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Insights from 2D numerical models on two-branch continental break-up: a single mantle plume's effect on a laterally heterogeneous lithosphere

Anouk Beniest (1,2), Alexander Koptev (1), and Sylvie Leroy (1)

(1) Université Pierre et Marie Curie, ISTEP, Géosciences, Resources Naturelles et Environnement, Paris, France , (2) IFP Energies nouvelles, Géosciences, Rueil-Malmaison, France (anouk.beniest@ifpen.fr)

We use 2D numerical models to investigate the impact of the location of one single mantle plume on the break-up evolution of realistic rheologically stratified continental lithosphere. The lithosphere is characterized by a laterally non-homogeneous rheology: a "weak" crust for the left half of the model box and a "strong" crust for the right one. We tested different experimental settings by varying three controlling parameters: the initial location of the mantle anomaly, Moho temperature and extension velocities.

The results of our experiments are two-folded. Firstly, in most of the models, break-up occurs within the central part of the model domain at the boundary between weak and strong crust. This "structurally inherited" mode of continental break-up persists even when the mantle plume has been initially seeded underneath the stronger lithosphere segment with considerable (up to 300 km) shift from the central position. When the initial plume is positioned at a significant distant from this structure (>=400 km), lithospheric rupture may also develop in the "strong" half of the lithosphere directly above the upwelled plume head ("plume-centered" mode). Secondly, when the plume anomaly is seeded between 300 km and 400 km away from the boundary between the "weak" and "strong" crust, the model cultivates a two-branch rift system when both "structurally inherited" and "plume-centered" break-up develop consecutively, under the influence of one single plume. The opening of the Labrador Sea and the North Atlantic can be a natural example of a two-branch system due to one single Iceland plume. Additional experiments show that hotter crustal geotherm favors "plume-centered" mode of lithospheric rupture whereas slower far-field extension always results in "structurally inherited" break-up regardless of initial plume location.

These results show that the "classical" model, where one plume anomaly produces a single break-up center situated directly overhead, is only one way of portraying plume-induced continental break-up. The different break-up modes shown here, are an indication for more complex continental break-up. They can help to explain certain observation related to rifting and break-up such as anomalous lower crustal bodies, topographic variations and diachronic development of multi-rift systems. We advocate that even though mantle plumes might not be the main driving force behind rifting and continental break-up, one mantle anomaly is capable of developing a variety of complex surface features that previously could not be explained as such.