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Characterization of the last deglacial transition in tropical East Africa: Insights from Lake Albert

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ABSTRACT

New biomarker analyses from Lake Albert, East Africa spanning ~15–9 ka show the most extreme, abrupt, multi-stage climate and environmental shifts during the last deglacial transition of anywhere in Africa. Records of hydroclimate expressed in compound specific δD values from terrestrial leaf waxes and a TEX_{86} paleotemperature record support multiple stages of pronounced drying and cooling from 13.8 to 11.5 ka and demonstrate the dynamic behavior of the low latitude tropics during the deglaciation. The vegetation response, illustrated by compound specific $\delta^{13}C$ values and fossil pollen records, was an expansion of C_4 grassland when the region was cool and arid. These results advance our understanding of a spatially and temporally complex regional response to global climate forcing, suggesting weakening of the Indian Ocean monsoon at the end of the Pleistocene that coincides with a minor decrease in the rate of the Atlantic Meridional Overturning Circulation (AMOC) and during a time of stepwise cooling in the northern high latitudes.

1. Introduction

Debate regarding the history of millennial scale climate variability in the African tropics includes the geographic extent, synchroneity of onset and termination, and potential forcing mechanisms associated with the global deglaciation. Difficulty in constraining the response and causal mechanisms during these intervals is associated with the seemingly abrupt, short-lived nature of events that involve nonlinear and complex feedbacks. Commonly defined from the Greenland ice cores, the 'deglacial transition' contains the Bølling/Allerød (BA), a warm, wet interstadial period, beginning ~14.7 ka and ending with the start of the Younger Dryas (YD) at ~12.7 ka (Alley and Clark, 1999), marked by pronounced cooling. The BA is punctuated by three abrupt, century-scale cold events: the intra-Bølling, the Older Dryas (OD), and the intra-Allerød (Alley and Clark, 1999). Near this time, the Southern Hemisphere also underwent a cold interval called the Antarctic Climate Reversal (ACR), ~14.8–12 ka (Jouzel et al., 1995). Records from the Northern and Southern hemispheres, specifically the high latitude polar regions, suggest an anti-phased climate response during the deglacial that has been termed the 'bipolar seesaw'(Broecker, 1998; Alley and Clark, 1999). These intervals are commonly attributed to a variety of mechanisms that include changes to oceanic circulation, atmospheric greenhouse gases, ice sheet extent, and orbital insolation (Alley and Clark, 1999). A statistical synthesis of global records that span the deglaciation characterized a first mode of variability related to rising CO_2, and a second mode that reflects the bipolar seesaw effects of the Atlantic Meridional Overturning Circulation (AMOC) (Shakun and Carlson, 2010).

The East African expression of these millennial-scale perturbations in climate during the shift from a relatively arid Last Glacial Maximum (LGM) to a wetter early Holocene (Gasse, 2000) is complex and is an ongoing area of research. This is in part due to the orographic complexity of East Africa, to shifting boundaries between major air masses, and to changing patterns of sea surface temperature in the Indian and Atlantic Oceans that can affect the timing and response to global and regional triggers. Paleorecords suggest both spatially uniform and variable African climate responses to perturbations during the last deglaciation. For instance, there is evidence of extensive aridity

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in tropical Africa contemporaneous with the YD, including decreased lake levels and river discharge and changes in wind regime (Talbot et al., 2007 and references therein). However, the interval immediately preceding the YD, a time when the Greenland ice core $\delta^{18}O$ records demonstrate a pronounced, step-wise cooling in the Northern high latitudes, shows a more spatially and temporally heterogeneous pattern of African climate response. Our understanding of this time period in Africa is far from complete.

In this study, we focus on the climate dynamics of the equatorial tropics around Lake Albert, specifically addressing the question of whether this region responded in a congruent way with other African records. We present new biomarker records from Lake Albert comparing TEX_{86} paleotemperatures and compound specific $\delta^{13}C$ and δD values of leaf waxes to provide records of temperature, vegetation change, and hydroclimate, respectively. These records indicate that the region surrounding Lake Albert underwent a multi-stage climatic and environmental shift after the LGM not seen everywhere across Africa.

2. Methods & background

Lake Albert lies at 2° N in the Rift Valley between Uganda and the Democratic Republic of the Congo at an altitude of 620 m (Fig. 1). The region today receives rain in two seasons: August–November and March–May (Nicholson, 1996), linked to the position and intensity of the Intertropical Convergence Zone (ITCZ). The Congo Air Boundary (CAB) is also nearby, marking the convergence of moisture derived from the Atlantic and Indian Oceans.

We analyzed sediment from Core F, collected in Lake Albert in 1971 (1°50.1′N, 31°10.2′E, 46 m water depth) by Prof. Dan Livingstone and his student, Thomas Harvey, of Duke University (Harvey, 1976). The upper 6.6 m of core consisted of dark gray–black diatomaceous mud overlying a thin sand layer. Between 6.6 and 8.4 m, the lithology changes dramatically into partially lithified sediments indicating frequent desiccation with few to no diatoms and ostracods but abundant root traces. The basal 80 cm of the core (8.4–9.2 m burial depth) consists of laminated black muds with visible diatoms and sponge spicules, interpreted to signify a shallow, well-mixed lake (Beuning et al., 1997). The top 1 m of core originally contained finely laminated muds, but these had been heavily sampled prior to this study.

We use a previously established age model based on 11 radiocarbon dates, 7 from Core F and 4 from core G (another core taken at the same site), correlated lithologically with Core F (Fig. 1, Table 1) (Beuning et al., 1997; Williams et al., 2006). Six of the eleven dates define a nearly constant sedimentation rate of about 1.0 m/ky that spans the interval in this paper, from 12,500 ± 190 ^{14}C ybp (14.76 ± 0.44 ka) at 640–665 cm depth in core (which lies just above a paleosol representing the Late Pleistocene desiccation of Lake Albert as described above (Beuning et al., 1997) to 8230 ± 60 ^{14}C ybp (9.21 ± 0.10 ka) at 84 cm depth in core. The core was sampled where intact, from 71 to 606 cm, corresponding to ~7.1–14.3 ka, with an average sampling interval of 15 cm, corresponding to ~150 years. Absolute age uncertainty within this sampled interval is about 200 years.

2.1. Sedimentary biomarker extraction and purification

Freeze-dried, homogenized sediments (typically 1–3 g dry weight) were extracted using soxhlet extraction with 2:1 DCM:MeOH for 24 h to produce a total lipid extract (TLE). The TLE was isolated into neutral, free fatty acid, and phospholipid fatty acid fractions using an aminopropylsilyl bond elute column, cleaned prior to use. Short column chromatography with activated alumina as the stationary

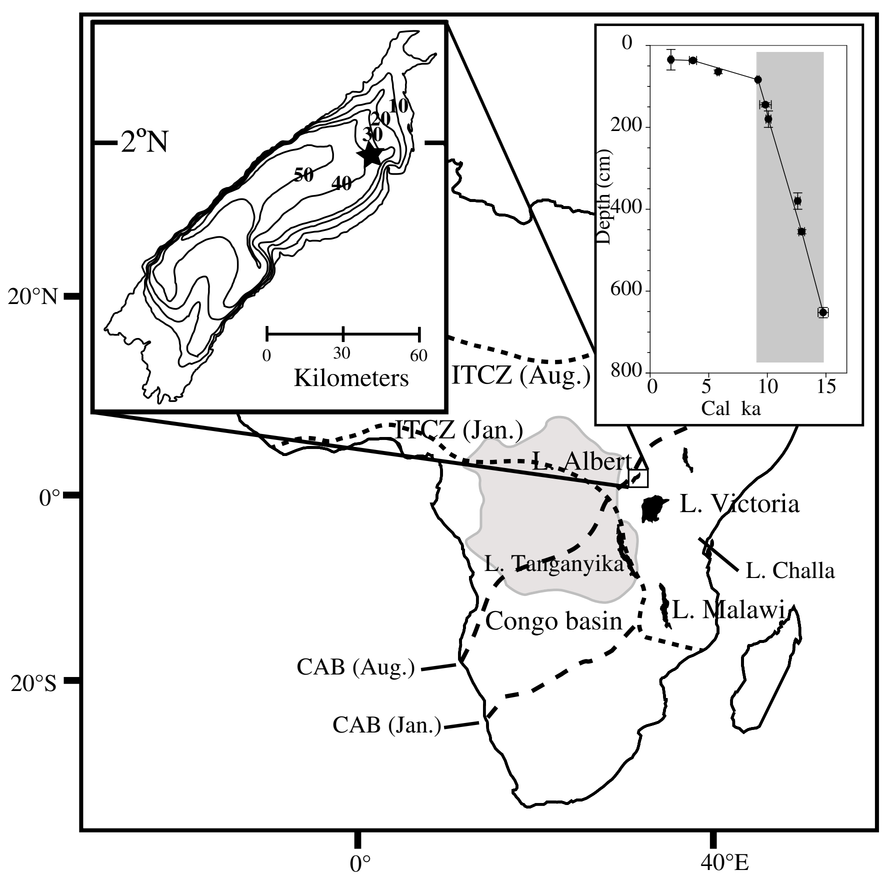

Fig. 1. Map of Lake Albert (star) and Lakes Malawi, Tanganyika, Victoria, Challa, and the Congo Basin. Inset: Chronology of Lake Albert Core F. The shaded section indicates the interval sampled for this study.