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A leaf wax biomarker record of early Pleistocene hydroclimate from West Turkana, Kenya

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ABSTRACT

Climate is thought to play a critical role in human evolution; however, this hypothesis is difficult to test due to a lack of long, high-quality paleoclimate records from key hominin fossil locales. To address this issue, we analyzed organic geochemical indicators of climate in a drill core from West Turkana, Kenya that spans ~1.9—1.4 Ma, an interval that includes several important hominin evolutionary transitions. We analyzed the hydrogen isotopic composition of terrestrial plant waxes (δD_{wax}) to reconstruct orbital-timescale changes in regional hydrology and their relationship with global climate forcings and the hominin fossil record. Our data indicate little change in the long-term mean hydroclimate during this interval, in contrast to inferred changes in the level of Lake Turkana, suggesting that lake level may be responding dominantly to deltaic progradation or tectonically-driven changes in basin configuration as opposed to hydroclimate. Time-series spectral analyses of the isotopic data reveal strong precession-band (21 kyr) periodicity, indicating that regional hydroclimate was strongly affected by changes in insolation. We observe an interval of particularly high-amplitude hydrologic variation at ~1.7 Ma, which occurs during a time of high orbital eccentricity hence large changes in processionally-driven insolation amplitude. This interval overlaps with multiple hominin species turnovers, the appearance of new stone tool technology, and hominin dispersal out of Africa, supporting the notion that climate variability played an important role in hominin evolution.

1. Introduction

Understanding the link between human evolution and environmental change is one of the most enduring challenges in the Earth Sciences. An early idea, dubbed the savannah hypothesis (Dart, 1925), posited that global cooling during the Plio-Pleistocene led to gradual drying of Africa, which in turn altered vegetation structure from closed-canopy forest to open savannah, and triggered anatomical and behavioral changes in early hominins (Cerling, 1992; Cerling and Hay, 1986; deMenocal, 1995; Feakins et al., 2005; Levin et al., 2011; Uno et al., 2016b). Although there is clear evidence for the development of drier conditions in Africa over the Plio-Pleistocene from paleoceanographic (deMenocal, 2004) and soil carbonate (Levin et al., 2004) records, it has proven difficult to associate individual transitions in specific locales in the hominin fossil records with these gradual, continental-scale environmental changes. More recent hypotheses suggest much more complex connections between hominins and their environment that account for abrupt changes and high variability evident in African paleoclimate records. The turnover pulse hypothesis (Vrba, 1980, 1989, 1995) suggests that rapid shifts between environmental extremes, caused by climatic or geologic events, force evolutionary changes, whereas the variability selection hypothesis posits that changes in environmental variability select for traits that lead to adaptability in hominin lineages to cope with highly variable landscapes (Bobe and Behrensmeyer, 2004; Grove, 2014, 2015; Maslin et al., 2014; Maslin and Trauth, 2009; Potts, 1996, 1998a, b; Potts and Faith, 2015; Trauth et al., 2010). Each of these hypotheses makes a specific prediction about the timing, rate, or pattern of

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African environmental change, which would be best tested against paleoenvironmental records obtained from the basins where our hominin ancestors lived.

African climate change during the Plio-Pleistocene occurred in the context of large changes in global climate boundary conditions and forcing. Over the course of the Pleistocene, global climate cooled and the northern high latitude ice sheets expanded and oscillated at 41 and 100 kyr periodicities (Lisiecki and Raymo, 2005; Zachos et al., 2001). Closure of the Indonesian seaway could have induced African aridification as early as 3–4 million years ago (Cane and Molnar, 2001) and the enhancement of tropical latitudinal temperature gradients (Walker Circulation) at ~1.7 Ma (Ravelo et al., 2004) may have driven changes in African rainfall (Brierley et al., 2009). These influences, as well as cyclic changes in insolation driven by orbital precession, are all thought to modulate African rainfall (Brierley et al., 2009; deMenocal, 2004; Pokras and Mix, 1987). Paleoclimate reconstructions from marine sequences, including inferences of tropical sea surface temperature (SST) and African dust accumulation, document environmental fluctuations that appear to be in phase with northern hemisphere glaciation (NHG; deMenocal, 1995; Herbert et al., 2010). On the other hand, changes in the magnitude of tropical insolation resulting from Earth-orbital precession, may strongly influence African monsoons; many paleoclimate records show strong ~21 kyr periodicity, particularly in North and East Africa (Hilgen, 1991; Joordens et al., 2011; Kingston et al., 2007; Lourens et al., 1996; Maslin et al., 2014; Maslin and Trauth, 2009; Rossignol-Strick, 1985; Trauth et al., 2007). Unfortunately, existing terrestrial records are generally of low temporal resolution, and are often short and discontinuous, and are therefore unable to determine the large-scale controls on tropical African rainfall. In contrast, marine sediment cores provide long, continuous climate histories but generally record environmental changes at the continental scale, thus ill-suited to investigate the environmental history of the specific regions in which hominins evolved.

The Hominin Sites and Paleolakes Drilling Project (HSPDP) is an international collaboration that drilled long cores from six paleolakes in the East African Rift System (EARS) to characterize the paleoenvironments in which our human ancestors lived and evolved (Campisano et al., 2017; Cohen et al., 2009, 2016). Because of fast sedimentation rates in these lacustrine basins, and a more limited sediment source area than offshore marine sites, these cores can provide environmental records with high temporal and spatial resolution to test the predictions of theories linking human evolution to climate change. Here, we present records of climate from the West Turkana Basin, Kenya, based on deuterium (D) to hydrogen (H) isotope ratios from terrestrial plant waxes (δD_{wax}) preserved in HSPDP core HSPDP-WTK13-1A (hereafter WTK13). The Turkana Basin has been well-characterized geologically and is the source of ~500 hominin fossil discoveries and contains over 100 archaeological sites (Wood and Leakey, 2011), including the earliest and most complete skeletons of *Homo rudolfensis* and *H. erectus* and Acheulean stone tools (advanced hand axes; Lepre et al., 2011). Our record spans almost 500 kyr of the early Pleistocene, from 1.86 to 1.37 Ma, which witnessed a critical evolutionary transition marked by the demise of *H. habilis* and *H. rudolfensis* and the rise of *H. erectus*. Our δD_{wax} record provides new insight into the patterns and causes of climate change during this important time window.

2. Regional setting

The Turkana Basin is comprised of half-graben subsiding blocks, extends from central Kenya northward into southern Ethiopia in the eastern branch of the EARS, and today houses Lake Turkana, the world's largest desert lake (Feibel, 2011). It receives less than 200 mm of precipitation annually, with rainfall occurring in two rainy seasons associated with the seasonal migration of the Intertropical Convergence Zone (ITCZ) across the equator (Yang et al., 2015; Yuretich and Cerling, 1983). The Congo Air Boundary (CAB), which separates Atlantic and Indian Ocean-derived moisture sources, currently lies well to the west of Lake Turkana over Central Africa. Modern Lake Turkana is fed mostly by the Omo River, which forms a large delta at the northern end of the lake. During the early Pleistocene, Lake Lorenyang filled much of the Turkana Basin (Fig. 1), with numerous fossils, including hominins, preserved in its lake-marginal and terrestrial sediment fill (Harris et al., 1988; Roche et al., 2003). Because of ongoing rifting, sediment deposition is and was highly dynamic, and was also impacted by extensive volcanism, fluctuating deltaic systems, and dramatic lake level changes (Feibel, 2011; Feibel et al., 1989). We focus on paleolake sediments drilled from west of modern Lake Turkana in the Nachukui Formation (~4°N, ~36°E; Fig. 1).

3. Material and methods

Core WTK13 was taken in 2013 from a borehole oriented at 10° from vertical, and achieved 94.1% recovery (Cohen et al., 2016). The bottom ~155 m of the 216.47 m core is mostly comprised of dark green fine siltstones, signifying deep lake environments, intermittently overprinted by weakly developed paleosols. Sediments above 61 m below the surface (mbs) are generally coarser red silts and sands, signifying a shift to shallower, more oxidizing lacustrine and deltaic environments. We determined a chronology for WTK13

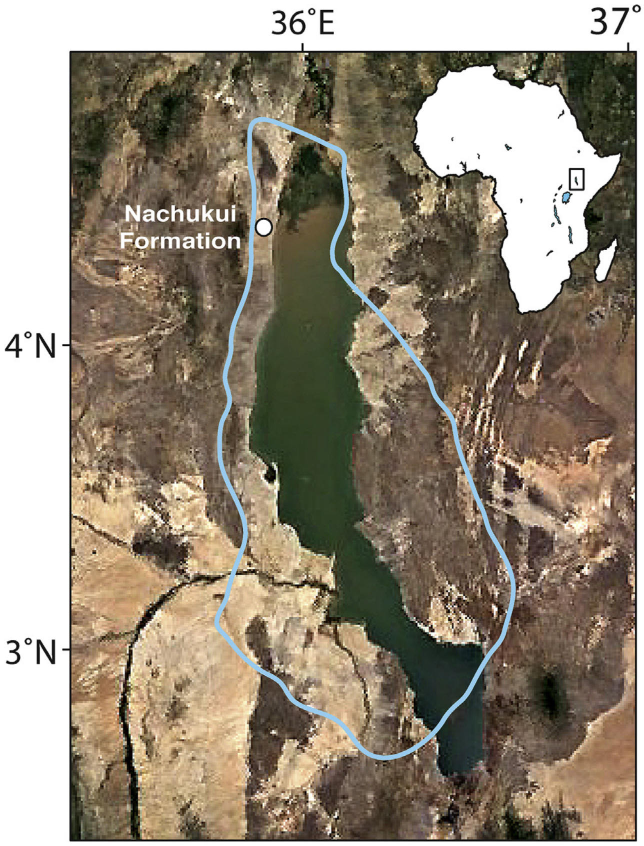

Fig. 1. The present-day Lake Turkana Basin (Google Earth) with paleolake Lorenyang ~1.9 Ma outlined in blue (Brown and Feibel (1991). The location of core WTK13 that sampled the Nachukui Formation is indicated by a white circle. (For interpretation of the references to color in this figure legend, the reader is referred to the Web version of this article.)