Making the calc-alkaline continental crust: a cumulate perspective

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The Fe-depleted calc-alkaline rocks dominate the continental crust, and reflect Earth's unique crustal differentiation processes among terrestrial planets. However, what drives calc-alkaline differentiation remains contentious. What fractionating phases deplete Fe from the melt? What is the origin of high oxygen fugacity of calc-alkaline rocks?

Here we approach these problems from a cumulate perspective. Our cumulate samples are garnet pyroxenite xenoliths from central Arizona, USA, and are compositonally complementary to calc-alkaline rocks that dominate continental arcs. In these cumulates, we find that primary oxides are only present in the evolved samples, coupled with a rapid increase in cumulate TiO_2 cointent as Mg# declines to below 0.6. On the other hand, application of experimentally calibrated Eu oxybarometer [1] to these cumulates shows that the magmas are progressively oxided from FMQ-1 to at least FMQ+1 with differentiation. This reconstructed redox evolution is consistent with the mineralogy of these cumulates, and suggests that calc-alkaline and thoeliitic differentiation series may initiate with similarly low fO_2 in the primitive magmas, and magnetite is undersaturated until the magma becomes fairly differentiated (corresponding to cumulate Mg# < 0.6).

We propose that garnet fractionation may drive calc-alkaline differentiation. Magmatic garnets crystallizing from basaltic and andesitic magmas are enriched in Fe [2], but have very low ferric Fe contents [3]. Thereby, garnet fractionation acts as a redox filter that simultaneously depletes Fe and causes progressive oxidation of the derivitive melt by increasing its $Fe^{3+}/\sum Fe$. Garnet fractionation is favored at high pressure and high water contents, which explains why calc-alkaline rocks are abundant in continental arcs [4]. This points to the central role of orogenic processess in generating the calc-alkaline continental crust. The redox filter effect associated with garnet fractionation in magmatic orogens may have profound influence on sulfur and chalcophile element cycles during crustal growth, giant ore formation, and redox evolution of the atmosphere.

[1] Burnham et al. (2015) *Chem. Geol.* 411, 248- 259; [2] Alonso-Perez (2009) *Contrib. Mineral. Petrol.* 157, 541-558; [3] Canil and O'Neill (1996) *J. Petrol.* 37, 609- 635; [4] Farner and Lee (2017) *Earth Planet. Sci. Lett.* 470, 96-107.