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Impact of lithosphere rheology and pre-existing tectonic stress field on surface topography, crustal and mantle deformation during plume-lithosphere interactions in continents: insights from 3D numerical experiments

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We implement high-resolution 3D thermo-mechanical numerical models to elucidate the impact of realistically implemented rheological structure of continental lithosphere and of far-field tectonic stress/strain field on the localization and style of deformation during the emplacement of a mantle plume at the bottom of continental lithosphere. Numerical models demonstrate strong dependence of crustal strain distributions and surface topography on the rheological composition of the lower crust and the initial thermal structure of the lithosphere. In contrast to the usual inferences from passive rifting models, distributed wide rifting takes place in case of cold (500° C at Moho depth) initial isotherm and mafic composition of the lower crust, whereas hotter geotherms and weaker (wet quartzite) lower crustal rheology lead to strong localization of rifting. Moreover, it appears that the prerequisite of strongly anisotropic strain localization (linear rift structures) refers to simultaneous presence of an active mantle plume and of some, even very weak, slow (< 3 mm/y) passive horizontal extension produced by far-field tectonic forces. Higher (than 1.5-3 mm/y) velocities of supplementary far-field extension expectedly lead to enlargement of the active fault zone for the same lapse of time. Yet, simultaneous rise of the lithospheric geotherm associated with active rifting has an opposite effect leading to the narrowing of the rift zone. Consequently, interplays between active and passive rifting result in highly varying rifts styles hence breaking common rift-style classifications. The importance of the rheological properties of the continental crust for deformation regime is demonstrated not only by considerable difference in surface morphology and crustal strain patterns between the models with different lower crustal rheology, but also by a noticeable distinction in deep distribution of the plume head material, with consequent effect for magmatic processes and mantle lithosphere stability.