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Tropical East African climate change and its relation to global climate: A record from Lake Tanganyika, Tropical East Africa, over the past 90+ kyr

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ABSTRACT

Forcing mechanisms of tropical climate in continental areas remain poorly understood, due in large part to a lack of continuous, long-term, high-fidelity records. Sediment core T97-52V from Lake Tanganyika provides new insight into the timing and mechanisms behind East African climate change over the past 90+ kyr. This record is particularly important, because, other than a recently recovered scientific drill core from Lake Malawi, there are no other continuous, well-dated records from East Africa prior to 60 ka. The high resolution age model presented here provides a large degree of age certainty for the past 45+ kyr, and our suite of proxies allows a thorough examination of Lake Tanganyika's dynamics. From core stratigraphy and chemical analyses, we present evidence of a lake level drop greater than 400 m sometime prior to ~90 ka, much greater than that inferred for the LGM, suggesting a period of intense aridity sometime around 100 ka. Additionally, core T97-52 V preserves evidence of worm burrows detected by X-radiographic imagery as indicated by burrow-shaped deposits of iron oxide, indicating a shallow lake at the time of deposition of that material. Intermittently high lake levels between ~78 ka and ~72 ka developed at the same time as a weakened Asian monsoon and a pluvial phase in Northeast Brazil, suggesting a global reorganization of climate, possibly forced by a reduction in orbital eccentricity. Over the past 60 ka this core preserves the same events recorded in a core collected ~100 km away in the southern basin of Lake Tanganyika, including an unexplained increase in biogenic silica at ~37 ka, suggesting that this vast lake is responding coherently across both major bathymetric basins to regional and global climate forcing.

1. Introduction and background

Records from the tropics are underrepresented in studies of paleoclimate, in particular records from continental Africa, the largest tropical land mass. Yet understanding how East Africa responds to external climate forcing, as well as how it behaves distinctly, is imperative to development of accurate models of global climate. Here we present a record from a sediment core from Lake Tanganyika that spans the last 90+ kyr. An extensive suite of proxies allows an expansive study of climate change recorded in Lake Tanganyika over the past 90+ ka, and a detailed age model allows us to correlate our record to other global records. In addition, this core covers a longer span of time than any other core taken from Lake Tanganyika to date, allowing insight into a period in East Africa that is currently poorly understood.

Previous studies suggest that changes in insolation and shifts in the mean annual position of the Intertropical Convergence Zone (ITCZ) do not fully explain observed variability in East African precipitation over the past 60 kyr (e.g. Castañeda et al., 2007; Tierney et al., 2007; Tierney et al., 2008). Other factors, such as the effect of western Indian Ocean sea surface temperatures on the summer and winter monsoons, modify the amount of precipitation delivered to this region. Understanding the roles that the ITCZ and other more regional phenomena play in the delivery of precipitation to East Africa is vital to understanding the long-term climatic history of this region.

1.1. Lake setting

With an estimated age of 9–12 Myr, Lake Tanganyika is the largest and likely the oldest of the East African Rift Lakes (Cohen et al., 1997). Lake Tanganyika occupies a series of structural half-graben basins that extend from 3° to 9° S and 29° to 31° E in the Western Branch of Africa's Great Rift Valley (Fig. 1) and is underlain by 5–6 km of syn-rift sediments (Burgess, 1985). It is the second deepest lake in the world and the second largest by volume, with a maximum depth of 1470 m (Capart, 1949; Rosendahl et al., 1988; Tiercelin et al., 1992).

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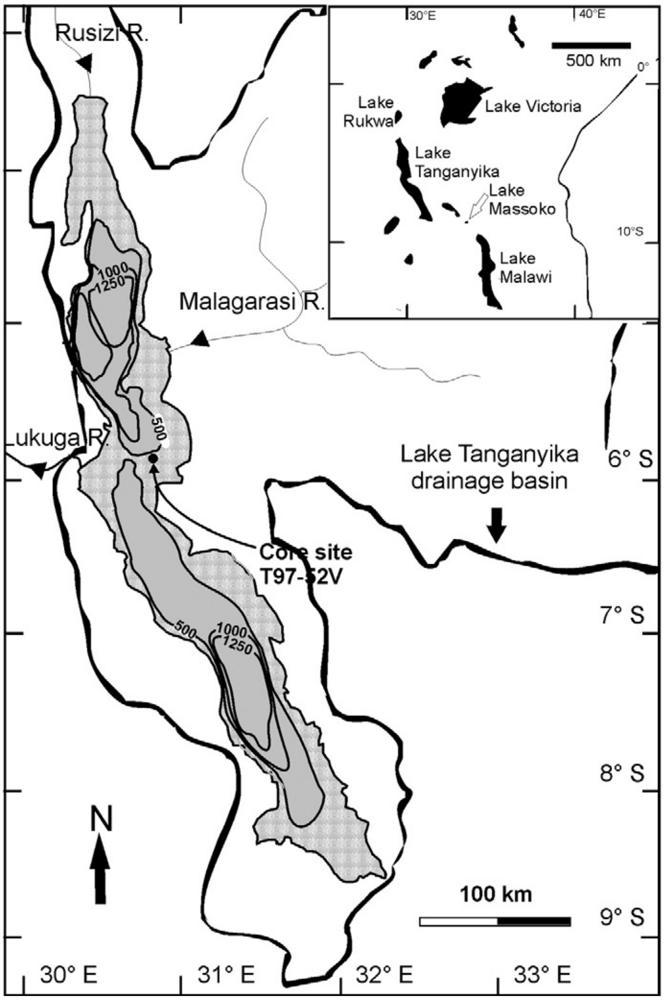

Fig. 1. Location. Upper right: location of Lake Tanganyika in relation to other locations cited in the text, including Lake Victoria, Lake Malawi and Lake Massoko. Lower left: Bathymetric map of Lake Tanganyika with depth below modern lake surface given in meters (modified from Scholz et al., 2007). The location where core T97-52 V, the basis of this study, was taken from Kavala Island Ridge in 1997 is indicated by an arrow. The heavy black line indicates the boundaries of Lake Tanganyika's drainage basin (modified from Bergonzini et al., 1997). The Rusizi and Malagarasi Rivers are the two main inflows and the Lukuga River is the only outflow.

The two largest inflows to the lake are the Rusizi River and the Malagarasi River. The Rusizi River drains Lake Kivu from the north; the flow is currently controlled by a dam and the modern effluent is ~3.2 km^3 per year (Degens et al., 1973). Lake Kivu previously drained to the north, away from Lake Tanganyika, but after ~10.6 ka Lake Kivu overflowed into the Rusizi River and began to drain into Lake Tanganyika (Haberyan and Hecky, 1987; Felton et al., 2007). It is unclear if overflow events occurred prior to this. The Malagarasi River drains an area that comprises about 60% of the lake's total catchment area, but the river contributes only ~16% of the total surface inflow (Gillman, 1933; Bergonzini et al., 1997) due to the high evapotranspiration rates in the extensive swamps covering much of the Malagarasi's lower catchment area (Gillman, 1933). In addition, ephemeral stream input comprises ~18% of surface inflow (Gillman, 1933), and the precipitation flux is estimated at ~66% of surface inflow (Edmond et al., 1993).

The only outflow from Lake Tanganyika is the Lukuga River to the west, with an outflow equivalent to ~9% of the total inflow; the rest is lost to evaporation (Edmond et al., 1993). The modern lake is meromictic, with permanently anoxic waters below ~240 m (Coulter and Spiegel, 1991).

Because of Lake Tanganyika's proximity to the equator, the seasonal differences in Lake Tanganyika's climate are characterized by changes in precipitation and wind regimes. Local precipitation is controlled by the migration of the ITCZ (Ogallo, 1989; Anyah and Semazzi, 2007), topography, and the state of the nearby Indian Ocean (Bergonzini et al., 2004; Marchant et al., 2007). The ITCZ migration causes two distinct rainy seasons north of Kigoma (~5° S): the long rains from March to May, and the short rains from October to December, which are more variable and probably responsible for the majority of modern lake level change (Nicholson, 2000; Bergonzini et al., 2004). South of 5° S the highest rainfall occurs from December to February (Tierney et al., 2008). The average annual rainfall for the Lake Tanganyika drainage basin is ~1000 mm/yr (Balek, 1977; Bergonzini et al., 1997). During Lake Tanganyika's dry season, when the ITCZ is north of the lake, strong southerly winds blow up the axis of the lake causing evaporative heat loss and upwelling of cooler waters in the southern basin (Coulter and Spiegel, 1991). During these southerly wind events, nutrient rich bottom water upwells and boosts diatom productivity (Hecky and Kling, 1981), which is ultimately preserved in the sediment as biogenic silica.

Higher regional precipitation also occurs during a positive Indian Ocean Dipole Mode (IOD), when warm water pools in the western Indian Ocean and the westerlies over the Indian Ocean are weak or reversed (Bergonzini et al., 2004; Marchant et al., 2007), a phenomenon that often occurs in conjunction with “El Nino” phases of the Pacific Southern Oscillation. Indeed, previous work documented a correlation between East African precipitation anomalies and the Southern Oscillation Index (SOI), with higher precipitation during an El Nino Southern Oscillation (ENSO) event when the SOI is low (Ogallo, 1989; Nicholson, 1996). However, more recent studies indicate a stronger link between African rainfall and the IOD (Saji and Yamagata, 2003; Bergonzini et al., 2004).

1.2. Previous records

There are very few high resolution records from this region prior to ~30 ka, particularly from Lake Tanganyika. Felton et al. (2007) and Tierney et al. (2008) published analyses on a 60,000 year core from the southern basin of Lake Tanganyika. Tierney et al. (2008) suggest a link between warm and wet conditions recorded in Lake Tanganyika and high Northern Hemisphere summer insolation. They conclude that, unlike South America, ITCZ migration is not the main climatic driver in East Africa; instead, precipitation and temperature are controlled by Indian Ocean sea surface temperatures (SSTs) and the winter Indian monsoon, which models suggest are linked to Northern Hemisphere insolation. Conversely, cold, dry millennial events in Lake Tanganyika are linked to cold Indian Ocean SSTs.

Over longer time periods, seismic reflection studies from Lake Tanganyika suggest lake level drops of as much as 600 m in the Pleistocene (Scholz and Rosendahl, 1988). Regional evidence from Lake Malawi, and also distant Lake Bosumtwi, suggests periodic severe regional “megadroughts” from at least 135 ka to 75 ka (Scholz et al., 2007). The authors propose that the transition to more stable modern climate conditions corresponds to reduced orbital eccentricity and a reduction in precession-dominated climatic extremes.

Felton et al. (2007) suggest that glacial aridity began abruptly at 32 ka. During the last glacial maximum (LGM), lake levels throughout the East African tropics were significantly lower (Gasse, 2000), woodland cover was sparse and savanna vegetation dominated the basin (Vincens, 1991; Vincens et al., 1993; Jolly et al., 1997). Evidence suggests a lake level drop of 250–350 m during the LGM (Haberyan and Hecky, 1987; Tiercelin et al., 1989; Vincens et al., 1993; Gasse, 2000; McGlue et al., 2008). A drop of 350 m corresponds to a lake volume decrease of 40–60% (Gasse et al., 1989), a surface area decrease of 42% and a modeled precipitation flux 40% lower than modern (Bergonzini et al., 1997).