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High resolution 2D numerical models from rift to break-up: Crustal hyper-extension, Margin asymmetry, Sequential faulting

Sascha Brune (1), Christian Heine (2), Marta Pérez-Gussinyé (3), and Stephan Sobolev (1)

(1) GFZ-Potsdam, Geodynamic Modeling Group, Potsdam, Germany, (2) EarthByte Group, School of Geosciences, The University of Sydney, Australia, (3) Royal Holloway College, University of London, UK

Numerical modelling is a powerful tool to integrate a multitude of geological and geophysical data while addressing fundamental questions of passive margin formation such as the occurrence of crustal hyper-extension, (a-)symmetries between conjugate margin pairs, and the sometimes significant structural differences between adjacent margin segments.

This study utilises knowledge gathered from two key examples of non-magmatic, asymmetric, conjugate margin pairs, i.e. Iberia-New Foundland and Southern Africa-Brazil, where many published seismic lines provide solid knowledge on individual margin geometry. While both margins involve crustal hyper-extension, it is much more pronounced in the South Atlantic. We investigate the evolution of these two margin pairs by carefully constraining our models with detailed plate kinematic history, laboratory-based rheology, and melt fraction evaluation of mantle upwelling. Our experiments are consistent with observed fault patterns, crustal thickness, and basin stratigraphy.

We conduct 2D thermomechanical rift models using the finite element code SLIM3D that operates with nonlinear stress- and temperature-dependent elasto-visco-plastic rheology, with parameters provided by laboratory experiments on major crustal and upper mantle rocks. In our models we also calculate the melt fraction within the upwelling asthenosphere, which allows us to control whether the model indeed corresponds to the non-magmatic margin type or not.

Our modelling highlights two processes as fundamental for the formation of hyper-extension and margin asymmetry at non-magmatic margins: (1) Strain hardening in the rift center due to cooling of upwelling mantle material (2) The formation of a weak crustal domain adjacent to the rift center caused by localized viscous strain softening and heat transfer from the mantle. Simultaneous activity of both processes promotes lateral rift migration in a continuous way that generates a wide layer of hyper-extended crust on one side of the rift basin. This mechanism implies that syn-rift deformation at the distal margin postdates faulting at the proximal margin by several million years. The succession of events holds intriguing implications not only for peak heat flow migration but also for processes like serpentinization and magmatic underplating.