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Three-dimensional numerical experiments on oblique rifting

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Normal continental lithosphere appears to be too strong to be broken by available plate-tectonic forces under pure extension. Therefore, additional processes leading to the weakening of the lithosphere or to stress concentration, must be taken into account like inherited weakness, melt generation and propagation, plumes, or oblique rifting. In this study we focus on the influence of oblique rifting, a process that occurred for instance during the initial stages of continental break-up between South America and Africa, 140 Myr ago.

Our research is conducted within SAMPLE (South Atlantic Margin Processes and Links with onshore Evolution), a Priority Program funded by the German Research Foundation. The project interconnects research on mantle dynamics, lithosphere structure and deformation, sedimentary processes, fluid systems and climate. Using thermomechanical models at both lithospheric and global scales, the task of our group is to define driving forces and mechanical weakening factors that resulted in break-up at the western margin of Southern Africa leading to the formation of the South Atlantic.

We use the thermomechanical, three-dimensional, finite element code SLIM3D to model rifting on lithospheric scale. The code features a true free surface and an elasto-visco-plastic rheology with diffusion and dislocation creep, Peierls mechanisms and Mohr-Coulomb plasticity. We compute the behavior of a rectangular segment consisting of 20 km upper crust (Quartzite), 15 km lower crust (Granulite), 85 km strong mantle (dry Olivine) and 30 km weak mantle (wet Olivine). The thermal lithospheric thickness as defined by the 1200 °C isotherm is set to 90 km. We initiate the system by a small vertical temperature deviation along the prospective rift zone.

Two setups are presented: (i) the rift zone lies parallel to the model boundaries where oblique velocities are applied, (ii) the rift zone is initiated obliquely while the boundary velocities are perpendicular. In both cases, we evaluate the force that is required to maintain the prescribed boundary velocities. This force amounts to 17 TN/m if velocities are perpendicular to the rift zone, reduces significantly for oblique rifting and falls below 10 TN/m in the purely strike-slip end member case. The robustness of our results has been tested by a thorough parameter study. We successively varied lithosphere thickness and rheology, in particular switched off friction softening or shear heating and introduced two potential rift zones of different obliquity. For any of these simulations, oblique rifting turns out to be energetically preferred to perpendicular rifting.