

# Nutrient assessment from Sediment pore waters at Kigoma Bay, Lake Tanganyika

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## INTRODUCTION

Lake Tanganyika has one of the world's richest ecosystems yet remains only partly understood. It has low nutrient levels but high fisheries production (Coulter, 1991). The hydrodynamics of the lake are relevant to its nutrient regime, because physical movement of water is the major factor which leads to translocation of dissolved nutrients (Hutchison, 1975).

Nutrients are chemicals essential for primary production (Coulter, 1991). Sources of nutrients include regeneration from decomposition of aquatic plants and primary producers in the water column and substrates, mixing processes between the sediments and the overlying waters, terrestrial sources such as domestic sewage, fertilizer leached soils or precipitation of particulate matter (Wetzel, 1983). Movement of nutrients from the sediment column to the water column is an important process whose significance depends upon the efficiency of the mixing mechanism. Bioturbation, diffusion, internal waves and thermal gradients can induce mixing. Nitrogen, silica and phosphate may be limiting factors for primary production. They occur in different forms. Phosphorus occurs mainly as orthophosphate. Nitrogen occurs mainly as nitrate, nitrite, ammonia and as ammonium ions.

Coarse-grained surface sediments, such as sand and mixtures of silt and sand, contain typically about 30 to 40% water. Fine-grained surface sediments, such as silty clays found in lake depositional areas contain about 90 to 95% water (Adams, 1994). Some of this water is held by surface forces such as adsorption and capillarity and is bound to the crystalline lattice of minerals in the sediments. The rest of the water filling the space between particles is called **pore water** or interstitial water (Adams, 1994). Bottom sediments in natural systems are formed by sedimentation process. During this process, water is trapped and entrained in the sediment, forming the **pore water** or interstitial water (Batley and Giles, 1979). During the sedimentation process, chemical species that were found in the water column and adsorbed to the suspended sediment will also be trapped in the bottom sediment. Due to diagenetic processes such as precipitation, adsorption, reduction, remobilization, biological degradation and biological uptake, the concentrations of nutrients in the pore water are higher than the overlying water. (Bufflap and Allen, 1994).

### *Statement of the Study*

Nutrient concentrations in sediment pore waters have so far received very little attention in Lake Tanganyika according to the literature survey from Nyanza reports and other studies. Adams and Charles (2000) in their studies on chemical analysis of deep waters of Kigoma sub-basin and Kalemie sub-basin of

Lake Tanganyika observed that conductivity increased with depth due to increased ions (nutrients) in the water column, particularly below the thermocline. A study by Ramadhani (2000) on nutrients distributions at Kigoma station shows that nutrients showed a strong vertical gradient in the water column resulting from the Lake's meromictic state. High nutrient values observed below the thermocline were probably caused by regeneration from particulate matter sedimenting from the epilimnion. Since most of the nutrients and chemicals (including organisms when they die) under normal circumstances tend to accumulate in the sediments, which later settle down at the lakebed, the study will address nutrient concentration in the sediment pore waters.

### *Objectives of the Study*

- To evaluate the contribution of sediment pore water to nutrient concentrations in the overlying hypolimnetic water.
- To study diagenetic processes taking place in the sediments.

### *Hypotheses*

Sediment pore water contains higher concentration of nutrients than the overlying water column.

## METHODS AND MATERIALS

### **Field Work**

Sediment cores were collected using a Benthos gravity corer deployed with crane and winch from aboard the *M/V Maman Benita* on 14 July, 2004 in Kigoma Bay from a depth of 137m at S04.87692, E029.59011. The cores were taken from an anoxic area with little or no slope, and the chosen site was located a sufficient distance from the influence of river discharge to avoid complications from variable sediment inflow (Lewis, 2002). A Raytheon echo sounder and cable-mounted meter were used to measure depth, and latitude and longitude were determined using a hand-held GPS (Global Positioning System) unit.

Sediment cores were collected into 2m long cylindrical polybutarate liners. The 118cm long collected core was capped and held in a vertical position while the length was measured. Water overlying the sediment-water interface was immediately siphoned off into vials for geochemical analysis. The cores were brought upright to the Nyanza Project research facilities at TAFIRI (Kigoma, Tanzania) and stored vertically. Cylindrical corers were chosen over other types of corers because they are easier to handle, especially in deep waters. They also provide samples that may be sealed to prevent oxidation of anoxic sediment (Bufflap and Allen, 1994).

### **Laboratory Work**

The 2 m sediment cores were sectioned into 1 cm thick slices, from which pore water was recovered. A piston inserted into the

bottom of the core liner was used to force the sediments upward along a graduated wood bar. The 1cm thick slices were spooned into whirl packs and immediately stored at 4°C in the project refrigerator. The cores were extruded while in vertical position to avoid mixing of the soft, surficial sediments that possess a high water content.

Various methods are commonly used for collection of pore water and potential artifacts from their use. Squeezing as one of the *ex situ* methods was used for pore water removal from the sediments (Adams, 1994). Squeezing was chosen over other *ex situ* methods because it offers relatively inexpensive and simple means of extracting sediment pore water. (Bufflap and Allen, 1994). A low-pressure mechanical squeezer (5 ton hydraulic jack) supported by a wooden screw frame for pressure control was used to force pore water through a 0.47µm. bottom filter and **exit port** of a stainless steel pore water squeezer into a disposable syringe (with in-line filters) mounted at the bottom of the device. At least 45 minutes were usually required to extract 5-7 ml of pore water from the core. Extracted pore water was filtered using Acrodisc® Syringe Filter 0.45µm Supor® Membrane then stored in rinsed plastic bottles ready for immediate analysis, eliminating a handling step, which may introduce contamination to the samples. However, vacuum filtration method was also used to obtain water out of the sediment pores, in order to speed up the pore water extraction process.

#### Chemical Analysis and Organic Matter Determination

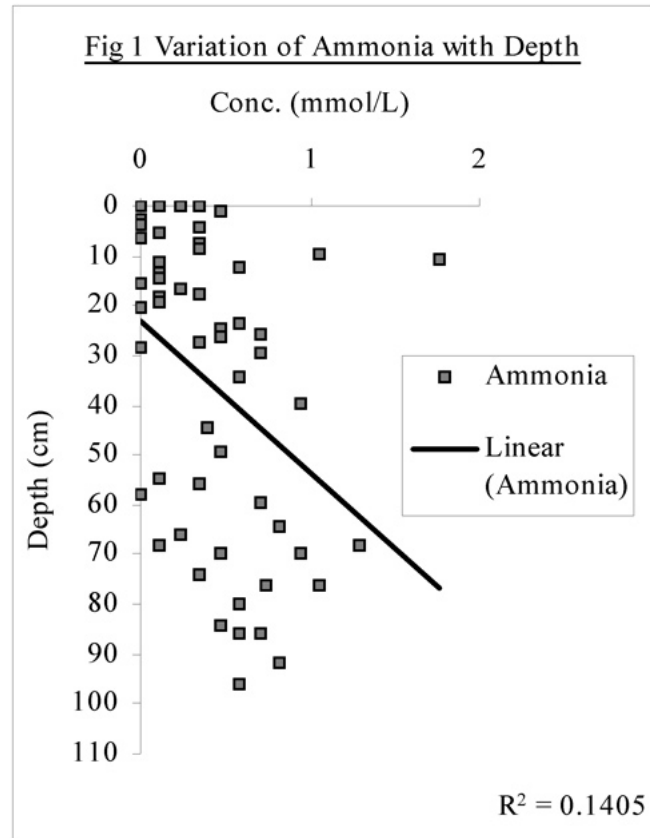
Laboratory analysis was performed following standard methods as described in the HACH Model DR/2400 portable spectrophotometer manual. Ammonia was measured with the Salicylate Method for high range ammonia (Program selected was 343 N, Ammonia HR TNT). Silica was analyzed with the Heteropoly Blue Method for low range (651 Silica LR program) and Silicomolybdate Method for high range (656 Silica HR program). Soluble Reactive Phosphorus (orthophosphate) was measured using the PhosVer®3 Method (535 P React PV TNT Program). Nitrate was analyzed using the Cadmium Reduction Method for low range (351 N, Nitrate LR). Ferrous iron was analyzed with the 1,10 Phenanthroline Method (255 Iron, Ferrous program) and alkalinity was measured using titration with sulfuric acid after addition of phenolphthalein.

For organic matter determination, as described by Bosworth et al. (this Report) a representative portion of the squeezed sediment sample was transferred into a pre-weighed aluminium foil and sample weight (A) was determined using an analytical balance. Samples were transferred into a drying oven at 110°C for 24 hours. After cooling, samples were weighed (B) then combusted at 550°C for 2 hours to remove organic matter. The samples were re-weighed (C) and organic matter percentages were determined as follows:

$$\% \text{ OM} = \frac{(B-C)}{(B-A)} * 100$$

## RESULTS AND DISCUSSION

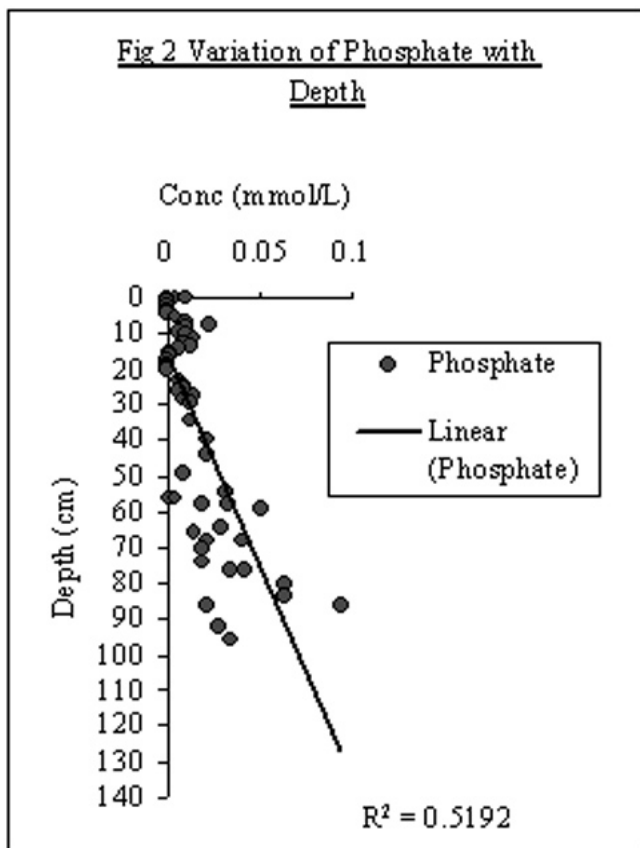
Pore water concentrations versus depth for ammonia, silica, phosphate, ferrous iron, nitrate, alkalinity and organic matter concentrations in the sediments are shown in Figures 1-7. There is an upcore decrease in ammonia concentrations, which levels off at about 15cm: this trend was similar in phosphate and silica profiles. Alkalinity and organic matter concentrations increase with depth while ferrous iron and nitrate concentrations decrease with depth. In fact, ferrous iron is absent in the sediments below 24cm. The nitrate concentrations are probably due to the oxidation of ammonia during storage and sample processing.



The distribution of organic matter degradation produced in pore waters (total carbonate, ammonia, phosphate) shows a near surface peak and a regular increase at deeper sediments levels (Spagnoli et al., 1997).

Phosphate concentration was between 0-0.0947mmolL-1. Phosphate positively correlated with silica and organic matter and negatively correlated with Iron (II) concentrations.

Lake bottom sediments can act as both sources and sinks for phosphate relative to the overlaying lake waters, depending on the redox and pH conditions and sedimentary iron concentrations and organic matter degradation. Organic degradation is a result of microbial activity. This results in a release of phosphate in the pore waters. (Cohen, 2003). Phosphates are readily adsorbed onto iron hydroxides. Under reducing conditions, iron (III) is reduced, releasing adsorbed phosphate into the pore waters. The influence of the reduction process of Fe hydroxides on phosphate regeneration in the uppermost sediments (i.e.



from 5cm and below) is confirmed by the profile of  $\text{PO}_4$ : Fe (II) (Figure 8). The  $\text{PO}_4$ : Fe (II) decreases rapidly in the solid phase and a gradual rise in the phosphate concentrations occurs at the same time. Spagnoli et al. (1997) also observed similar trends.

Silica is essential for the growth of diatoms, and its consumption, depletion, and cycling in lakes are closely tied to mixing and diatom productivity (Cohen, 2003). As diatoms die, they sink and redissolve in the water column. Dissolution rates in the water column decline as the concentration approaches saturation, so most dissolution occurs near the surface and decreases toward the lake floor and in the sediments. A lack of secondary consumption below the mixed layer causes most meromictic lakes (e.g. Lake Tanganyika in this case) to have relatively high concentrations of silica in their sediments, which are effective sinks for silica. The silica concentrations ranged from 0.1997-1.8640  $\text{mmolL}^{-1}$ . The silica concentrations increase in the few upper centimeters (due to the dissolution of the biogenic silica) and the highest concentration is near the bottom of the core. This may be due to diffusive fluxes from the top pore waters (Lyons et al., 1996). The silica concentrations were high, nearing saturation, suggesting mineral precipitation as an important sink for silica.

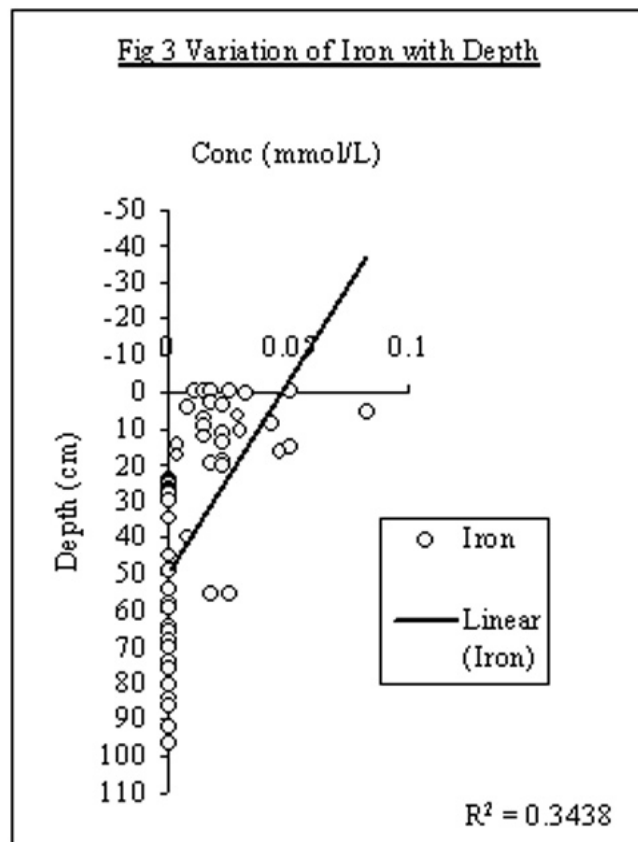
Ferrous iron had a concentration range of 0.00-0.0824  $\text{mmolL}^{-1}$ . The fact that the core was from the depth of 137m having very little oxygen (0.72  $\text{mgL}^{-1}$  – Kuboja, this Report), explains the fact that the iron (II) concentrations were high. This was because of either the dissolution of more crystalline Fe hydroxides, or because diffusive fluxes from the sediment-water interface caused a weak increase in the Fe concentration (Spagnoli et al., 1997). Iron (II) and phosphate are inversely correlated, although this data pattern may result from processing of the

samples, both retrieving sediment samples from the core and the analysis of the ferrous iron, which was done in the presence of oxygen.

The concentration of ammonia was in the range of 0.00-1.7651  $\text{mmolL}^{-1}$  and the concentration increased with depth. As the organic matter concentrate in the sediments decomposes, ammonia is released into pore waters. This process is called remineralization and results in ammonia being adsorbed to sediment particles. Ammonia diffuses into water and/or oxidized to nitrate. A large percentage of the nitrate produced in the sediments is denitrified. In many fresh water sediments much of the organic nitrogen mineralized in the sediments is lost through nitrification and denitrification (Wetzel, 2001).

When appreciable amounts of sedimenting organic matter reach the hypolimnion of the lake, ammonia can accumulate. The accumulation of ammonia greatly accelerates as the hypolimnion becomes anoxic. In the sediments a large percentage of the ammonia is adsorbed on the sediment particles. The high ammonia content suggests high rates of sedimentary remineralization, suggesting that sediments are an important source of nitrogen to the overlying waters. The low concentrations of nitrate were due to the oxygenation of ammonia when processing the sediments.

Alkalinity decreases in the water column near the surface due to carbon uptake by the autotrophs and increases again below, in the hypolimnion and in the sediments, because of the heterotrophs that respire and also because of sulphate reducers that contribute to the increase  $\text{HCO}_3^-$  levels in the sediments.



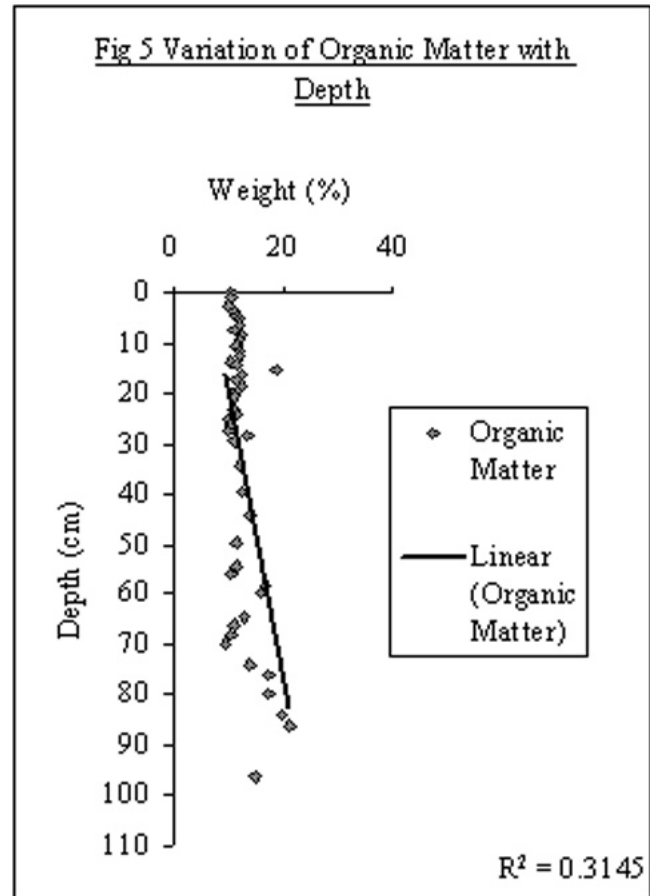
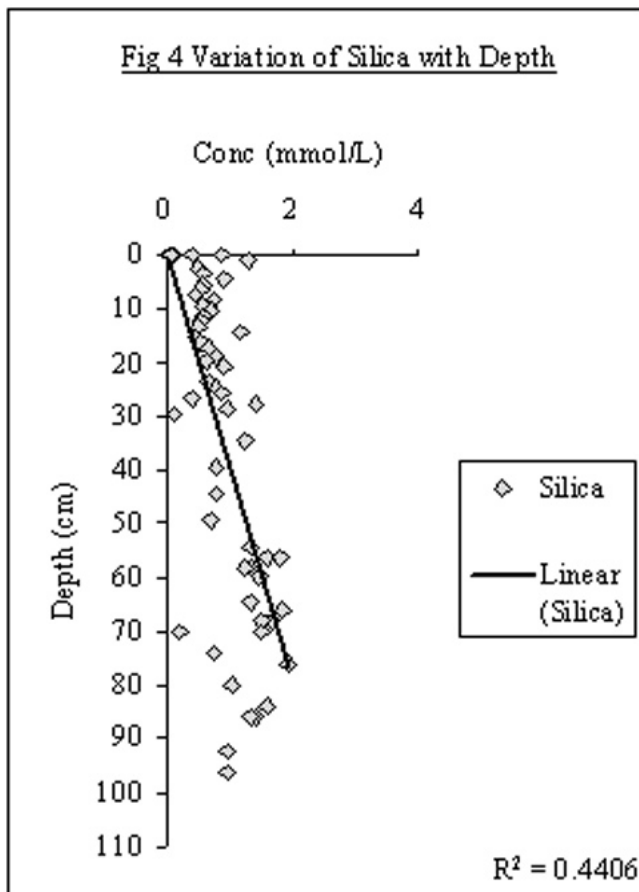
## CONCLUSIONS

The sediment column as an important sink for nutrients and it is likely that during mixing across the sediment-water interface some nutrients may be transported from the sediment column to the overlying water column. The composition of the pore water depends upon the chemistry of the water column at the time of deposition of the sediments. The extent to which this is altered is dependent on the processes taking place in the sediment column at that particular time. The ability of the sediments to retain nutrients depends on the conditions of the overlying water and the biota within the sediments that alters exchange equilibria and effect nutrients transport back to the water.

## RECOMMENDATION

It is important that the anoxic sediments should be handled in an inert atmosphere, usually nitrogen or argon, within a glove bag or glove box when extracting pore water. The time between sampling and processing should be short and desirably fast, this reduces the oxygen contamination of the samples and the reliability of the results as they occur in the sediments. This was seen when processing the test core, (for which the sampling was delayed) and the project core (for which the sampling was done immediately, see Figure 10).

The collection of the pore water from the recovered sediments through *ex situ* methods such as squeezing and vacuum filtration can result in changes in the pore water concentration of dissolved species when collection temperatures differ from *in situ* conditions. An even greater problem is the potential for



oxidation during sample manipulation. To avoid this situation, collection, processing and analysis of pore waters would be better accomplished by squeezing the sediments on board as soon as the core is retrieved (see Figure 9).

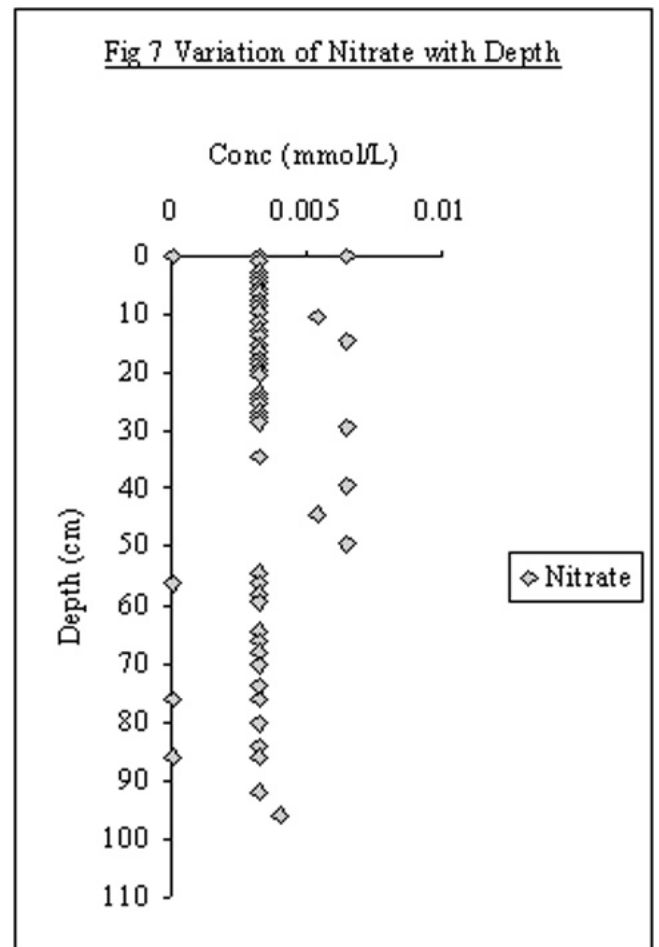
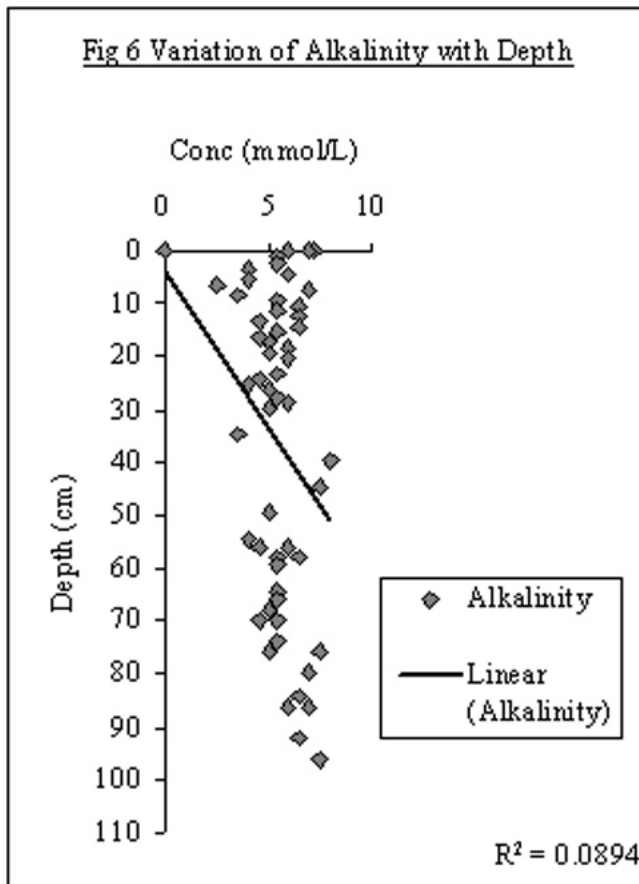
Further studies should be conducted on the effect of temperature on the pore water composition and more samples should be analyzed for different anions and cations.

## ACKNOWLEDGEMENTS

We would like to thank the US National Science Foundation for funding the project (ATM # 0223920). We would like to thank Dr. H. Nkotagu for introducing us to the Nyanza Project and advising us. Many thanks to Willy Mbemba, Jim, Pete and Ellinor for supporting and taking time out of their very busy schedule to advise us and teach us. We thank Dr. Andy Cohen for getting us the necessary equipments for the pore water analysis, Dr. Tom Johnson for volunteering to help us in doing the other analysis which we unfortunately could not do. We are extremely grateful to Dr. Kiram Lezzar and Christine Gans and the entire Geo Team for getting us the core. We would like to acknowledge Bigeyo and Anna to help us with data and methods of measuring the organic matter.

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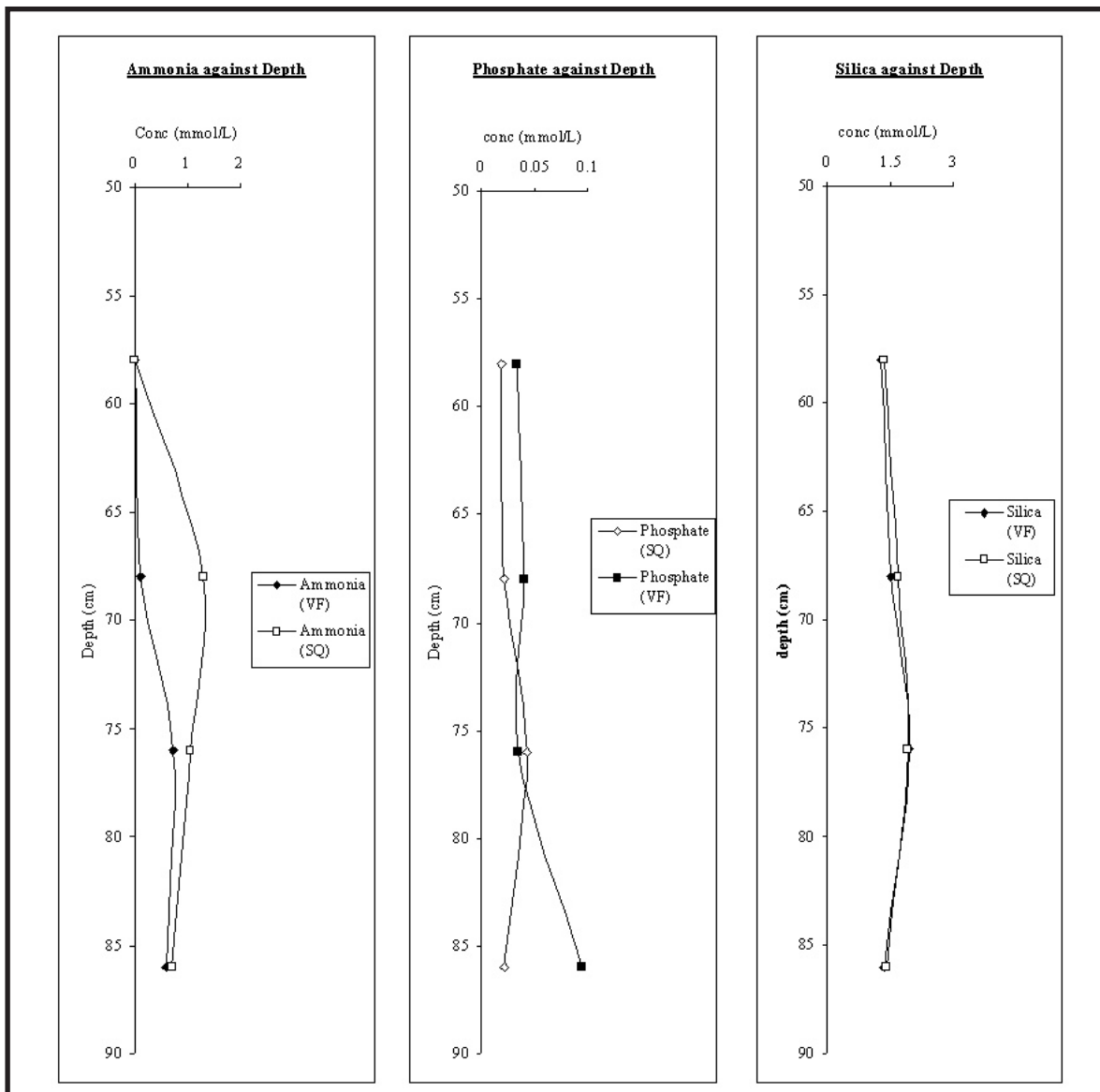
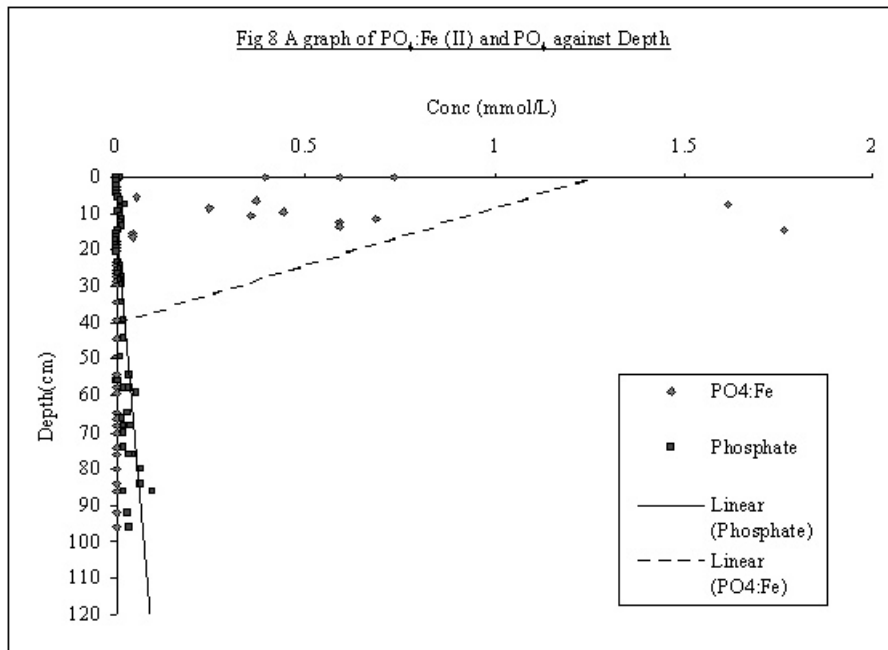
	Mean	Std. Deviation	N
AMMONIA	.4129	.36931	58
PHOSPHATE	.0163	.01849	58
IRON	.0121	.01695	58
SILICA	.9209	.50334	58
NITRATE	.0033	.00142	58
CARBON	12.6117	2.66080	47
ALKALINITY	5.4000	1.52787	58

**Table 1: DESCRIPTIVE STATISTICS**

		AMMONIA	PHOSPHATE	IRON	SILICA	NITRATE	CARBON	ALKALINITY
AMMONIA	Pearson Correlation	1						
	Sig. (2-tailed)	.						
PHOSPHATE	Pearson Correlation	.293	1					
	Sig. (2-tailed)	.026	.					
IRON	Pearson Correlation	-.280	-.447	1				
	Sig. (2-tailed)	.034	.000	.				
SILICA	Pearson Correlation	.217	.461	-.404	1			
	Sig. (2-tailed)	.102	.000	.002	.			
NITRATE	Pearson Correlation	.125	-.031	-.159	-.181	1		
	Sig. (2-tailed)	.350	.816	.233	.174	.		
CARBON	Pearson Correlation	.057	.613	-.111	.305	-.198	1	
	Sig. (2-tailed)	.702	.000	.458	.037	.183	.	
ALKALINITY	Pearson Correlation	.224	.321	-.322	.161	.055	.267	1
	Sig. (2-tailed)	.091	.014	.014	.226	.679	.069	.
	N	58	58	58	58	58	47	58

**Table 2: CORRELATION**

\* Correlation is significant at the 0.05 level (2-tailed)  
 \*\* Correlation is significant at the 0.01 level (2-tailed)



**Figure 9:** Comparison of two methods of extracting pore water (VF:Vacuum Filtration;SQ:Squeezing)

Fig 10a: Comparison of Ammonia Between two cores

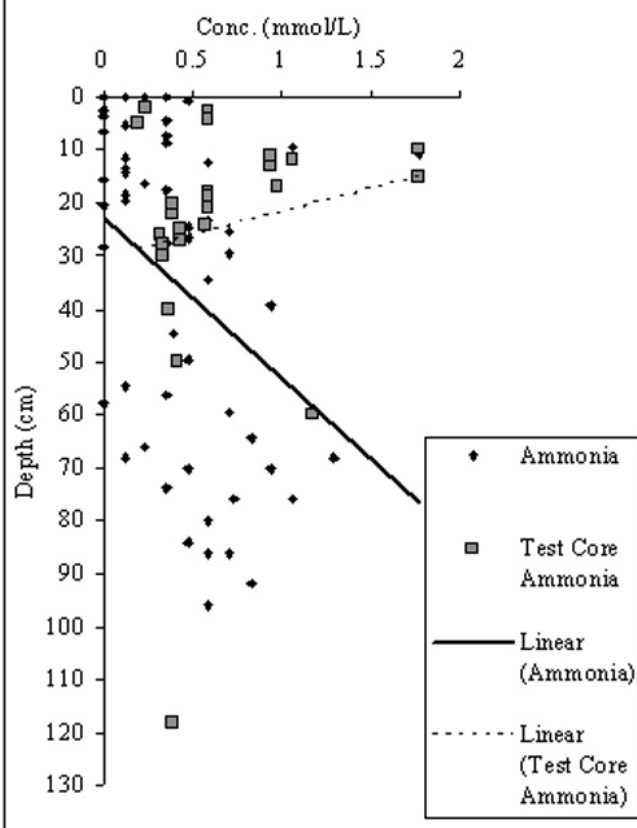


Fig 10b: Comparison of Phosphate Between two cores

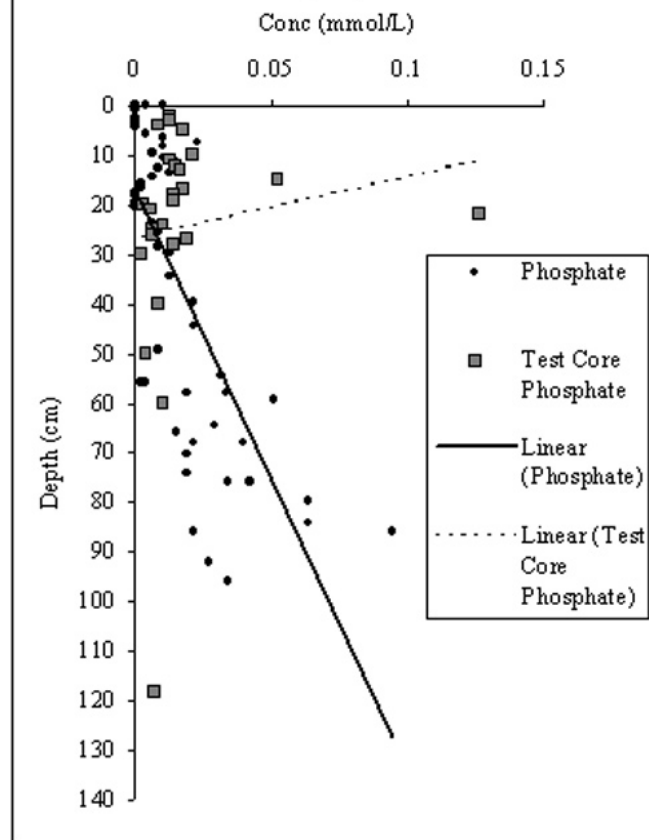


Fig 10c: Comparison of Silica in two Cores

