Comparison of stratigraphic records between contrasting depositional environments from the North and South Mahale Mountains, Lake Tanganyika, East Africa

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Introduction

In order to understand the global climate system, it is critical to demonstrate the relationship that tropical climates have with the entire system. It is believed that the tropics provide the energy that drives global circulation, so climate data from all points can potentially be linked to tropical climate change.

The great lakes of Africa have been shown to be important reservoirs of climatically sensitive material (e.g. Pilskaln, 1991; Cohen et al., 2000; Cohen et al., 1997; Wells et al., 1999). Analysis of these records can help elucidate the link between East African climate changes with other records (e.g. Gasse, et al., 1989). Lake Tanganyika (elevation 773m) fills a basin on the western rift of the East African Rift Zone bordering the countries of Zambia, Democratic Republic of the Congo, Burundi, and Tanzania. This rift valley lake is ancient, and as the second deepest lake in the world (1470m), it potentially contains sediment dating back approximately 9-12 million years (Cohen et al, 1993). Because of the basin morphology and fetch of the lake, bottom waters (below 100-130m) are continually anoxic (Cohen et al, 1993). This lack of oxygen, combined with the bi-seasonal climate, has allowed laminated sediment to accumulate in dark and light intervals. Similarly laminated sediment from Lake Malawi is interpreted by Pilskaln (1991) to be a record of the rainy and dry seasons respectively.

NYANZA Project gravity cores were collected from the Kalya Ridge in the summer of 2000 and analyses of organic carbon, carbonate, stable isotopes, and lamination thickness were completed. As gravity cores occasionally over-penetrate, the sediment/water interface is often lost. One of the successful goals of this year's research cruise involved the use of a multi-coring apparatus to collect the sediment/water interface at core locations LT00-02 (S 6.5543°, E 29.9737°, 309m water depth) and LT00-03 (S 6.6861°, E 29.8610°, 608m water depth) in order to complete the sediment record, including lamination bundle measurement. The preliminary analysis of these two new multi-core records is discussed here, with further lamination counting and geochemical data to test Pilskaln's interpretation of light and dark lamination origins to be completed in the United States.

An additional goal was to obtain new gravity cores from the horst and slope of the Kavala Island Ridge (KIR), north of the Mahale Mountains, to compare these related but sedimentologically and limnologically separate parts of the rift-basin.

Study Site

Central Lake Tanganyika has been an actively studied area for many decades, but only since the 1980's has it been intensely researched for paleoclimatological and paleolimnological research.

In the northern part of the central lake lies the Kavala Island Ridge and to the south the Kalya Ridge, both acting as accommodation zones within the lake (Rosendahl, 1987). The Halembe horst (part of the KIR) and Kalya horst are NW-SE trending structural highs that, at times of low lake levels, act as water barriers that may separate the lake into 3 separate basins. During periods of high lake stands, anoxic conditions prevail preserving the organic matter accumulating in the sediment column, which is useful for studying lake productivity through time.
**Figure 1:** NP01-MC1 from the slope South of the Mahale Mountains comparing stratigraphy to percentages of organic and inorganic carbon and water content.

**Figure 2:** Constraining GC and MC Overlap

The carbonate peak in MC-01 does not appear in LT00-02

Bundle thickness patterns allow bottom three bundles of MC-01 to overlap the top three countable bundles of LT00-01

The organic carbon values do not disallow the overlap

This should be checked with 14C dating
The Kalya and Kavala Island Ridges exist in what is assumed to be limnologically distinct water as a result of the presence of the Mahale Mountains on the eastern shore of Central Lake Tanganyika that act as a divide to watersheds feeding the lake. Drainage patterns are altered by the >1500m high mountain range, which provides different sediment input to the northern and southern parts of the central lake, given that both ridges are approximately 20km removed from terrestrial input. Wind patterns have been affected by the mountain range and given the season on Lake Tanganyika, southerly winds in the dry season and northerly winds in the rainy season have limnological influences on each location in this study (Plisnier, 2001).

In 2000, NYANZA PROJECT staff and students retrieved gravity cores from the Kalya slope and horst and focused their study on organic geochemistry, stratigraphy, and lamination bundle thickness contained within. This summer, multi-cores were taken on the Kalya slope and horst to capture the sediment/water interface in order to supplement last year’s study. Also this year, gravity cores were obtained from the Halembe slope and horst, and through additional geochemical and stratigraphic analyses, sediment from the Kalya Ridge and KIR can be juxtaposed in an attempt to illustrate the sedimentological differences between these two contrasting depositional environments of Lake Tanganyika.

Methods

Multi-cores and gravity cores were collected aboard the *M/V Maman Benita* during an eight-day research cruise. The multi-core apparatus, which allowed recovery of four cores per site, was employed on the Kalya slope and horst (Figure 1). At each of these sites, one core was archived, a second was studied for CH$_4$ and CO$_2$ gas concentrations (Ochola, 2001), another was sub-sampled by slicing 1-cm slabs for geochemical analyses, and the final core was taken for stratigraphic analysis (NP01-01-MC[a-d] water depth 303m, core length 57cm) and (NP01-02-MC[a-d] water depth 613m, core length 53cm). In 2001, two additional gravity cores were exhumed from Lake Tanganyika: one from the Halembe slope (NP01-GC01, water depth 395m, core length 142 cm) and another from the Halembe horst (NP01-GC02, water depth 306m, 160cm) (Figure 4). At the TAFIRI research facilities in Kigoma, Tanzania, these sediment cores were split into working and archive halves. After the cores were photographed and studied for stratigraphic relationships, they were sub-sampled for organic and inorganic carbon (OC and IC respectively). Since the sediment/water interface was preserved in these gravity cores, they were sampled in 1cm intervals from 0--50-cm downcore; from 51-cm—150-cm the cores were sampled in 5cm intervals.

Using the Loss on Ignition (LOI) method, samples from both multi-cores and gravity cores underwent drying in a 60°C oven, followed by firing in a muffle furnace at 550°C (OC) and 925°C (IC). Percentages of organic carbon and carbonate were determined using the following equations (modified from Zilifi and Eagle, 2000 Nyanza Report):

\[
\frac{(\text{Pre-fired sample weight} - 550 \text{ fired sample weight})}{\text{Beginning sample weight (after drying)}} \times 100 \times R_{OC} = \%OC
\]

\[
\frac{(550 \text{ fired sample weight} - 925 \text{ fired sample weight})}{\text{Beginning sample weight (after drying)}} \times 100 \times R_{IC} = \%IC
\]

\*R$_{OC}$ and R$_{IC}$ are correction factors based on the percent of carbon in organic matter and the carbonate fraction where R$_{OC}$ is 0.40 (CH$_2$O) and R$_{IC}$ is 0.12 (CaCO$_3$). These values are used in the equations above in the absence of known organic and carbonate matter for each sediment core from both Kalya and Kavala Island Ridges (Zilifi and Eagle, 2000 Nyanza Report).

Lamination light and dark bundle measurement of cores NP01-MC1 and NP01-GC02 was completed to compare with Cohen et al. (manuscript). Representative light and dark bundles from each core were dissected into light and dark laminae for geochemical, stable isotope, and diatom analyses.
Figure 3
NP01-MC02
Horst
Southern Mahale

<table>
<thead>
<tr>
<th>Length (cm)</th>
<th>% OC LOI corrected</th>
<th>% IC LOI corrected</th>
<th>% Water Content</th>
</tr>
</thead>
<tbody>
<tr>
<td>0</td>
<td>6</td>
<td>7</td>
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</tr>
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</tr>
<tr>
<td>50</td>
<td>100</td>
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</table>

Figure 4
NP01-GC2
Slope
Northern Mahale

<table>
<thead>
<tr>
<th>Length (cm)</th>
<th>% OC LOI corrected</th>
<th>% IC LOI corrected</th>
<th>% Water content</th>
</tr>
</thead>
<tbody>
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</table>

Legend:
- Dark bundle
- Light bundle
- Unusual light
- Laminated clay
- Grass fragment (130cm)
Results

For the multicore NP01-MC01 and gravity core NP01-GC02, percents of organic carbon, inorganic carbon, and water content were juxtaposed to its related stratigraphic column. Organic and inorganic carbon percentages have been corrected for loss on ignition error.

NP01-MC1—Kalya Slope (Figure 1)

Percent water content of this core ranges from ~85% to ~96%, differing throughout the length of the core. Water content is relatively low from 4-8 cm (88-89%), 15 cm (89%), 44 cm (85%), and 49 cm (84%) and high at 13 cm (94%), 27 cm (95%), and 41 cm (96%).

Percent of inorganic carbon values are very low, commonly less than 0.5% down the core. There is a spike of inorganic carbon at 3 cm (1.3%) but values return to ~0.5% above this depth.

Percent of organic carbon values range between ~5.5% and ~9.5% throughout the length of this slope core, but above 17 cm downcore organic carbon is more constrained between ~7.5% and ~9.5%. Below 17 cm, values appear to be more erratic between the percentages.

The stratigraphy of this core displays light and dark bundles of laminated material, similar to that described by Cohen, et al. (manuscript). Thickness of the bundles ranges from 1.5 to 8.0 cm. Visual inspection of the stratigraphic column and water content curve displays an apparent covariance between dark bundles and lower water content.

The bottom three bundles (dark, light, dark) are 2.0, 3.5, and 1.5 cm thick, respectively. These values are similar to the values for the top three bundles of core LT00-02, (dark, light, dark) at 2.1, 5.55, and 1.29 cm respectively. Because of the similarity of values, and because LT00-02 coring seems to have over penetrated the 3cm-deep inorganic carbon anomaly, we are using this bundle thickness data to approximate the overlap between gravity core LT00-02 and multicore NP01-MC02 (Figure 2).

NP01-MC2—Kalya Horst (Figure 3)

On average, percent water content of this horst core ranges from ~80% to ~95%, however at 46 cm length water content nears a relatively low value of 75%.

Percentages of inorganic carbon remain mostly at 0.4% or less between 10-52 cm, yet there is a spike of IC at 2 cm depth in this core. Above this depth, values return to less than 1%.

Organic carbon values in this horst core range between ~6% and 11.5%, but the majority of the core has OC values between ~8% and 11%.

As of the time of this writing, NP01-MC02 has not been opened for stratigraphic description, although inspection through the core barrel reveals obvious lamination bundles and the sediment/water interface.

NP01-GC02—Halembe Slope (Figure 4)

Percent of water in this core ranges from 75% at 155 cm to 94% at 17 cm and fluctuate between these depths. From 100 cm to the top of the core the sediment consists of approximately 90% water, however below 100 cm, water content decreases to a low value of 75% at 155 cm.

Very low percentages of inorganic carbon commonly between ~0.3% and ~0.5% exist throughout this entire gravity core, however there largest peak of IC occurs at 44 cm (0.6%) with no distinguishable high above this depth.
Figure 5

This figure is the age model used to relate the different values of organic carbon on the Kalya Slope and Horst, showing that sedimentation rates are higher on the slope than on the horst.

Figure 6

Comparison of Two Slope Cores--%OC--South vs. North Mahale Mountains

Kalya Slope

Halembe Slope

Depth (cm)
Organic carbon percentages range between ~6% and ~10% for the whole length of the core. Above 60 cm depth, OC values are constricted between ~6% and ~9% yet below 60 cm, values are more variable from 6% to ~10%.

The core bottom up to ~120cm is composed of massive then laminated greenish-black clay. A grass fragment was found at 130cm, and will be radiocarbon dated. Above this there is a transition to light and dark laminated material that appears to have been deposited rhythmically, which will be tested by lamination counting and Fourier transform analysis.

NP01-GC01- Kavala Horst (no figure)

The Kavala Horst core was opened on the last day of the 2001 Nyanza Project. Briefly, the bottom of the core contains laminated grayish black clay from 142-124cm, overlain by non-laminated massive gray clay from 124-70cm depth. There is a transition to clumpy clay laminasets, interbedded with discontinuously (whispy) laminated (brown, black and white) sets. This comprises 70 to 45cm. The top of the core displays the light and dark bundles characteristic of many of the cores in this part of the lake (e.g. Ellis, et al., 2000).

Discussion

In obtaining multicores from South of the Mahale Mountains and gravity cores north of the Mountains, two different types of comparisons can be made. First, the multicores retrieved this year (NP01-MC01, MC02) can be used to complement sediment/water interface data that was lost in the acquisition of gravity cores last year during the 2000 Nyanza Project; this comparison will be termed ‘Slope—Horst Comparison.’ A second evaluation of the cores taken this year will be to study the similarities and differences of gravity cores North and South of the Mahale Mountains. Gravity core NP01-GC02 from the Halembe slope will be compared to NP01-MC01 and LT00-02 (a combination core from the Slope—Horst Comparison); this will be termed ‘Slope—Slope Comparison.’

Slope—Horst Comparison

The water content of both multicores is very similar down the length of the cores. There seems to be a similar trend from high water content at the top of the cores to lesser percent water content near the bottom of the cores, however this trend is more prevalent in NP01-MC02 than in MC01. Percent of water in samples throughout the core may be related to the different types of bundles where light bundles have more water in them than do the dark bundles.

Percentages of inorganic carbon are very low in both of the multicores, however, there is one interesting pattern seen near the top of the core. In both IC curves, there are very low values until there is a jump in inorganic carbon at 3 cm depth. Cohen, et al (1997) have found that the surface waters of Lake Tanganyika are supersaturated with respect to calcium carbonate. The carbonate anomaly may be attributed to an episodic whiting event (biomediated calcite precipitation), a brief change in the depth of the Calcite Compensation Depth, or it may be related to active carbonate reduction processes in the sediment column (Talbot and Kelts, year).

At a first glance, organic carbon values show a similar trend through the length of the two cores, however the curves must be corrected for different sedimentation rates on the slope and horst (discussed below). When juxtaposed on a depth scale, organic carbon does appear to be higher on the Kalya horst than on the slope.

Sedimentation rates are much slower on the Kalya Horst than on the slope, therefore the horst sediment represents much more time than the slope sediment does (Cohen et. al; manuscript). Therefore, the curves for organic carbon cannot be compared in relation to depth. In order to compensate for this inconsistency, an age model must be compiled to relate the different values of organic carbon (Figure 5). Still, organic carbon values are higher on the horst than on the slope.
**Slope—Slope Comparison**

Inorganic carbon values for NP01-GC02 again show very low values, however, compared to the Kalya Slope, the Halembe Slope does not show a spike in IC at 3 cm. Actually, percentages remain stable through the length of the core.

Organic carbon percentages can be compared from the combination core (NP01-MC01 and LT00-02) on the Kalya Slope to the gravity core (NP01-GC02) from the Halembe Slope (Figure 6). Above 60 cm, both cores show similar organic carbon values between ~6% and 9%. Below 60 cm depth, the organic carbon curves do not appear to be correlated. The Halembe Slope appears to have an asymmetric shape in its’ organic carbon curve while the Kalya Slope remains mainly constant.

**Conclusions**

From comparisons between slope and horst sediment South of the Mahale Mountains, as well as slope sediment between the KIR and Kalya Ridge, North and South of the mountains respectively, conclusions about depositional environments can be made about different patterns on Lake Tanganyika.

Organic carbon values have been shown to be higher on the Kalya horst than on the slope, and also sedimentation rates are slower. Since dilution of the organic matter with terrestrial input is less common on the horst than on the slope, these percentages of OC appear to be correct.

The two slope long cores show very different deep-core organic carbon patterns, but they behave similarly higher up in the sediment column. This points to different depositional environments between these sites some time in the geologic past, but the environments have converged to show similar patterns more recently.

The differences seen between the North and South Mahales are inferred to be due to orographic effects on microclimates and different wind mixing patterns related to the rainy and dry seasons on Lake Tanganyika.

**Future work**

Lamination composition and thickness will be measured on core NP01-MC01 and NP01-GC02. Grain size analysis, as well as C/N and stable isotope analyses, will also be completed on all cores in this study. The gravity core from the Halembe horst (NP01-GC01) north of the Mahale Mountains will be studied for organic/inorganic carbon, C/N ratios, and other geochemical analyses. This data will provide information that can be compared to cores obtained from the Kalya Horst to show the effects that the Mahale Mountains have on sedimentation in Central Lake Tanganyika.

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