## Preliminary investigation of diatom flora distribution in transitional sediment sequences as a possible indicator of annual to decadal precipitation fluctuations

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### *Introduction*

The potential of East African Rift Valley lakes as sources for robust equatorial climate records has been greatly demonstrated (Gasse, 1989; Johnson, 1996; Livingstone, 1965; Livingstone, 1975), yet studies of annual-to-decadal scale late-Holocene climatic variations are few (Cole et al., 2000; Johnson, 2001; Russell et al., 2003; Verschuren et al., 2000). Such studies are exceedingly important for East Africa where slight climatic alterations often can result in dramatic consequences on the highly agrarian human population of the region (i.e. widespread droughts and associated famine) (Hulme, 1992).

Lake Tanganyika is located along the western branch of the East African Rift system. It is the deepest lake in Africa (>1400 m) with an estimated age of 9-12 Ma, and therefore offers a particularly extensive paleoenvironmental archive in the form of deep sediment deposits (Cohen et al., 1993). The permanently anoxic conditions present in Tanganyika's hypolimnion often result in the preservation of bi-annual sediment laminations with allochthonous and autochthonous deposits occurring during the wet and dry seasons, respectively (Cohen et al., submitted; Scholz et al., 2003). Such annual layers, termed varves, allow for detailed investigations into the past chemical, biological, and sedimentological characteristics of the lake, and provide an excellent chronological tool due to their annually occurring nature (Wheeler et al., submitted). When lamination counts are coupled with reliable dating techniques (i.e. $^{14}C$, $^{210}Pb$), highly accurate age models can be developed to reconstruct lake system and climate variations over fine time scales (Cohen et al., submitted).

Cohen et al. (submitted) documented a varying pattern of thick and thin lamination sequences occurring in mid-to-late Holocene sections of sediment cores retrieved from the Kalya slope, south central Lake Tanganyika. The distribution of these sequences, termed "bundles", was hypothesized to be a direct function of varying rates of precipitation and the associated response of aquatic primary production (Cohen et al., submitted). Specifically, thick varved couplets were hypothesized to represent periods of heightened precipitation due to an increased flux of both nutrients and terrestrially-derived material into the lake system (Cohen et al., submitted). Although measurements of lamination thickness support this hypothesis, other studies suggest variations in upwelling greatly influence changes in deep-water sedimentation processes (Johnson et al., 2002, Haberyan and Hecky, 1989). Specifically, upwelling events promote phytoplankton production, thereby increasing winter-layer thickness through the increased deposition of diatom frustules.

Extensive studies on diatom distributions have shown a genus-specific response to changes in the relative abundance of the nutrients Si and P. In Lake Tanganyika, the Si:P ratio of inflowing waters differs from deep, upwelled, hypolimnetic waters, therefore variations in fossil diatom genera provide a means by which to discern alterations in nutrient regimes and, ultimately, the climatic factors that govern them (Kilham and Kilham, 1985). The transitional zones present between Lake Tanganyika sediment bundle sequences stand to provide a wealth of information concerning diatom assemblage distributions and the climatic environments they represent. Are changes in diatom genera abundances present across bundle transition zones? Do such assemblage variations provide any indication for varying amounts of precipitation and surface flow into the lake, or do they suggest upwelling as the dominant factor in sedimentation variations? The aim of this study is to initiate a preliminary investigation into the relative abundance of diatom flora during such transition zones in an attempt to effectively approach these fundamental questions.

### *Field Methods*

In July of 2004, four piston cores and two gravity cores were retrieved from the Kalya region of Lake Tanganyika as part of a University of Arizona and International Decade for East African Lakes' (IDEAL) Nyanza Project expedition. Core NP04-KH-1-1K was recovered from the Kalya slope (S 06º33.147, E 29º58.480) at 303m water depth and measured 534cm in length. The sediment core was immediately sectioned into ~ 150cm lengths and subsequently transported to the Tanzania Fisheries Research Institute (TAFIRI) facilities where it was split, photographed, and sampled.

### *Laboratory Methods*

Three separate beds containing transitions from thin to thick laminations in NP04-KH-1K Section I were sampled at a 0.2-0.5cm interval depending on their respective widths. These beds occur at 35.5-38cm, 62-66cm, and 99-102cm depths. An attempt was made to sample only austral winter deposits (diatomaceous sediments), but lack of resolution in the thin bundles limited seasonal isolation. The samples were immediately placed in 3-5ml of $H_2O_2$ (50%) and heated to 100ºC, oxidizing all organic matter within the sediment. After 60 min. the reaction was ended by adding distilled $H_2O$. The samples were allowed to settle for two 8-hour periods with two intervening distilled $H_2O$ rinses. In order to retard the electrostatic attraction between diatom frustules, 0.01ml of HCl (33%) were added to each sample prior to slide preparation. The samples were then diluted with distilled $H_2O$ until appropriate solution clarity was acquired. Aliquots were withdrawn from each solution, evenly applied to glass slide coverslips, and allowed to dry for ~12 hours. The coverslips were mounted on glass slides with Permount mounting medium and heated for approx. 2 min. to hasten the curing process.

Diatoms were counted with a Leica CM EX3 light-microscope at 1000X until 300-500 diatom valves were identified and counted across an appropriate representative proportion of the coverslip (Battarbee et al., 2001). Care was taken to avoid over-counting fractured valve fragments in order to prevent bias in the diatom assemblage distribution. With respect to *Nitzschia* spp., only valve tips were counted and final counts were halved. All other genera were counted only if central portions of the valves were preserved. Diatom genus identifications were based on Barber and Haworth (1981), Gasse (1986), and Cocquyt (1998).

***Results***

Core NP04-KH-1-1K-I lithostratigraphy is discussed in detail in (Bosworth et al., this volume). All abundance values reported in the following section are averaged for each respective lamination sequence. The dominant genus counted was *Nitzschia* spp., which accounted for 87.5% of all diatoms on average. Sequence A is characterized by an initial thick lamination sequence from 35.5-36.5cm followed by a thin lamination sequence extending from 37-38cm (Fig.1 a). Relatively high abundances of littoral taxa, such as *Navicula* spp. (15.8%), *Cymbella* spp. (6.5%), and *Gomphonema* spp. (4.1%) occur in the thin lamination sequence. The populations of these genera dramatically decline in the thick lamination sequence. All other littoral genera were summed and constitute a minor percentage (1%) of the flora distribution, yet nonetheless also display higher values in the thin sequence portion. *Nitzschia* spp. populations increase by 25% in the thick lamination sequence. *Stephanodiscus* spp. are entirely absent throughout Sequence A. Sequence B is characterized by a thick lamination sequence from 62-64cm followed by a thin lamination sequence from 64.5-66cm (Fig.1 b). Moderate abundances of *Navicula* spp. (5.6%), *Cymbella* spp. (2.7%), and *Gomphonema* spp. (6.5%) as well as the general littoral-specific genera (2%) again occur in the thin laminations and decline in distribution following the thick sequence transition. *Nitzschia* spp. abundance increases from 80% to 97% across the transition from thin to thick laminae. *Stephanodiscus* spp. are present in moderate abundances (4.5%) in the thin lamination sequence and are entirely absent in the thick sequence. A thick bed of laminations from 99-100.8cm, and a thinly laminated bed from 101-102cm comprise sequence C (Fig. 1 c). *Navicula* spp. are present in moderate levels (8.7%) during the thin bundle sequence, decline in abundance (.8%) across the transition zone, then increase to 10.8% at 99.6cm. *Cymbella* spp. are present in low abundances (2%) in the thin laminations, are absent across the transition zone and increase to .6% at 99.6cm. *Gomphenoma* spp. are present in low abundances in the thin lamination sequence. Other littoral-specific genera decline from 10% at 101.6cm to 0% at 100.4cm, followed by a slight increase to 1% from 100.1-99.6cm. *Nitzschia* spp. generally increase through the thin lamination sequence, display an 100% abundance value at 100.5 and then decrease to 88% at 99.6cm. *Stephanodiscus* spp. are again present in moderate abundances (4.5%) in the thin lamination and are entirely absent in the thick lamination sequence. The diatom population variations are generally uniform throughout NP04-KH-1-1K-I with the exception of *Stephanodiscus* spp. as it is absent in the upper sediments. The validity of small counts of *Stephandiscus* spp. representing an actual departure from an evenly distributed mean count was shown through a Chi square test, when the mean count size (expected value) was set equal to the average abundance (5% of counts). This test shows that the changes in *Stephanodiscus* spp. abundance between thick and thin laminations are statistically significant at the $p = 1.9\ E^{-14}$ level.

***Lake Tanganyika diatom genus distribution and paleoenvironmental interpretation***

Planktonic diatom distribution within Lake Tanganyika has previously been shown to vary in relation to fluctuating Si:P ratios. Specifically, *Stephanodiscus* spp. generally thrive in low Si:P environments while *Nitzschia* spp. prevail in higher Si:P conditions (Haberyan and Hecky, 1987; Kilham and Kilham, 1985). Lake Tanganyika's epilimnion is enriched with Si as compared to P (5.2 moles $m^{-2}$ to 0.23 moles $m^{-2}$, respectfully (Hecky et al., 1991)), therefore availability of P highly limits algal growth. Internal sources (deep waters) provide the largest overall contribution to the photic zone's P budget (90%) (Hecky et al., 1991); however, the hypolimnion has a higher ratio of Si:P than the epilimnion. A greater depth of mixing therefore results in a higher Si:P ratio in the photic zone, promoting the growth of *Nitzschia* spp. relative to *Stephanodiscus* spp. (Haberyan and Hecky, 1987). On seasonal-to-decadal time scales rates of upwelling are determined by wind intensity and direction. The latent heat loss due to the evaporative cooling of the epilimnion in part governs thermal stratification and thereby directly affects the degree of annual upwelling (Coulter and Spigel, 1991).

The relative abundance of benthic and littoral-specific planktonic diatoms deposited in deep-water sediments have been interpreted as an indicator of material transport from marginal regions of the lake system. The increased abundance of such diatoms is generally related to periods of lake level regression (Gasse et al., 1989), yet on seasonal-to-decadal time scales littoral sediment disturbance and the introduction of allocthonous material into pelagic zones via increased river and surface flow input may also influence lake-wide algal deposition (Barker and Gasse, 2003). Littoral-specific genera relevant to this study primarily include *Navicul*a spp., *Gomphonema* spp., and *Cymbella* spp. with minor occurrences of *Fraglaria* spp., *Diploneis* spp., *Amphora* spp., *Surirella* spp., *Synedra* spp., *Caloneis* spp., and *Gyrosigma* spp.(Cocquyt, 1998).

***Discussion***

The presence of *Stephanodiscus* spp. in the thin lamination sequences indicates a relatively moderate range of water column mixing (Haberyan and Hecky, 1987) during a hypothesized arid climatic phase (Cohen et al., submitted). This relation is at odds with instrumental records that link arid periods to enhanced wind conditions in both East Africa and Lake Tanganyika (Climlake 2002 Report; Johnson et al., 2002). During dry/windy periods a shallow thermocline is expected due to evaporative cooling of surface waters via air movement, effectively promoting high rates of upwelling {Coulter, 1991; Nicholson, 1996). Such upwelling would increase the Si:P ratio, adversely affecting the *Stephanodiscus* spp. population and leading to a near homogenous *Nitzschia* spp. population as seen in the thick lamination sequences (Haberyan and Hecky, 1987).

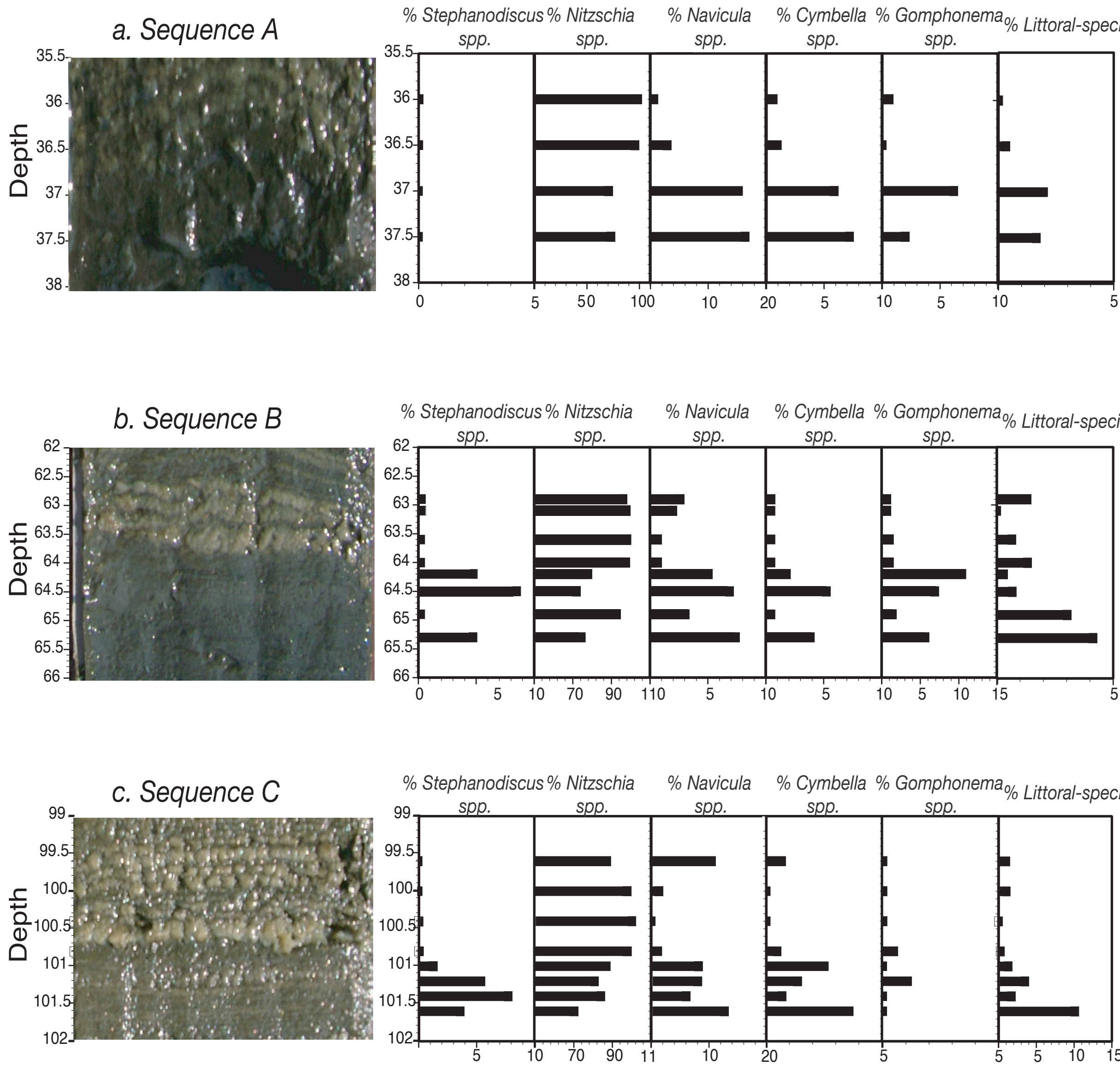


**Fig. 1.** Relation of diatom genera abundance to lamination sequence depths. Note the abrupt decrease in *Stephanodiscus spp*. and increase of *Nitzschia spp*. across the thin/thick transition. This change coincides with a decrease of *Navicula spp., Cymbella spp., Gomphonema spp*. and other littoral-specific genera across such thin/thick transitions. Littoral-specific spp. include *Fraglaria spp., Diploneis spp., Amphora spp., Surirella spp., Synedra spp., Caloneis spp.*, and *Gyrosigma spp*. **a)** Sequence A profile (35.5-36.5cm thick laminations, 37-38cm thin laminations) Note complete absence of *Stephanodiscus spp*. . **b)** Sequence B profile (62-64cm thick laminations, 64.1-66cm thin laminations). **c)** Sequence C profile (99-100.6cm thick laminations, 100.7-102 thin laminations). Note strong changes in Stephanodiscus spp. across lamination transitions, in contrast with Sequence A.

Benthic and littoral-specific planktonic diatom abundances are more pronounced in the thin lamination sequences than in the thick. Although such occurrences could represent an enhanced proximity of the littoral zone to the deep-water site through a lake-level decline, on seasonal-to-decadal time scales the probable range of lake-level fluctuations (1.5 m yr $^{-1}$) would be relatively insignificant (Coulter and Spigel, 1991). The presences of littoral diatom taxa is more likely to reflect an increased flux of river and surface flow into the lake system associated with the transport of littoral diatoms and sediments to the core-site during periods of increased regional humidity. This hypothesis is supported by grain size measurements of Bosworth et al. (this volume).

If our interpretations of diatom abundances and ecology are correct, the variations in the planktonic diatom assemblages across lamination sequence transition zones demonstrate the dominant significance of upwelling during arid climatic periods in the deposition of thick laminations. Furthermore, the presences of littoral-specific spp. in the thin laminations together with their absence from the thick laminations imply a transition from wet to dry conditions. These results are in accord with instrumental records.

*Conclusion*

High-resolution analyses of diatom assemblages across transition zones between thick and thin laminations in a sediment core from the Kalya region, Lake Tanganyika, suggest that such bundle transitions represent changes from stratified, wet, conditions to better-mixed, arid conditions. Changes in upwelling are modulated by shifts in Si:P ratios that affect representative algal populations, while changes in littoral-specific genera reflect variations in hydrologic discharge affecting the transport of nearshore sediments to the core site. Such hypothesized relations are supported by both general lithostratigraphic information as well as more general diatom assemblage distributions throughout the NP04-KH-1-1K sediment core (Steinkamp, this volume). In order to constrain possible biased sampling practices or random diatom population disseminations, a more intensive sampling distribution is required. Separating genera into species-specific assemblages will further allow for a more detailed investigation into past lake system variations and should therefore also be incorporated into future work.

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