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A Middle Pleistocene intense monsoonal episode from the Kapthurin Formation, Kenya: Stable isotopic evidence from bovid teeth and pedogenic carbonates

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ABSTRACT

Carbon and oxygen isotope values of bovid tooth enamel and pedogenic carbonates were used to reconstruct the paleoenvironments associated with Middle Pleistocene archeological and paleontological sites from the Kapthurin Formation, Kenya. Fossil teeth and pedogenic carbonates were collected from lacustrine and fluvial facies (K3 and K3') of the Kapthurin Formation (~543–509 ka). Twenty teeth from six bovid tribes and twenty four pedogenic carbonates were sequentially sampled for stable oxygen and carbon analysis. The primary aims of this work are to reconstruct the vegetative habitats of bovids and environmental landscapes from the Kapthurin Formation, assessing the presence of C_3, C_4, or mixed vegetation and foragers. We also assess general paleoclimate factors, such as overall aridity, seasonal shifts in water availability, and broad habitat reconstructions. Carbon isotope values suggest a wide range of foraging strategies were available to bovids, and are characterized by both C_3 dominated and C_4 dominated diets, with little evidence for mixed feeders, while pedogenic carbonates suggest the landscape combined a mix of C_3 and C_4 vegetation sources, structurally similar to wooded grasslands. Paleoclimatic conditions, based on the reconstructed mean annual water deficit from $\delta^{18}O_{enamel}$ values suggest a hyper mesic environment, most comparable to the modern Ituri rainforest, indicating a much wetter climate than the modern Lake Baringo Basin. This environment coincides with an intensified Middle Pleistocene African monsoonal system at the onset of Marine Isotope Stage 13 (~533 ka). The Middle Pleistocene Lake Baringo regional habitat appears to have been one dominated by woodland areas, perennially active streams, marsh and sumpland environments, and a surrounding grassland ecosystem. This lush basin would have provided hominins with a diverse and productive ecosystem. Perhaps not surprisingly, archeological sites are found in all habitats, including wet, forested, and grassland environments.

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1. Introduction

Changes in environments have long been associated with the evolution and technological choices of hominins (Ambrose, 1998; Bräuer, 2008; Darwin, 1871; deMenocal, 1995; Potts, 1996; Reed, 1997; Vrba, 1993). Stable carbon and oxygen ($\delta^{13}C$; $\delta^{18}O$) values derived from herbivorous mammal biogenic carbonated apatite (tooth enamel) and pedogenic carbonates provide valuable data for environmental reconstructions (Cerling, 1984; DeNiro and Epstein, 1978; Kingston et al., 1994; Koch et al., 1989; Levin et al., 2011; Quade et al., 1992). The stable isotope values of tooth enamel are independent of taxonomic identification of fossil specimens, and provide a useful way to confirm or falsify environmental reconstructions based on the habitat preferences of modern analogs. Despite potential taphonomic biases, Western and Behrensmeyer (2009) suggest that modern bone assemblages accurately represent the relative proportions of different taxonomic groups of living animals, implying that fossils of animals are good indicators for past habitats. Unfortunately, not all habitats are equally represented in the fossil record (Behrensmeyer and Hill, 1988; Hill, 1979) and habitats differentially "fossilize". Isotope analysis of tooth enamel can be used to verify reconstructions based on habitat preferences of modern analogs and relative taxonomic abundance, because the preferences of modern taxonomic groups may have differed in the past.

Pedogenic carbonates form at depth (>40 cm) in equatorial soils at negative water balance conditions through the combined contribution of plant decay and diffusion (CO_2) at equilibrium with soil water (Cerling and Quade, 1993). Pedogenic carbonate carbon isotope values reflect soil CO_2 carbon isotope values and oxygen isotope values of pedogenic carbonates reflect soil water oxygen isotope values (Cerling, 1984). Thus, the isotopic composition of pedogenic carbonates can serve as a useful proxy for local vegetation and hydrological habitats (Kingston, 2007; Levin et al., 2011; Quinn et al., 2013).

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Here, we use stable isotopes of carbon and oxygen from tooth enamel to reconstruct the dietary habits of fossil bovids collected at paleontological and archeological sites from the Middle Pleistocene sediments of the Kapthurin Formation, Kenya. These dietary data, associated with taxonomic uniformitarian behavior of bovids (Bibi et al., 2009), are used to reconstruct a landscape exploited by Acheulian hominins and chimpanzees between 543 ± 3 ka and 509 ± 9 ka (Leakey et al., 1969; McBrearty et al., 1996; McBrearty and Jablonski, 2005). We also use stable isotopes of carbon and oxygen derived from pedogenic carbonates to augment these paleoecological reconstructions. Finally, we use stable isotopes from both pedogenic carbonates and tooth enamel to test the regional paleoclimatic predictions (Rossignol-Strick et al., 1998; Schefuß et al., 2003) of an intense monsoonal system affecting East Africa at ~528 ka. This research is directly relevant to comprehending the paleoenvironmental context of the terminal Acheulian and the beginnings of the Middle Stone Age technocomplexes, and the foraging behavior of hominins.

The Middle Pleistocene, 781–126 ka, formerly the Ionian (International Commission on Stratigraphy, 2014), of Africa records a significant time period in human evolution; it marks the appearance of *Homo sapiens*, the development of new technologies often referred to as "modern", and the Middle Stone Age shift to the occupation of diverse habitats (Clark, 1988; Henshilwood and Marean, 2003; McBrearty and Brooks, 2000). Acheulian technology has long been assumed to be relatively uniform from its inception during the early Pleistocene, 2.58 Ma – 781 ka, formally the Calabrian and Gelasian (International Commission on Stratigraphy, 2014) through its eventual disuse during the later Middle Pleistocene (Clark, 1977; Isaac, 1972; Leakey, 1971). Researchers have documented the variability in lithic manufacture, including the production of flakes via the Levallois method and the systematic production of blades during the terminal Acheulian (Adler et al., 2014; Johnson and McBrearty, 2012; McBrearty, 2001; Tryon et al., 2005). Some of these technological innovations occur prior to the appearance of the Middle Stone Age technocomplex, and could indicate a period of technological experimentation and innovation, focused around perennial freshwater springs and biomass rich habitats (Johnson et al., 2009; Johnson and McBrearty, 2012), similar to foraging behavior associated with some later Middle Stone Age hominins (Curnoe et al., 2006; McCarthy et al., 2010). The Kapthurin Formation preserves evidence of late Acheulian behavior and the only documented fossil *Pan* remains (McBrearty and Jablonski, 2005). Detailed environmental reconstructions will help elucidate this period of innovation that precedes the Middle Stone Age, the habitat range of hominins, and the habitat range of chimpanzees during the Middle Pleistocene.

2. Background

2.1. Kapthurin formation

Lying to the west of Lake Baringo, the Kapthurin Formation is part of the Middle Pleistocene sedimentary sequence of the Tugen Hills succession in the Kenyan Rift Valley (Figs. 1 and 2). The formation consists of interstratified alluvial, lacustrine, and volcanic sediments, is exposed over an area of 150 km^2, and has an observed thickness of approximately 125 m (Martyn, 1969; Tallon, 1978; Tryon and McBrearty, 2002). All ages quoted are direct dates generated with the $^{40}Ar/^{39}Ar$ method (Deino and McBrearty, 2002) (Fig. 1). Martyn (1969) subdivided the formation into 5 members; K1, K3, and K5 are informally named the Lower, Middle, and Upper Silts and Gravels and are largely composed of terrigenous sediments from the Tugen Hills; K2, the Pumice Tuff Member, dated to 543 ± 3 ka, and K4, the Bedded Tuff Member, with successive eruptive facies dated to 284 ± 12 ka and 235 ± 2 ka separate the Silts and Gravel Members; K3 is also subdivided by the Grey Tuff, dated to 509 ± 9 ka, and by fluviolacustrine facies to the west (K3) and lacustrine facies to the east (K3'); K3' sediments consist of red, black, and green claystones and siltstones (Tallon, 1978), and the sedimentary and geochemical structures of the clays and silts indicate deposition in a shallow lake that alternated between freshwater and saline-alakaline (Johnson and McBrearty, 2012; McBrearty et al., 1996; Renaut et al., 1999).

The Kapthurin Formation lies unconformably above the Chemeron Formation, and is underlain by the Ndau Trachymugearite, which is dated to 1.57 Ma (Deino et al., 2002; Hill et al., 1986) using the K/Ar

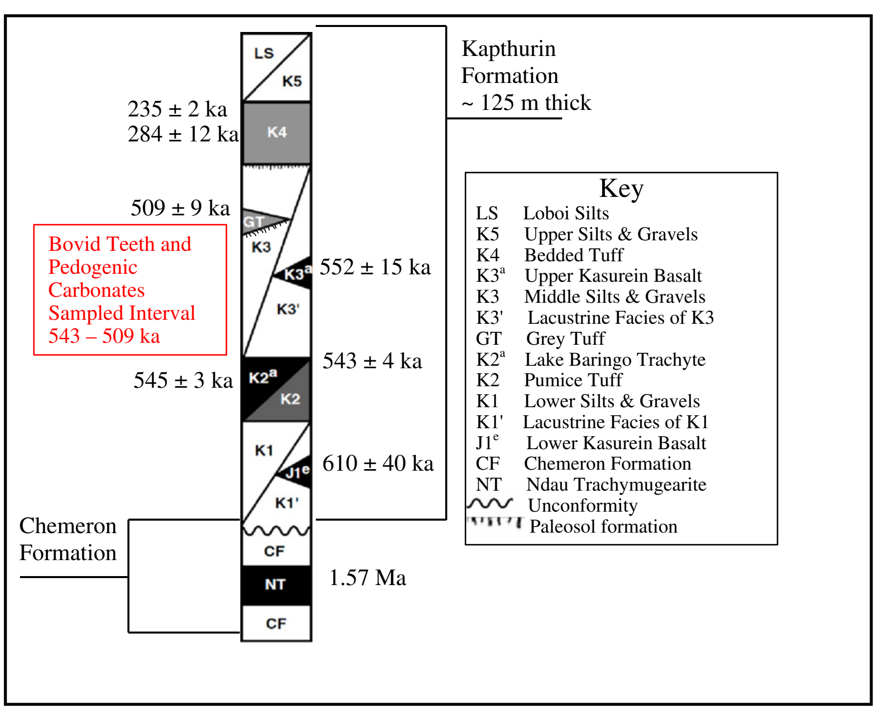

Fig. 1. Generalized stratigraphic section of the Kapthurin Formation. Section is after Deino and McBrearty (2002). All dates are derived from the $^{40}Ar/^{39}Ar$ method, except the Ndau Trachymugearite, reported by Hill et al. (1986) using the K-Ar method. Shaded areas represent volcanic layers, light areas represent fluviolacustrine sediments.