Palaeogeography, Palaeoclimatology, Palaeoecology xxx (xxxx) xxx–xxx

Contents lists available at ScienceDirect

Palaeogeography, Palaeoclimatology, Palaeoecology

journal homepage: www.elsevier.com/locate/palaeo

Sub-Milankovitch paleoclimatic and paleoenvironmental variability in East Africa recorded by Pleistocene lacustrine sediments from Olduvai Gorge, Tanzania

Devon E. Colcord[a,*], Andrea M. Shilling[a], Peter E. Sauer[a], Katherine H. Freeman[b], Jackson K. Njau[a,e], Ian G. Stanistreet[c,e], Harald Stollhofen[d], Kathy D. Schick[a,e], Nicholas Toth[a,e], Simon C. Brassell[a]

[a] Department of Earth and Atmospheric Sciences, Indiana University, Bloomington, IN, United States
[b] Department of Geosciences, The Pennsylvania State University, University Park, PA, United States
[c] Department of Earth and Ocean Sciences, University of Liverpool, Liverpool, United Kingdom
[d] GeoZentrum Nordbayern, Friedrich-Alexander-Universität (FAU), Erlangen, Germany
[e] The Stone Age Institute, Gosport, IN, United States

A R T I C L E I N F O

Keywords:
n-Alkane
Compound-specific isotope analysis
Sediment core

A B S T R A C T

Over the past century, numerous discoveries throughout East Africa have advanced our understanding of hominin evolution and provided substantive evidence that climatic and environmental variability played a critical role in evolutionary developments. Stratigraphic records with high temporal resolution aid in testing evolutionary hypotheses that invoke changes in climate and environment at various timescales as drivers of hominin evolution. Olduvai Gorge, Tanzania has a rich history of hominin fossil discoveries from its ~2.0 Ma sedimentary sequence, which includes multiple deep lake intervals. In 2014, the Olduvai Gorge Coring Project (OGCP) recovered a sequence of sediment cores that provide an extensive record of the Pleistocene sedimentary history, including paleolacustrine systems in this area. With > 94% core recovery, these cores are ideally suited for high-resolution analyses of organic geochemical proxies and provide an exceptional opportunity to build on previously published outcrop-based paleoenvironmental data from Olduvai. The OGCP core 2A section between 76.6 and 86.9 m depth is considered as a time-stratigraphic equivalent of strata that host the hominin fossils OH24 and OH56 at the Olduvai DK archaeological site. This depositional interval age-bracketed between ~1.88 Ma (Bed I Basalt) and ~1.85 Ma (Tuff IB) was sampled for organic geochemical analyses. The carbon isotopic composition of organic matter ($\delta^{13}C_{TOC}$) from this section varies between values representative of more forested and open grassland ecosystems over ~21 kyr. This observation is consistent with the Milankovitch precession cycle driving the availability of water, which was previously observed in lower resolution studies of outcrop samples. Complementary organic geochemical proxies provide further evidence of these shifts in environmental conditions and record sub-Milankovitch scale changes superimposed on the precession cycle. This suggests the occurrence of short-term fluctuations in the environments inhabited by hominins, which opens new lines of investigation on how environmental scenarios may affect particular evolutionary mechanisms that drove various evolutionary responses.

1. Introduction

Over the past century, studies in East Africa have provided an unprecedented wealth of evidence that has enhanced our understanding of hominin evolution and its environmental context. However, many fundamental questions remain unanswered, including why and how hominins evolved and what factors influenced both anatomical and cognitive developments. Many evolutionary hypotheses, such as the aridity hypothesis (e.g. deMenocal, 1995), variability selection hypothesis (e.g. Potts, 1998), deep-lake hypothesis (e.g. Trauth et al., 2005), and pulsed-climate variability hypothesis (e.g. Maslin and Trauth, 2009) invoke changes in the climate and environment as critical factors in hominin evolution. The ability to better refine these hypotheses, however, requires a more complete and detailed record of

* Corresponding author.
E-mail address: dcolcord@indiana.edu (D.E. Colcord).

https://doi.org/10.1016/j.palaeo.2018.01.023
Received 20 October 2017; Received in revised form 14 January 2018; Accepted 17 January 2018

the variability of the climate and environment experienced by hominins, especially during key intervals in their evolutionary history.

The capability to determine the extent and magnitude of short-term climate and environmental variability is critical for hypotheses such as the pulsed-climate variability hypothesis, which emphasizes the importance of short intervals with extreme climate variability (Maslin and Trauth, 2009). Existing paleoclimate records available for East Africa, specifically Olduvai Gorge (e.g. Ashley et al., 2010, 2014; Deino, 2012; Magill et al., 2013a, 2013b; Deocampo et al., 2017), do not provide the fine temporal resolution necessary to capture the full extent of short-term climate variability during key periods in hominin evolution. However, recent successes in the recovery of cored paleolacustrine sequences by continental drilling projects, such as the Hominin Sites & Paleolakes Drilling Project (HSPDP; Cohen et al., 2009, 2016), Olorgesailie Drilling Project (ODP; Potts and Faith, 2015), and the Olduvai Gorge Coring Project (OGCP; Njau et al., 2018), now afford the opportunity for the determination of high-resolution paleoclimatic and paleoenvironmental reconstructions at sites of anthropological importance.

The period from ~2.0 to 1.7 Ma was a dynamic interval in both the evolutionary and climatic history of East Africa. It marks a time of peak diversity among hominin species in East Africa (Shultz et al., 2012; Maslin et al., 2014) coupled with the beginning of a significant increase in their cranial capacity (deMenocal, 1995, 2011; Shultz et al., 2012; Antón et al., 2014; Maslin et al., 2014, 2015), and coincides with a hominin dispersal event (Agustí and Lordkipanidze, 2011; Antón et al., 2014; Maslin et al., 2014). This period also corresponds to a major change in the climatic coupling of ocean and atmosphere, namely the development of the Walker Circulation (e.g. Trauth et al., 2005; Maslin et al., 2014), although there is some evidence suggesting zonal circulation in equatorial regions prior to this time (Zhang et al., 2014).

At Olduvai Gorge, Bed I preserves a wealth of archaeological and vertebrate fossil assemblages, including early hominins. One of the oldest and richest Bed I archaeological sites is DK in the eastern Olduvai Basin, where a level of lithic artefacts and bones was excavated in several trenches, interpreted as an “occupation floor” (Leakey, 1971). Artefacts and bones, including the partial *Homo habilis* skull OH24 and OH56 parietals, occur in the interval between the Bed I Basalt and Tuff IB, two marker horizons, well constrained by volcanic facies, phenocryst assemblages, geochemistry (Habermann et al., 2016), and $^{40}Ar/^{39}Ar$ dating at 1.877 ± 0.013 to 1.848 ± 0.003 Ma (Deino, 2012). Other assemblages directly beneath Tuff IB were discovered at geological Localities No. 10 (LK), 11 (MK), 14 (JK), 34, and 61 (Hay, 1976). This suggests, that the Bed I Basalt to Tuff IB interval is crucial for the understanding of hominin paleolandscapes.

Here, we present a paleoclimatic and paleoenvironmental reconstruction of part of this key interval, based on investigation of organic geochemical proxies in lacustrine sediment cores drilled at Olduvai Gorge, Tanzania. The high sedimentation rate of this sequence permits determination of environmental variability at a temporal resolution unprecedented for this region and time interval, making it possible to characterize changes at frequencies higher than those caused by orbital forcing.

2. Background

2.1. Study site

Olduvai Gorge in northern Tanzania (Fig. 1) forms part of the East African Rift System (EARS) and is located directly northwest of the Ngorongoro volcanic highlands. Outcrops within the gorge expose a dominantly fluvio-lacustrine sedimentary sequence spanning ~2.0 Ma, designated as Beds I-IV, Masek, Ndutu, and Naisuisui Beds (Hay, 1976). They comprise a series of mixed clastic and volcaniclastic stratigraphic units with the Bed I Basalt and various geochemically fingerprinted tuff beds providing a robust stratigraphic framework (e.g. Hay, 1976; McHenry et al., 2008; Habermann et al., 2016). Since the early 1900s, the gorge has provided a rich history of hominin fossil and stone tool discoveries of exceptional paleoanthropological importance (e.g., Leakey, 1959, 1971; Leakey et al., 1964; Hay, 1990). These discoveries influenced the development of hypotheses regarding hominin evolution, many invoking climatic and environmental forcings as influences in the evolutionary process (e.g. Cerling and Hay, 1986; deMenocal, 1995, 2004; Potts, 1998; Maslin and Trauth, 2009; Maslin et al., 2014). The well-documented and well-dated sedimentary record at Olduvai Gorge (e.g. Hay, 1976; Deino, 2012; Stanistreet, 2012) includes multiple lacustrine intervals that have served as the intervals of primary interest for paleoenvironmental reconstructions (e.g. Ashley et al., 2010; Blumenschine et al., 2012; Magill et al., 2013a, 2013b; Magill et al., 2016; Deocampo et al., 2017). All of these prior studies utilized sediment from outcrops within the gorge, which are affected by weathering and represent only fragmented chronological intervals.

Some studies have shown that over the past few million years, East Africa has experienced a general trend towards more arid conditions, punctuated by multiple humid periods (i.e., 2.7–2.5, 1.9–1.7, and 1.1–0.9 Ma; e.g. Trauth et al., 2005; Behrensmeyer, 2006; deMenocal, 2011; Maslin et al., 2014), although recently it was suggested that not all locations experienced this aridification (Johnson et al., 2016). Bed I deposits from Olduvai Gorge correspond to the 1.9–1.7 Ma humid period and consist mainly of lacustrine sediments (e.g. Hay, 1976; Potts, 1998; Hay and Kyser, 2001; Stanistreet, 2012; Magill et al., 2013a, 2013b) whose ages are well constrained by dating of associated tuffs and basalts (e.g. Deino et al., 2012). The Bed I lacustrine sequence is characterized by wet-dry climate cycles consistent with the Milankovitch precession cycle (e.g. Magill et al., 2013a, 2013b; Ashley et al., 2014). These precessionally paced cycles are also recorded at other East African locations (e.g. Deino et al., 2006; Joordens et al., 2011; Potts and Faith, 2015). This period of rapidly changing climate from ~1.9–1.7 Ma corresponds to the development of the Walker Circulation (e.g. Trauth et al., 2005; Maslin et al., 2014), the peak in East African hominin diversity (Shultz et al., 2012; Maslin et al., 2014, 2015), and the beginning of increased cranial capacity in East African hominins (deMenocal, 1995; Shultz et al., 2012; Maslin et al., 2014). Consequently, this interval represents a critical phase in hominin evolution coincident with significant climatic change.

At present, the availability of precipitation is the dominant variable controlling the climate at Olduvai Gorge (located ~3°S), as seasonal temperature fluctuations are relatively small in equatorial regions. This region currently experiences two distinct rainy seasons, the “long rains” (March–May) and the “short rains” (October–December) (e.g. Magill et al., 2013b), resulting in annual precipitation totals of < 800 mm (Nicholson, 2000). Changes in precipitation in this part of Africa are influenced by rain-shadow effects associated with the Ngorongoro Volcanic Highlands and the positions of two atmospheric convergence zones: the Intertropical Convergence Zone (ITCZ) and the Congo Air Boundary (also referred to as the Interoceanic Confluence, IOC) (Nicholson, 2000; Tierney et al., 2011; Magill et al., 2013b). The exact location and extent of these convergence zones are sensitive to changes in insolation and the resulting surface heating (e.g. Nicholson, 2000).

2.2. Core sampling

In the summer of 2014, the Olduvai Gorge Coring Project (OGCP) collected ~245 m of sediment core from borehole 2A (S 02° 58′ 43.0″, E 035° 19′ 25.5″), which targeted the thickest Bed I sequence corresponding to the depocenter of Paleolake Olduvai during Bed I times (Njau et al., 2018). The focus for this study is a lacustrine sequence that spans ~10 m (76.6–86.9 m well depth) and registers the most eastward transgression of Paleolake Olduvai (Hay, 1976), most probably reflecting maximum lake size and deepening. Outcrop analogues include the well-known DK paleoanthropological site (Leakey, 1971). The cored section chosen for this study contains laminated intervals with