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Thermo-mechanical modeling of continental rift evolution over mantle upwelling in presence of far-field stresses

Alexander Koptev (1), Evgueni Burov (1), Eric Calais (2), Sylvie Leroy (1), and Taras Gerya (3)

(1) Sorbonne Universités, UPMC Univ Paris 06, CNRS, Institut des Sciences de la Terre de Paris (iSTeP), 4 place Jussieu 75005 Paris, France, (2) Ecole Normale Supérieure, Department of Geosciences, PSL Research University, CNRS UMR 8538, Paris, France, (3) ETH-Zurich, Institute of Geophysics, Sonnegstrasse 5, Zurich, Switzerland

We conducted fully-coupled high resolution rheologically consistent 3D thermo-mechanical numerical models to investigate the processes of mantle-lithosphere interaction (MLI) in presence of preexisting far-field tectonic stresses.

MLI-induced topography exhibits strongly asymmetric small-scale 3D features, such as rifts, flexural flank uplifts and complex faults structures. This suggests a dominant role of continental rheological structure and intra-plate stresses in controlling continental rifting and break-up processes above mantle upwelling while reconciling the passive (far-field tectonic stresses) versus active (plume-activated) rift concepts as our experiments show both processes in action.

We tested different experiments by varying two principal controlling parameters: 1) horizontal extension velocity and 2) Moho temperature used as simplified indicator of the thermal and rheological lithosphere layering.

An increase in the applied extension expectedly gives less localized deformation at lithospheric scale: the growth of external velocity from 1.5 mm/years to 6 mm/years leads to enlargement of the rift zones from 75-175 km to 150-425 km width. On the contrary, increasing of the lithospheric geotherm has an opposite effect leading to narrowing of the rift zone: the change of the Moho isotherm from 600°C to 800°C causes diminution of the rift width from 175-425 km to 75-150 km. Some of these finding are contra-intuitive in terms of usual assumptions.

The models refer to strongly non-linear impact of far-field extension rates on timing of break-up processes. Experiments with relatively fast far-field extension (6 mm/years) show intensive normal fault localization in crust and uppermost mantle above the plume head at 15-20 Myrs after the onset of the experiment. When plume head material reaches the bottom of the continental crust (at 25 Myrs), the latter is rapidly ruptured (<1 Myrs) and several steady oceanic floor spreading centers develop. Slower (3 mm/years) far-field velocities result in disproportionally longer break-up time (from 60 to 70 Myrs depending on initial isotherm at the crust bottom).

We conclude from our modeling that localization of large-scale linear normal faults in rifted zones can be triggered and maintained by mantle flow that impacts on the base of a pre-stressed lithosphere, so that the final state of the rifted lithosphere is an indicator of the far-field stress at the time the plume arrived. This suggest efficient mechanism for continental rift initiation and breakup that involves passive and active rifting processes that interact each other resulting in development of large continental rift.