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Imaging segmentation in early stage rifting (prior to breakup) using a joint inversion of Rayleigh waves from teleseisms and ambient noise tomography in the northern East African Rift

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Within the melt-rich northern East African Rift system, extension progresses from continental rifting in the Ethiopian rift to near continental breakup in Afar. Multiple models have been proposed to understand the evolution of lithospheric stretching and magmatism, but previous studies do not provide a single absolute seismic velocity model of the crust and upper mantle for all stages of the rift. Here we jointly invert surface waves from ambient noise and teleseismic Rayleigh waves to obtain shear velocity maps from 10 to 210 km depth, enabling us to analyse variations in crustal and upper mantle shear wave velocity structure spatially and in depth. Using one model allows us to interpret and understand the pattern of crustal and lithospheric thinning from the rift flanks into the rift, the depth and locus of melt generation, and how these processes vary as a rift evolves towards incipient seafloor spreading.

We observe in areas unaffected by rifting, a fast lid (>0.1 km/s faster than surroundings) at lithosphere-asthenosphere-boundary depths (~60 - 80 km). The fast-lid is not visible directly beneath the rift and we instead observe slow velocities (slow enough to contain partial melt ($3.95 - 4.10 \pm 0.03$ km/s)), which we interpret as evidence for melt infiltration into the uppermost mantle beneath the rift. In addition, the fast lid thins into the rift, until it is no longer observed, suggesting the rift is more stretched than the surrounding plate (~18% thinner). The slow velocities in the asthenosphere beneath the rift are segmented, ~110 km wide, ~60 - 120 km deep with ~70 km spacing between segments. The shallowest and slowest anomalies occur beneath Afar, which is at later stage rifting. At crustal depths we observe a broadening in the slow velocity zones along the length of the Main Ethiopian Rift. Furthermore, the slow crustal velocities laterally spread to beneath areas of the Ethiopian Plateau that were affected by flood basalt volcanism (velocities of $3.30 - 3.80 \pm 0.04$ km/s). We interpret the broadening of the slow velocity as the Moho acting as a barrier causing lateral migration of melt into areas of pre-existing weakness. Our model provides the first comprehensive seismic model of the northern East African Rift allowing us to interpret rift structure. The segmented slow velocities in the asthenosphere suggest discrete melt-rich upwelling may drive the early the breakup process, with shallowing of the top of the melt-rich zone as the rift evolves and the lithosphere is modified by melt infiltration, with the Moho and lithosphere thinning later in the rifting process.

