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Paleogeographic variations of pedogenic carbonate $\delta^{13}C$ values from Koobi Fora, Kenya: implications for floral compositions of Plio-Pleistocene hominin environments

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Abstract

Plio-Pleistocene East African grassland expansion and faunal macroevolution, including that of our own lineage, are attributed to global climate change. To further understand environmental factors of early hominin evolution, we reconstruct the paleogeographic distribution of vegetation (C_3-C_4 pathways) by stable carbon isotope ($\delta^{13}C$) analysis of pedogenic carbonates from the Plio-Pleistocene Koobi Fora region, northeast Lake Turkana Basin, Kenya. We analyzed 202 nodules (530 measurements) from ten paleontological/archaeological collecting areas spanning environments over a 50-km^2 area. We compared results across subregions in evolving fluviolacustrine depositional environments in the Koobi Fora Formation from 2.0–1.5 Ma, a stratigraphic interval that temporally brackets grassland ascendancy in East Africa. Significant differences in $\delta^{13}C$ values between subregions are explained by paleogeographic controls on floral composition and distribution. Our results indicate grassland expansion between 2.0 and 1.75 Ma, coincident with major shifts in basin-wide sedimentation and hydrology.

Hypotheses may be correct in linking Plio-Pleistocene hominin evolution to environmental changes from global climate; however, based on our results, we interpret complexity from proximate forces that mitigated basin evolution. An ~2.5 Ma tectonic event in southern Ethiopia and northern Kenya exerted strong effects on paleography in the Turkana Basin from 2.0–1.5 Ma, contributing to the shift from a closed, lacustrine basin to one dominated by open, fluvial conditions. We propose basin transformation decreased residence time for Omo River water and expanded subaerial floodplain landscapes, ultimately leading to reduced proportions of wooded floras and the establishment of habitats suitable for grassland communities.

Keywords: Paleogeography; Savannas; East Africa; Carbon isotopes

Introduction

Global climate is often elected as a catalyst for environmental changes acting as selective pressures on Plio-Pleistocene African hominins (Stanley, 1992; Vrba, 1995, 1999; deMenocal, 2004). Habitat theory of Vrba (1992) and variability selection hypothesis of Potts (1998) credit mammalian evolutionary pattern and process to climate change. Feibel (1999: 276) argues the need for a middle ground, tethering the ‘‘global-scale climatic phenomena’’ to ‘‘environmental change, habitat shift, and biotic evolution’’, and offers the sedimentary basin as a scale for analysis. Environments within individual basins respond to climate with different sensitivities and thresholds influenced by basin size, topography, depositional and tectonic regime, and water availability (Carroll and Bohacs, 1999; Withjack et al., 2002).

Stable carbon isotope ($\delta^{13}C$) records from pedogenic carbonates are interpreted as reflecting the spread of C_4 grasses in East Africa beginning as early as the Miocene (Cerling, 1992). From these data, environmental change and increased

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aridity associated with global climate are temporally correlated with faunal macroevolution including the branching pattern of the hominin lineage and the origins of genus *Homo* (see review in deMenocal, 2004). Unlike proxies of global climate from the marine realm, pedogenic carbonate isotopes offer direct and local environmental information from the habitats of hominins and other members of the mammalian community. Isotopic studies of pedogenic carbonates in the Turkana Basin have interpreted terrestrial East Africa as responsive to global climate over approximately the last four million years (Cerling et al., 1988; Wynn, 2004). Here we employ stable isotopic values of paleosol carbonates from hominin-bearing sediment in the Koobi Fora region of the basin to examine paleoenvironmental change. We focus on the interval 2.0–1.5 Ma, which brackets a marked shift in aridity (Wynn, 2004) and the appearance of early African *Homo erectus* in the area (Antón and Swisher, 2004; Wood and Strait, 2004). We enlarge the current database to place our isotopic measures of floral community structure into a paleogeographic framework and integrate climatic and tectonic influences on a basin-wide scale.

Study region

Geographic setting

The Turkana Basin of northern Kenya and southern Ethiopia lies within the eastern branch (or Gregory Rift) of the East African Rift System between the Kenyan and Ethiopian domes (Ebinger et al., 2000). The basin presently contains one of the largest rift lakes, Lake Turkana, with an area of 7,500 km^2 (Frostick, 1997). Today, the lake is a saline-alkaline and closed-basin lake that receives over 90% of its water from rainfall over the Ethiopian Highlands, via the Omo River (Fig. 1), with minor inputs from the Turkwell and Kerio River systems (Yuretich, 1979). The general climate within this rift bottom setting is arid to semi-arid and receives 250–500 mm of rainfall annually (Nicholson, 1996). Bushland grasslands dominate the landscape, with gallery forests clustered along perennial and ephemeral river channels (Lind and Morrison, 1974).

The Koobi Fora region, situated within the northeast Turkana Basin of Kenya (Fig. 1), is one of the richest fossil and archaeological localities in East Africa (Leakey and Leakey, 1978; Isaac and Isaac, 1997). Plio-Pleistocene sediments exposed in the region are attributed to the Koobi Fora Formation (Brown and Feibel, 1986), which preserves a record of hominin evolution and environmental change for the period ~4.0–1.0 Ma (Feibel et al., 1989, 1991; Brown and Feibel, 1991). Lake Turkana constrains the western margin of the Koobi Fora Formation, while Miocene-Pliocene volcanics to the west define the eastern border (Watkins, 1986). The formation is exposed in geographic subregions of the Koobi Fora region, including Ileret, Il Dura, Karari Ridge, and Koobi Fora Ridge (Fig. 2A), which are segregated into numbered paleontological and archaeological collecting areas (Fig. 1). The extensive geographic exposure of the Koobi Fora Formation, and its well-documented stratigraphy and geochronology, affords

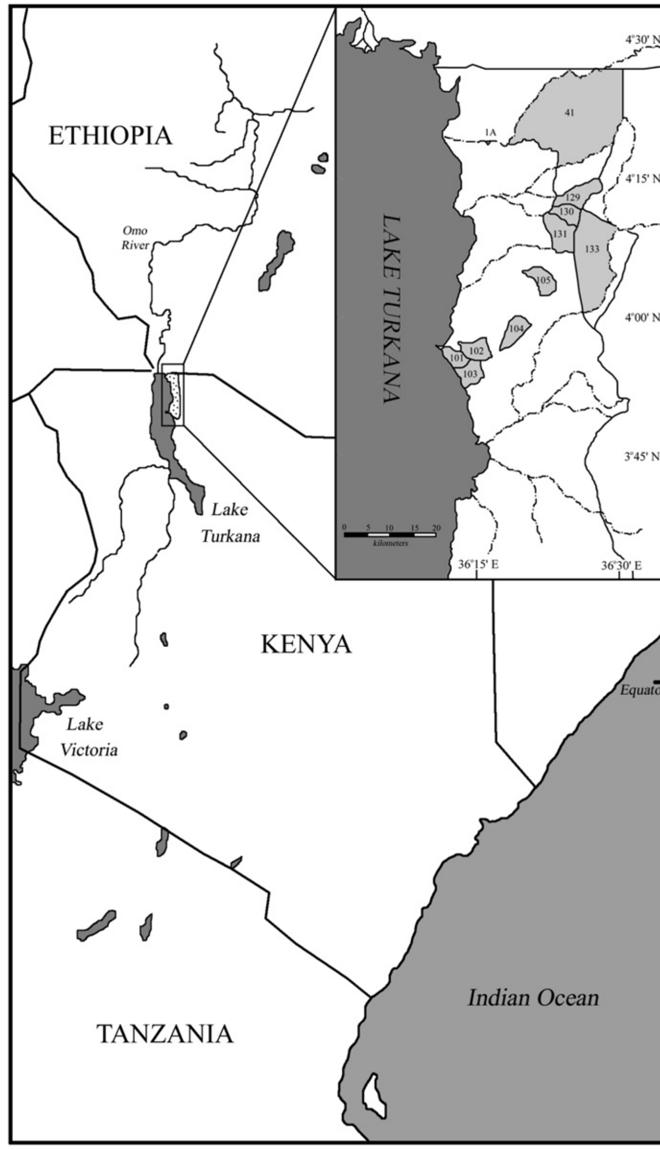

Fig. 1. Location map of Lake Turkana and the Koobi Fora Formation (stippled area). Inset map shows shaded collecting areas used in this study (after Brown and Feibel, 1991; Feibel et al., 1991; Feibel, 1999).

reconstruction of a range of habitats across paleolandscapes at discrete temporal intervals.

Stratigraphy and paleogeography

Although outcrops of the Koobi Fora Formation are discontinuous, stratigraphic control has been determined by radiometrically dated and correlated tuffs, aerially extensive bioclastic lacustrine marker beds, and an established geomagnetic polarity stratigraphy (McDougall, 1985; Brown and Feibel, 1986, 1991; Hillhouse et al., 1986; Feibel et al., 1989; McDougall et al., 1992; Brown et al., 2006; McDougall and Brown, 2006; Fig. 3). Here we focus on the upper Burgi, KBS, and lower Okote Members of the formation, approximately representing the period between 2.0 and 1.5 Ma (McDougall, 1985; Brown and Feibel, 1986, 1991: *Age of Lorenyang Tuff is approximated by sedimentation rate (scaled age).