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Along-axis transition between narrow and wide rifts: Insights from 3D numerical experiments

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Based on performed high-resolution rheologically consistent three-dimensional thermo-mechanical numerical models, we show that there is a significant difference in the influence of the rheological profile on rifting style in the case of dominant active (plume-activated) rifting compared to dominant passive (far-field tectonic stresses) rifting. Narrow rifting, conventionally attributed to cold strong lithosphere in passive rifting mode, may develop in weak hot ultra-stretched lithosphere during active rifting, after plume impingement on a tectonically pre-stressed lithosphere. In that case, initially ultra-wide small-amplitude rift patterns focus, in a few Myr, in large-scale faults that form a narrow rift. Also, wide rifting may develop during ultra-slow spreading of strong lithosphere, and "switch" to the narrow rifting upon plume impingement.

For further understanding the mechanisms behind the interactions between the mantle plume and far-field stresses in case of realistic horizontally heterogeneous lithosphere, we have tested our models on the case of the central East African Rift system (EARS).

The EARS south of the Ethiopian Rift Valley bifurcates in two branches (eastern, magma-rich and western, magma-poor) surrounding the strong Tanzanian craton. Broad zones of low seismic velocity observed throughout the upper mantle beneath the central part of the EARS are consistent with the spreading of a deep mantle plume. The extensional features and topographic expression of the Eastern rift varies significantly north-southward: in northern Kenya the area of deformation is very wide (some 150-250 km in E-W direction), to the south the rift narrows to 60-70 km, yet further to the south this localized deformation widens again.

Here we investigate this transition between localized and wide rifting using thermo-mechanical numerical modeling that couples, in a dynamic sense, the rise of the upper mantle material with the deformation of the African lithosphere below the Tanzanian craton, with account for geological and geodynamic settings of this region. The models focus on the eastern branch of the EARS. Our experiments indicate that small initial asymmetric emplacement of the plume leads to strongly asymmetric system, with a development of large rift zone along the eastern side of the craton right above the plume head deflected by craton keel, with a lot of magmatic material arriving to the surface. Produced surface strain distribution is in good agreement with one observed along eastern branch of the EARS: narrow high strain zone above bulk of plume material (Kenya Rift) passes into wide distributed deformations within northern (northern Kenya, Turkana Rift) and southern (Tanzania divergence, Masai block) areas. It is noteworthy that this alteration of the rift width along the eastern branch is a natural result of the spatial variation of the lithospheric geotherm associated with mantle plume impingement. It means that in our models narrowing within the central part of the rift zone does not require an artificial predefined weakening between the craton and the embedding lithosphere. Consequently, observed in eastern branch of the EARS along-axis transition between narrow and wide rifts is not mandatory related to inherited structures such as rheologically weakened suture zones to east of Tanzanian craton.