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The life cycle of continental rifts: Numerical models of plate tectonics and mantle convection.

Martina Ulvrova (1), Sascha Brune (2), and Simon Williams (3)

(1) Laboratoire de Geologie de Lyon, Claude Bernard University Lyon 1, Villeurbanne, France (mulvrova@gmail.com), (2) Helmholtz Centre Potsdam, GFZ German Research Centre for Geosciences, Potsdam, Germany (brune@gfz-potsdam.de), (3) EarthByte, School of Geosciences, University of Sydney, Sydney, New South Wales, Australia (simon.williams@sydney.edu.au)

Plate tectonic processes and mantle convection form a self-organized system whose surface expression is characterized by repeated Wilson cycles. Conventional numerical models often capture only specific aspects of plate-mantle interaction, due to imposed lateral boundary conditions or simplified rheologies. Here we study continental rift evolution using a 2D spherical annulus geometry that does not require lateral boundary conditions. Instead, continental extension is driven self-consistently by slab pull, basal drag and trench suction forces.

We use the numerical code StagYY to solve equations of conservation of mass, momentum and energy and transport of material properties. This code is capable of computing mantle convection with self-consistently generated Earth-like plate tectonics using a pseudo-plastic rheology. Our models involve an incompressible mantle under the Boussinesq approximation with internal heat sources and basal heating. Due to the 2D setup, our models allow for a comparably high resolution of 10 km at the mantle surface and 15 km at the core mantle boundary. Viscosity variations range over 7 orders of magnitude.

We find that the causes for rift initiation are often related to subduction dynamics. Some rifts initiate due to increasing slab pull, others because of developing trench suction force, for instance by closure of an intra-oceanic back-arc basin. In agreement with natural settings, our models reproduce rifts forming in both young and old collision zones. Our experiments show that rift dynamics follow a characteristic evolution, which is independent of the specific setting: (1) continental rifts initiate during tens of million of years at low extension rates (few millimetres per year) (2) the extension velocity increases during less than 10 million years up to several tens of millimetres per year. This speed-up takes place before lithospheric break-up and affects the structural architecture of rifted margins. (3) high divergence rates persist until break-up is achieved and often reduce several tens of millions of years after continental separation.

By illustrating the geodynamic connection between subduction dynamics and rift evolution, our results allow new interpretations of plate tectonic reconstructions. Rift acceleration during the transition from phase 1 to phase 2 induces elevated convergence rates at the opposite side of the continents. This leads to enhanced subduction velocities, e.g. between North America and the Farallon plate 200 million years ago, or to the closure of potential back-arc basins such as in the proto-Andean ranges of South America. Post-rift deceleration occurs when the global plate system re-equilibrates after the phase of enhanced stress during continental rupture. This phenomenon of a plate slow-down after mechanical rupture occurred in the real-world aftermath of Australia-Antarctica separation, South Atlantic opening, and North Atlantic break-up.