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Different modes of continental break-up triggered by a sole mantle plume: a 2D and 3D numerical study

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We used 2D and 3D numerical models to investigate the impact of a single mantle plume on continental rifting and breakup processes. We varied the thermo-rheological structure of the continental lithosphere, its geometry and the initial plume position. Based on the results of our 2D experiments, three continental break-up modes can be distinguished: A) 'central' continental break-up, the break-up center is located directly above the original mantle anomaly position, B) 'shifted' break-up, the break-up center is 50 to 200 km displaced from the initial plume location and C) 'distant' break-up, due to convection and/or slab-subduction/delamination, the break-up center is considerably shifted (300 to 800 km) from the primary plume position. Our 3D model, with a laterally homogeneous initial setup also results in continental break-up with the axis of continental break-up hundreds of kilometers shifted from the original plume location.

The model results show that the classical, 'central' view of mantle plume induced continental break-up is not the only mode of break-up. When considering a diversity of break-up styles, it is possible to explain a variety of observed geophysical and geological features. For example, the mantle material glued to the base of the lithosphere at shallower depths corresponds geometrically and location-wise to high-velocity/high-density bodies observed on seismic data below the thinned continental lithosphere and the transition zone of the South Atlantic domain. During migration, products of partial melting of the mantle material can move vertically to (shallow) lower crustal levels. They might resemble high density bodies observed at lower crustal levels inside continental crust with similar geometries observed with gravity modelling. Also, topographic variation form in the very early stages of rifting on the first impingement of upwelled plume material. These variations remain visible, as the final position of the spreading center is shifted from the point of impingement and can be interpreted as aborted rifts, observed along passive margins. Our modelling demonstrates that both simple and perfectly symmetric preliminary settings as well as complex initial setups can result in a variety of break-up systems.