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Enigmatic thermal pulse and subsidence retardation during the early stages of lithosphere thinning explained by asynchronous depth-dependent necking

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On the one hand, field observations from the European Alps and several seismic data from present-day rifted margins testify for the existence of sedimentary unconformities in their so-called “necking domain” (i.e. region where the crust thins rapidly from about ∼30 km to ∼10 km). On the other hand, recent thermo-chronological studies show that lower crustal rocks from the former necking domain of the Alpine Tethys rifted margin recorded an intense thermal pulse during early stages of rifting (the “necking stage”). Yet, the origin of both the thermal pulse and sedimentary unconformities remains enigmatic.
Using results from two-dimensional thermo-mechanical numerical simulations, we show that both features can be explained by asynchronous lithospheric necking of first the upper mantle, and subsequently the crust. When the upper crust is mechanically decoupled from the upper mantle by a weak ductile lower crust and in the absence of a pervasive rheological heterogeneity, upper mantle necking occurs before crustal necking because of the larger effective viscosity and associated stresses in the upper mantle. As extension progresses, strain localization within the crust leads to the formation of necking zones on both sides of a little deformed block, referred to as the (crustal) keystone. The earlier necking of the upper mantle causes a local high geothermal gradient at the base of the future keystone. This thermal support beneath a region of little thinned crust causes the keystone to remain topographically higher than adjacent domains during the early stages of its formation. The peculiar isostatic evolution of the keystone during lithosphere necking, namely its local subsidence retardation with respect to adjacent areas followed by a rapid deepening, may explain the diagnostic unconformity observed in the necking domain of several hyperextended rifted margins.