Controls on Strain Accommodation in Rift Development across the Turkana Depression

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Strain localization in actively deforming continental rift systems depends on gravitational potential energy, lithospheric heterogeneity, local and regional stresses, and the presence or absence of melt. East Africa's Turkana Depression is an unusual 300 km-wide depression that initiated at low elevation, unlike the Main Ethiopian Rift (MER) to the north, and the Eastern (ER) rift to the south. The Turkana Depression hosts the region's earliest Cenozoic magmatism at ~ 40 Ma, extension at ~ 25 Ma, and magmatism continues to the present in some areas. The Depression has lithospheric-scale compositional and thickness heterogeneities associated with Pan-African collision (~ 550 Ma) and subsequent Mesozoic to Cenozoic rifting phases. The objectives of our seismicity studies in the Turkana Depression are to delineate the zones of active deformation and magmatism within the Depression; compare these zones with time-averaged deformation as determined from crustal imaging and basin subsidence analyses, and to evaluate the role of pre-existing rift zones on Miocene-Recent rifting. The 2019 – 2021 Turkana Rift Array to Investigate Lithospheric Structure (TRAILS) project comprises 32 seismometers and 10 GPS stations deployed in the southern MER, northern ER, and the intervening Turkana Depression. The broadband seismic data acquired include 2150 absolute earthquake locations precisely located using a new 1-D velocity model. The local magnitudes of the earthquakes range from $1.0 < M_L < 4.5$ with a b-value of 1.29 ± 0.05 and the magnitude of completeness M_L 1.79. We determined focal mechanism solutions for 77 earthquakes with $M_L > 1.5$. Using this database, we map seismogenic layer thickness and seismic moment release throughout the region. Preliminary results show that modern-day strain accommodation is localized to three sub-parallel rift zones with sedimentary basins bounded by deep normal faults, whereas other parts of the depression are aseismic. Summarizing only a 1/3 of the breadth of the depression is presently active, arguing against some analog and numerical models. The displacement vector of active motion (Knappe et al., 2020) of the region relative to the stable Nubia plate, and velocity profiles are used as well. Seismically active zones coincide with zones with opening velocities of 2-4 mm/yr, and seismic and geodetic extension directions coincide spatially. These results are interpreted in light of receiver function imaging that constrains Moho depths (Ogden et al., submitted) and body wave tomography (Kounoudis et al., 2021) that images the upper mantle. A new finding is the spatial coincidence of low-velocity anomaly in the upper mantle and crustal strain. Areas where the active deformation and time-averaged deformation coincide include: the seismically active three sub-parallel rifts south of the MER, the Lake Turkana rift segments, and the complex zone that has the NW – SE refractory cold, stronger Proterozoic lithosphere imaged in upper mantle tomography. However, in the low velocity anomaly, strain accommodation at crustal depths is localized whereas in the cold and strong high velocity anomalies the breadth of deformation is wider. The rate of extension as determined from Kostrov summation indicate that the localy deforming Lake Turkana rift segments extend at the same rate (2×10^{-9} yr^{-1}) as the diffusely deforming northern region of the Turkana depression that comprises of the zone of trapped Proterozoic lithosphere and the 3-4 sub-parallel rift basins. Future works include determining the shear wave velocity variations in the crust, evaluating geothermal viability, and determining crustal rheology.