

# **An examination of factors controlling biogenic silica preservation in modern sediments from east-central Lake Tanganyika, East Africa**

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## **Introduction**

The biogenic silica (BSi) content of sediments has been used to infer past primary productivity in marine and lacustrine systems (Johnson et al., 2002; Verschuren et al., 2002). Biogenic silica is derived from the fossil remains of diatoms, sponge spicules, and plant phytoliths; however, diatoms make up the overwhelming source of BSi in most aquatic systems. Diatoms are important primary producers in Lake Tanganyika, comprising on average 12-15% of phytoplankton chlorophyll A in the upper 20 m in the southern basin and Kigoma area (Climlake, 2005). Although BSi abundance in historical sedimentary records can be a powerful primary productivity indicator when applied carefully, it is essential to have a thorough understanding of the physical and chemical processes involved in the production, transport, and preservation of BSi in sediments before interpreting past sedimentary records.

Biogenic silica accumulation in sediments may be controlled by several biological, chemical and physical factors. Most importantly, diatom productivity must be high enough for diatoms to reach the sediments in a quantifiable abundance, which requires sufficient nutrients such as SiO<sub>2</sub>, phosphorous and nitrogen within the photic zone. Assuming that initial diatom productivity is sufficient, several chemical characteristics of the water column provide more or less suitable conditions for BSi preservation. The thermodynamics of silica solubility suggest that biogenic silica dissolution in natural waters is controlled by pH and secondarily by temperature and pressure (Stumm and Morgan, 1996). Highly alkaline, high pH (especially pH>9.1) conditions will increase silica dissolution as the diatoms fall through the water column (and at sed-H<sub>2</sub>O interface). Bacterial grazers may also increase the dissolution of diatoms by removing the protective organic layer surrounding the diatom frustule and exposing that silica to dissolution in undersaturated waters (Van Cappellen et al., 2002). Residence time of diatoms in the epilimnion will control its exposure to these processes.

Diatom frustules are typically fine grained (< 30 μm) and have a density much lower than siliciclastic sediments. Although benthic diatoms are capable of attaching themselves to their substrate, pelagic diatoms are free-living in the water column and are therefore subject to the physical sedimentation processes acting on sediments of their size class. Wave action will transport diatoms and other fine-grained material into deeper, lower energy environments where they can accumulate in sediments (Johnson, 1980).

It is unclear what role oxygen plays in sedimentary diatom preservation, however, and all other factors being equal, changes in pH cannot explain the patterns of biogenic silica preservation seen previously in sediments of other rift lakes (Powers, unpubd. data; J. Russell, unpubd. data). Oxidic waters above the sediments may facilitate increased microbial attack on diatoms resulting in increased dissolution (Van Cappellen et al., 2002). Alternatively, the presence of oxygen at the sediment-water interface may facilitate other microbially-mediated reactions that enhance the dissolution of biogenic silica.

Lake Tanganyika, East Africa, lies at approximately 3.5° – 9° S and is an old and deep clear-water lake. The southern end of the lake is dominated by southerly winds during the dry season, resulting in upwelling in the southern basin and high primary productivity. The relaxing of the seiche created by the southerly winds results in secondary upwelling in the north basin causing increased productivity on a cycle of approximately 28-33 days in austral spring (Plisnier, 1999).

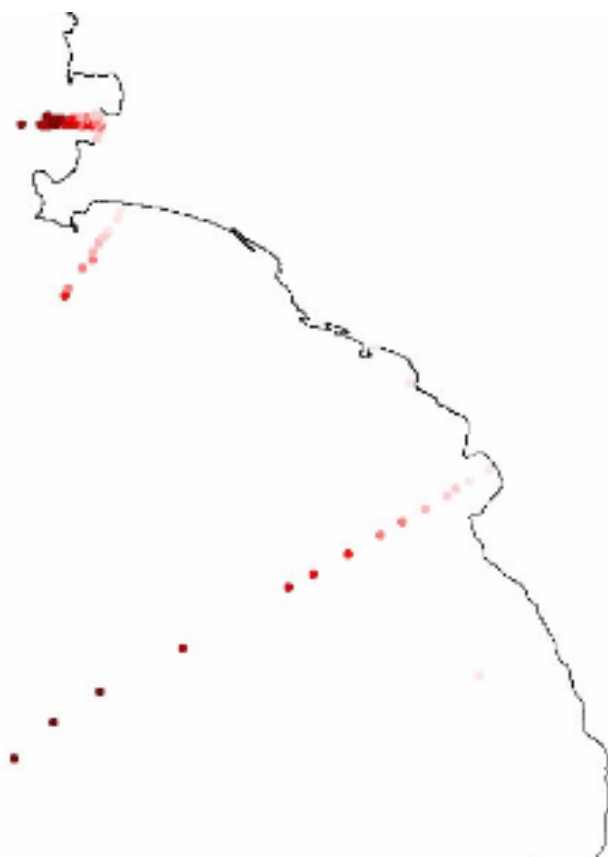
The epilimnion in north-central Lake Tanganyika has a mean SiO<sub>2</sub> concentration of ~ 1.0 mg/L (Climlake, 2005) over an annual cycle, which suggests that diatom productivity is not limited by silica availability. Diatom productivity is highest during the dry season (June-September) offshore from Kigoma (Climlake, 2005), when increased winds cause localized destabilization of the thermocline delivering nutrients to the epilimnion. Productivity is extremely low during the rest of the year.

Recent evidence of global warming in Lake Tanganyika (O' Reilly et al., 2003; Verburg et al., 2003) has resulted in an increasingly shallower thermocline. Increased periods of stable stratification in Lake Tanganyika will reduce the recycling of nutrients, including silica, from the hypolimnion to the epilimnion, resulting in nutrient limitation for primary producers. This will result in decreased diatom productivity and may provide a climate change signal in sedimentary records from Lake Tanganyika.

Here we examine BSi abundance in modern sediments over a depth and oxygen gradient to determine the effects of these factors on BSi preservation and to improve our understanding of BSi preservation in relation to its use as a paleoproductivity and paleoclimate indicator.

## Methods

Surface sediments were collected using a ponar grab sampler aboard the *R/V Echo*, operated by the Tanzania Fisheries Research Institute (TAFIRI). Sediments were collected along East-West transects at 2 sites along the east-central shores of Lake Tanganyika, Tafiri Bay and the Southern Luiche River platform (Fig. 1). Two transects totaling 25 surface sediment grab samples were collected in Tafiri Bay. Two transects were also collected on the Luiche Platform, totaling 21 surface sediment grab samples. Sedimentation rates in Tafiri Bay are estimated to be ~ 1mm/yr (A. Cohen, unpubd. data).

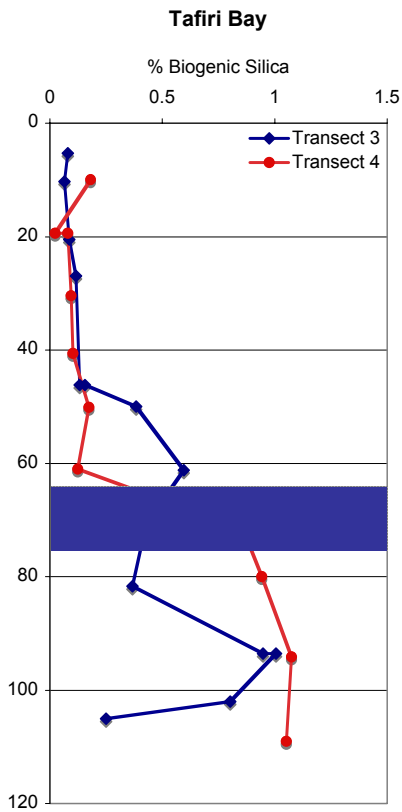


**Figure 1.** Surface sediment grab sample locations in Tafiri Bay, N. Luiche Platform and S. Luiche Platform, respectively, from north to south.

Sediments were dried at 60 °C and pulverized with a mortar and pestle. BSi analyses were conducted using a single extraction technique similar to Mortlock and Froehlich (1989). Sediments were digested in 40 mL of 0.5 M NaOH at 85 °C for 60 minutes, and a 4 ml aliquot of this solution was removed and added to 16 ml de-ionized water; some

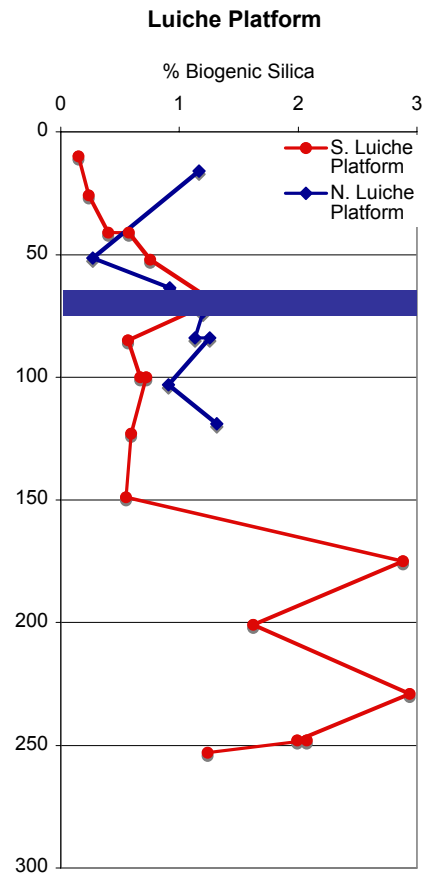
samples required further dilution to be within range of the Hach analytical method. A 10 ml aliquot was analyzed spectrophotometrically using HACH method 8186 (LR Heteropoly Blue Method 0.1-1.6 mg/l SiO<sub>2</sub>) for low range silica analyses. Data is presented as weight percent of biogenic silica of total sediment.

## Results



### Tafiri Bay

The weight percent of biogenic silica in the sediments from Tafiri Bay range from 0.01-1.07 % (Fig. 2). In transect four, the southernmost Tafiri Bay transect, %BSi increases substantially below ~ 60 m water depth. The increase in BSi at this water depth is coincident with the depth of the oxycline at ~ 70 m (Nyanza Report, 2005). Transect three shows a slightly different pattern with % BSi increasing moderately at ~ 50 m and then increasing to ~ 1% at 90 m, then decreasing to ~ 0.2 % in deeper water (105 m).



### Luiche Platform

Surface sediments on the Luiche Platform range in biogenic silica content from 0.1-2.9 %. The N. Luiche Platform site was only sampled to 119 m and does not exhibit a clear increase in sedimentary BSi with depth or decrease in oxygen. The S. Luiche Platform transect shows a clear increase in BSi content below 150 m. The oxycline in this region is from 65 to 74 m.

Exploration with linear regression suggests that there is no significant relationship between %BSi and bottom water oxygen content within any of the transects.

## Discussion

Overall the results of this study suggest that diatom productivity is extremely low in these regions of Lake Tanganyika. Although diatoms are known to be a substantial component of sediments in the north and south basins (Hecky, 1991) comprising ~50% of the sediments in southern Lake Tanganyika (J. Russell, unpubd. data), they appear to be much less abundant in the sediments and, probably, the plankton of the east central regions of the lake.

Oxygen concentration in the bottom water appears to be uncorrelated to BSi concentration in the sediments in east central Tanganyika, particularly on the Luiche Platform, where BSi accumulations do not increase until ~ 80 m below the oxycline. In Tafiri Bay the depth of the oxycline does coincide with an increase in % BSi along transect 4; however, the lack of this correlation at transect 3, only ~200 m to the north, suggests that this may be coincidence and is likely controlled by another factor.

It is likely that storm wave depth is the primary control on BSi sedimentation in this region. Fine particulates such as diatom frustules should be transported beyond ~ 50 m during average storm activity (Zhang, 2005; Hartwell and Florence, 2005). This would explain the increased BSi at depth in the Tafiri Bay area. The S. Luiche Platform is a very gently sloping environment with increased turbidity in shallow water. It is yet unclear what drives the increased BSi below 150 m in this region of the lake.

Taken together, the results above suggest that changes in sedimentary BSi concentrations through time (in cores) are more likely controlled by changes in diatom productivity than by changes in water level. To the extent that diatom productivity reflects algal productivity in general in Lake Tanganyika, these results suggest BSi as a potentially useful paleoproductivity indicator in central Tanganyika. In addition, the results of this work emphasize the importance of careful site selection when initiating a paleoclimate study in a large dynamic lake. A thorough understanding of the factors controlling primary productivity and the sedimentary processes controlling sediment dispersal are necessary when choosing an adequate coring site for reconstructing past primary productivity.

## Acknowledgements

I would like to thank the Geo Team for their committed effort to sample collection and analysis, which has resulted in an excellent holistic research project on Tafiri Bay. R.J. Hartwell kindly provided Figure 1. Thanks to Mupape, Issa, and the crew of the *R/V Echo* for keeping our fieldwork moving along on somewhat choppy seas. This research was supported by NSF grant ATM-0223920.

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