O-3 Interactions between active and passive rifting in ultra-slow extension context: Insights from 3D numerical models

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We reconsider previous ideas on the role of active and passive rifting processes for rifting style and basin evolution. We argue that complex brittle-ductile rheological stratification of the continental lithosphere modifies its response over the zones of plume-lithosphere interactions, converting large-scale plume-induced impact to multi-harmonic short-wavelength undulations and strain localizations that are largely controlled by far-field stresses ('active/passive' rifting scenario). We study these interactions using new ultra-high resolution 3D models incorporating a rheologically realistic lithosphere, phase changes and partial melting. Results demonstrate that dynamic topography in the "real" Earth exhibits strongly asymmetric small-scale 3D features, which include rifts, flexural flank uplifts and complex fault structures. We conclude from our modeling that localization of large-scale linear normal and strike-slip 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 (Figure 1). This suggests efficient mechanism for continental rift initiation and breakup that involves passive and active rifting processes that interact with each other resulting in development of large continental rifts (e.g., Afar, Golf of Aden, Dead Sea, Baikal or East-African rift and plate-scale strike-slip faults (e.g. North-Anatolian fault). We show also that there is a significant difference in the impact of the rheological profile on rifting style in the case of dominant active rifting compared to dominant passive rifting (Figure 2). 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 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.

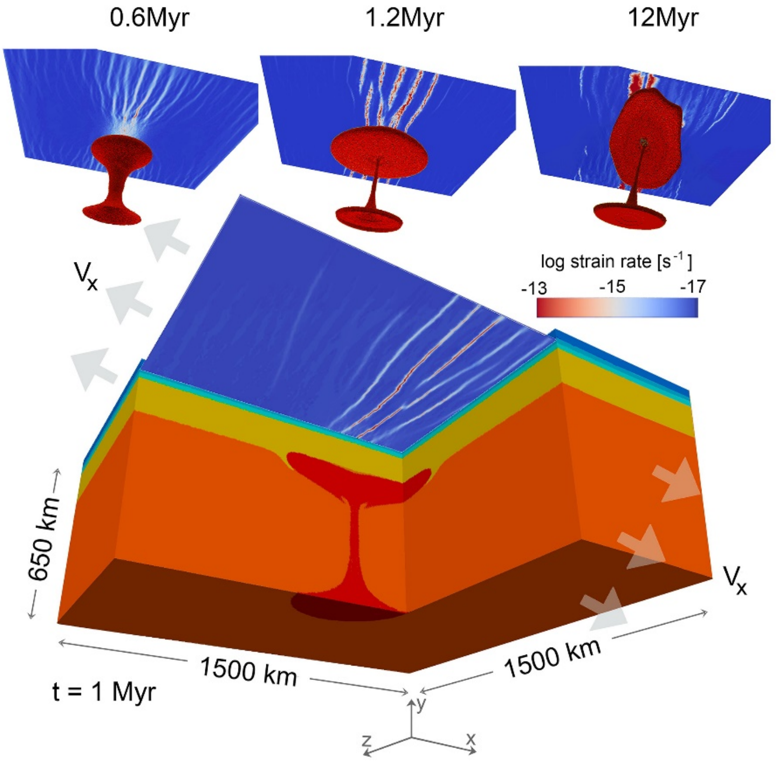

Figure 1. Combination of active-passive rifting results in fast localization of deformation

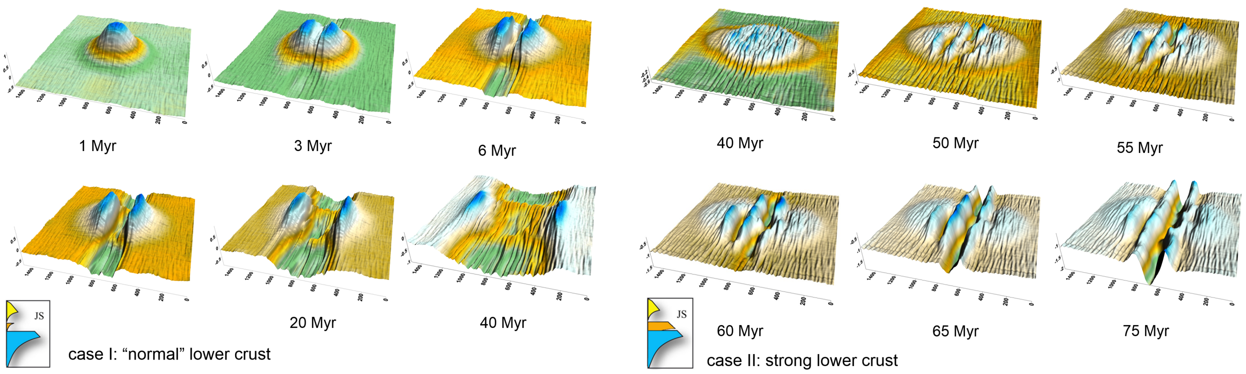

Figure 2. Surface topography in case of “normal” (left) and “strong” lower crustal composition (all other model parameters are indentical).

To further understand the mechanisms behind the interactions between the close field and far-field processes in case of realistic horizontally heterogeneous lithosphere, we have tested our models on the case of the Central East African Rift (CEAR).

This rift, lying south of the Ethiopian Rift Valley, bifurcates in two branches (eastern, magma-rich and western, magma-poor) that surround the strong Tanzanian craton. Intensive magmatism and continental flood basalts are largely present in many of the eastern rift segments, but other segments, first of all the western branch, have only very small volumes of volcanic rock. Within the Eastern rift characterized by southward progression of the onset of volcanism, the overall extension and topographic expression of the rift varies significantly from north to south: in northern Kenya the area of deformation is very wide (some 150-250 km in E-W direction), towards the south the rift narrows to 60-70 km, but further south this localized deformation is changed back into a wide deformation zone in the so-called Tanzania divergence. Widening of the Eastern branch within its southern part is associated with the impingement of the southward-propagating rift on a strong lithospheric domain of Masai block situated to east of the Tanzanian craton.

The preferred model has a plume seeded slightly to the northeast of the craton center, consistent with seismic tomography, and produces surface strain distribution that is in good agreement with observed variation of deformation zone width along eastern side of Tanzanian craton: localized above bulk of mantle material deflected by cratonic keel narrow high strain zone (Kenia Rift) is replaced by wide distributed deformations within areas situated to north (northern Kenya, Turkana Rift) and to south (Tanzania divergence, Masai block) of it.

These results (Figure 3) confirm a significant difference in the impact of the rheological profile on rifting style in the case of dominant active rifting compared to dominant passive 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 few Myr, into large-scale faults that form a narrow rift.

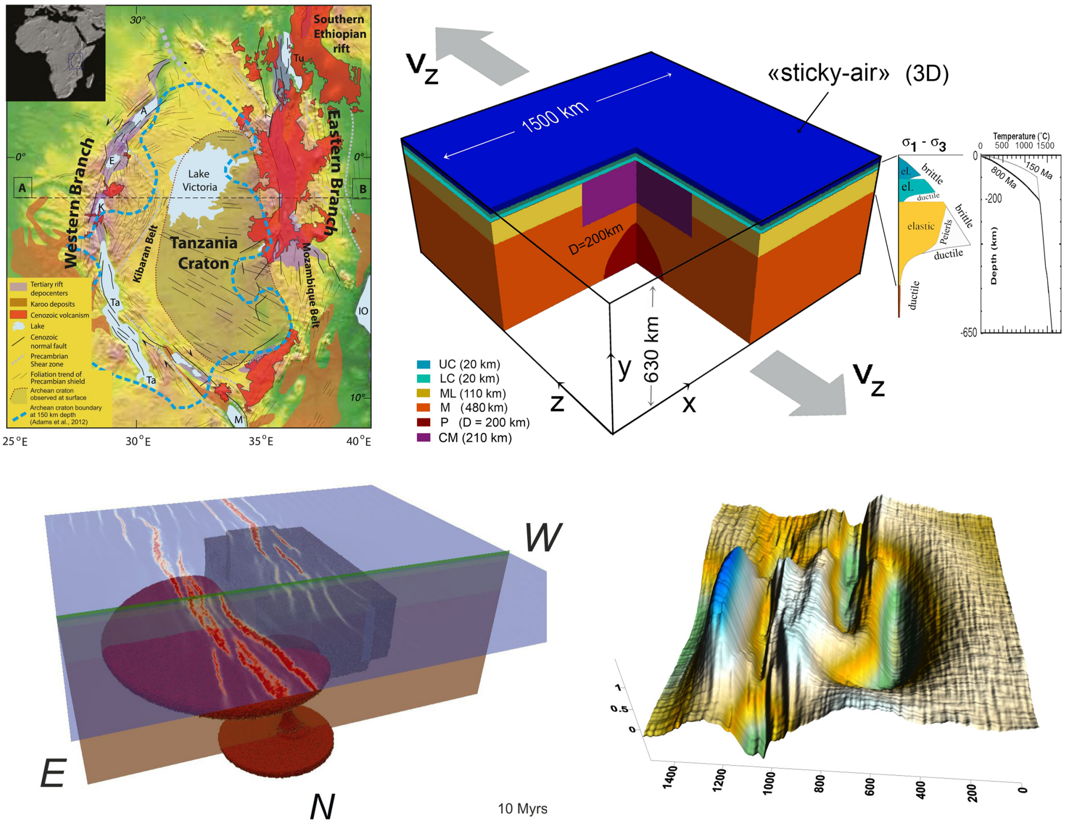

Figure 3. Application of the model to the case of CEAR. In this experiment, mantle upwelling is initialized below the a strong lithospheric heterogeneity presented by the Tanzania craton, in presence of slow (3 mm/y) passive far-filed extension in WE direction. As result mantle plume material is deviated towards one side of the craton producing a magmatic Eastern rift branch and practically amagmatic Western rift branch.