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Plio-Pleistocene facies environments from the KBS Member, Koobi Fora Formation: implications for climate controls on the development of lake-margin hominin habitats in the northeast Turkana Basin (northwest Kenya)

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Abstract

Climate change is hypothesized as a cause of major events of Plio-Pleistocene East African hominin evolution, but the vertically discontinuous and laterally confined nature of the relevant geological records has led to difficulties with assessing probable links between the two. High-resolution sedimentary sequences from lacustrine settings can provide comprehensive data of environmental changes and detailed correlations with well-established orbital and marine records of climate. Hominin-bearing deposits from Koobi Fora Ridge localities in the northeast Turkana Basin of Kenya are an archive of Plio-Pleistocene lake-margin sedimentation though significant developmental junctures of northern African climates, East African environments, and hominin evolution. This study examines alluvial channel and floodplain, nearshore lacustrine, and offshore lacustrine facies environments for the approximately 136-m-thick KBS Member (Koobi Fora Formation) exposed at the Koobi Fora Ridge. Aspects of the facies environments record information on the changing hydrosedimentary dynamics of the lake margin and give insights into potential climatic controls. Seasonal/yearly climate changes are represented by the varve-like laminations in offshore mudstones and the slickensides, dish-shaped fractures, and other paleosol features overprinted on floodplain strata. Vertical shifts between facies environments, however, are interpreted to indicate lake-level fluctuations deriving from longer-term, dry-wet periods in monsoonal rainfall. Recurrence periods for the inferred lake-level changes range from about 10,000 to 50,000 years, and several are consistent with the average estimated timescales of orbital precession (~20,000 years) and obliquity (~40,000 years). KBS Member facies environments from the Koobi Fora Ridge document the development of lake-margin hominin habitats in the northeast Turkana Basin. Environmental changes in these habitats may be a result of monsoonal rainfall variations that derive from orbital insolation and/or glacial forcing.

Keywords: Depositional environments; Lacustrine sedimentation; Hominin evolution; East Africa

Introduction

Analyses of benthic $\delta^{18}O$ records from marine cores place the onset of Northern Hemisphere Glaciation at ~2.7 Ma (Shackleton et al., 1984; Lisiecki and Raymo, 2005). The consequences of increased climate variability and aridity across northern low-latitude Africa are evident in marine dust-flux (deMenocal et al., 1993; deMenocal, 1995) and palynological (Dupont and Leroy, 1995) sequences. These increases are roughly contemporary with significant periods of grassland ascension in East Africa, as suggested by terrestrial evidence from mammal fossil assemblages (Vrba, 1999; Bobe and Behrensmeyer, 2004; Fernández and Vrba, 2006), isotopic

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proxy records from paleosol carbonates (Cerling, 1992; Levin et al., 2004; Wynn, 2004), and pollen spectra (Bonnefille, 1995) at hominin sites. Grassland expansions are a main selective force behind open-habitat adaptations and the divergence of the human lineage from quadrupedal apes (Dart, 1925; Robinson, 1954; Jolly, 1970). Therefore, the onset and subsequent intensifications of Northern Hemisphere Glaciation are considered to be potential causes of important East African hominin events (Brain, 1981; Potts, 1998; Vrba, 1999), such as the origins of the genus *Homo* and material culture dated to 2.5–2.3 Ma (Hill et al., 1992; Kimbel et al., 1996; Semaw et al., 2003), and the evolution of African *Homo erectus* at 1.9–1.8 Ma (Wood, 1991; Antón and Swisher, 2004).

Other perspectives, however, call into question the linkage between East African Plio-Pleistocene hominin evolution and Northern Hemisphere Glaciation. For example, research on marine cores (Denison et al., 2005) and lacustrine sequences (Trauth et al., 2003; Deino et al., 2006) highlight the important influence of low-latitude insolation budgets on African climate change (Kutzbach and Street-Perrott, 1985; Rossignol-Strick, 1985; Pokras and Mix, 1987; Prell and Kutzbach, 1987; Molfino and McIntyre, 1990; Hilgen, 1991; Lourens et al., 1996; Tuenter et al., 2003; Clement et al., 2004). New data from tectonic models demonstrate the feasibility for rift valley extension and uplift to restrict zonal atmospheric movements, leading to a damping of rainfall over eastern Africa (Sepulchre et al., 2006). Additionally, Cane and Molnar (2001) suggest the temporal resolution of hominin paleoenvironmental records does not permit the reconstruction of short-term climate changes or the recognition of unambiguous spatial differences in the pattern of increasing African aridity. These authors argue that the present state of the data indicates a protracted drying period induced by a gradual force, like changes in global oceanic and atmospheric circulation deriving from a tectonic closure of seaways. These last viewpoints highlight fundamental challenges because it is difficult to debate alternate environmental hypotheses of hominin evolution when the relevant terrestrial geological sequences are of lower chronostratigraphic resolution than marine climate records (Feibel, 1997).

To overcome problems of geological resolution, East African studies are now turning attention to lacustrine sedimentary sequences from Plio-Pleistocene hominin sites (Ashley and Driese, 2002; Trauth et al., 2005; Deino et al., 2006). The lacustrine sedimentology, stratigraphy, and depositional environments of East African basins and other rift settings are excellent tools for reconstructing past lake-level oscillations and evaluating regional paleoclimatology, tectonic setting, and the history of basin infilling (Butzer et al., 1972; Owen et al., 1982; Tiercelin, 1990; Feibel et al., 1991; Olsen and Kent, 1996; Cohen et al., 1997; Scholz et al., 1998; Keighley et al., 2003; Ilgar and Nemec, 2005; Gasse, 2006). Lacustrine deposits are ideal for obtaining detailed geological records because they typically have fast rates of sedimentation and may be punctuated with few depositional hiatuses (e.g., Sadler, 1981). Lacustrine environments also have a high potential to record "Milankovitch" climate changes caused by orbital cycles that operate at timescales on the order of 10^4 to 10^5 years (de Boer and Smith, 1994). There is great possibility for reconstructing East African climate and assessing links with hominin evolution through an understanding of lacustrine depositional systems.

Our study concerns the lake-margin sedimentary record for the hominin-bearing KBS Member (~1.9–1.6 Ma) of the Koobi Fora Formation, and examines Koobi Fora Ridge localities in the northeast portion of the Turkana Basin (Figs. 1 and 2). For these localities, studies by Bowen (1974), Feibel (1983, 1988), and Tindall (1986) document sedimentary facies successions that archive information on lake-level oscillations. These authors note that many of the facies changes are predictably sequential, which may suggest a cyclic influence on deposition like Milankovitch climate forcing. However, apart from the exploratory discussions of Brown (1995), there has been little detailed work on the deposits to understand connections between the paleoenvironmental changes and probable climatic controls. The KBS Member is also noteworthy because it brackets the period 1.8–1.7 Ma, which is thought to be an interval of heightened aridity and grassland expansion in East Africa, possibly due to global climate change (e.g., Cerling, 1992; Bonnefille, 1995; deMenocal, 1995; Bobe and Behrensmeyer, 2004; Fernández and Vrba, 2006). It also preserves some of the earliest fossils of African *Homo erectus* (Leakey and Leakey, 1978; Feibel et al., 1989; Wood, 1991; Antón and Swisher, 2004).

The main objectives of this paper are twofold: examine the facies and depositional environments for the KBS Member at the Koobi Fora Ridge, and assess the probable controls on the formation of the lake-margin strata. The goal of this study is to establish a basic paleoclimate framework from sedimentology and stratigraphy to be refined by ongoing research. Our subdivisions of the KBS Member sediments into discrete facies environments and chronostratigraphic units, which reflect distinctive phases of lake-level and climate conditions, provide detailed information on the origin and evolution of lake-margin hominin habitats of Koobi Fora.

Methods and geological setting

A lake formed in the Turkana Basin at ≥2.0 Ma and was largely infilled by ~1.5 Ma (Brown and Feibel, 1991). Its origination, subsequent phases, and timing are well studied from the KBS Member deposits of the Koobi Fora Formation at Koobi Fora Ridge localities in the northeast Turkana Basin (Bowen, 1974; Feibel, 1983, 1988; Brown and Feibel, 1986, 1991; Tindall, 1986; Brown et al., 2006; McDougall and Brown, 2006; Figs. 1 and 2). We use the stratigraphic patterns of facies in the KBS Member at the Koobi Fora Ridge to infer successive, short-term hydrological and sedimentary changes for a marginal area of the lake. Sedimentary facies analysis is the fundamental approach used to resolve the depositional setting and paleogeography of the Koobi Fora Formation (e.g., Bowen, 1974; Feibel, 1983, 1988; Brown and Feibel, 1986, 1991; Tindall, 1986). Our classification and interpretative schemes are based on these prior studies, and incorporate