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Three-dimensional numerical models of continental break-up: Oblique rifting requires less force

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The initial stage of continental break-up was and is often associated with oblique rifting. That includes break-up of Gondwana in the South Atlantic region as well as in many recent rift systems, like Gulf of California, Ethiopia Rift and Dead Sea fault. We investigate the reason for that association by means of three-dimensional numerical modelling.

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) and 85 km strong mantle (dry Olivine) that is underlain by 30 km of weak mantle material (wet Olivine). The thermal lithospheric thickness as defined by the 1200 °C isotherm is set to 90 km, a typical value for mobile belts. 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 13 TN/m if velocities are perpendicular to the rift zone, reduces significantly for oblique rifting and falls below 7 TN/m in the purely strike-slip case. This behavior is due to the fact that oblique and strike-slip deformation requires less force in order to reach the plastic yield limit than rift-perpendicular extension. We verified that result by means of an analytical calculation for an elasto-plastic end-member case. Another important finding of this study is that for two competing rifts, with one perpendicular and one oblique to the direction of extension but otherwise identical properties, the oblique rift zone attracts more strain and hence continental break-up occurs there.