Cumulate melting as the origin for chemical gradients in crystal-poor bodies of silicic magma

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Chemical gradients in zoned ignimbrites with compositions near the water-saturated granite minimum (e.g. Bishop and Bandelier tuffs) are consistent with mineral/melt partitioning predicted from the observed phenocryst assemblage, and suggest little to no mixing with more mafic magma. In contrast, high-temperature ‘Snake River’ type ignimbrites typically lack compositional zoning. Bulk Nd isotopic variations are weak or absent in both types of rhyolite, even where associated volcanic rocks exhibit wide isotopic variation and strong contrasts exist between the isotopic compositions of mantle and crust. Both types of ignimbrite commonly contain crystal aggregates interpreted as fragments of cumulate mush. In zoned systems, these aggregates exhibit evidence for partial resorption of early-formed crystals. We infer that chemical zoning is a near closed-system process and propose that it arises through melting of cumulate mush beneath a crystal-poor body of melt due to heating by invading mafic or intermediate magma with very limited mass transfer to the eruptible magma. Small-volume alkaline systems (Tenerife, Laacher See, Pantelleria) exhibit analogous behavior. If the crystal mush is fusible (e.g. dominated by sanidine + quartz), part of it melts to yield mobile, water-poor rhyolite that pools at the interface between the mush and the overlying rhyolitic liquid. This new melt has a cumulate composition and is thus less evolved and more dense than the original supernatant melt lens. The result is a chemically zoned crystal-poor rhyolitic magma produced with little mass contribution from the invading magma. This model reconciles evidence for open-system behavior and thermal rejuvenation, preserved in crystals, with evidence for the production of zoning by crystallization-differentiation apparent in whole-rock chemistry. Fusibility of the cumulate is key to the process; high-temperature 'Snake River' type rhyolites are not zoned because their cumulates are dominated by a refractory assemblage of pyroxene + plagioclase + Fe-Ti oxide.