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Forming continental crust: Density sorting in subducted arcs

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In recent work (Hacker, Kelemen & Behn EPSL 2011; Behn, Kelemen, Hacker, Hirth & Massone, Nature Geoscience 2011) we investigated pathways for *relamination*: return of compositionally buoyant, subducted material to the base of arc crust. *Delamination* of dense lithologies from the base of arc crust is invoked to convert mafic arc sections to felsic bulk continental crust (BCC; e.g., Ringwood & Green Tphys 66; Herzberg et al CMP 83; Kay & Kay Geol. Rundsch. 91; Ducea & Saleeby 96; Jull & Kelemen JGR 01). However, even in arcs where evidence for delamination of dense roots is compelling, remaining crust can be mafic (e.g., Kelemen et al. Treatise Geochem (ToG) 03; Green et al. J Petrol 06). To form felsic crust may require that more than 50% of the crust reaches granulite facies, perhaps during multiple episodes of thickening. In contrast, subduction of arc lithologies to eclogite facies (via arc-arc collision or subduction erosion) and *relamination* provides an opportunity for density sorting in a single stage.

When arc crust is subducted to eclogite facies, what compositions are buoyant and might return to the crust? We evaluate this using Perple_X (Connolly AJS 90) to calculate densities for volcanic rocks (Aleutians: Kelemen et al. AGU Monogr 03; Singer et al. JGR 07; IBM: Jordan, CentAm & IBM Geochem Database v. 1.02, 12), plutonic rocks in the Aleutians (Kelemen et al. AGU Monogr 03), and plutonic rocks representative of IBM mid-crust (Kawate & Arima Island Arc 98; Haraguchi et al. CMP 03; Saito et al. J Petrol 07; Tamura et al. J Petrol 10).

More than half of Aleutian lavas and plutons are buoyant relative to mantle peridotite in eclogite facies conditions (700-800 C, 3-4 GPa). Density instabilities could return them to the overlying crust. In detail, compared to the range estimated for BCC, Ta concentrations are slightly higher (average volcanics) and lower (average plutons), but a 1:1 mixture of volcanic and plutonic components is within the range for all major and trace elements with sufficient data. Western Aleutian volcanic rocks have the lowest Pb and Sr, and the highest Nd and Hf isotope ratios of any arc worldwide; recycled continental material is absent or negligible. BCC created there is juvenile, derived from the depleted mantle, not from recycling.

Density sorting of IBM compositions produces a similar result. Most primitive and high Mg# IBM lavas and plutons are depleted in K and highly incompatible elements compared to BCC (Kelemen et al. ToG 03). However, more than 80% of IBM lavas and plutonic samples are denser than the mantle in eclogite facies. The remaining, buoyant fractions are similar to BCC, though density sorted IBM data contain slightly higher HREE and lower Ta and Nb, and have a lower Mg#, compared to BCC.

In subduction erosion, forearc material in the subducting package can be $>$ 200 C before erosion so buoyant lithologies reach 700-800 C faster, and in larger volumes at a given time, than in arc-arc collision, facilitating the formation of buoyant diapirs. Subduction erosion rarely, if ever, transports compositionally buoyant material deep into the convecting mantle. Because subducted buoyant material can return to the crust, it is questionable to add eroded material to observed arc volumes to derive crustal growth rates.

Buoyancy instabilities during subduction erosion or arc-arc collision accumulate buoyant, felsic components into the crust, with the composition of BCC. This provides a uniformitarian, end-member process for genesis and evolution of BCC.

Ongoing calculations (similar to Tatsumi et al. G-cubed 2000) will estimate isotope characteristics for the denser fraction of subducted arc crust remaining in the mantle.

Keywords: Continental Crust, Density sorting, Subduction zone