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The Afar Region: Numerical Modeling Using Geological Data

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The separation of Arabia from Africa led to formation of the Afar triple junction, which includes the Red Sea, Gulf and Aden, and Ethiopian Rift System. This tectonic history is the consequence of complex interaction between far-field forces and the Afar plume. Far-field stresses originate due to the closure of the Tethyan ocean since the Mesozoic resulting in the Birlis-Zagros-Makran collision-subduction zone. The time-evolution of this plate boundary can be inferred from paleogeographic reconstructions, which suggests along trench variation of convergence velocity as the subduction zone transforms into collision zone.

Previous efforts to understand the influence of the time-varying subduction dynamics on the separation of Arabia were performed using analog modeling (Bellahsen et al., 2003). Their results indicate that a heterogeneous distribution of far-field forces can generate internal deformation of the African plate that is broadly consistent with development of the Red Sea - the Gulf of Aden rift system. This suggests the following scenario for the tectonic evolution of this region. An initially cold, strong lower crust with a high-viscosity promotes the available extensional stresses to concentrate in the relatively weaker upper crust. This leads to extension in the form of rifting system as opposed to the development of a crust-mantle detachment system. Additional extensional force supplied by the rising Afar plume, and associated uplift of the Afar dome, resulted in simultaneous deformation of the crust and mantle, ultimately caused the entire lithosphere to break. The scenario proposes that neither the pull from the subduction, nor the push from the plume were separately strong enough to trigger rifting in the cool lithosphere, but were only successful in combination.

We present numerical models performed using the software, SNAC (www.geogynamics.org). The model set-up is motivated by previously obtained results from geological, geophysical and analog studies. In particular, time-varying subduction dynamics are implemented through variation of velocity boundary conditions. The model is primarily focused on deformation in the crust, and thus attempt to simulate large scale deformation distributed along extensional faults. This is accomplished by introducing a number of pre-existing weak zones. The influence of these weak zones in various locations (such as the Carslberg ridge) is tested in the experiments. This model then builds in the influence of the Afar mantle plume, which can thermally weaken (by heating the lithosphere) and also mechanically weaken (by thinning the lithosphere). We model the Afar plume's activity through the temperature field. Such a model allows for testing the influence of individual factors on the deformation of African plate, as well their combined effects.