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Orogenic delamination - dynamics, effects, and geological expression

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Unbundling of continental lithosphere and removal of its mantle portion have been described by two mutually rather exclusive models, convective thinning and integral delamination. Either disburdens the remaining lithosphere, weakens the remainder, and causes uplift and extension. Increased heat flux is likely to promote high-degree crustal melting, and has been viewed as a source for voluminous granitic intrusions in late or collapsing orogenic settings. Collapse may be driven by any of gravitational potential differences from orogen to foreland, by stress inversion in the unburdened domain, or by suction of a retreating trench. In this study, we investigate prerequisites, mechanism, and development paths for orogeny-related mantle lithosphere removal.

Our experiments numerically reproduce delamination which self-consistently results from the dynamics of a decoupling collision zone. In particular, it succeeds without a seed facilitating initial separation of layers. External shortening of a continent – ocean – continent assembly, such as to initiate oceanic subduction, is lifted before the whole oceanic part is consumed, leaving slab pull to govern further convergence. Once buoyant continental crust enters, the collision zone locks, and convergence diminishes. Under favourable conditions, delamination then initiates close to the edge of the mantle wedge and at deep crustal levels. While it initially separates upper crust from lower crust according to the weakness minimum in the lithospheric strength profile, the lower crust is eventually also delaminated from the subducting lithospheric mantle, owing to buoyancy differences. The level of delamination within the lithosphere seems thus first rheology-controlled, then density-controlled. Subduction-coupled delamination is contingent on retreat and decoupling of the subducting slab, which in turn is dependent on effective rheological weakening of the plate contact. Weakening is a function of shear-heating and hereby of collision rate, melting and hydration, the latter two incorporating the effects of sediment subduction and phase changes. The drag available for slab retreat scales with the age of the descending oceanic lithosphere; integrated strength of the lithosphere and activation volume for mantle creep additionally control angle and depth of the descent. Fully developed delamination is observed from between 10 to 15 Ma after collision ceases, with following trenchward migration of the delamination front. Consequently, the main maximum extension migrates, while local, partly intermittent compression can be observed on smaller scale. Across the orogen, extension thus has a strongly diachronous main component. We track common surface observables such as heat flow, partially melted rocks (domal migmatites), and predicted geo-/thermochronological ages over the evolving plate boundary. Geochemical projections of our observations confirm potential contamination of reservoirs – although the net delamination level follows the Moho, some crustal remnants along the old slab still sink through the 660-discontinuity. On the other hand, the base of the delaminated domain is not as plain a contact as in concept. Where the contact of asthenosphere with delaminated crust is the location of high-degree melting, also traces of original lithospheric mantle can be entangled.

Our results do not fully support the conceptual distinction between convective thinning and blockwise delamination. While the foundering portion initially retains a fairly coherent, slab-like perimeter, the actual separation of layers in a limited process-zone occurs in smaller -scale eddies. Also, convection of the whole uprising asthenosphere wedge is dynamically not discernible from the latter and crucial for the removal of lithospheric mantle. The removed lithosphere does initially not convect, but subsequently shows an increasing tendency to drip down. In the presented case, extension in the axial zone of the orogen is not (only) caused by unsupported gravitational potential of the core domain itself, but actively driven by slab retreat with a shallow mantle dynamic contribution.