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Break-up of continental lithosphere interacting with upper mantle and surface processes

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Lithospheric deformation during rifting involves complex interactions between mantle, crust and surface processes. We investigate the interactions of both upper mantle and lithosphere, and of lithosphere and surface processes, using three-dimensional numerical models. We employ a thermomechanical, visco-plastic code that we couple to a surface process model. The latter evolves the surface by linear diffusion and coupling is accomplished through horizontal advection of topography. This model is used to investigate the effects of erosional efficiency and the impact of mantle plume generation. We investigate the use of integrated work metrics as a measure of rift progression.

In the simplest case, extension along one direction and not including plumes, two factors are found to control rift initiation. The timing of rift initiation is primarily determined by the Moho temperature and thus the integrated rheological strength, but surface process efficiency also plays a significant role. Under fixed thermomechanical conditions, timing of initiation of rifting varies by up to 15%, or ca. 1 Myr, depending on surface process efficiency (i.e. diffusivity). Plume impingement localizes extension and strongly accelerates rift initiation, with earlier initiation for larger plumes. Despite the efficient rift localization by plumes, an impact of mass redistribution by surface diffusion on the timing is also observed. Triaxial far-field forcing (slow horizontal convergence in the direction normal to extension) delays relative rift initiation. In this case, spreading of plume material can facilitate secondary delamination around the tips of the propagating central rift zone.

Analysis of the mechanical work in the entire model over time, measured as energy conversion due to viscous deformation (shear heating, or viscous dissipation; including plastic deformation, which is incorporated through an effective viscosity), depicts the long-term differences in model evolution. Output of total work over time follows a common pattern. Plumes and surface-process variations offset these curves relative to each other, and reflect the effect both have on rifting, even if differences are not apparent from model structures alone.