterns due to fast diffusion and homogenization of divalent cations. However, complex zoning patterns in phosphorus are typically preserved due to slow intracrystalline diffusion, thus making this a suitable element for reconstructing cooling histories and evolution of the host magma. Zoning of igneous olivine in P has been linked either to crystallization rate variations and diffusion controlled growth or to strong compositional controls on melt-mineral partitioning. Here, we investigate partitioning and zoning of phoshorus in igneous olivines by a comparison of natural and experimentally-grown olivines. We explore the importance of variable degrees of undercooling and cooling rates in crystallizing melt with a starting composition equivalent to that of an Italian high-potassium basalt (T_{liq}=1274 °C). Olivine crystallization experiments were conducted in rhenium capsules suspended in a vertical 1-atm gas-mixing furnace at Vrije Universiteit Amsterdam (VUA) with f_{O2} buffered at 1.4 to 1.7 log units below the Ni-NiO buffer. Sets of dynamic crystallization experiments with different degrees of undercooling and controlled cooling rate experiments with varying cooling rates were performed.

We compare the results with our comprehensive EPMA and LA-ICPMS dataset on olivines from Italian K rich mafic lavas and primitive melt inclusions (MI) that they host. The natural olivines contain up to 435 ppm P with MIs containing up to 2.2 wt.% P_2O_5. High resolution (1-2 μm per pixel) element maps show both fine oscillatory and large scale sector zoning in P, uncorrelated with zoning in any other element. The MIs are surrounded by P-depleted zones that are also depleted in Cr and enriched in Al and Ti, which we attribute to a combination of supply-limited slow growth and melt compositional controls on partitioning behavior imposed by the boundary layer. Our combined approach provides more precise constraints on partitioning behaviour of P, than inferences from natural samples alone.