Paleoenvironmental change in the late Middle Pleistocene–Holocene Kibish Formation, southern Ethiopia: Evidence from ungulate isotopic ecology

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A B S T R A C T

East Africa has produced the earliest record of *Homo sapiens* ~ 200 ka and a punctuated record of Middle Stone Age and Later Stone Age behaviors. We lack, however, a detailed late Quaternary paleoenvironmental record for the region, particularly during humid periods. Without a regional record, hypotheses about the evolution and ecology of early *Homo sapiens* in East Africa remain vague and untestable. The Kibish Formation of southern Ethiopia presents a long, albeit punctuated, record of late Middle Pleistocene to Holocene faunal change in East Africa, which was deposited during humid periods. Here, we present oxygen and carbon stable isotope data of the Kibish ungulates and test whether there are environmental changes within the Kibish Formation. Significant differences in $\delta^{18}O$ enamel isotopes are consistent with more humid conditions during the Holocene-age Member IV (~ 13–4 ka) than either Pleistocene-age Member I (~ 196 ka) or Member III (~ 104 ka). Mesowear data document a shift toward more attritional wear among grazers in Member IV and are correlated with more depleted $\delta^{18}O$ enamel values, suggesting that the wear pattern shift is linked to the onset of more humid conditions during the Holocene. $\delta^{13}C$ enamel values show subtle variations through time, but do not suggest any major changes in diets. We propose that the paleoenvironmental differences evident in Member IV, based on $\delta^{18}O$ enamel values, mesowear, and bovid abundances, may be explained by cooler and wetter conditions at the beginning of the Holocene in the lower Omo Valley. The evidence suggesting that the Holocene humid phase is more pronounced than earlier humid phases may explain why arid-adapted grassland ungulates became extinct in East Africa by the Pleistocene–Holocene transition, but persisted through previous humid phases of the late Quaternary.

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1. Introduction

We know very little about paleoenvironments in East Africa from the Middle Pleistocene through the Holocene associated with Middle Stone Age (MSA) and Later Stone Age (LSA) toolkits, and early *Homo sapiens* fossils. This is especially true compared to the Middle and Late Pleistocene cave sites in South Africa that provide rich archeological (Henshilwood et al., 2002; d'Errico et al., 2005; Marean et al., 2007; Marean, 2010; Brown et al., 2009, 2012a) and paleoenvironmental records (Klein, 1980; Klein et al., 1999; Chase and Meadows, 2007; Bar-Matthews et al., 2010; Faith, 2013). The lack of data for East Africa is problematic, as documenting the temporal and spatial complexity of paleoenvironments during the late Quaternary is critical to contextualizing hypotheses about the ecology and evolution of early *Homo sapiens*. Understanding how early human populations responded to such changes via geographic, demographic, or behavioral shifts are central goals of paleoanthropology (Barham and Mitchell, 2008; d'Errico and Stringer, 2011; Blome et al., 2012). While fieldwork in southern and western Kenya has greatly expanded our knowledge of paleoenvironments during arid phases of the Late Pleistocene (Marean and Gifford-Gonzalez, 1991; Marean, 1992a, 1992b; Faith et al., 2013, 2014, 2015; Tryon and Faith, 2013; Tryon et al., 2010, 2014, 2015), the paucity of paleoenvironmental data for humid intervals confounds our ability to address these questions.

The Kibish Formation of southern Ethiopia has yielded a relatively large sample of late Middle Pleistocene to early to mid-Holocene faunal remains, including the earliest modern human fossils (McDougall et al., 2005; Fleagle et al., 2008). This record ranges in age from roughly 196 thousand years ago (ka) to ~ 13–4 ka, with three fossil-bearing members (Members I, III, and IV) deposited during humid phases linked to intensification of the African monsoon during precessional minima (Leakey, 1969; McDougall et al., 2005; Brown and Fuller, 2008; Fleagle et al., 2008; Brown et al., 2012b). Although it is by no means continuous (McDougall et al., 2005; Brown and Fuller, 2008; Brown et al., 2012b), the temporal span of the Kibish Formation is greater than other late

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Quaternary sites in East Africa (Gramly, 1976; Phillipson, 1977; Clark et al., 1984; Barham, 2000; Clark et al., 2003; Brandt et al., 2012; Gliganic et al., 2012; Tryon and Faith, 2013; Assefa et al., 2014; Tryon et al., 2014, 2015; Faith et al., 2015). Thus, the Kibish Formation offers a potential 'yardstick' through which a Pleistocene–Holocene chronology of East African paleoenvironmental change can be built. Here, we present new data that better our understanding of late Quaternary paleoenvironments in East Africa using carbon and oxygen stable isotope data of the Kibish Formation ungulates (Table 1).

2. Geological context

The Kibish Formation outcrops to the north of Lake Turkana in southern Ethiopia and has been mapped over an area roughly 50 × 190 km (Fig. 1) (Butzer et al., 1969; Butzer, 1971; Davidson, 1983; McDougall et al., 2005; Brown and Fuller, 2008; Brown et al., 2012b). Butzer (1971) divided the Kibish Formation into Members I, II, III, and IV (McDougall et al., 2005; Brown and Fuller, 2008; Fleagle et al., 2008; Brown et al., 2012b).

Deltaic deposits dominate the Kibish Formation, although fluvial and lacustrine facies do occur (Brown and Fuller, 2008). The formation was deposited in the delta of the Omo River that empties into Lake Turkana, which extended ~100 km northward during humid periods of the late Quaternary (McDougall et al., 2005, 2008). During these humid periods, the Omo River swelled due to increased rainfall over the Ethiopian Highlands coincident with precessional minima and intensification of the African monsoon (Rossignol-Strick et al., 1982; McDougall et al., 2008). These periods of increased rainfall have been linked with sapropel development in the Mediterranean Sea and their correlation with the fossil-bearing layers suggests that deposition of each Kibish Member was relatively rapid (McDougall et al., 2008). Thus, here we consider each member to be equivalent in age to the absolute dates derived from tephra in the formation, with little time-averaging across multiple climatic regimes (McDougall et al., 2005, 2008; Brown and Fuller, 2008; Brown et al., 2012b). For each member, fossils were concentrated in discrete sedimentary lenses.

The oldest member, Member I, is late Middle Pleistocene in age and is dated to ~196 ka by the Nakaa'kire Tuff (McDougall et al., 2005; Brown et al., 2012b). This member rests unconformably over the Nkalabong and Mursi Formations (Brown and Fuller, 2008). Member II

has yielded little faunal remains and is only tentatively dated to between 180 and 150 ka, although correlation with Mediterranean sapropels suggests deposition ~172 ka (Brown and Fuller, 2008; McDougall et al., 2008; Brown et al., 2012b). Due to the lack of faunal remains recovered from Member II, it is not considered here. The Aliyo Tuff dates Member III to the Late Pleistocene, ~104 ka (Brown and Fuller, 2008; Brown et al., 2012b). Finally, Member IV is Late Pleistocene to mid-Holocene in age, ~13–4 ka, based on ^{14}C dating of fossil mollusks (Owen and Renaut, 1986; Brown and Fuller, 2008).

3. Materials and methods

3.1. Carbon and oxygen stable isotopes

Stable isotope characterization of fossil teeth for paleobiological, paleoecological, and paleoenvironmental reconstruction has been a well-developed method for decades (Lee-Thorp, 1989; Koch et al., 1989; Kohn, 1996; Sponheimer and Lee-Thorp, 1999a, 1999b; Schoeninger et al., 2003; Cerling et al., 2003; Kingston and Harrison, 2007; Sponheimer and Lee-Thorp, 2007; Harris et al., 2008). This is because the carbonate fraction of tooth enamel is minimally affected by diagenesis and can be used as a proxy for diet, which is in turn used to infer paleoenvironments (DeNiro and Epstein, 1978; Wang and Cerling, 1994; Cerling and Harris, 1999; Sponheimer and Lee-Thorp, 1999a; Lee-Thorp, 2002; Lee-Thorp and Sponheimer, 2003). Seasonality, competition, migration, social behavior, and other factors may complicate the link between diet and environmental proxies (Caswell et al., 1973; Behrensmeyer and Hook, 1992). Thus, in order to minimize these factors, diets and paleoenvironments are primarily interpreted and reconstructed through a community-based approach (Sponheimer and Lee-Thorp, 1999a; Kingston, 2007, 2011).

Terrestrial plants predominantly use two different photosynthetic pathways based on differences in the fractionation of ^{12}C and ^{13}C from atmospheric CO_2. Trees, shrubs, and high-altitude grasses (>2000 m) in tropical Africa utilize the C_3 photosynthetic pathway and have a modern $\delta^{13}C$ range of −22‰ to −36‰ (mean: −27.1 ± 2.0‰; Tieszen et al., 1979; O'Leary, 1981; Cerling et al., 2003; Passey et al., 2005; Kohn, 2010; Brookman and Ambrose, 2012). This variability in C_3 plants is partially driven by photosynthetic recycling of respired CO_2 in closed canopy forests, known as the canopy effect, and variability in water

Table 1
Faunal list of Kibish Formation ungulates compiled from Rowan et al. (2015) for Bovidae and Assefa et al. (2008) for non-bovid taxa. Number of identified specimens (NISP) is shown for each taxon for each member.

Family	Subfamily	Tribe	Species	Member I	Member III	Member IV
Bovidae	Antilopinae	Aepycerotini	Aepyceros melampus	–	–	1
			cf. Aepyceros	3	–	–
		Alcelaphini	Connochaetes taurinus	5	3	1
			Damaliscus hypsodon	3	1	–
			Damaliscus lunatus	2	–	1
		Antilopini	Nanger cf. granti	2	1	–
			Madoqua sp.	19	1	–
		Cephalophini	cf. Cephalophini	1	–	–
		Hippotragini	Oryx cf. beisa	2	2	–
			Hippotragus equinus	3	3	3
		Reduncini	Kobus ellipsiprymnus	14	12	6
			Kobus kob	3	3	6
	Bovinae	Bovini	Syncerus caffer	23	11	2
		Tragelaphini	Tragelaphus scriptus	19	–	1
			Tragelaphus cf. strepsiceros	–	–	1
			Tragelaphus sp.	1	–	–
Elephantidae			Loxodonta africana	–	1	1
Equidae	Equinae	Equini	Equus cf. quagga	2	–	–
			Equus cf. grevyi	2	–	1
Giraffidae	Giraffinae		Giraffa camelopardalis	3	–	1
Hippopotamidae			Hippopotamus amphibius	10	3	5
Suidae		Suini	Hylochoerus meinertzhageni	–	2	–
			Phacochoerus africanus	22	6	8
			Potamochoerus porcus	–	1	–