Lower crustal recycling: Reconciling Petrological and Numerical Constraints from the Pamir

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Geochronological and thermobarometric data from a lower crustal xenolith suite in the Pamir offer a unique record of the transport of lower crust to mantle depths after an episode of slab breakoff. We compare petrologically constrained pressure-temperature-time paths from the xenoliths to pressure-temperature-time (P-T-t) paths of tracked markers in 2-D numerical geodynamic models of density foundering with thermodynamically calculated densities. We investigate whether gravitational “drip” instabilities or the peeling back of a dense layer—delamination—can reproduce the P-T-t paths seen in the xenoliths, with the ancillary goal of capturing the positive feedback between mechanical thickening and densification of the lower crust. Key thermobarometric observations from the xenoliths we try to match in our numerical study are: (1) initial heating at near-constant pressure followed by (2) a sharp increase in pressure with continued heating. We find that thick crustal sections develop P-T-t paths in numerical models of delamination that match the observations from xenoliths: the lower crust initially heats due to return flow from upwelling asthenosphere, and then foundering mantle lithosphere and crust show a marked increase in pressure with additional heating. Initial gravitational drip instabilities founder with relatively little heating yet may thin the mantle lithosphere sufficiently to allow for subsequent delamination or asymmetric drips to nucleate in the region of hotter, thinner mantle lithosphere. Such subsequent asymmetric drips or delamination entrain crust that closely follows the P-T-t path from xenoliths. This suggests that the xenoliths were not derived from an initial drip instability, but instead from later instabilities or delamination enabled by thinning of the lithosphere. In all models where density foundering occurs, the positive feedback between contraction and densification of the lower crust leads to the loss of initially positively buoyant lower crust. The combination of geological and numerical methods constrains the geometry and triggers of lower crustal foundering during collision. Contraction alone does not match the record of foundering; the lithosphere must have also been asymmetrically thinned.