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Numerical modeling of continental rifting: Implications for the East African Rift system

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The East African Rift system (EARS) provides a unique system with juxtaposition of two contrasting yet simultaneously formed rift branches, the eastern, magma-rich, and the western, magma-poor, on either side of the old thick Tanzanian craton embedded into younger lithosphere.

Here we take advantage of the improvements in our understanding of deep structures, geological evolution and recent kinematics, together with new cutting edge numerical modeling techniques to design a three-dimensional ultra-high resolution viscous plastic thermo-mechanical numerical model that accounts for thermo-rheological structure of the lithosphere and hence captures the essential geophysical features of the central EARS.

Based on our experiments, we show that in case of the mantle plume seeded slightly to the northeast of the craton center, the ascending plume material is deflected by the cratonic keel and preferentially channeled along the eastern side of the craton, leading to formation of a large rift zone characterized by important magmatic activity with substantial amounts of melts derived from mantle plume material. This model is in good agreement with the observations in the EARS, as it reproduces the magmatic eastern branch and at the same time, anticlockwise rotation of the craton. However, this experiment does not reproduce the observed strain localization along the western margin of the cratonic bloc.

To explain the formation of contrasting magmatic and amagmatic rift branches initiating simultaneously on either side of a non-deforming block as observed in the central EARS, we experimentally explored several scenarios of which three can be retained as specifically pertaining to the EARS:

(1) The most trivial first scenario assumes rheologically weak vertical interface simulating the suture zone observed in the geological structure along the western border of the craton;

(2) The second scenario involves a second smaller plume initially shifted in SW direction;

(3) Finally, a relatively big plume, which initial position is slightly shifted to the eastern side of the craton that also results in contrasted double rifting with an asymmetric distribution of mantle material on either side of the craton. This model does not require weakening of the interface between the craton and the embedding lithosphere.

Notably, only the third scenario is compatible with two important features of the geological evolution of the EARS: 1) the quasi-simultaneous initialization of the both rift branches and 2) their feeding from a single mantle source.

Our results reconcile the passive (far-field tectonic stresses) and active (plume-activated) rift concept and demonstrate the possibility of developing both magmatic and amagmatic rifts in identical geotectonic environments.