Numerical experiments on oblique rifting

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Objectives

Regular continental lithosphere appears to be too strong to be broken by available tectonic forces under pure extension (e.g. Buck 2004). Therefore, additional strength-reducing factors have to be taken into account like melt generation and propagation, inherited weakness, plumes, or oblique rifting. In this study we focus on the influence of oblique rifting, a process that has been observed during initial stages of continental break-up, e.g. during the separation of South America and Africa, 140 Myr ago (MacDonald et al. 2003). We use the thermomechanical, three-dimensional, finite element code SLIM3D (Popov and Sobolev, 2008) to model rifting on lithospheric scale. We investigate the effect of strike-slip components on the strength of the lithosphere for both slow (6 mm/yr) and fast (30 mm/yr) extension rates.

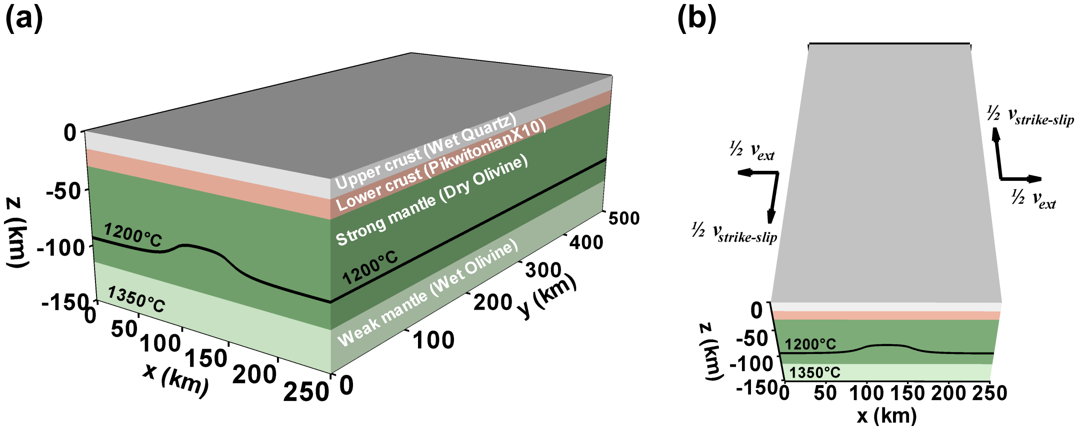

Figure 1. *Model setup.* ***(a)*** *Our model involves 4 layers of distinct rheology. The 1200 °C isotherm marks the lithosphere asthenosphere boundary.* ***(b)*** *Velocities are prescribed at the lateral boundaries.*

Numerical model setup

The implicit, Lagrangean, three-dimensional FEM code SLIM3D (Popov and Sobolev 2008) involves a coupled thermomechanical treatment of deformation processes with true free surface and incorporates an elasto-visco-plastic rheology with diffusion and dislocation creep, Peierls mechanisms as well as Mohr-Coulomb plasticity. We compute the behavior of a rectangular lithosphere/asthenosphere segment sized 500 × 250 × 150 km (Fig. 1). We adopt a 20 km thick upper crustal layer of wet quartzite rheology (Gleason and Tullis, 1995), a lower crustal layer of 15 km thickness and granulite properties (Wilks and Carter, 1990), and a 85 km thick layer of strong mantle material with dry olivine rheology (Hirth and Kohlstedt, 2003). Taking into account the higher water content of the asthenosphere, we use rheological parameters of wet (i.e. 500 ppm H/Si) olivine in the lowermost layer of 30 km thickness (Hirth and Kohlstedt, 2003).

The system is initiated with a small vertical temperature deviation along strike for the 1200 °C isotherm. Dirichlet boundary conditions are applied at the right and left boundary, prescribing the velocities (½ v_{ext}, i.e. half extension velocity and ½ $v_{strike\text{-}slip}$, i.e. half strike-slip velocity). Furthermore, we apply a free surface at the top, an open boundary at front and back side, as well as Winkler support at the bottom boundary. The model includes three weakening mechanisms: (1) Friction softening in the crust linearly decreases the Mohr-Coulomb friction coefficient to 10 % of the initial value for strains between 0 and 1. For larger strains, it stays constant at 10 %. (2) Shear heating weakens materials by the following feedback mechanism: Shear heating increases the temperature and thereby lowers the viscosity. Low viscosity leads to higher strain rate which in turn increases shear heating. (3) Dislocation creep features a power law dependency between strain rate and stress. This causes a decreasing viscosity if stresses increase (i.e. stress softening).

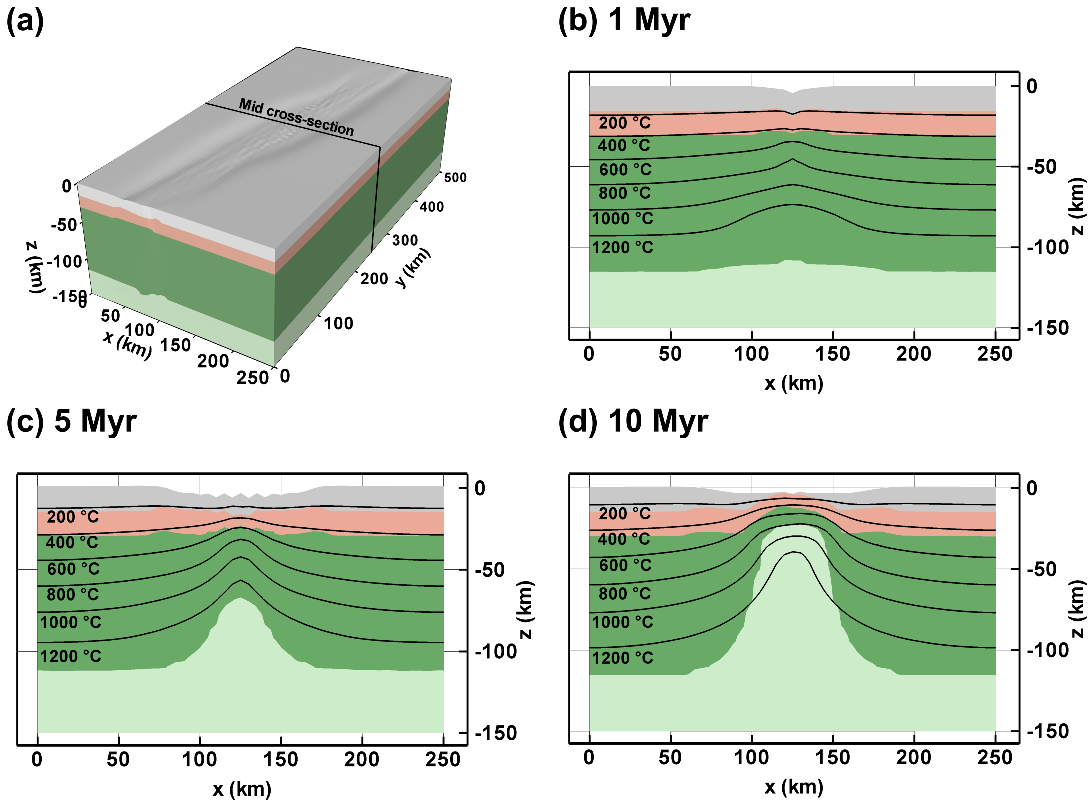

Figure 2. Lithospheric necking through time for 6 mm/yr extension and 30 mm/yr strike-slip. Layer colors indicates phase, contour lines temperature. **(a)** 3d block indicating the position of the following cross sections. **(b-d)** Mid cross section after 1, 5, and 10 Myr, respectively.

Results

Our calculations show a straight area of strain localization at the center of the computational domain subparallel to the y-axis (Fig. 2). Here, the uppermost mantle and crust exhibit outward motion and undergo necking. Lithospheric material in the rift center is replaced by advective upwelling in the hot center of the rift. The strength of the lithosphere in the deformation region decreases with time, as the replacement of weak crust by strong mantle material does not balance the advective temperature increase. We compute forces at the lateral domain boundaries. The influence of additional strike-slip components on the force is small for fast extension (30 mm/yr): The lithosphere is already softened significantly by high extension velocities alone so that obliquity has only minor influence. For more realistic, relatively slow extension (6 mm/yr), however, oblique rifting causes a significant force reduction.

Literature

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