Amphibole fractionation—A constraint on the depth of arc magma evolution?

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We have attempted to constrain the depth(s) at which the main differentiation processes in arc lavas occur, using two main approaches;

REE characteristics. The REE patterns of volcanic rock suites produced by crystal-liquid differentiation processes are sensitive to garnet or amphibole fractionation at deep or intermediate levels, respectively. Not surprisingly La/Yb increases with differentiation (SiO_2) in most of the volcanic suites we have studied. La/Yb increases are, however, not very great and cannot accommodate significant garnet fractionation. Perhaps more surprising, Dy/Yb *decreases* with SiO_2, which is consistent with amphibole fractionation. Garnet fractionation would overprint this effect. Gabbro (ol-cpx-plag) fractionation has limited effect on both La/Yb and Dy/Yb. Thus, it appears that a significant amount of differentiation occurs at intermediate crustal depths where amphibole is stable. Most of the suites studied do not contain modal amphibole. If it is responsible for the REE characteristics observed, amphibole fractionation is cryptic—consistent with the common occurrence of the mineral in cumulate inclusions if not in lavas.

Ra-Th isotope systematics. The timescale of magma differentiation informs on the depth where it occurs: schematically, the deeper, the slower. Decreases in ($^{226}Ra/^{230}Th$) with increasing differentiation at arc volcanoes such as Mt St. Helens indicate timescales of differentiation of the order of a few thousand years. Moreover, modeling shows that if wall rock assimilation occurs, this timescale is significantly reduced, to times as low as a few hundred years. Thus if assimilation and concomitant crystallisation is important, it must happen quickly—which seems unlikely in the deep crust where high temperatures ought to make crystallisation rates slow. Interestingly amphibole fractionation may itself be responsible for some of the decrease in ($^{226}Ra/^{230}Th$) observed with differentiation, which would also tend to reduce inferred timescales.