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The sedimentary response to a rapid change in lake level in Lake Tanganyika

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ABSTRACT

We present records of sedimentary organic carbon, nitrogen, and carbonate, and stable isotope records of organic material and carbonate from a series of sediment cores that straddle the permanent chemocline in Lake Tanganyika. Sedimentation rates for these cores are consistent among the sites (~0.05–0.1 cm y^{-1}), and all records show an increase in sedimentary carbonate (aragonite) content centered at ~1879. The mid-19th century coincides with a major (~10 m) lake level transgression. Throughout the period of lake level transgression and subsequent regression, the organic matter $\delta^{13}C$ and $\delta^{15}N$ records develop a prominent and coincident negative excursion followed by a return to values similar to those prior to the lake level transgression. This negative excursion in $\delta^{15}N$ and $\delta^{13}C$ is also coincident with an increase in carbonate-corrected organic carbon. We interpret the $\delta^{13}C$ results as a decline in primary production during the transgression with the $\delta^{15}N$ results signaling a concomitant increase in the reliance on nitrogen fixation as the nitrogen source. The coincident peak in organic carbon is interpreted as being a result of enhanced preservation driven by the precipitation and burial of aragonite.

1. Introduction

Lake Tanganyika is a large, deep (~1470 m maximum depth) tropical lake nestled within the East African Rift system between ~3° and 9° S (e.g., Coulter, 1991; Fig. 1). The half-graben basins that cradle the lake create a bathymetry whereby the lake has relatively steep sides with a number of shelf platforms (e.g., Rosendahl et al., 1986). These platforms make exquisite localities for sediment coring for geochemical and paleo-climatological studies.

Like any aquatic system, lake chemistry is controlled by a combination of internal physical, chemical, and biological processes as well as new inputs via the atmosphere and rivers. Although many rivers contribute to the lake's chemical composition, Lake Tanganyika's major element chemistry is likely dominated by inputs from the Ruzizi River, which drains Lake Kivu (e.g., Craig, 1975; Cohen et al., 1997). Lake Kivu is alkaline and is responsible for Lake Tanganyika's high Mg to Ca ratio (Craig, 1974; Cohen et al., 1997). Lake Tanganyika also has a relatively high pH with the shallower reaches having a pH of ~9 and an alkalinity of ~6.5 mM (Fig. 2, Degens et al., 1971; Edmond et al., 1993; Plisnier et al., 1999). These waters are supersaturated with respect to calcite, aragonite, and magnesian calcite (Cohen et al., 1997), and this supersaturation fosters a diverse assemblage of carbonate deposits (Cohen and Thouin, 1987; Haberyan and Hecky, 1987; Cohen et al., 1997). The lake's carbonate system does seem to vary significantly over time, however, and prior to ~2–4 ky, chemical conditions were such that there seems to have been very little or no carbonate burial in contrast to the present conditions (Degens et al., 1971; Haberyan and Hecky, 1987; Felton et al., 2007).

Because of its tropical setting, Lake Tanganyika has a permanent thermocline (e.g., Degens et al., 1971; Coulter and Spigel, 1991; Fig. 2). This permanent stratification provides a density barrier, which results in inefficient mixing between the lake's deep and surface waters, and coupled with its internal biogeochemistry, this physical stratification generates persistent chemical stratification with dissolved oxygen generally restricted to the upper ~100 m in the north basin and sulfide present below ~150 m (Edmond et al., 1993; Plisnier et al., 1999; Fig. 2). The macronutrients nitrate, silicic acid, and phosphate have low concentrations in the shallowest water column depths (e.g., Edmond et al., 1993; Plisnier et al., 1999). As a consequence of its great depth, stratification, and the presence of a chemocline, the deep waters are also rich in the nutrients ammonium, phosphate, and silicon, and the upwelling of this water is the primary nutrient supply mechanism for the lake ecosystem with nitrogen fixation also being an important, if not the primary, source of fixed nitrogen (e.g., Hecky et al., 1991; Verburg and Hecky, 2009). There is considerable temporal variability in the

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0031-0182/

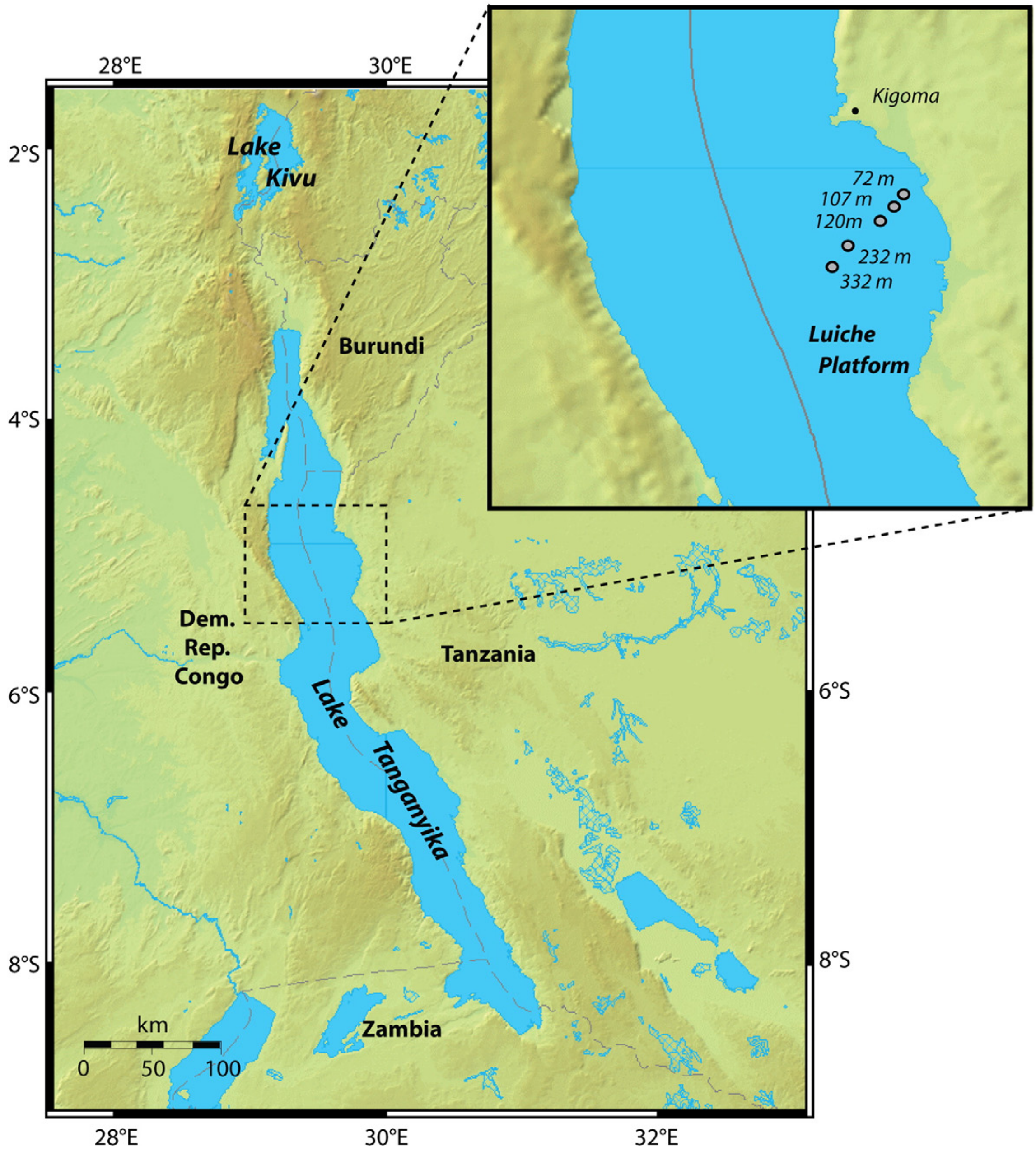

Fig. 1. Map of study area. Inset shows locations of multicore deployments on the Luiche Platform. Base map was generated using Demis Web Map (http://www.demis.nl) and modified after Brucker et al. (2011).

chemistry of Lake Tanganyika's waters (Plisnier et al., 1999). This variability is driven by a variety of biogeochemical and hydrodynamic processes, which vary on seasonal to interannual timescales (Coulter and Spigel, 1991; Hecky et al., 1991; Plisnier et al., 1999).

There has been considerable interest in Lake Tanganyika's response to climate change. Lake level has varied between roughly 700 and 785 m above sea level over the past ~3000 years (Cohen et al., 1997; Alin and Cohen, 2003). These changes in lake level are generally viewed as being forced by changes in regional climate, the elevation of the lake's outlet, or a combination of these two factors (e.g., Alin and Cohen, 2003). Germane to the current work, a lake low stand dominated the latter part of the Little Ice Age (LIA, 1550–1850) followed by a relatively rapid lake level rise that reached its maximum around 1879 (Nicholson, 1999; Alin and Cohen, 2003). Although increased precipitation certainly played a role in lake level rise, the extent of the transgression, followed by the abrupt regression, was regulated in part by the lake's present-day primary outlet to the Lukuga River being blocked by vegetation and sediment (Nicholson, 1999). Once this debris dam was breached, the lake regressed rapidly to a fairly stable level over the next one to two decades (see a detailed review in Nicholson, 1999), and this lake level stability has been relatively persistent up to the present (Alin and Cohen, 2003).

It has also been pointed out that the lake has been warming and that this warming is likely increasing thermal stratification (O'Reilly et al., 2003; Verburg et al., 2003). Increasing stratification in turn diminishes the exchange between the nutrient-rich deep waters and surface waters (Verburg et al., 2003; Verburg and Hecky, 2009). Because biological production relies on this nutrient exchange (e.g., Hecky et al., 1991), it can be reasoned that lake productivity can be expected to decline as thermal stratification increases (O'Reilly et al., 2003) and biogenic silica (Tierney et al., 2010) data from lake sediments have been used to support this inference.

In this paper, we examine the sedimentary records of Lake Tanganyika to investigate changes in lake chemistry over the past ~200 years.