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High-Fe ("tholeiitic") and low-Fe ("calc-alkaline") differentiation trends in arcs: an attempt to unravel the influence of fO2, water content, slab component, bulk composition, melting % and pressure

M. Elburg

Department of Geology and Soil Science, Ghent University, Ghent 9000, Belgium (marlina.elburg@ugent.be)

Previously suggested models for generating low-Fe (Arculus, 2003: J. Petrol. 44, 929-935) differentiation trends ("calc-alkaline" in the definition of Miyashiro, 1974: Am. J. Sci. 274, 321-355) include assimilation of continental crust (only in continental arc volcanoes) and mixing between basaltic and felsic magmas, that have already undergone Fe-oxide fractionation (e.g. Grove & Baker, 1984: J. Geophys. Res. 89, 3253-3274). The latter mechanism illustrates the importance of Fe-oxides, in arcs generally magnetite. The moment when magnetite starts forming during fractional crystallisation is controlled by several factors. H2O suppresses the crystallisation of silicate minerals more effectively than of magnetite, and high water-contents should therefore lead to a low-Fe differentiation trend (Berndt et al., 2005: J. Petrol. 46, 135-167). As frontal arc volcanoes are generally richer in water than rear-arc volcanoes, one would expect to see more pronounced Fe-depletion in frontal arc volcanoes, which is not borne out by data.

The oxidation state of the magma (fO2) influences the amount of Fe3+ present, and high fO2 magmas should therefore crystallise magnetite early, leading to Fe-depletion. The question is what controls the fO2 of the magma. It is possible that the degree of melting of the mantle source plays a role, as Fe3+ is more incompatible than Fe2+. This could explain the low-Fe trend in magmas with higher K-contents towards the rear of arcs. Although high-K contents could also be generated by the addition of a sediment melt to the mantle source rather than lower degrees of melting, across-arc potassium increases are also seen when isotopic evidence argues against sediment involvement (Stern et al., 2006: Contrib. Mineral. Petrol. 151, 202-221), and also in this case, the more K-rich rear-arc volcanoes display the lower-Fe trend. It is also possible that the observed high fO2 in the rear arc is related to serpentinite dehydration.

Fractionation of amphibole may play a supporting role, since amphiboles generally have somewhat higher Fe/Mg ratios than (clino)pyroxenes. Amphiboles occur more readily in higher-K magmas, and are also stabilised by fractionation at higher pressures.

Finally, remelting of mafic underplates or intrusions may be an often overlooked mechanism of generating intermediate-felsic magmas (Zellmer & Turner, 2007: Lithos 95, 346-362), and is likely to also lead to a low-Fe differentiation trend.