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# Paleohydrology of Lake Turkana and its influence on the Nile River system

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ABSTRACT

The detailed paleohydrological record of Lake Turkana, the largest lake in the eastern branch of the East African Rift, is necessary for determining the connectivity between adjacent watersheds in tropical Africa. The migration of both the Intertropical Convergence Zone (ITCZ) and the Congo Air Boundary (CAB) constrains rainfall amount and duration for most of East Africa. Lake Turkana, in northern Kenya, is the world's largest desert lake and experiences two ITCZ-associated rainy seasons annually, with cumulative rainfall of ~200 mm/yr. Evidence from new continuous, high-fidelity sediment core records and high-resolution CHIRP seismic reflection data suggests that Lake Turkana received enough rainfall during the African Humid Period (AHP) to fill the lake to its sill (100 m above current lake level) and spilled over into the White Nile River system. An atmospheric configuration with an eastward-shifted CAB over the Turkana region and the northern Kenya Rift is invoked as an additional source of rainfall for the catchment. This configuration began abruptly at ~11 ka and lasted until ~5 ka when Lake Turkana became a closed basin and was cut off from the White Nile. Prior to the AHP, Lake Turkana experienced at least two desiccation events following the Last Glacial Maximum at 18.5 and 17 ka when the lake was at least 100 m lower than modern, as evidenced by basin-wide, high amplitude reflections and $^{14}C$-dated shallow water facies in sediment cores. Lake level fluctuations generally follow trends in mean solar insolation, however the onset of lake level extremes are much more abrupt than rates of insolation change. Lake Turkana's location in relation to atmospheric convergence and dynamic rainfall patterns makes its susceptible to extreme climate change over relatively short timescales.



## 1. Introduction

Solar insolation change and the Intertropical Convergence Zone (ITCZ) migration are commonly invoked as causes for changes in amount and geographical distribution of rainfall in tropical climate on orbital timescales (Trauth et al., 2001). More abrupt climate shifts may be associated with sea surface temperature (SST) variability and vegetation feedbacks (deMenocal et al., 2000; Camberlin et al., 2001; Castañeda et al., 2009; Tierney and Russell, 2009, 2011a,b, 2013; Verschuren et al., 2009). These different influences are more or less important depending on the geography and the latitudinal position of a study area (Fig. 1). This study presents multiproxy paleoclimate data from Lake Turkana, the world's largest desert lake and an area that until now contributed only limited information from continuous offshore records on the late Quaternary climate history of tropical Africa. Data presented here constrain high and low lake level extremes associated with changes in the ITCZ and SSTs through time in the Turkana region, and provide insight into African paleoclimate patterns and atmospheric circulation since the Last Glacial Maximum (LGM).

This study extends and refines the record of climate variability and lake level change in the Turkana catchment of tropical East Africa to at least 20 ka. Lake Turkana's extreme desert environment, limited outcrops, and rapid sedimentation rates limited the length and fidelity of late Quaternary paleolimnologic records in past studies (e.g. Butzer et al., 1972; Owen et al., 1982; Halfman and Johnson, 1988; Halfman et al., 1992, 1994; Ricketts and Johnson, 1996; Garcin et al., 2012). The continuous deepwater sediment core and high-resolution seismic records presented here provide a more detailed paleohydrologic record of the Turkana basin that extends further back in time than previous studies (Fig. 2).

The aridity established in parts of East Africa during peak glaciation (Gasse, 2000) continued intermittently through the latest Pleistocene until it slowly gave way to a wetter environment beginning ~12 ka BP. More favorable conditions lasted until the mid-Holocene. This interval when moist conditions prevailed in much of northern hemisphere tropical Africa is commonly referred to as the African Humid Period (AHP) (e.g. Ritchie et al., 1985; deMenocal et al., 2000; Castañeda et al., 2009). This study demonstrates that Lake Turkana experienced more humid conditions and a higher lake level for several thousand

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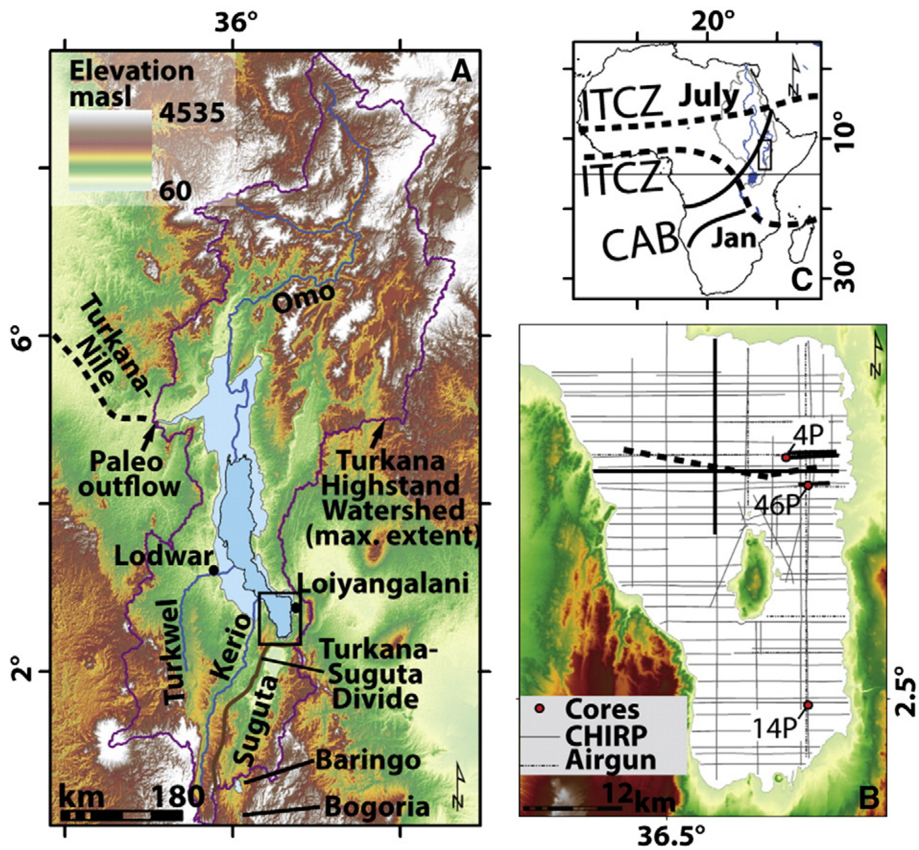


**Fig. 1.** (A) Topography of Lake Turkana and its watershed with black box indicating study area. Lake Turkana Highstand Watershed delineated (fuchsia). Blue polygon with black outline defines current Lake Turkana shoreline. Palest blue polygon indicates highstand shoreline of Lake Turkana. Brown line indicates current drainage divide between Suguta Valley and Lake Turkana. Black dashed line delineates paleo-river connecting Lake Turkana to the White Nile. Black arrow indicates location of outflow location of Lake Turkana during highstand. Other geographic locations added for reference. (B) Data map of South Basin of Lake Turkana. Gray solid lines are CHIRP seismic tracklines, featured profiles traced in black. Thin, dot-dashed black lines indicate Airgun seismic tracklines. Bold dashed line is MCS trackline. Red dots are piston core locations. (C) Black box outlines location of Lake Turkana on the African continent and bold dashed lines denote northern- and southernmost extent of the annual migration of the ITCZ and thin, solid lines denote the location of the CAB at its extremes. Nile River watershed is (including highstand Lake Turkana) in gray, and blue lines are major rivers.

years during the AHP, and it provides new constraints on the timing and rates of onset and demise of this climatic optimum.

The watersheds of large lakes commonly span several degrees of latitude, and accordingly, long-term lake level records integrate climate processes across space. Thus, the impact of hydrological connectivity of climate-sensitive lake basins between adjacent watersheds through time is not always taken into consideration in paleoclimate reconstructions. Rainfall throughout East Africa is associated with the migration of enhanced equatorial convection (the ITCZ) that moves several degrees of latitude both north and south of the equator on both seasonal (Fig. 1) and longer timescales. Changes in evaporation associated with vegetation cover and catchment size can exacerbate or inhibit lake level changes during periods of aridity and high humidity (Castañeda et al., 2009; Lyons et al., 2011). Reconstructed water level records from lakes across the region display consequential, sometimes drastic, lake level fluctuations over just a few centuries (Lamb et al., 2007; Garcin et al., 2009; Verschuren et al., 2009; Lyons et al., 2011), leading to opening and closing of adjacent lake systems.

The amount and distribution of water across the African continent controls the dispersal of human populations (Gasse, 2000). Overflow conditions for Lake Turkana provide an additional input into the Nile system (Hopson, 1982; Johnson et al., 1987), which affected the annual flow dynamics of the Nile and likely impacted nascent communities living near the river in the mid- to late-Holocene. The hydrologic closure of Lake Turkana into the Nile River in the mid Holocene reduced Nile flow and likely had negative societal ramifications for groups of people living near the Nile River in Predynastic Egypt (Stanley et al., 2003; Williams et al., 2006; Williams, 2009). The Nile River played a critical role in sustaining human communities of northeast Africa for thousands of years and continues to do so today (Butzer, 1976; Nicoll, 2001; Stanley et al., 2003; Williams, 2009). The loss of Lake Turkana outflow and associated aridification of the Nile region likely promoted the consolidation of groups along the Nile River, which led to land cultivation and planned irrigation.

Here we focus on the paleoclimatological factors that impact lake level change in Lake Turkana by analyzing changes in lithology in sediment cores along with correlative high-resolution seismic sequences that provide a detailed record of deepwater lake deposits that have accumulated since the LGM. The objective of this paper is to present a global climate context for a 20 ka paleoclimate record from Lake Turkana in northern Kenya and describe its role in East African hydrology. This continuous record provides a new perspective on Turkana paleoclimate since the LGM that has not yet been discussed in a context of paleohydrological connectivity and associated changes over time.

## 2. Study area

Lake Turkana is the largest lake in the Eastern Branch of the East African Rift System at 250 km long, ~30 km wide, and with a maximum depth of ~120 m (Fig. 1). It is situated between 2.3° and 4.6° N latitude in the northern Kenya Rift within a depression between the Kenyan and Ethiopian Highlands. The entire water column is well mixed because the mean lake depth is only ~30 m and the area experiences pervasive unidirectional winds from the north with an average