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Modelling late-orogenic collapse: A combined thermo-mechanical and chemical approach

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We have explored the geodynamics of late-orogenic collapse via numerical models to study the effects of lithospheric thinning on mantle and lower crustal melting. Our goal is to better understand the formation of migmatitic terrains and the role of mantle melt in generating the geochemical spectrum of granitoids observed during the lithospheric re-equilibration. These numerical models combine finite elements thermo-mechanical modelling coupled with a Gibbs free energy minimization strategy that allow tracking melt composition. Our models assume a "jelly sandwich" strength profile of the lithosphere and the existence of sub-lithospheric small-scale convection caused by the increased post-subductional mantle water contents. The models take into account the viscosity lowering effects of water and partial melts, and dynamically adjust the composition of the mantle and crustal residue after extraction of partial melts. Effects of mantle magmas underplating the crust have been studied. Using Gibbs energy minimization allows for precise tracking of the crustal melt composition (major oxides) as a function of time and location.

Our results show that minor lithosphere thinning causing low degree lower crustal melting can grow into large scale lithospheric mantle delamination via a positive feedback mechanism between the thinning of the lithosphere and the strength weakening by the partial melts in the lower crust. The melt percolation threshold (percentage of melt at which melts are extracted) affects this feedback mechanism: Extracting melts disable the weakening effect by the partial melts, but also removes most of the water in the source, leaving behind a depleted high viscosity residue layer. For this reason we also found that underplating of mantle melts below the crust initially enhances the positive feedback in lithosphere thinning, but overall has no major – or has even negative – impact on the lithosphere thinning and crustal melting. If asthenospheric melts are extracted and underplated, they leave behind a strong layer that shields the lithosphere from further thinning from below.

Because the feedback mechanism causes a sudden thinning of the lithosphere, removal of the lithospheric mantle, and exposes the lower crust to the asthenosphere, we found that the appearance of crustal melt and the overall final geometry, as well as the dynamics of lithospheric delamination, is similar to the geological record. Indeed, our models show long lasting migmatization of the crust followed by relatively sudden emplacement of granitic plutons, interposed by mantle derived potassic magmas, which, in the geological record, are often found as enclaves in the granites. This phase is usually related with the collapse of the orogen and is compatible with the extensional stress fields found at the upper crust level in our models.