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Topographic and thermal evolution during the necking phase of rifting: a numerical modelling study

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The topographic and thermal evolution of rift systems are poorly understood. At present, both are commonly described by the classical model of McKenzie (1978), where lithosphere extension is instantaneous and uniform with depth. In this model lithosphere extension generates: (1) immediate surface subsidence related to mass redistribution; and (2) instantaneous geothermal gradient increase without any material heating (the lithospheric material is simply advected upward). Then, thermal relaxation results in slow lithosphere cooling and progressive surface subsidence. While this model has been successfully applied to describe the topographic and thermal evolution of rift basins within the proximal domain, it fails accounting for the complex topographic and thermal evolution observed during the subsequent necking phase, when the crust is thinned from $\sim$ 30–35 to $\sim$ 10 km.

On the one hand, seismic observations as well as drill hole and field data from both present-day and fossil 'magma-poor' hyperextended rift systems indicate that the (future) 'distal domain' of many continental margins remained at shallow water depth during more or less advanced stages of extension, hence show evidence for uplift and erosion (e.g. the Briançonnais domain in the fossil European distal margin of Alpine Tethys (Claudel & Dumont, 1999); the Campos Basin offshore Brazil (Lewis et al., 2014); and the East India margin (Haupert et al., 2016)). On the other hand, thermo-chronological data from fossil rifted margins exposed in the Alps and Pyrenees testify to a transient but intense heating event during the necking phase of rifting (Smye & Stöckli, 2014; Seymour et al., 2016; Hart et al., 2017).

Here we use two-dimensional thermo-mechanical numerical modelling to investigate the topographic and thermal evolution of extensional systems during the necking phase of rifting depending on the rheology of both the crust and the mantle. Our results suggest that the initial rheology of the lithosphere has a major impact on the shape, relief and topography evolution of rift systems, as well as on the intensity of relative cooling/heating within the lithosphere. Extension of a lithosphere comprised of strong, mechanically coupled, crust and mantle favours the rapid development of one single narrow, deep and continuously subsiding rift basin with steep margins. In contrast, extension of a lithosphere where the crust and mantle are mechanically decoupled by a weak lower crust is protracted and the rift system shows lower relief and a much more complex morpho-tectonic evolution, with formation of temporary insulated basins and/or transient uplift of parts of the future distal margin.

Mechanical decoupling between the crust and the mantle favours also intense heating and cooling of specific regions within the lithosphere. Modelled processes like strain softening, erosion, sedimentation and melt impregnation have a limited impact on the primary morphology and thermal state of rift systems but slightly increase the relief and thermal heterogeneities.