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Evolution of crustal stress patterns and fault orientations during oblique extension: Numerical 3D experiments from rift to break-up

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In continental rifts, extension is often oblique to the rift trend. This was the case during formation of the South Atlantic (especially in the Equatorial Segment), and the North Atlantic (Baffin Bay and Fram Strait). Oblique extension formed the Gulf of California, the Gulf of Aden and is presently active in the Ethiopian Rift System, as well as the Dead Sea Fault System.

This study addresses the evolution of crustal stress patterns and fault geometries during oblique extension. It presents 3D numerical experiments on lithospheric scale that cover the rift evolution from initial deformation to break-up. Each simulation involves a different direction of extension in order to explore the whole extensional spectrum (i.e. rift-orthogonal extension, low to high obliquity, strike-slip deformation). The applied elasto-visco-plastic numerical model (SLIM3D) is based on the finite element method which allows an efficient implementation of a free surface and involves nonlinear stress- and temperature-dependent viscosity with laboratory-based parameters.

Analog experiments have a rich history in studying the fault patterns of oblique rifts, however, reproducing realistic rheologies and temperature-dependent viscosity is problematic. While these issues are overcome in present day numerical models, they are limited by computational power which constrains 3D models to a relatively coarse resolution. In this study, I widen the scope of numerical 3D models by introducing a post-processing method that uses the stress-tensor to evaluate both the stress regime (extensional, strike-slip, compressional) and the preferred fault azimuth at each surface element assuming that faults are formed with optimal orientation in the stress field. Numerical results are validated by comparison to previous analog experiments.

The numerical models exhibit a characteristic three-phase rift evolution. Individual phases can be characterised in terms of rift-parallel, extension-orthogonal, and intermediate normal fault directions as well as strike-slip faults with Riedel shear orientations. In experiments with low obliquity, sigmoidal en-echelon patterns emerge that result from the rotation of long-lived shear zones. Strain partitioning occurs in models of intermediate and high obliquity where the rift center and the rift flanks experience strike-slip deformation and normal faulting, respectively.