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New insights into continental rifting from a damage rheology modeling

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Previous studies have discussed how tectonic processes could produce relative tension to initiate and propagate rift zones and estimated the magnitude of the rift-driving forces. Both analytic and semi-analytic models as well as numerical simulations assume that the tectonic force required to initiate rifting is available. However, Buck (2004, 2006) estimated the minimum tectonic force to allow passive rifting and concluded that the available forces are probably not large enough for rifting of thick and strong lithosphere in the absence of basaltic magmatism (the "Tectonic Force" Paradox). The integral of the yielding stress needed for rifting over the thickness of the normal or thicker continental lithosphere are well above the available tectonic forces and tectonic rifting cannot happen (Buck, 2006). This conclusion is based on the assumption that the tectonic stress has to overcome simultaneously the yielding stress over the whole lithosphere thickness and ignore gradual weakening of the brittle rocks under long-term loading.

In this study we demonstrate that the rifting process under moderate tectonic stretching is feasible due to gradual weakening and "long-term memory" of the heavily fractured brittle rocks, which makes it significantly weaker than the surrounding intact rock. This process provides a possible solution for the tectonic force paradox. We address these questions utilizing 3-D lithosphere-scale numerical simulations of the plate motion and faulting process base on the damage mechanics. The 3-D modeled volume consists of three main lithospheric layers: an upper layer of weak sediments, middle layer of crystalline crust and lower layer of the lithosphere mantle. Results of the modeling demonstrate gradual formation of the rift zone in the continental lithosphere with the flat layered structure. Successive formation of the rift system and associated seismicity pattern strongly depend not only on the applied tectonic force, but also on the healing parameters of the crustal rocks. Results of the modeling also demonstrate how the lithosphere structure and especially depth to the Moho interface affects the geometry of the propagating rift system. With the same boundary conditions and physical properties of rocks as in the case of the flat continental structure, a rift terminates above the passive continental margin and a new fault system is created normal to the direction of the rift propagation. These results demonstrate that the local lithosphere structure is one of the major key factors controlling the geometry of the evolving rift system, faulting and seismicity pattern.

Results of simulations suggest that under wide range of conditions a rift propagating through a continental lithosphere might cease before it reaches the margin where transition to oceanic lithosphere occurs. Close to the margin different tectonic styles might take over the propagation. This behavior has been suggested for the NW continuation of the active Red Sea-Suez rift system and initiation of the Dead Sea Transform (Steckler and ten Brink, 1986). With the onset of the Red Sea opening (about Oligocene) the sub-parallel Azraq-Sirhan rift was also activated and propagated in a NW direction from the Arabian continent toward the Levant basin oceanic crust. By applying our 3-D lithosphere-scale numerical simulations on the Azraq-Sirhan rift system, we conclude that thinning of the crystalline crust and strengthening of the Arabian lithosphere led to a decrease or even termination of the rate of rift propagation next to the continental margin.