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P-rich olivines in a melt vein of a composite mantle xenolith: implications for crystal growth and kinetics

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The mineral chemistry of mantle xenoliths, and in particular the presence of phosphorus (P) — a moderately incompatible and slowly diffusing element — may preserve the history of mineral growth and constrain timescales of pre-eruption petrogenetic processes (Boesenberg & Hewins 2010). P-rich zones in olivine may reflect incorporation of P in excess of equilibrium partitioning during rapid growth, in which case zoning patterns primarily record crystal growth rate variations (Milman-Barris *et al.* 2008; Stolper *et al.* 2009).

We investigated using EMP analyses and X-ray maps a composite amphibole-bearing, mantle xenolith (sample: Ci-1-196) from Cima Volcanic Field (California, USA) that contains second generation P-rich olivines. The xenolith contains multiple lherzolite, websterite, and dunite layers. The host magma (not preserved in our hand-specimen) is thought to be a hawaiite (Wilshire *et al.* 1988).

A thin (average $\sim$200 μm width), dark layer is present along the contact between lherzolite and websterite. Interpreted as a rapidly crystallized melt, this layer consists of olivine + glass + plagioclase + spinel + clinopyroxene + apatite + ilmenite. The layer contains olivines ($Fo_{83-89.3}$) with 0.03-0.52 wt.% P_2O_5; the P-rich olivines (P_2O_5 >0.1 wt.%) are Fo_{85} to $Fo_{89.3}$. Apatite inclusions are present near the rim of P-rich olivine (Fo_{85}) and in plagioclase (An_{54}). Glass is widespread ($\sim$15 vol.%) in the layer, having variable composition with P_2O_5 up to 1.2 wt.%. Plagioclase occurs as prismatic, flow-oriented crystals, parallel to the elongation of the layer or intergranular crystals between olivine and/or clinopyroxene. Clinopyroxene formed either as crystallized products within the melt layer or by reaction at the interface between melt and matrix olivine. Spinel occurs as inclusions in the olivine or associated with plagioclase and glass, showing anhedral shape and linear edges; spinel composition varies from chromite to Ti-chromite from core to rim, with an outer rim rich in ulvöspinel. Ilmenite occurs as idiomorphic crystals within the layer or as thin rims (<2-3 μm) on plagioclase.

In an EMP traverse across the most P-rich zones (<7 μm) of olivines, we mapped two sub-areas with minimum P surrounded by P-rich planes parallel to crystal edges. The thickness of such P-rich zones never exceeds 3-7 μm. In the P-rich olivines within the melt layer, P concentration is negatively correlated with Si and with Mg+Fe+Ca, suggesting a predominant substitution of P^{+5} for Si^{+4} balanced by M site vacancies: $Mg_2SiO_4 + {}^1\!/_2P_2O_5 \rightarrow Mg_{1.5}Vac_{0.5}PO_4 + {}^1\!/_2MgO + SiO_2$(Agrell *et al.* 1988). There is a slight correlation between P and Al, implying either diffusive relaxation of Al gradients or, judging by the recent dynamic crystallization experiments of Grant and Kohn (2013), cooling rates >10 °C/h that generate disequilibrium solute trapping of P but near-equilibrium incorporation of Al.

References

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