

Fossil ostracode taphonomy and abundance in Tafiri Bay, Lake Tanganyika: Implications for lake-level reconstruction

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Introduction

Lake Tanganyika is an ancient tropical rift lake that formed approximately 9-12 Ma (Cohen et al., 1993). The long sedimentary record of the lake preserves valuable information about lake level change, hydrodynamics, sediment provenance and budget, and water and sediment chemistry. Thus lake sediments and their contents are a powerful tool for interpreting paleoclimate, particularly over the past 3000 years (e.g. Alin, and Cohen, 2003; Palacios-Fest et al., 2005). This study analyzes ostracode taphonomy in recent sediments as a potential indicator of physical and chemical conditions within the depositional environment of Lake Tanganyika: Kigoma Bay.

Lake Tanganyika is home to at least 700 endemic species (Coulter, 1994) of which at least 200 are ostracode crustaceans (A. Cohen, pers. comm.). Within the lake, ostracodes, found at the sediment-water interface, are widespread and abundant. The carapace of an ostracode is composed of two valves made of CaCO₃ and chitin (Thorp and Covich, 1999), and is well preserved within the lake's sediment. After death, the ostracode's carapace is subject to forces and conditions that affect the environment in which it has died. These forces, which primarily include wave energy and water and sediment chemistry, have the potential to transport, disarticulate, fracture, encrust and stain the carapace valves. A study conducted by Van Alstine (2002) on samples taken from the Luiche Delta Platform, south of Kigoma, demonstrated that there is a significant correlation between ostracode abundance and taphonomic variables and environmental conditions, including a statistically significant correlation between valve breakage and water depth, as well as abundance and total organic carbon (TOC). This study aims to test the applicability of ostracode taphonomy in Kigoma Bay using grab samples from the Tafiri Bay region of Lake Tanganyika. Once the taphonomic features of ostracodes are understood in the present depositional environment, this knowledge can potentially be used to interpret past climate/depositional environments in sediment cores from the same area.

Study Area

The Tafiri Bay area is one of three bays that border the city of Kigoma, TZ located at S4°46' E29°36'. The bay is relatively protected from turbulence caused by wind and does not have a significant water inlet, and is thus considered a moderate energy depositional environment.

Methods

I collected samples in Tafiri Bay aboard the *R/V Echo* using a Ponar Grab Sampler that has a maximum sampling surface area of 600 cm². This study is concerned with modern sediments, thus only the top 5 cm of the grab sample was collected. Sampling occurred along two east-west running transects (transects 3 and 4) in water depths between 5.3 m and 110 m (Figure 2, Geology and Paleoclimatology Introduction, this volume). Samples were collected at approximately ten-meter water depth intervals along each transect. For each sampling site, a GPS coordinate and water depth was recorded. The sediment was recovered using a clean spatula or metal scoop and stored in a Whirl Pak. The grab sampler was thoroughly rinsed with lake water after each sample was collected.

A portion of each grab sample large enough to contain at least 100-200 ostracodes was weighed using a microbalance. Sediment weights ranged between 0.5-2.0 g. Each sample was gently washed through a 106 µm brass sieve to remove the clay fraction and transferred to a labeled petri dish. Excess water was siphoned off and the sample was set aside to dry. Samples were visually inspected to approximate the ostracode count and determine if it was necessary to take a sub-sample (this was done if the initial sample portion contained well over 200 ostracodes). If a sub-sample was necessary, the dried sample was weighed before taking a sub-sample. The sub-sample was obtained using a metal spatula to ensure a homogenized representation of the whole sample, weighed, and distributed onto a metal sampling tray. Samples that did not require a sub-sample were kept in their petri dish for analysis.

Ostracode valves were counted under a Nikon SMZ-2T stereomicroscope for each sample. If a valve was fractured, it was counted only if more than 50% of the valve was present. Abundances (# valves/g of dry sediment) were calculated using the valve count, wet weight and water content data (Jimenez, this volume) with the following equation:

$$\text{valve count}/[\text{wet weight}-(\text{wet weight} \times \text{water content})]$$

The sample was then analyzed for taphonomic indicators which include: valves as carapaces vs. disarticulated valves (must have >50% of valve to be counted), # valves oxidized vs. # valves reduced vs. # non-stained valves, wholes valves vs. fractured valves and # encrusted valves vs. # non-encrusted valves. Counting stopped when 100-150 ostracodes within the sample had been counted; the ratios were then recorded and converted to percentages. To test repeatability of abundance and taphonomic feature counts, four sub-samples from sample TB3-GB1 (20.5 m water depth) were analyzed.

Results

Results from sample TB3-GB1 suggest that my methods for counting taphonomic damage are replicable (Table 1) with 1 standard deviation ranging from 3-16% of the measured features. Abundance counts were more variable with a standard deviation of 37%. It should be noted that the applicability of these errors may be limited, as errors were calculated for a single shallow-water sample only.

Ostracode abundance values range from 1,334-14,210/gm for transect 3 and from 1,907-23,489/gm for transect 4 (Figure 1). Abundance values do not exhibit a linear correlation with water depth (m); instead values peak between 50 and 60 m water depth in both transects. The values in shallow water (5-40 m) are more variable than those in deep water, where they rapidly decrease below 60 m water depth and remain low. Unlike Van Alstine (2002), ostracode abundance and % TOC (Jimenez, this volume) are not correlated along these transects.

Taphonomic features generally demonstrate similar trends along depth in both transects 3 and 4 (Figure 2; graph A-F), with the exception of an anomalously high value along transect 3 in % encrusted valves vs. water depth (m). Strong correlations exist between water depth (m) and the following: % disarticulated valves ($R^2 = 0.563$, F-ratio <0.0001), % encrusted valves ($R^2 = 0.744$, F-ratio <0.0001), % oxidized valves ($R^2 = 0.633$, F-ratio <0.0001), and % non-stained valves ($R^2 = 0.854$, F-ratio = <0.0001) (Figure 3, graphs A,B,D,E). There is no significant correlation between water depth (m) and % reduced valves ($R^2 = 0.220$, F-ratio = 0.0157) and % fractured valves ($R^2 = 0.010$, F-ratio = 0.6307) (Figure 3, graphs C and F).

Many taphonomic features exhibit rapid changes along depth in both transects. The % encrusted valves rapidly declines to approximately zero below 60 m water depth. The % oxidized valves declines to approximately zero between 50-55 m water depth. The % reduced valves declines to approximately zero below 75 m water depth, while the % non-stained valves increase and remain close to 100% above 70-80 m water depth.

Discussion

The goal of this study is to determine whether strong relationships between measured taphonomic features and water depth exist in the modern depositional environment in order to develop a model for paleo-lake level reconstruction in the Tafiri Bay area. This study reveals that relationships do exist between taphonomic variables and water depth, although these relationships are not always simple ones. For example, % encrustation vs. water depth exhibits a strong inflection point and % fractured valves vs. water depth may possibly be polymodal (breakage). Additionally, many features rapidly decline to zero or increase to 100% between 50 and 80 m water depth, but exhibit linear relationships above these depths. Ostracode taphonomic measurements may be most useful for lake-level reconstruction if they are applied to cores collected from the depth in which they exhibit the most significant amount of change, ~ 0-70 m. Certain taphonomic features do not show a correlation with water depth (e.g. % fractured) and may be excluded from future lake-level studies with caution.

I anticipated a correlation between water depth and % valves fractured based on the results of Van Alstine (2002), who reported a significant negative correlation. These contrasting results could be due to differences in the

depositional environments between the two studies. This study took place in a moderate-energy depositional environment that has no significant water inlet. The 2002 study was conducted on the Luiche Delta platform, a high-energy depositional environment with a major river inlet. Thus the coastline in this study was more protected from wave energy than that of the 2002 study. There may have also been variation in sample processing that could have biased results in either study.

Oxidation and reduction staining occur due to the mobilization of Fe and Mn in anoxic sediments, followed by the precipitation of these metals onto ostracode carapaces at the sediment-water interface or during shallow burial. Transects 3 and 4 exhibit two peaks in % valves reduced with depth, one occurring at ~30 m water depth, the other at ~55 m water depth. In both transects, values rapidly decline to zero at ~80 m water depth, which likely results from generally anoxic conditions below that depth. Although reduction staining does not linearly correlate with water depth, the % non-stained valves (valves that are neither reduction nor oxidation stained) show the strongest linear correlation with water depth in this study ($R^2 = 0.854$, F-ratio = <0.0001) (Figure 3, graph E). Based on these results, this taphonomic feature would be the most useful for paleo-lake level reconstruction in the Tafiri Bay area. Because % non-stained values increase to ~100% below water depths of ~80 m, the utility of this proxy would be limited below this level. When % non-stained valves are plotted against % TOC, the R^2 value (= 0.716, F-ratio < 0.0001) suggests that the sedimentary % OC may influence staining. The presence of organic matter likely alters O_2 content and pH, mobilizing oxidized and reduced metals at the sediment-water interface.

Although the correlation between water depth and % non-stained valves is the most significant, it is noteworthy that a strong correlation also exists only between % oxidized valves and water depth ($R^2 = 0.633$, F-ratio < 0.0001) (Figure 3, graph D). However, oxidation staining rapidly drops to zero below ~60 m water depth. This likely indicates that Fe is generally soluble below this depth in Tafiri Bay. Above 60 m water depth, there is a general decreasing trend, particularly in transect 4, with two peaks occurring at ~20 m and ~40 m water depth. When samples above 60 m water depth are plotted against depth, a significant linear correlation remains ($R^2 = 0.500$, F-ratio = 0.0022). The % oxidized valves may therefore be a useful tool for reconstructing shallow-water depth profiles.

There is a general decreasing trend in % encrusted valves with water depth within each transect, but with considerable variability (Figure 2, graph B.) Encrustations in transect 3 decrease before reaching an anomalously high value at 50 m water depth, which is followed by an abrupt decrease to near zero values. This anomaly may be related to the sample's proximity to a 20 m fault scarp, which is approximately 230 m up-slope of the sample (Smith, G., this volume). Transect 4 is also variable, showing peaks at ~20 m and ~40 m water depth, below which % encrusted valves rapidly drop to near zero. Regardless of local variability within transects, there is a roughly linear correlation with water depth (m) ($R^2 = 0.744$, F-ratio < 0.0001). Because values rapidly decline to zero at ~60 m water depth, zero values were eliminated from the analysis to quantify the significance of a correlation in shallow water. This correlation also appears to be strong ($R^2 = 0.646$, F-ratio = 0.0001). The % encrusted valves is most likely correlated to water depth due to declining levels of aragonite or calcite supersaturation with respect to water depth, a trend which occurs due to effects of lake temperature and primary productivity on Lake Tanganyika's carbonate chemistry and pH. Encrustations may also control valve disarticulation in Tafiri Bay. Although a correlation between % disarticulated valves and water depth is present, values are variable in shallow water and show little change (particularly in transect 4) below 30 m water depth. However, when % encrusted valves is plotted against % disarticulated valves, a significant relationship exists ($R^2 = 0.694$, F-ratio < 0.0001) which suggests encrustations may exhibit a larger control on disarticulation than water depth.

In addition to the use of taphonomic features as possible tools for use as paleo-lake level indicators, abundance must also be considered. Although the relationship between abundance and water depth is not linear (Figure 2), the magnitude of abundance maximum values (which occur between 50 and 60 m water depth) could make abundance a significant tool in identifying the 50-60 m depth range in Tafiri Bay. Conversely, the shallow and deep water abundance values overlap in range, limiting the use of abundance values to reconstruct these water depths. Past studies (e.g. Cohen, 2000) have demonstrated that ostracode species associations are extremely spatially variable. There can be local colonization and extinction events that could potentially skew abundance results. For example, a low point in abundance in transect 3 (~55 m water depth) corresponds with the highest abundance value in transect 4. Therefore, one must proceed with caution when using abundance to indicate depth.

Future Work

More grab samples along depth transects in Tafiri Bay are needed before a depth reconstruction using ostracode taphonomy can be applied with any degree of confidence. It may also prove useful to compile a species abundance list for water depths within the bay as some species are more robust and thus better resist fracture and disarticulation. Once additional taphonomic work in the modern depositional setting of Tafiri Bay is completed it may be possible to construct a sound paleo-lake level model using cores from the bay.

Acknowledgements

I would like to thank my mentor Jim Russell and T.A. Lindsay Powers for their patience, humor and statistics knowledge. They were two of the most enjoyable people I have ever had the pleasure to do science with. I would also like to thank Andy Cohen for his generosity in offering his time and knowledge for the betterment of my project. I would have had no idea where to start with my project if it were not for the unbelievable breadth of knowledge offered up to me by Kiram Lezzar, Catherine O'Reilly, Ellinor Michel, Katie Wagner, Yvonne Vadeboncoeur, and Willy Mbemba about the workings of Lake Tanganyika in all of its glorious facets. Thanks to the local Nyanza staff, TAFIRI and the *R/V Echo* crew for your technical expertise. I would like to recognize the NSF grant ATM-0223920 for making the Nyanza Project possible. And lastly, I would like to thank the students in the Nyanza Project for being so wonderful. Everyday I spent with you was a once in a lifetime treat. Thank you.

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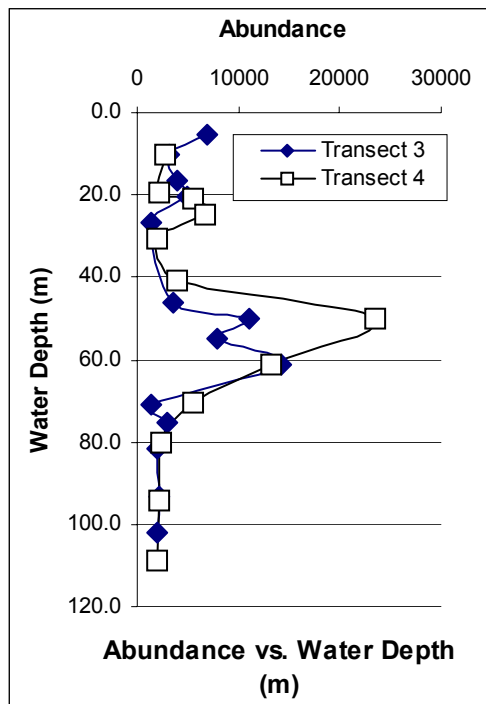
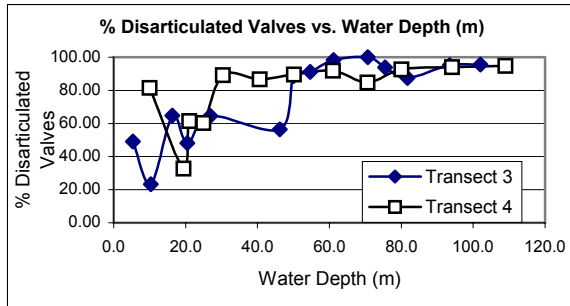
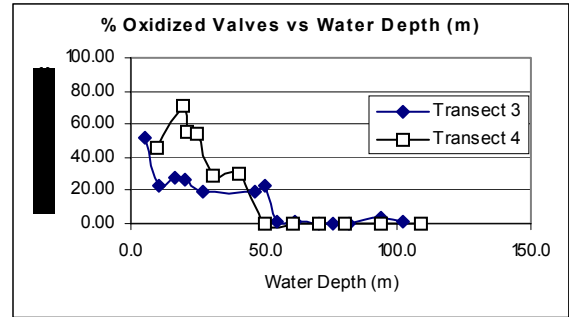


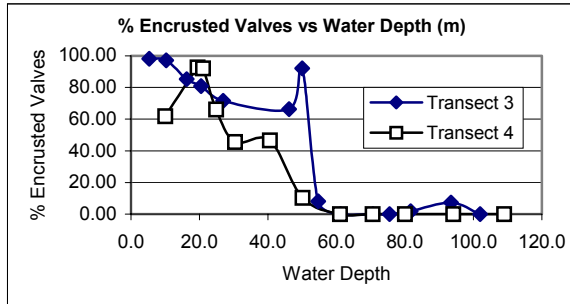
Figure 1. Ostracode abundance (valves / g. dry sediment) vs. water depth (m). Maximum abundance occurs between 50 and 60 m water depth. Ostracode populations can be variable along transect and depth.



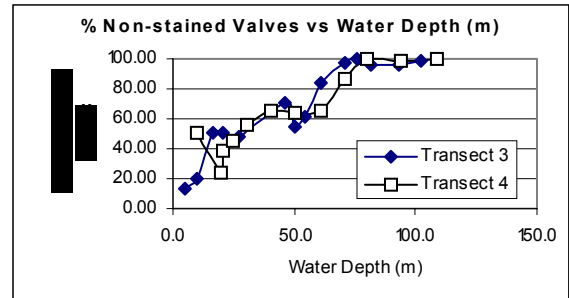
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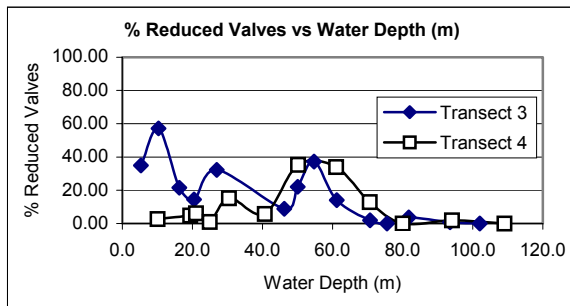
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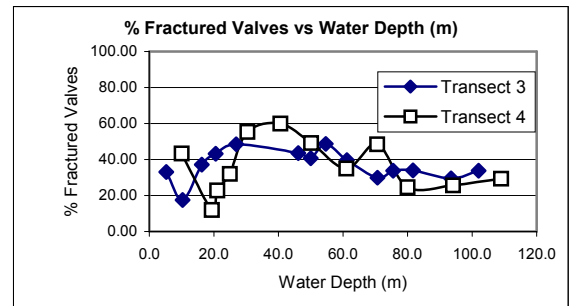
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Figure 2. Taphonomic features vs. water depth (m) for transects 3 and 4. Graph A (% disarticulated valves) demonstrates a correlation with water depth ($R^2 = 0.563$, F-ratio = <0.0001) and an increase in valves to $\geq 90\%$ at approximately 30 m water depth in transect 4 and 50 m water depth in transect 3. Graph B (% encrusted valves) demonstrates a correlation with water depth ($R^2 = 0.744$, F-ratio = <0.0001). However, there is a rapid decline in encrustations below approximately 60 m water depth—which occurs near the oxycline, placed at ~ 75 m in Kigoma Bay (?), this report)—and an anomalously high value in transect 3 at 50 m water depth—approximate 230 m down-slope of a fault scarp (Smith, this volume). Graph C (% Reduced valves) does not show a clear correlation with water depth ($R^2 = 0.220$, F-ratio = 0.0157). Graph D (% Oxidized valves) demonstrates a correlation with water depth ($R^2 = 0.633$, F-ratio = <0.0001). However, there is a rapid decline in number of oxidized valves below approximately 50 m water depth (m). Graph E (% Non-stained valves) shows a strong linear correlation with water depth ($R^2 = 0.854$, F-ratio = <0.0001). Graph F (% Fractured valves) does not show a clear correlation with water depth.

Tables

	Abundance	% Valves as carapaces	% Encrusted valves	% Oxidized valves	% Reduced valves	% Fractured valves
Mean	3366	46.11	88.36	31.58	15.57	42.70
1 STD	1236	4.08	5.10	5.05	1.76	1.39
% 1 STD	37	8.85	5.78	15.98	11.28	3.26

Table 1. Repeatability results for sample TB3-GB1 collected in 20.5m water depth.