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Modelling Afar plume dynamics and the southward migration of the Afar hotspot over the last 45 million years

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Anomalous topographic swells and Cenozoic volcanism in east Africa have been associated with mantle plumes. Several models involving one or more fixed plumes beneath the northeastward migrating African plate have been suggested to explain the space-time distribution of magmatism in east Africa. We devise paleogeographically constrained global models of mantle convection and, based on space-time analytics of flow in the deepest lower mantle, show that the Afar plume migrated southward throughout its lifetime. We show that the mobile Afar plume provides a dynamically consistent explanation for the spatial extent of the southward propagation of the east African rift system (EARS), normally difficult to explain by the northeastward migration of Africa over one or more fixed plumes alone, over the last ≈45 Myrs. Although the double-plume model was proposed to reconcile geochemical data, it has not proven consistent with all the observational constraints — particularly the propagation of plume material from southern Ethiopia towards Afar, in a direction opposite to that predicted by plate motion over a fixed plume. Our analysis suggests that a southward moving Afar plume — consistent with lower mantle flow regimes under Africa over the last 45 Myrs — better explains age-progressive volcanism over the same period in the EARS. A fully dynamic model Afar plume as modelled here shows that plume flux can reach its peak subsequent to eruption, which may explain the onset of magmatism associated with the Ethiopian and Yemen flood basalts at 30 Ma. We suggest that as the model plume weakens over its lifetime, it samples progressively shallower parts of the deep mantle, which could explain the systematic geochemical variation observed in the age-progressive mag- matism. Our results have important implications for interpreting the geodynamic evolution of the EARS and consequently, the geomorphological evolution of paleo-drainage systems in east Africa.