



East African mid-Holocene wet–dry transition recorded in palaeo-shorelines of Lake Turkana, northern Kenya Rift

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ABSTRACT

The 'wet' early to mid-Holocene of tropical Africa, with its enhanced monsoon, ended with an abrupt shift toward drier conditions and was ultimately replaced by a drier climate that has persisted until the present day. The forcing mechanisms, the timing, and the spatial extent of this major climatic transition are not well understood and remain the subject of ongoing research. We have used a detailed palaeo-shoreline record from Lake Turkana (Kenya) to decipher and characterise this marked climatic transition in East Africa. We present a high-precision survey of well-preserved palaeo-shorelines, new radiocarbon ages from shoreline deposits, and oxygen-isotope measurements on freshwater mollusk shells to elucidate the Holocene moisture history from former lake water-levels in this climatically sensitive region. In combination with previously published data our study shows that during the early Holocene the water-level in Lake Turkana was high and the lake overflowed temporarily into the White Nile drainage system. During the mid-Holocene ($\sim 5270 \pm 300$ cal. yr BP), however, the lake water-level fell by ~ 50 m, coeval with major episodes of aridity on the African continent. A comparison between palaeo-hydrological and archaeological data from the Turkana Basin suggests that the mid-Holocene climatic transition was associated with fundamental changes in prehistoric cultures, highlighting the significance of natural climate variability and associated periods of protracted drought as major environmental stress factors affecting human occupation in the East African Rift System.

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1. Introduction

Deciphering the long-term climate history and accurately identifying the mechanisms underlying variations in hydrologic budgets is an important task in light of ongoing global change, water stress, and the associated environmental and socioeconomic impacts in the African tropics (Boko et al., 2007). In this context climatic variability, climatic extremes, and the transitions between episodes with different environmental conditions, have become the focus of numerous investigations in tropical Africa (e.g., Shanahan et al., 2009; Tierney et al., 2008).

A period of particular interest in the climatic history of Africa is the African Humid Period or AHP (cf. deMenocal et al., 2000; Ritchie et al., 1985). The AHP occurred approximately between $\sim 12,000$ and ~ 5000 calendar years before present (cal. yr BP) and resulted in a northward expansion of vegetation zones (e.g., Hoelzmann et al., 1998). Extensive parts of tropical Africa subsequently experienced pronounced and rapid hydrologic changes associated with the termination of the AHP during the mid-Holocene, about 5000 years ago (e.g., deMenocal et al., 2000). This transition toward drier conditions

fundamentally impacted ecosystems across northern Africa, prompting a return to arid and semiarid vegetation in the Sahara and the Sahel regions (Jolly et al., 1998). These environmental changes are also believed to have led to important demographic shifts (Brooks, 2006; Kuper and Kröpelin, 2006).

The origin of, and underlying mechanistic principles for, the AHP termination are not yet fully understood and remain the subject of ongoing investigations. This episode, which may have lasted a few centuries, is considered to have been too rapid to be solely driven by a linear response to gradual insolation changes (e.g., Claussen et al., 1999; Cole et al., 2009; deMenocal et al., 2000). On the other hand, the existence of an abrupt and spatially synchronous AHP termination has recently been called into question (e.g., Chase et al., 2010; Kröpelin et al., 2008; Marshall et al., 2011).

Here, we present a detailed study of multiple abandoned Holocene shorelines from the Lake Turkana basin in the northern Kenya Rift of the East African Rift System (EARS, Fig. 1). These palaeo-shorelines provide a record of the East African moisture history that helps in unravelling the characteristics and environmental impacts of the AHP termination in a region that is located in the immediate vicinity of the equator. Preliminary studies of these palaeo-shorelines provided an unprecedented insight into the environmental history of the Holocene (e.g., Butzer et al., 1972; Owen et al., 1982). However, the

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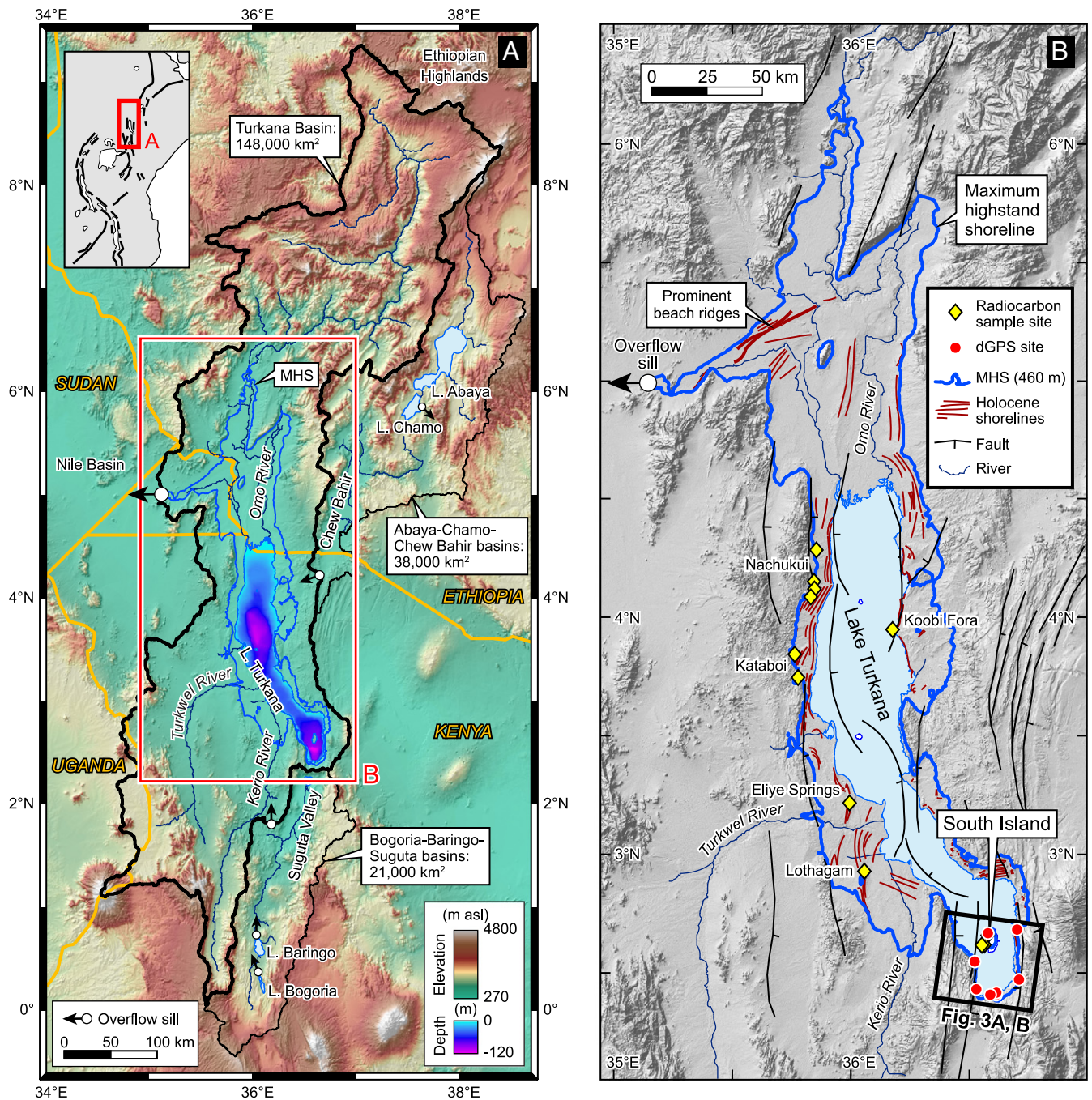


Fig. 1. (A) Map of the Turkana Basin and adjacent basins (SRTM topography). Also shown are rivers (thin blue lines), catchment boundaries (thick and thin black lines), the maximum extent of Lake Turkana during the Holocene (MHS, thick blue line) approximated using a present-day surface elevation of 460 m, and the various overflow sills in the area (arrows linked to white circles). The overflows were active during the early to mid-Holocene when the Turkana Basin received inflow from the Bogoria, Baringo, and Suguta basins to the south and the Abaya, Chamo, and Chew Bahir basins to the east; at that time Lake Turkana overflowed into the Nile Basin. Bathymetric map of Lake Turkana (below 360 m) from Johnson et al. (1987). Inset is a structural map of the EARS. (B) Location map for the radiocarbon sample sites and dGPS survey sites. Also shown are the Holocene shorelines, the approximate position of the maximum highstand shoreline, and the main recent (late Quaternary) faults; all were mapped using field observations, SPOT satellite imagery, and SRTM data, together with previously published data (e.g., Baker et al., 1972; Dunkelman et al., 1989; Johnson et al., 1987; Morley et al., 1992).

exact nature and timing of some inferred environmental changes derived from lake water-level fluctuations were subsequently found to be equivocal and/or irreproducible (cf. Barton and Torgersen, 1988; Cerling, 1986; Halfman et al., 1992; Ricketts and Johnson, 1996). In our study we have focused primarily on the largely unexplored southernmost margin of the Turkana Basin (Fig. 1B), where steep slopes have helped preserve a unique staircase morphology of palaeo-shorelines, between 0 and 80 m above the present-day lake water-level. In order to reconstruct lake water-level fluctuations in the Turkana

Basin and use them as indicators of past variations in the moisture regime, we mapped shoreline elevations with a high-precision differential global positioning system (dGPS) and measured oxygen-isotope ratios of *in situ* fossil mollusk shells collected from shoreline deposits. By combining 21 new ^{14}C ages obtained from these shells with other published ages we have constrained the timing of past lake water-level changes and provided insights into the environmental history of Lake Turkana, particularly during the mid-Holocene. We also used the abundantly available archaeological data from the Turkana

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