The role of the upper plate in arc magmatic differentiation

EMILY J. CHIN[1]

[1]Scripps Institution of Oceanography, UC San Diego, La Jolla, CA, USA. e8chin@ucsd.edu

Why arc volcanoes are distinctly calc-alkaline compared to all other tectonic settings on Earth has persisted as a debate for over 100 years. The question is besieged by two diametrically opposed camps: 1) is calc-alkalinity inherited from a slab-modified source unique to arcs, or 2) is calc-alkalinity a product of magmatic differentiation? The prevailing perspective relies on erupted lavas, melt inclusions, and shallow-level igneous rocks. Here, I explore the complementary perspective – that of crystalline cumulates, restites, and melt residues left behind in, and comprising much of, the upper plate lithosphere. I present a synthesis of recent results using 1) a global compilation of deep crustal cumulates and 2) specific petrological/microstructural examples from deep lithospheric arc rocks. The data compilation shows that arc cumulate whole-rock Fe is positively correlated with overriding crust thickness. This correlation is consistent with the hypothesis that overriding plate lithosphere, which responds tectonically to variations in magmatic flux, may regulate degree of mantle wedge melting, and thus primary melt H_2O, Fe^{3+} and consequently, Fe-oxide saturation. Dynamic upper plate processes are not only active in the deep crust, but also the upper mantle, as revealed by coupled petrological & microstructural investigations of residual arc peridotites. Despite extremely low water contents, olivines show subgrain orientations indicating earlier deformation under hydrous conditions ((001)[100] slip system). Orthopyroxenes are zoned from high-Al, high-H_2O cores to low-Al, low-H_2O rims, consistent with subsolidus cooling. These features suggest that although hydrous melt metasomatism is ubiquitous in arc mantle, the process of stabilizing arc lithosphere itself entails significant cooling (and in some cases, increase in pressure through thickening). Such cooling strongly lowers solubility of water in nominally anhydrous minerals, reducing effective viscosity and resulting in a cold and strong lithosphere disconnected from active melt generation. In summary, the upper plate governs arc processes in two ways: 1) its thickness controls Fe content and thus calc-alkalinity of early-formed arc magmas and 2) its P-T evolution, which is tied to arc magmatism and the geometry of the subduction zone, provides a self-consistent regulating mechanism governing magmatic flux and lithospheric stability.