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A Reassessment of the Origins of Silicic Magmas in Subduction Zones

Robert P. Rapp (rapp@sbmp04.ess.sunysb.edu)

Department of Geosciences and Mineral Physics Institute, State University of New York, Stony Brook, New York, United States

It is a widely held view that to understand the origins of arc magmatism in subduction zones is to understand the origin and growth of the continental crust. The paradox of the standard andesite model for crustal growth is that the net mass flux from the mantle to the crust is basaltic in composition (Ellam and Hawkesworth, 1988), yet the composition of average continental crust approximates to magnesian andesite (or "HMA" of Kelemen, 1995). Intracrustal processes of crystal fractionation and assimilation produce silica-rich magmas of the calc-alkaline suite (andesites, dacites and rhyolites) from parental basalts, but net growth of the continental crust requires that either (i) mafic complements to the evolved magmas are returned to the mantle via lower crustal delamination, or (ii) much of the continental crust has grown by processes unlike those taking place at modern convergent plate margins (Rudnick, 1995). From this perspective, the only truly primary silicic magmas in subduction zones may be those produced by direct melting of hydrous basalt of the oceanic crust in subducted slabs.

Dehydration melting experiments on natural basalts at 2-4 GPa and 900-1100 ºC produce sodium-rich, silicic liquids (granitoids) at relatively low- to moderate-degrees of melting (<30%), in equilibrium with rutile-bearing eclogitic crystalline residues. These melts are characterized by high SiO_2 contents (65-72 wt%) and low Mg-numbers (Mg# < 0.48, where Mg# = Mg/(Mg+Fe*)), and possess distinctive trace-element abundance patterns which reflect their experimental "petrogenesis" (e.g., overall enrichment in large-ion lithophile elements (LILEs), high La/Yb, Sr/Y, La/Nb ratios, strong relative depletions in Ti, Nb, Ta, Y and HREEs). At these low-degrees of melting, Ti concentration (and Nb and Ta) in the liquid is buffered by the solubility of rutile in the melt, which shows a strong temperature dependence, such that liquids produced at temperatures below 1000 ºC possess distinctly "negative" Ti anomalies. Thus "pristine", slab-derived, sodic granitoids in subduction zones can readily be identified by their characteristic major- and trace-element geochemical signature. Migration of these slab-derived melts into the overlying mantle wedge results, conceivably, in a range of effects, from hybridization of the original melt, to modal and/or cryptic metasomatism of the peridotitic mantle, with the consequences of slab melt-peridotite rock interaction depending upon the "effective" melt:rock ratio (Rapp et al., 1999). Assimilation experiments at 3-4 GPa suggest that reaction between low-degree, Na-granitoid slab melts and depleted peridotite, at high melt:rock ratios, results in hybridized melts with elevated Mg#'s (Mg# = 50-60), but with the overall shape of their distinctive trace element abundance patterns largely intact. At lower melt:rock ratios, the initial slab melt exhausts itself in modal metasomatic reactions that consume peridotitic olivine, producing a reaction assemblage consisting of orthopyroxene, sodic-amphibole, and Mg-rich garnet. Thus, depending upon the effective melt:rock ratio, reaction between slab-derived melts and depleted mantle can produce hybridized slab melts (which might erupt on the surface as adakitic arc lavas), and melt-metasomatized (refertilized) peridotitic assemblages in the overlying wedge (which might serve as a future, geochemically-enriched, source of "mantle-derived", primary melts).

Arc lavas possessing the distinctive signature associated with "slab melts" (so-called 'adakites') have been identified in a number of intra-oceanic and continental margin subduction zone settings, generally in association with "unusual" geodynamic or thermal conditions; these adakites are virtually identical to the pristine slab melts produced experimentally. Adakites can be shown to be compositionally continuous with high-magnesian andesites (HMA) also possessing the "slab melt" signature (e.g. Sajona et al., 1994; Yogodzinski et al., 1995), with trace element abundance patterns of the adakites essentially parallel to those of high-Mg# magnesian andesites (and parallel to those of the experimental slab melts in either their pristine or hybridized form). There thus appears to be a compositional continuum in these silicic lavas, from low-Mg# examples representing relatively pristine, low-degree melts of eclogitized oceanic crust in the subducted slab (true "adakites"), to high Mg# examples representing either hybridized slab melts, or partial melts of depleted mantle, subsequently enriched by (slab-derived) adakite melts (Kay, 1978).

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