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Highlights of the evolution of various rift configurations and the influence of strain healing

Rift systems play a crucial role in the Wilson cycle, where the extension and breakup of continental plates can lead to the formation of new oceans. Earth's rift systems exhibit various stages, from initiation to breakup, with the latter representing 'successful' rifting, as observed along the Atlantic margins. Whereas rifted margins can record successful extensional plate dynamics, deformation can also stop at earlier stages or shift to more favourable locations, resulting in 'failed' rifts, such as the North Sea or the Atlas rift. However, the mechanisms that control whether a rift fails or is successful are not very well known.

Understanding the dynamics of continental extension and tectonic processes in rift systems requires examining their initial conditions and subsequent evolution, with the latter influenced by both strengthening and weakening processes of the lithosphere. Here we numerically simulate rift evolution using geodynamic finite-element 2D ASPECT models incorporating shear zone ("fault") dynamics and strain softening within a visco-plastic rheological framework. We use the landscape evolution model FastScape to simulate surface processes.

To understand which processes lead to the success or failure of a rift, we explore the role of strengthening and weakening processes. Our modelled strengthening processes comprise (1) lithospheric cooling, which enhances the strength of ductile domains via temperature-dependent viscosity, (2) gravitational potential energy gradients that impose a degree of compression outboard of high-elevation domains; and (3) fault healing, which strengthens frictionally weakened regions over time as a function of temperature. We also account for the following weakening processes: (1) frictional softening, which causes an increase in fault activity; (2) lithospheric necking, which thins and thereby heats the lithosphere beneath the rift centre; (3) erosion and sedimentation, as simulated by FastScape, which alters the distributions of surface loads in a way that increases fault longevity. Within the framework of these processes, we examine the effects of crustal thickness, extension rate, rheology, and friction angle, on the spatial and temporal occurrence of rift success and failure. To quantify the results, we analyse fault geometry and dynamics, as well as the forces required for continued extensional plate motion.

Preliminary results indicate the existence of a lower limit for the full extension velocity to achieve breakup. For models with typical continental lithosphere this limit is ~2 mm/yr. Lithosphere that is extending at a smaller velocity thins temporarily, but strengthening mechanisms ultimately outweigh weakening processes, resulting in relocalisation of deformation. Our analysis highlights the internal and external processes that influence rift systems at different evolutionary stages and provides criteria for understanding and predicting rift evolution.

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