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Mn/Mg ratios of arc lavas show that early garnet fractionation occurs near the Moho of thick continental arcs

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The fractionation of garnet from arc magmas is hypothesized to play an important role in a wide range of geologic processes including the formation of continental crust, the oxidation of arc magmas and the development of porphyry copper deposits. However, garnet is only stable in mafic to intermediate hydrous arc magmas at pressures of at least 0.8-1 GPa and is extremely rare in erupted arc magmas. It is therefore difficult to directly document and study garnet fractionation in the field. Instead, garnet fractionation is frequently inferred based on trace element proxies such as La/Yb, Dy/Yb and Sr/Y. As garnet stability is strongly pressure sensitive, these ratios are also commonly used as proxies for fractionation pressure and crustal thickness. However, this approach is problematic as these ratios span a wide range of values in primary mantle melts independent of crustal thickness, and can also be modified within the crust by amphibole fractionation and plagioclase accumulation.

We show here that Mn/Mg ratios provide an attractive alternative method for inferring garnet fractionation in erupted lavas. Primary mantle melts have highly restricted Mn/Mg ratios that are consistent with melt in equilibrium with mantle olivine. Therefore, this ratio does not appear to keep a record of subducted slab contributions, unlike most trace element proxies. Using a large compilation of experimental data and new high-precision analyses of Mn partitioning in existing garnet-bearing experiments, we show that all common cumulate silicate phases except garnet have Mn/Mg K_D values below 0.5, while the garnet K_D is greater than 1, and thus garnet fractionation produces derivative magmas with distinctly lower Mn/Mg ratios. Using the compiled experimental data, we parameterized an empirical model of Mn partitioning in garnet as a function of pressure and temperature. This model allows for the rigorous investigation of the role of garnet fractionation at both modern and ancient subduction zones. We find clear evidence for garnet fractionation in most arcs with seismically estimated crustal thicknesses greater than ~45 km. This garnet fractionation signature is observable at relatively unevolved melt compositions (≤54 wt. % SiO_2). At these melt compositions garnet is likely only stable at pressures of at least 1.5 GPa, suggesting that garnet fractionation initiates at or below the Moho.