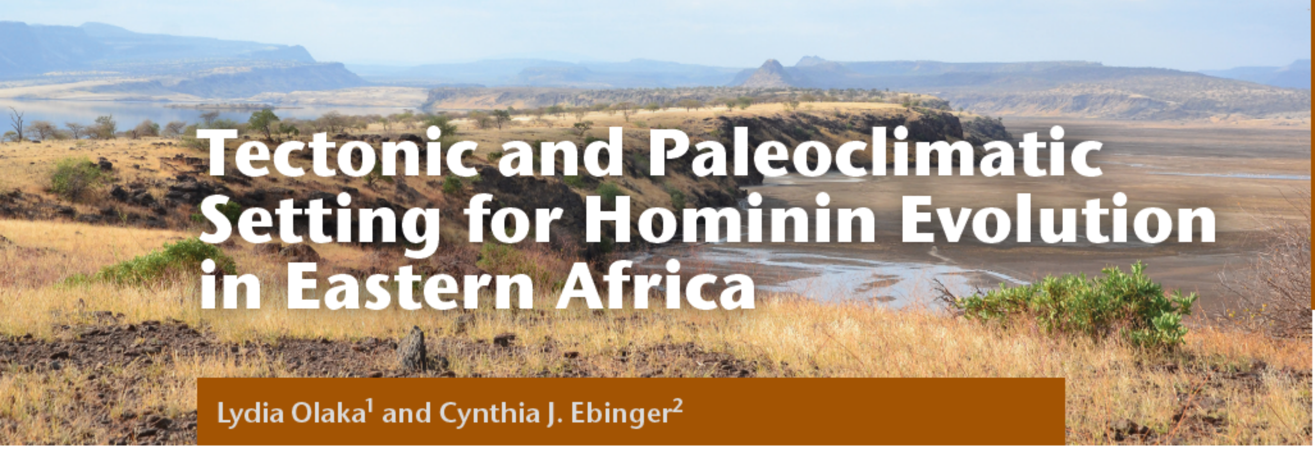

Tectonic and Paleoclimatic Setting for Hominin Evolution in Eastern Africa

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As dynamic processes in the Earth's mantle stretch and thin large sectors of the African plate, broad plateaus interrupted by deep valleys and flanking mountains have formed at the Earth's surface. These vertical and horizontal crustal movements occur concurrent with global climate changes, both of which happen over diverse spatial and temporal scales. Together, they modulated eastern Africa's habitats for early hominins, and for flora and fauna in general. The habitat for hominin evolution, therefore, is shaped by bottom-up and top-down processes. Broad plateau uplift in Ethiopia had initiated by 30 Ma, coincident with or after flood magmatism at 45 Ma when dry seasonal woodland environments initiated in eastern Africa. The fossil-rich sedimentary sequences partially filling the 30–70-km-wide rift basins record the history of human evolution, as well as the complex interplay between climate change, uplift, volcanism, and faulting in equatorial Africa. The lake shorelines and hydrothermal systems served as oases for hunter-gatherers, and the rough topography of the faulted landscape may have served as refugia. Here, we outline the relevant time–space patterns to establish the geodynamic and paleoclimatic context for human evolution in eastern Africa.

KEYWORDS: plateau uplift; paleoclimate; hydrology; geodynamics; eastern Africa; rift

INTRODUCTION

Modern humans living in large sectors of the African plate, including oceanic islands, experience earthquakes, volcanic eruptions, and associated subaerial and submarine landslides in what is referred to as the East African Rift system (FIG. 1). Eastern African residents are also experiencing the effects of modern climate change that influence rainfall and temperature patterns on the high plateaus, uplifted rift flanks, and low-lying sedimentary basins in different ways. The present tectonic configurations and environments inform our progressively blurred vision of tectonic and climate interactions moving backward in time. **Yet, as revealed in this special issue, high-resolution geochronological data and consideration of the temporal variations in rifting processes allow the time–space scales of tectonic and climatic changes that may have influenced hominin evolution to emerge.**

Eastern African crustal movements have occurred over the past 45 My, initiating when lava started to erupt in southwestern Ethiopia, signaling the initial impact of a mantle plume beneath the African plate. One or more mantle plumes led to the formation of ~1000-km-scale dynamic uplifts, which fundamentally altered drainage across Africa and changed Atlantic and Indian monsoonal patterns. Climate modeling studies show that the changing orographic relief of eastern Africa dramatically influenced climate at the continental scale by reorganizing atmospheric circulation. The precipitation in tropical eastern Africa decreased in response to the uplift within the East African Rift system (e.g., Sepulchre et al. 2006; FIG. 1).

The consequent plateau uplift and dynamic processes caused extensional stresses in the plate that were locally released through faulting and thinning to create the East African Rift valleys. Rift faulting, crustal and mantle heating and thinning, and isostatic compensation for density changes led to the formation of 30–70-km-wide sedimentary basins with broad uplifted flanks (e.g., Ebinger et al. 2013). The topographic relief of the East African Rift valleys is superposed atop broad plateaus, and their 70–300-km-wide low-lying basins are flanked by 100–200-km-wide uplifts that can rise 2 km above the surrounding topography. These extensional basin systems developed diachronously, as early as 35 Ma in some areas, and are just initiating at present in other areas. **Owing to the ongoing elevation changes accompanying basin formation, Miocene–Recent hominin depositional sites may have undergone many hundreds of meters of uplift or subsidence, as well as faulting and rotation, as outlined below.**

The thousands of meters of topographic relief across rift zones creates a variety of microclimates and refugia in the face of climatic changes or other adversities (e.g., Bailey and King 2011). The long sinuous rift valleys and their uplifted flanks serve both as physical barriers and as conduits to hominin and animal migration, and may have aided speciation on various timescales (e.g., Bobe et al. 2007). The volcanic systems punctuating some sectors of the East African Rift create drainage divides and rain shadow effects, and the volcanic products create and maintain fertile, nutrient-rich soils. The major global and regional climatic changes have modified and shaped the plateau uplifts, uplifted rift flanks, and broad deep basins.

This brief overview illustrates how tectonics and climate are complexly intertwined owing to their distinct temporal and spatial variations. Not only do the length scales vary

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for the different processes shaping the African plate, but the timescales also vary over six orders of magnitude: 10^6 years for plateau uplift, 10^6–10^4 years for rift flank uplift, 10^5–10^4 years for orbitally driven changes in insolation, 10^3–10^0 years for earthquake and volcanic eruption cycles, and 10^3–10^0 years for variations in solar irradiance (Trauth et al. 2007; Ebinger et al. 2013).

Although Eocene–Recent faulting and magmatism occurred and are ongoing throughout continental and oceanic parts of the African plate, we focus here on patterns occurring in the Horn of Africa, Eastern Rift, and Malawi Rift that hosted early hominins (Fig. 1). Different sectors of the East African Rift system developed at different times, but with similar developmental patterns in the sequences of uplift and subsidence and of faulting and magmatism, as outlined below. Global, regional, and local climatic variations regulate the erosional and depositional cycles as the landscape changes, as well as modulate lake level variations. Our goal is to outline regional time–space correlations between tectono-magmatic and climatic changes that may have influenced hominin evolution and migration, providing a foundation for the articles in this issue.

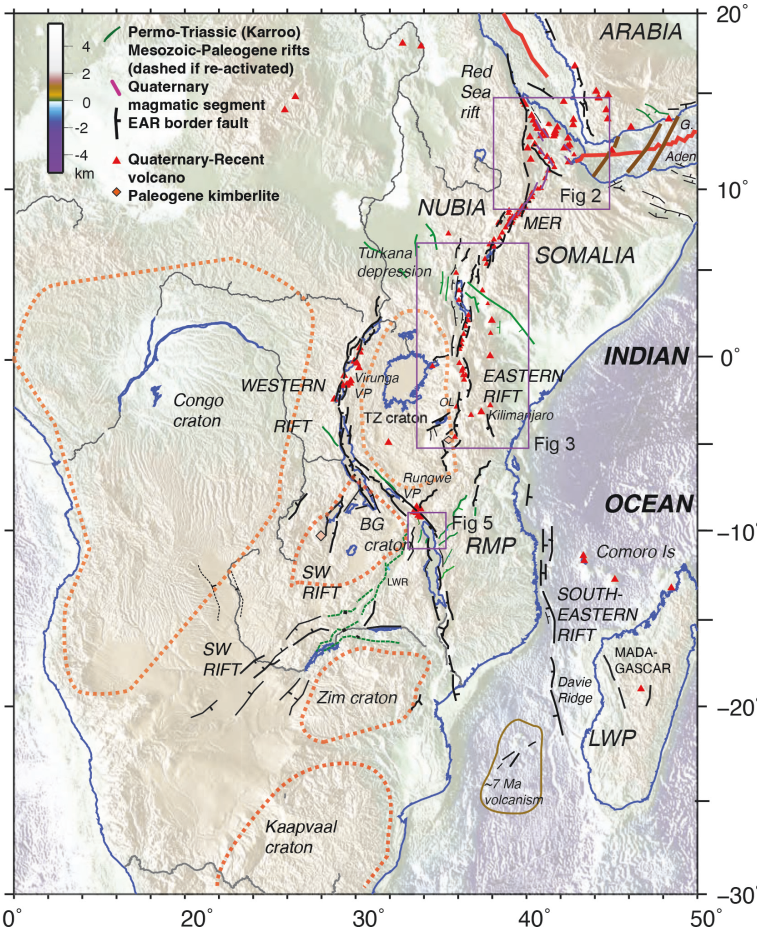

Figure 1 Major fault systems of the Red Sea, Gulf of Aden, Main Ethiopian Rift (MER), Eastern Rift, Western Rift, Southwestern (SW) Rift, Southeastern Rift, and Comoros-Madagascar Rift zones with respect to the Nubia, Somalia, Arabia and Rovuma (RMP), Victoria (Tz craton), and Lwandle (LWP) microplates. The green lines indicate Permian–Mesozoic normal fault systems associated with Gondwana breakup, as well as the poorly understood Paleogene rifting period (dashed if reactivated in the Late Cenozoic). Mesozoic rift zones in Kenya (Anza), coastal Tanzania (Pangani), and southwestern Tanzania (Rukwa-Malawi) also show evidence for renewed faulting and exhumation at 60–45 Ma. The brown ellipse outlines an area of ~7-Ma magmatism and platform formation in the Indian Ocean between Africa and Madagascar. Nm indicates the Nyamuragira Volcano, and Ng indicates the Nyiragongo Volcano in the Virunga volcanic chain. Boxes enclose the areas of Figures 2, 3, and 5.

BACKGROUND

Climate Change Setting

The climate of eastern Africa since 65 Ma has oscillated between warm and cool periods in the Cenozoic. "Greenhouse" climates dominated between 65 and 51 Ma. These were followed by a cooling between 34.1 and 33.6 Ma. Warm climates followed in the early to middle Miocene climatic optimum (~17–14.7 Ma) (e.g., Levin 2015). The Neogene was a period of long-term global cooling and increased climate variability. Global cooling and associated aridification in continental Africa occurred at 3.5–3.35, 2.5–2, and 1.8–1.6 Ma interspersed by warm and wet conditions at ~5.3 and ~3.3 Ma (e.g., Levin 2015).

Since ~2.8 Ma, it is thought that eastern African climate change has largely been governed by ocean–atmosphere interactions at high latitudes. While it has been argued that changes in surface-ocean circulation, controlled by the final closing of the Indonesian seaway at ~4–3 Ma, were responsible for the aridification of eastern Africa (Cane and Molnar 2001), this is an alternative hypothesis to the commonly held opinion that the main driver for aridification in eastern Africa was the onset of significant Northern Hemisphere glaciation (de Menocal 2004).

The climate changes to wet phases in the Pleistocene, namely at 1.9–1.7 and 1.1–0.9 Ma, coincided with an intensification of Walker circulation (1.9–1.7 Ma) and mid-Pleistocene revolution (1.0–0.7 Ma) (Trauth et al. 2007). High-latitude forcing could have impacted the Intertropical Convergence Zone such that eastern Africa became locally sensitive to precessional forcing, resulting in rapid shifts from wet to dry conditions.

Recurring humid periods from the Miocene to the Quaternary (de Menocal et al. 2004; Trauth et al. 2007; Tierney et al. 2011) caused past hydrological connectivity between adjacent river systems and hydrological sensitivity of lakes to climate change (Olaka et al. 2010), in addition to the large-scale climatic shift that occurred. The development of rain shadow effects and large lakes are considered major factors for the increased variability of moisture and hydrology throughout eastern Africa (Trauth et al. 2007).

Geodynamic and Tectonic Setting

The African continent comprises unusually thick Archaean and Proterozoic continental lithosphere that amalgamated during the Pan-African orogeny. Regions between cratons experienced rifting during the breakup of Gondwana in the Permo–Triassic and Cretaceous when Madagascar separated to form the western Indian Ocean (Fig. 1).

Several lines of reasoning indicate that the ~1000-km-wide Ethiopian Plateau existed by 30–35 Ma, but probably after initial flood volcanism at ~45 Ma in southwestern Ethiopia. The timing of uplift in the East African Plateau is more poorly constrained, but uplift had initiated by ~18 Ma (e.g., Wichura et al. 2015). Seismic tomographic imaging indicates two separate low-velocity zones rising from the core–mantle boundary beneath the South Atlantic margin of South Africa and below the Indian Ocean north of Madagascar (e.g., Boyce et al. 2021), consistent with diachronous plateau uplift and consequent ecological change associated with monsoonal deflection(s). In Ethiopia and Yemen and some parts of Kenya and Tanzania, 1–2-km-thick lavas augment the dynamic and isostatic basement uplift.

Diachronous Evolution of Hominin-bearing Rift Sectors

Despite earlier suggestions of a north to south propagation of rifting, the growing geochronological and thermochronological database shows a more complex pattern of both northward and southward rift propagation as well as abandonment and migration over time (e.g., Roberts et al. 2012), with implications for the spatial distribution of flora and fauna, including hominins.

Afar Triple Junction: Southern Red Sea–Gulf of Aden–Main Ethiopian Rift: The Afar depression encompasses the complex plate boundary linkage between the Nubia, Somalia, and Arabia plates: the Red Sea (Arabia–Nubia) and Gulf of Aden (Arabia–Somalia) rifts that bound the Arabian plate, and the Main Ethiopian Rift sector of the East African Rift (Nubia–Somalia) (Figs. 1 and 2). The Red Sea and Gulf of Aden rift zones formed in response to far-field stresses from the closure of the Tethys Ocean that led to the separation of Arabia from Africa starting at about 35 Ma (e.g., Wolfenden et al. 2005). Their evolution, therefore, is distinct from rifting in the Main Ethiopian Rift (MER) and southward. Between 31 and 29 Ma, as faults and basins started to form in the Red Sea Rift, up to 2 km of basalts and rhyolites erupted along both sides of what is now the Red Sea and western Gulf of Aden rifts. Extension in the MER initiated after 18 Ma, 10 My later than in the southern Red Sea Rift, and extension across the northern MER now overprints the Oligo–Miocene basin structures (e.g., Wolfenden et al. 2005).

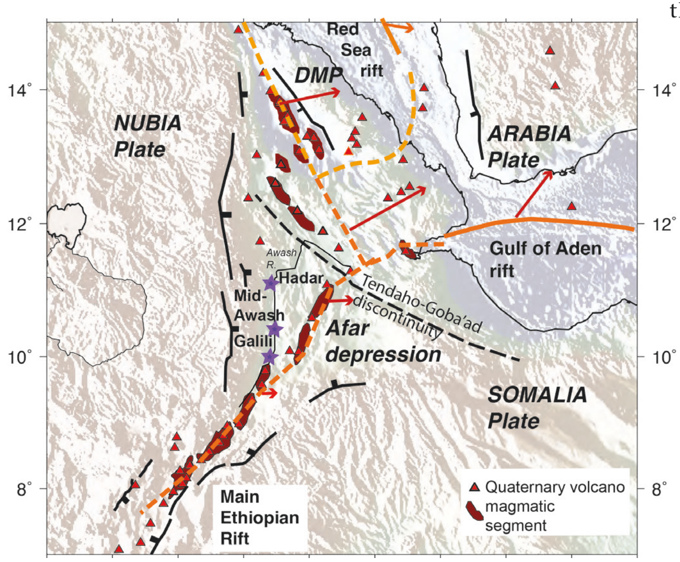

Figure 2 Afar triple junction zone and Danakil microplate (DMP) with respect to the Nubia–Arabia–Somalia plates. Orange lines indicate seafloor spreading plate boundaries (lines are dashed where plate rupture has not occurred), and plate boundary deformation occurs across a <50-km-wide zone. Stars indicate hominin sites cited in the text. Red arrows scaled to velocity indicate the plate opening direction based on rigid block models of Global Navigation Satellite System data (Viltres et al. 2020). The Tendaho-Goba'ad discontinuity separates the northeast-directed extension in the Red Sea and Gulf of Aden rifts from the ~east–west opening at ~5 $mm \cdot y^{-1}$ in the Main Ethiopian Rift; only segments of the fault zone are currently seismically active. Magmatic segments include zones of localized magma intrusion, volcanism, and faulting and the locus of plate boundary deformation (similar to mid-ocean ridge axial segments). The Main Ethiopian Rift (MER) overprints 30–20-Ma structures in the Afar depression. Plate opening is effectively transferred from the Red Sea into Afar along the length of the Danakil horst, which is separated from Arabia along a poorly understood strike-slip fault zone (Viltres et al. 2020). The Danakil depression was connected to the Red Sea in the Pleistocene before volcanic construction blocked the narrow inlet at 120 ka and the ocean basin dried, forming a thick evaporite sequence that is hostile to most vegetation.

As plate thinning, faulting, and magmatism progressed, the stretched area broadened and subsided. Since about 13 Ma in the Afar depression, faulting and magmatism migrated eastward from the rift margin faults to ~20- and 30–50-km-long zones within the central rift valley. The profound crustal thickness differences produced more than 2 km of elevation change along the margins of the Afar depression, and facilitated the formation of deeply incised river systems that originate in the highlands. These rift-perpendicular rivers reach the low-lying zone of the stretched lithosphere and form larger rivers that enter the rift depression and flow along the axis of the rift valley. As a consequence of the migration of rifting, previous sedimentary basins are uplifted along the shoulders of rift flanks or are cut by new faults, exposing fossil-rich lake sequences on the western side of the currently active rift and volcanic axis (e.g., Hadar, Middle Awash, Galili; Fig. 2). This cannibalization of older basins after rift migration is a characteristic feature of eastern Africa.

The Afar depression experienced a period of renewed, widespread magmatism at ~3–2 Ma associated with the propagation of the Gulf of Aden into the African continent, and many new basins with restricted drainage formed at or near sea level across the Afar depression. Some of the eruptions were explosive and showered parts of the region with ash or potentially deadly pyroclastic flows. The rift jump left the Awash River west of the ~2 Ma–Recent rift axis (Fig. 2). Persistent lake basins along the course of the Awash River preserve multiple hominin sites, all of which have airfall volcanic layers interbedded with lake sediments (e.g., DiMaggio et al. 2015). Depositional sequences younger than about 2.9 Ma show an increase in coarse sediments, consistent with a new phase of tectonic activity. Concomitant with the increase in volcanic activity was a change to more arid conditions in the Awash River region, as climate oscillations influenced rainfall. Did increasing aridity create a more hostile environment that promoted evolutionary change (e.g., DiMaggio et al. 2015)? At about 240 ka, the northern Afar depression had subsided below sea level and was flooded by Red Sea waters. Thus, a large area may have hosted coastal forests.

Southern Main Ethiopian Rift and Turkana depression: The Ethiopia–Yemen and East–Central African plateaus are separated by a ~300-km-wide topographic depression that is underlain by crust stretched during Mesozoic and Paleogene rifting: the Turkana depression (Fig. 3). The multiple, superposed episodes of rifting created a zone of pronounced crustal thinning that, in large part, explains the low elevation of the Turkana depression. The Turkana depression hosts three important hominin sites: Koobi Fora in the Turkana Rift, the Omo-Kibush Shungura Formation north of Lake Turkana, and the Nachukui Formation in West Turkana (Fig. 3).

The earliest known faulting south of the Afar depression occurred perhaps as early as 30 Ma and by 25 Ma west of modern Lake Turkana (e.g., Morley et al. 1992). Between ~20 and 15 Ma, primarily basaltic magmatism occurred along what is now the southern termination of the MER as extension initiated in half graben basins. Likewise, by 15 Ma, magmatism and faulting initiated in the Eastern Rift south of the Turkana depression with the formation of 50–60-km border fault systems and 40–70-km-wide sedimentary basins.

Unlike the Afar depression, the Turkana depression is flanked by a ~1500-km-high uplifted flank on its western side, but elevations decrease east of Lake Turkana into the Mesozoic Anza Rift where crustal stretching created a permanent depression. This area was at or below sea level at ~17 Ma and was connected to the Indian Ocean (Wichura

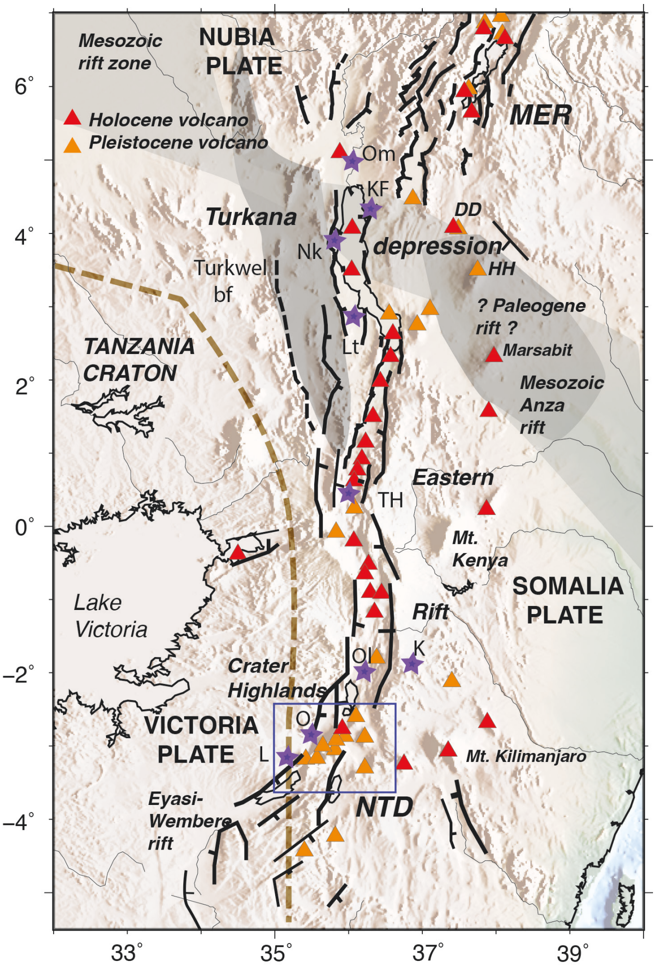

FIGURE 3 Hominin sites (stars) within the southern MER and Eastern Rift that link in the unusually broad Turkana depression. The Victoria microplate comprises the thick, cold Tanzania craton, whose northeastern boundary is only loosely defined. The shaded areas are zones of Mesozoic rifts and a second, poorly understood phase of rifting in the Paleogene. The Turkwel–Elgeyo escarpment is denoted by a black dashed line. Widespread, primarily basaltic lavas erupted at ~45–28 Ma in southwestern Ethiopia and northern Kenya prior to the development of the MER and Eastern Rift. Note that some faults and volcanoes of the Eastern Rift formed in Archaean lithosphere, outlined by the brown dashed line. From south to north: L = Laetoli; O = Oldupai; Ol = Olorgesailie; K = Kantis; TH = Tugen Hills; Lt = Lothagam; Nk = Nakuchui; KF = Koobi Fora; and Om = Omo-Kibish-Shungura.

et al. 2015). The Turkana depression, therefore, has been a low-lying area throughout rift evolution, but has experienced ~200–300 m of uplift since 17 Ma.

By the early Pliocene, an ancient Omo River system draining the Ethiopian Plateau and Turkwel escarpment had formed and semi-permanent lakes formed in the Turkana depression. The predominantly fluviolacustrine Omo, Koobi Fora, and Nachukui formations and Lothagam sequences host rich hominin sequences that enable the evaluation of climatic influences on hominin evolution (FIG. 3). During the Plio–Pleistocene, magmatism and faulting migrated eastward to the basins of the Omo-Turkana Rift, the current locus of subsidence and magmatism. A phase of magmatism and faulting at 3–2 Ma along the eastern side of the modern Turkana Basin led to the creation of large shield complexes that deflected and then blocked lake outflow to the east. This low-lying area (Chalbi Desert) east of Lake Turkana was a playa lake basin 2–2.5 Ma when large shield complexes with extensive monogenetic cone complexes started to form (e.g., Marsabit; FIG. 3). Lava flows from the ~1.6-Ma Barrier volcanic complex at the southern end of Lake Turkana blocked along-axis drainage from the south by about 50 ka, or perhaps earlier. Bobe and Carvalho (2019) suggest that the punctuated tectonism and climate change in the early Pleistocene provided ecological opportunities that enabled the coexistence of three or more hominin species in the Omo-Turkana area.

Eastern Rift

The Eastern (Gregory) Rift marks the plate boundary between the Nubia and Somalia plates south of the Turkana depression. Faults bounding the Eastern Rift initiated between 15 and 6 Ma in southern Kenya to form sedimentary basins, soon after the outpouring of silica-poor phonolites and alkali basalts between 14 and 11 Ma in central Kenya (e.g., Baker 1986; FIG. 3). At the southern end of the Eastern Rift, the Magadi Basin is partially filled with ≤7-Ma lavas from volcanic complexes on the eastern side of the basin. The faulted basins were at times filled by shallow lake systems that also accumulated sedimentary and volcanic strata.

The Tugen Hills in the Baringo Basin of north–central Kenya contain fossiliferous fluviolacustrine strata punctuated by volcaniclastic units spanning the past 16 My, including hominins. By ~2.6 Ma, strain migrated from border faults to <50-km-wide zones of magma intrusion and faulting within the central rift valley (e.g., Baker 1986). Lupien et al. (2021) suggest that rapid and large variations in vegetation created stressors for hominin evolution. Hominin fossils at the Kantis site on the uplifted flank of the Eastern Rift in Kenya document the distribution of hominins in higher elevation grassland habitats at ~3.5 Ma (FIG. 3). The elevation of the rift shoulder, however, was probably lower at 3.5 Ma as rift flank uplift has continued to present day.

North Tanzania Divergence

The Eastern Rift splays into a ~300-km-wide zone of seismically active faults at its southern termination in northern Tanzania where the rift intersects the eastern side of the ~150–200-km-thick Tanzania craton. Radiometric dating reveals an eastward migration of magmatism from ~6 Ma along a roughly east–west-trending line of volcanoes (Mana et al. 2015). This line of volcanoes and dikes represents a broadly distributed transfer fault zone linking the Natron extensional basin to the Pangani Rift zone to the east. The western arm is the northwest-trending Wembere-Eyasi Rift, where Miocene–Recent normal faults have developed in Archaean lithosphere (FIG. 3).

Separating the western arm and the central arm are the Olduvai–West Natron Basin and the Crater Highlands, a northeast-trending chain of calderas and faulted shield volcanoes. The West Natron Basin is bounded on its west by the apparently inactive Oldonyo Ogol fault, and this <3-Ma basin is now uplifted along the flank of the Natron Basin to the east (FIG. 4). In an evolutionary pattern similar to the Turkana and Eastern rift examples, initial rift basins near the craton margin migrated eastward in the last 1.2–1 My as the Songo border fault developed to connect the Nguruman and Manyara border faults. By 1.23 Ma, eruptive centers started to form within the basin bounded by the Songo fault and the monocline on its eastern side. This rift sector hosts some of the youngest topographic relief in the East African Rift system, with many of the elevation changes happening after the deposition of fossil sequences hosting hominins.

The now uplifted flank of the Eyasi Rift basin hosts a fossil-rich sedimentary sequence that includes hominin footprints. The upper Laetoli beds (3.6–3.85 Ma) were deposited in an environment that lacked permanent rivers or other large bodies of water. Given that this is one of the youngest rift sectors, it is likely that these sequences formed at lower elevations and have been uplifted by isostatic changes accompanying extension. The region was a mosaic of grassland–shrubland–woodland habitats that were affected by seasonal rainfall and periodic volcanic tephra and ashfall (Su and Harrison 2015).

At least one hominin site within the Oldupai Basin was occupied after a catastrophic pyroclastic flow from one of the nearby volcanoes filled river and stream channels at ~2 Ma. The earliest Oldupai hominins occupied environments periodically stressed by lava flows and air fall deposits from volcanic eruptions, thereby exhibiting the adaptability of early hominins (Mercader et al. 2021).

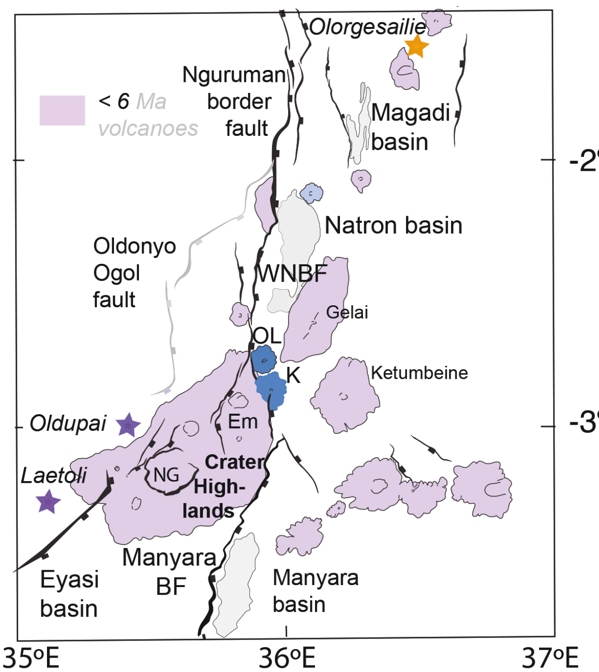

FIGURE 4 Detail of the southernmost sector of the Eastern Rift that encompasses the Magadi, Natron, Manyara, and Eyasi basins and the 6 Ma–Recent volcanoes, including the Crater Highlands at the intersection of the northeast-striking and north–south-striking rift border faults. WNBF = West Natron border fault; OL = Oldoinyo Lengai and K = Kerimasi, both being carbonatite volcanoes (blue); Em = Embagai Volcano; NG = Ngorongoro crater; and Manyara BF = Manyara border fault. Stars indicate hominin sites.

Malawi Rift

The Malawi Rift lacks the widespread pre- and syn-rift magmatism of sectors to the northeast (FIG. 5). Only the northern basins formed on the uplifted East African Plateau. Periods of rifting in the Permo–Triassic and Cretaceous affected parts of the area, and Miocene–Recent strata overlie the older sequences in some areas. In the basin north of Lake Malawi, ~17-Ma–Recent lavas, ignimbrites, and airfall deposits of the Rungwe volcanic province are interbedded with fluviolacustrine strata (e.g., Fontijn et al. 2012). Structural and stratigraphic patterns onshore indicate that the present-day fault architecture developed after about 8 Ma (e.g., Fontijn et al. 2012; FIG. 5).

The Plio–Pleistocene alluvial-lacustrine Chiwondo and Chitimwe beds on the northwestern side of the lake host two hominin localities (Uraha and Malema). Unlike the savannah-type environments of Pliocene hominins in the Eastern Rift, this environment was more heavily wooded. The variety of landscapes and habitats in which hominins lived indicates habitat flexibility and nutritional versatility.

INTERPLAY BETWEEN CLIMATE, TECTONICS, AND EVOLUTION

The hominin evolution spans between 7 Ma and the present, a time when eastern Africa experienced important climatic, tectonic, and environmental changes. The climate cycles resulting from orbital forcing, namely, Milankovitch cycles (orbital precession, axial obliquity, and orbital eccentricity), may have in part controlled precipitation, environmental, and ecological changes in Africa.

The size and depth of lakes reflect the changing climatic conditions. During different humid periods, higher lake levels beyond the overflow sill led to overflow and the hydrological connectivity of different lake basins and the mixing of aquatic species. Evidence of increased precipitation beyond this threshold point is not preserved in the geomorphological proxies within lacustrine basins. However, below the overflow sill where the rift lakes are hydrologically closed, the lakes that correlate positively to humid–arid transitions and have been used to reconstruct paleoclimate transitions are called amplifier lakes (e.g., Olaka et al. 2010). These lakes tend to occur at the crest of the East African Plateau and have a graben-shaped morphology such as Naivasha and Ziway (Olaka et al. 2010). In addition, crustal-scale fault systems trending north–south have been important in transmitting groundwater laterally and vertically within the rift to far flung lakes following the hydraulic gradient (Olaka et al. 2022). Thus, groundwater input supports high lake levels for an extended period and buffers the climate.

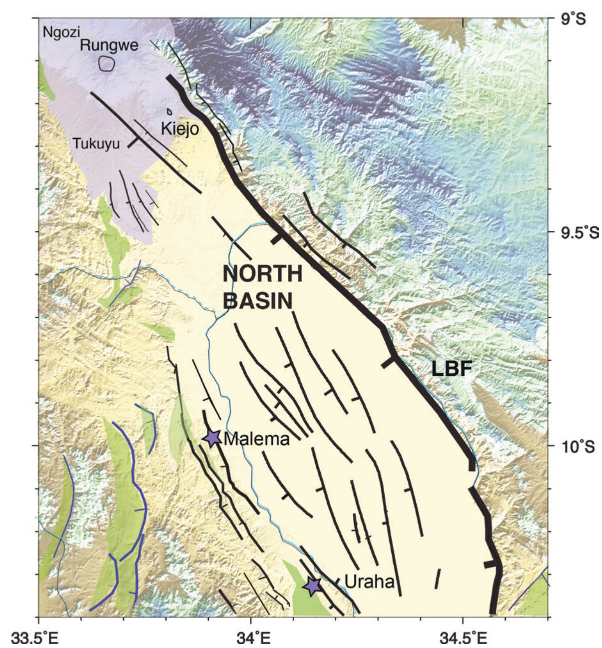

FIGURE 5 Hominin localities in the northern Malawi Rift relative to Miocene–Recent faults (black) and eruptive centers, and Permo–Triassic and Cretaceous faults (purple). Green indicates Mesozoic sedimentary strata, including dinosaur beds. LBF indicates the Livingstone border fault. Stars indicate hominin sites.

Groundwater systems in the rift have also been critical in supporting isolated networks of hydro-refugia (wetland and woodland environments) during periods with scarce surface water, and co-exist with hominin and/or archeological remains (e.g., Mercader et al. 2021) in arid eastern Africa. Their occurrence may have facilitated unexpected variations in the isolation and dispersal of hominin populations in the past (Cuthbert et al. 2017). While the topographic differences resulting from extensional tectonics in the Mio–Pleistocene also created micro-climate systems, spring- and groundwater-fed rivers provided ecological continuity through time and diverse habitats at multiple spatial scales. These ecosystem functions favored connectivity and migration for animals and early hominins during dry periods (Mercader et al. 2021).

Ecological and Biodiversity Consequences of Tectonics and Climate Change

The shifts in vegetation between open wooded grasslands and grasslands (Cerling 1992; Bonnefille 2010) occurred at ~10 Ma in eastern Africa after the 15.5–12.5-Ma cooling event. Another pronounced change took place at 6.3–6.0 Ma and triggered a decrease in tree cover across all of tropical Africa (Bonnefille 2010). Microbiomes along the uplifting flanks of subsiding rift basins and volcanoes may have hosted forests and more humid conditions.

Climate change is considered to have shaped the evolution and diversification of biodiversity in eastern Africa (e.g., Potts et al. 2020), and landscape-scale shifts in ecological resources are thought to have shaped hominin adaptations (e.g., Potts et al. 2020). The earliest hominins (*Orrorin*) found in the Kenyan and Ethiopian rifts are thought to have inhabited mixed C3/C4 environments (Cerling 1992). During the Pliocene–Pleistocene, floral changes were accompanied by a faunal change, leading to an increase in taxa adapted to more xeric (i.e., very dry) grassland conditions and ultimately to the appearance of hominins and *Homo* in eastern Africa (Pickford 1990; Bobe et al. 2007).

SUMMARY

The fault-bounded rift valleys and their uplifted flanks superposed on broad plateaus of the eastern African Rift system formed in response to dynamic processes in the Earth's mantle. The surface expression of rifting is highly diachronous. The vertical tectonic movements accompanying rifting played major roles in moderating climate, rainfall, and, consequently, the biodiversity of eastern Africa as well as it habitats. The isolation and evolution of hominins were, therefore, in large part controlled by the time–space patterns of faulting, magmatism, uplift, and accompanying climate transitions.

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