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Inter-event strain localization modulated by background stresses across the Natron Basin, East African Rift

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While it is well documented that continental extension involves discrete tectonic or magmatic rifting events, little is known about how deformation accumulates between these events. Here we focus on strain localization across the Natron Basin, which is part of the eastern branch of the East African Rift, that experienced a major tectono-magmatic event in 2007.

A cross-rift profile of horizontal GNSS velocities (2013–2017) reveals a gradual transition between the rigid Tanzanian Craton and the Somalian Plate, with ~2 mm/yr of extension distributed across ~100 km (stretching zone). Such a pattern is commonly interpreted through the lens of dislocations in an elastic half-space. Here, an east-dipping border fault locked down to ~10 km may explain the observed width of the stretching zone, provided it extends to great depths, and creeps at a constant rate of ~3 mm/yr. The extent to which this is compatible with a hot lower crust riddled with magmatic intrusions is still debatable.

We thus explore an alternative model where the width of the stretching zone is entirely determined by the history of past, finite deformation, and the corresponding ambient stress state. We use a 2-D thermo-mechanical model to stretch a visco-elasto-viscoplastic brittle layer, first creating a major border fault that slips continuously, flexing its footwall and hanging wall. We then artificially "lock" this fault by instantaneously strengthening it, drastically reduce our computational time steps, and continue stretching the layer. While the system should behave as an homogeneous, elastic layer under far-field extension, i.e., produce a linear displacement profile, we obtain an arctangent-shaped profile with a characteristic stretching zone width.
This suggests that strain localization is controlled by the heterogeneous distribution of pre-existing stresses. Specifically, regions of high stresses that accrued during flexure of the fault blocks are brought to failure first during inter-event stretching, prompting the localization of elasto-plastic strain in a wide zone centered on the border fault. This process explains the width of velocity gradients in rift zones without invoking a deep, continuously creeping fault.

We therefore suggest that long-term stress buildup plays a key role in short-term strain localization, and discuss its implications for active deformation in magma-rich continental rift settings like the Natron Basin.