WEST KITIKMEOT / SLAVE STUDY SOCIETY

Re: Reading Water Quality Record in West Kitikmeot/Slave Sediment

STUDY DIRECTOR RELEASE FORM

The above publication is the result of a project conducted under the West Kitikmeot / Slave Study. I have reviewed the report and advise that it has fulfilled the requirements of the approved proposal and can be subjected to independent expert review and be considered for release to the public.

Study Director

Aug 27/98

Date

INDEPENDENT EXPERT REVIEW FORM

I have reviewed this publication for scientific content and scientific practices and find the report is acceptable given the specific purposes of this project and subject to the field conditions encountered.

Reviewer

Sept. 1/98

Date

INDEPENDENT EXPERT REVIEW FORM

I have reviewed this publication for scientific content and scientific practices and find the report is acceptable given the specific purposes of this project and subject to the field conditions encountered.

Reviewer

Sep - 20/85.
Date

BOARD RELEASE FORM

The Study Board is satisfied that this final report has been reviewed for scientific content and approves it for release to the public.

Oct. 1/98

Chair
West Kitikmeot/Slave Study Society

Date

WEST KITIKMEOT / SLAVE STUDY

Final Report for

Results from Sediment Cores Collected from an Arctic Tundra Lake, Northwest Territories

Submitted by

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January, 1999

SUMMARY

The undisturbed lake sediments can provide a valuable tool in interpreting changes over time with regard to water quality, climate change and deposition rates of long range contaminants. Various lake sediment cores were collected from Slipper Lake and Lac du Sauvage in March 1997, and the sediment cores from Slipper Lake are investigated in this report. The analysis of the core consisted of dating and diatom analysis and identification as well as metal and grain size analysis. The diatom analysis indicated a gradual change over time in community structure. The metal analysis was conducted for 28 parameters, but the focus is on 10 parameters which have Ontario or Canadian guidelines. In general, the concentrations of the various parameters have changed over time and in no particular pattern. The sediment core was composed mainly of clay followed by silt and sand.

ACKNOWLEDGEMENTS

Research is never done without the help of a lot of people. Special mention must be given to John Smol and Kathleen Ruhland at the Paleoecological Environmental Assessment and Research Lab (PEARL), Queen’s University for agreeing to do the dating and diatom analysis and Bill Coedy and his staff at Taiga Environmental Laboratories, for doing the metal and grain size analysis. As always, I must thank John McCullum and Peter Cullun for their understanding and outstanding patience. It seems that I am always testing it.

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1.0 OBJECTIVES

Through the use of lake sediment cores, the goal of this study is to:

- Infer historical changes in quality of selected areas in the study area through analysis of sediment cores;
- Produce a knowledge base to assess possible cumulative effects of natural and man-made processes on the West Kitikmeot / Slave Study (WKSS) area; and
- Begin a process to obtain appropriate traditional knowledge relating to the sediment record.

2.0 DESCRIPTION

2.1 BACKGROUND

The idea to use lake sediments cores as a tool in the interpretation of historic conditions including water quality and inputs is possible because of the nature of the sedimentation process that happens in every lake. Material which is continuously being eroded from the land or carried by the air is eventually transported to lakes where it settles out of the water column and rests on the bottom. When this sediment remains undisturbed over the years, it provides a record of geochemical and sediment transfer processes in a lake. The deeper the sediment, the older the material and hence the more history that has been recorded. By laboratory analysis it is possible to approximate the age of specific sediment layers which enables the quantitative comparison of different times and environments (Lockhart et al, 1995).

From the analysis and comparison of the various sediment layers deposited in a lake, it is possible to estimate:

- The historic water quality in the lake or region (Wetzel, 1983; Peinitz and Smol, 1993). These data are used to infer changes over time;
- The historical river discharges, especially during unusually high and low flow years, might be estimated from the depth of sediment layers and composition since different flow rates may transport more sediment or sediment from different areas; and
- The rate of contaminant transport by air to the NWT (eg. organochlorines, mercury) from southern regions through the detection of various concentrations in the sediment. This can provides a clear link between pre- and post-industrial inflow of these compounds can be made.

2.2 STUDY AREA

Two sediment cores were collected at Slipper Lake (64°37'N 110°50'W) as well as a partial core at Lac du Sauvage (64°37'N 109°58'W). Slipper Lake is located in the BHP claim block while Lac du Sauvage is located just to the west (Figure 1). The lakes were selected primarily because they are within the West Kitikmeot Slave Study area and because Slipper Lake represents a lake that could potentially be impacted by mining activity while Lac du Sauvage is outside the mine’s immediate drainage basin but is still close enough to have similar characteristics. The two lakes will permit future studies on the effects of mine operations.

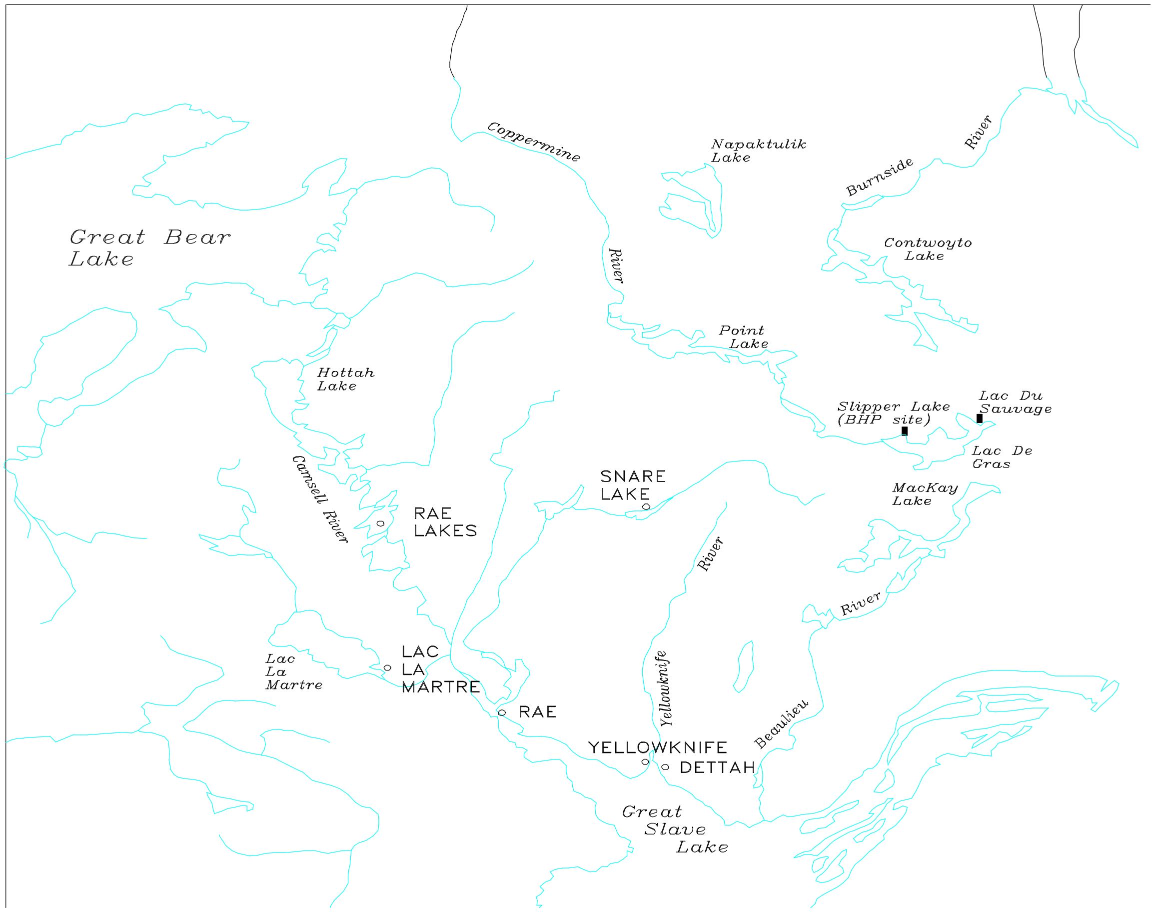

FIGURE 1. Map of the sites from which lake sediment cores were collected.

2.3 METHODOLOGY

Bathymetric surveys were conducted on the two lakes during the summer of 1996 to determine the shape of the lake bottom in order to allow the selection of a suitable area for the sampling. In this case, it was near the deepest part of the lake away from any disturbances. The sampling was conducted in the spring of 1997. Core 1 was collected using a modified KB gravity corer (10 cm inside diameter) while Core 2 was retrieved with a mini-Glew modified KB-type gravity corer (4.0 cm inside diameter core tube). Slipper Lake Core 1 was 45.5 cm long and partitioned in 0.5 cm intervals for the top 6.5 cm and then at 1.0 cm intervals for the remained of the core. Slipper Lake Core 2 was 17.5 cm long and was separated at 0.5 cm intervals for the entire length. The separate samples or intervals were packaged in Whirlpak® bags, labelled and placed in a cooler.

The dating and diatom analyses were conducted at the Paleoecological Environmental Assessment and Research Lab (PEARL), Queen's University. Detailed description of the methods used can be found in Appendix A. The metal and grain size analyses was performed by Taiga Environmental Laboratory, Yellowknife. Analyses methodologies can be found in Appendix B.

3.0 ACTIVITIES FOR THE YEAR 1997-1998

The Memorandum of Understanding (MOU) was signed in September 1997 which permitted the laboratory work to start. In order to meet the analysis requirements of the various laboratories, the sediment cores were initially sent to the Paleoecological Environmental Assessment and Research Lab (PEARL), Queen's University for dating and diatom analyses. When the dating and diatom analyses was completed, the remaining portion of each sample was sent to Taiga Environmental Laboratory in Yellowknife, NWT for metal and grain size analyses.

4.0 RESULTS

The dating and diatom results are presented in Appendix A while the metal and grain size data are in Appendix B.

5.0 DISCUSSION/CONCLUSIONS

The two sediment cores from Slipper Lake have a high degree of resolution with very little mixing or disturbance which suggests that neither site was subject to rapid or chaotic sedimentation that is generally associated with catastrophic events. This conclusion is possible since both cores have the Year 1900 occurring at a depth of about 2.5 cm. By taking two cores, one serves as a quality assurance / quality control (QA/QC) duplicate which gives confidence to the results. It also illustrates the utility of both the modified KB gravity corer (10 cm ID core tube) and the smaller mini-Glew modified KB-type gravity corer (4 cm ID core tube).

5.1 DATING

The Pb-210 concentration profile decreases from the top to the bottom which indicates that there has been very little disturbance over time. The Pb-210 profile is consistent with an area that had a relatively constant accumulation rate. The most accurate dates are before 1847 because of the relatively short half-life of Pb-210. For more detailed information, refer to Appendix A.

5.2 DIATOM ANALYSIS

The diatom analyses indicates that there have been gradual changes in the taxonomic composition of the diatom community over time. Through cluster analysis, the cores have been divided into three distinct zones. The zones are:

- Zone 1 (45.5 - 13.0 cm in core 1; 17.5 - 13.5 cm in core 2);
- Zone 2 (13.0 - 4.75 cm in core 1; 13.5- 5.25 cm in core 2); and
- Zone 3 (4.75 - 0.0 cm in core 1; 5.25 - 0.0 cm in core 2).

The changes in taxonomical structure are thought to be caused by Slipper Lake's gradual shift from an oligotrophic system towards a slightly more acidic environment. Also contributing to the change in taxonomic structure is an increase in open water (less ice cover).

5.3 METAL ANALYSIS

Each layer of Slipper Lake Core 1 was analysed for 28 parameters (Appendix B). Table 1 outlines the subset of parameters that will be investigated further in this report because of the availability of the Ontario and National Interim Guidelines for Sediment Quality Guidelines (Table 1).

TABLE 1. Sediment quality guidelines for Ontario and Canada. The units are in µg/g

PARAMETER	DETECTION	ONTARIO		NATIONAL INTERIM	
		LEL	SEL	TEL	PEL
Iron	200	20,000	40,000	-	-
Mercury	0.005	0.2	2.0	0.174	0.486
Chromium	0.4	26	110	37.3	90
Manganese	0.2	460	1,100	-	-
Nickel	0.2	16	75	18	35.9
Copper	0.2	16	110	35.7	197
Zinc	1.0	120	820	123	315
Arsenic	0.1	6	33	5.9	17
Cadmium	0.2	0.6	10	0.596	3.53
Lead	0.2	31	250	35	91.3

Note:
LEL - lowest effect level
SEL - severe effect level
TEL - threshold effect level
PEL - probable effect level
wt% -equals 10,000 µg/g

Using the three zones identified in the diatom analysis, the parameters identified in Table 1 were tested to see if there were any statistically significant differences between the zones. The results from the Kruskal-Wallis Test, a nonparmetric method that tests the assumption that the medians of the samples are equal (Siegel, 1956), are presented in Table 2.

TABLE 2. Summary of Results for the Kruskal-Wallis Test to Examine the Differences in Metal Analyses Over the Depth of Core 1.

Parameter	P-Value	Decision	Meaning
Iron	0.00000041	Reject	Different between zones
Mercury	0.00000009	Reject	Different between zones
Chromium	0.00086490	Reject	Different between zones
Manganese	0.00000007	Reject	Different between zones
Nickel	0.00005624	Reject	Different between zones
Copper	0.00281414	Reject	Different between zones
Zinc	0.00002874	Reject	Different between zones
Arsenic	0.78109000	Accept	Similar between zones
Cadmium	0..71226800	Accept	Similar between zones
Lead	0.00554369	Reject	Different between zones

Note:
The significance level was set at 0.05 for the Kruskal-Wallis Test which tests the null hypothesis that the medians within the three zones are the same. Therefore, a rejection of the null hypothesis indicates that medians of the three zones are significantly different.

Since the Kruskal-Wallis Test confirmed that the metal concentration in Slipper Lake Core 1 had changed over time, Table 3 summarizes the metal analyses according to each zone as well as the total core.

When compared to the guidelines listed in Table 1, all parameters exceeded at least one of the guidelines in some way. Only mercury, zinc and cadmium did not have mean concentrations above the guidelines. Iron, manganese and copper had mean concentrations in all zones that exceeded the “severe effects level.”

Table 3. Summary of the Metal Analyses for Slipper Lake Core 1.

Parameter	Detection Limit	Units	Maximum	Minimum	Mean	Median	Std Dev	Skewness	Kurtosis	Count
Iron (Total)	0.02	wt%	26.50	2.90	5.73	4.03	4.56	3.106	10.106	48
Iron (Zone 3)	0.02	wt%	13.40	5.26	7.03	5.73	2.93	2.247	5.121	7
Iron (Zone 2)	0.02	wt%	26.50	3.65	10.82	8.26	7.85	1.078	0.030	10
Iron (Zone 1)	0.02	wt%	5.27	2.90	3.79	3.73	0.48	0.865	1.801	31
Mercury (Total)	0.005	ug/g	0.190	0.044	0.075	0.061	0.037	1.997	3.209	48
Mercury (Zone 3)	0.005	ug/g	0.190	0.130	0.157	0.150	0.026	0.356	-1.942	7
Mercury (Zone 2)	0.005	ug/g	0.088	0.063	0.078	0.079	0.008	-0.831	0.476	10
Mercury (Zone 1)	0.005	ug/g	0.073	0.044	0.056	0.055	0.008	0.539	-0.202	31
Chromium (Total)	0.4	ug/g	84.6	34.4	69.6	73.6	11.0	-1.532	1.770	48
Chromium (Zone 3)	0.4	ug/g	60.7	46.9	56.0	57.3	4.6	-1.557	2.605	7
Chromium (Zone 2)	0.4	ug/g	79.7	34.4	62.9	72.4	17.5	-0.655	-1.497	10
Chromium (Zone 1)	0.4	ug/g	84.6	68.5	74.9	73.9	3.5	0.642	0.640	31
Manganese (Total)	0.2	ug/g	14700	315	1194	473	2222	5.068	29.044	48
Manganese (Zone 3)	0.2	ug/g	14700	1340	4463	2260	4802	2.097	4.451	7
Manganese (Zone 2)	0.2	ug/g	2660	651	1333	963	710	0.918	-0.520	10
Manganese (Zone 1)	0.2	ug/g	582	315	412	392	72	0.634	-0.463	31
Nickel (Total)	0.2	ug/g	82.9	27.6	59.0	60.9	10.8	-0.648	1.364	48
Nickel (Zone 3)	0.2	ug/g	55.7	49.1	51.9	51.1	2.2	0.724	0.448	7
Nickel (Zone 2)	0.2	ug/g	64.7	27.6	46.9	47.1	12.6	-0.170	-1.070	10
Nickel (Zone 1)	0.2	ug/g	82.9	54.0	64.5	63.2	6.8	0.942	1.154	31

Parameter	Detection Limit	Units	Maximum	Minimum	Mean	Median	Std Dev	Skewness	Kurtosis	Count
Copper (Total)	0.2	ug/g	108.0	52.8	79.1	80.9	13.1	-0.002	-0.263	48
Copper (Zone 3)	0.2	ug/g	66.7	61.6	63.7	62.7	2.0	0.498	-1.834	7
Copper (Zone 2)	0.2	ug/g	108.0	52.8	79.2	83.8	21.4	-0.086	-1.844	10
Copper (Zone 1)	0.2	ug/g	106.0	68.9	82.5	81.9	7.9	0.821	1.296	31
Zinc (Total)	1	ug/g	157	70	105	103	20	0.658	0.110	48
Zinc (Zone 3)	1	ug/g	98	85	91	91	5	0.311	-0.740	7
Zinc (Zone 2)	1	ug/g	107	70	87	86	13	0.175	-1.522	10
Zinc (Zone 1)	1	ug/g	157	87	115	112	18	0.611	-0.187	31
Arsenic (Total)	0.1	ug/g	231.0	5.1	27.8	17.2	39.8	4.271	18.610	48
Arsenic (Zone 3)	0.1	ug/g	48.8	13.2	23.3	17.3	13.1	1.597	1.783	7
Arsenic (Zone 2)	0.1	ug/g	231.0	5.1	62.3	16.7	81.1	1.568	1.165	10
Arsenic (Zone 1)	0.1	ug/g	25.8	10.9	17.7	17.1	4.4	0.441	-0.568	31
Cadmium (Total)	0.2	ug/g	0.7	L0.2	0.3	0.3	0.1	1.039	0.582	48(14)
Cadmium (Zone 3)	0.2	ug/g	0.4	L0.2	0.3	0.3	0.1	0.000	-2.600	7(3)
Cadmium (Zone 2)	0.2	ug/g	0.6	L0.2	0.3	0.3	0.1	1.156	0.201	10(5)
Cadmium (Zone 1)	0.2	ug/g	0.7	L0.2	0.3	0.3	0.1	1.106	0.843	31(6)
Lead (Total)	0.2	ug/g	187.0	6.5	36.5	15.8	46.8	2.174	3.808	48
Lead (Zone 3)	0.2	ug/g	85.3	9.6	23.8	12.4	2.5	2.473	6.223	7
Lead (Zone 2)	0.2	ug/g	100.0	6.5	19.8	11.4	3.1	3.138	9.892	10
Lead (Zone 1)	0.2	ug/g	187.0	7.2	44.8	18.5	1.8	1.824	2.061	31

Note:
() - indicates the number of non-detects.

TABLE 4. Correlations of Metal Analyses against Depth for Slipper Lake Core 1.

Correlation	Iron	Mercury	Chromium	Manganese	Nickel	Copper	Zinc	Arsenic	Cadmium	Lead
Depth (Total)	SS	SS	SS	SS	SS	SS	SS	NSS	NSS	NSS
Depth (Zone 3)	SS	SS	SS	SS	NSS	NSS	NSS	SS	NSS	NSS
Depth (Zone 2)	SS	SS	SS	SS	SS	SS	SS	NSS	SS	NSS
Depth (Zone1)	NSS	NSS	NSS	SS	SS	NSS	NSS	SS	NSS	NSS

Note:
The significance level was set at 0.05 for the analysis of variance. The null hypothesis states that there is a statistically significant relationship between the parameter and the indicated zone. Therefore, a rejection of the null hypothesis indicates that there is not a statistically significant relationship (ie. there is no correlation).

SS - Statistically significant
NSS - Not statistically significant

5.3 GRAIN SIZE ANALYSIS

Grain size analysis is used to determine the texture and composition of sediment in terms of the percent sand (particle size 62.6 - 1000 µm;), silt (particle size 3.90 - 62.5 µm) and clay (particle size 0.01 - 3.90 µm). Percent organic matter was also calculated since some metals are associated with it and it can also indicate changes in the deposition environment. Like metal analyses, grain size was also broken into the three zones to determine if there was any changes. The results of the Kruskal-Wallis Test is presented in Table 5.

TABLE 5. Summary of Results for the Kruskal-Wallis Test to Examine the Differences in Metal Analyses Over the Depth of Core 1.

Parameter	P-Value	Decision	Meaning
% Organic Matter	0.00000133	Reject	Different between zones
% Sand	0.00164709	Reject	Different between zones
% Silt	0.00496896	Reject	Different between zones
% Clay	0.000226152	Reject	Different between zones

Note:
The significance level was set at 0.05 for the Kruskal-Wallis Test which tests the null hypothesis that the medians within the three zones are the same. Therefore, a rejection of the null hypothesis indicates that medians of the three zones are significantly different.

The grain size composition of Core 1 from Slipper Lake was predominately silt (73.5%) with some clay (15.9%) and very little sand (10.6%). Percent organic matter was present in all samples (Table 6).

Table 7 summarizes the relationships between the metal analyses and grain size for Slipper Lake Core 1.

TABLE 6. Summary of Grain Size Analyses for Slipper Lake Core 1.

Parameter	Detection Limit	Units	Maximum	Minimum	Mean	Median	Std Dev	Skewness	Kurtosis	Count
% Organic Matter (Total)	-	%	19.0	6.8	11.6	11.3	2.3	0.972	1.362	48
% Organic Matter (Zone 3)	-	%	19.0	12.2	14.8	14.4	2.1	1.326	2.645	7
% Organic Matter (Zone 2)	-	%	16.3	10.6	13.0	12.7	1.8	0.668	-0.462	10
% Organic Matter (Zone 1)	-	%	13.8	6.8	10.3	10.0	1.3	0.018	10251	31
% Sand (Total)	-	%	27.3	0.0	10.6	8.7	8.5	0.598	-0.966	48
% Sand (Zone 3)	-	%	24.0	0.0	5.7	1.9	8.7	2.013	4.261	7
% Sand (Zone 2)	-	%	10.0	1.9	4.6	3.4	3.0	1.091	-0.119	10
% Sand (Zone 1)	-	%	27.3	0.6	13.7	12.0	8.4	0.122	-1.245	31
% Silt (Total)	-	%	91.0	63.1	73.5	73.2	6.3	0.612	0.303	48
% Silt (Zone 3)	-	%	91.0	68.5	82.1	82.4	7.3	-0.949	1.323	7
% Silt (Zone 2)	-	%	80.4	66.2	73.2	74.6	4.9	-0.365	-1.023	10
% Silt (Zone 1)	-	%	81.9	63.1	71.6	72.2	4.9	0.116	-0.358	31
% Clay (Total)	-	%	30.9	7.5	15.9	14.8	5.4	0.422	-0.490	48
% Clay (Zone 3)	-	%	18.9	7.5	12.2	12.1	3.7	0.735	1.079	7
% Clay (Zone 2)	-	%	30.9	17.5	22.2	22.3	3.8	1.164	2.422	10
% Clay (Zone 1)	-	%	23.0	7.5	14.7	13.6	4.6	0.412	-1.056	31

TABLE 7. Correlations of Metal Analyses against Grain Size for Slipper Lake Core 1.

Correlation	Iron	Mercury	Chromium	Manganese	Nickel	Copper	Zinc	Arsenic	Cadmium	Lead
% Organic Matter (Total)	SS	SS	SS	SS	SS	SS	SS	SS	SS	NSS
% Organic Matter (Zone 3)	SS	NSS	SS	SS	NSS	NSS	NSS	SS	NSS	SS
% Organic Matter (Zone 2)	SS	NSS	SS	SS	SS	SS	NSS	NSS	NSS	NSS
% Organic Matter (Zone 1)	NSS	NSS	SS	NSS	NSS	SS	NSS	NSS	SS	NSS
% Sand (Total)	NSS	SS	NSS	NSS	SS	NSS	SS	NSS	NSS	NSS
% Sand (Zone 3)	NSS	NSS	NSS	NSS	NSS	NSS	NSS	NSS	NSS	NSS
% Sand (Zone 2)	NSS	NSS	NSS	NSS	NSS	NSS	NSS	NSS	NSS	NSS
% Sand (Zone 1)	NSS	NSS	NSS	NSS	NSS	NSS	NSS	SS	NSS	NSS
% Silt (Total)	NSS	SS	SS	SS	NSS	SS	NSS	NSS	NSS	NSS
% Silt (Zone 3)	NSS	NSS	NSS	NSS	NSS	NSS	NSS	NSS	NSS	NSS
% Silt (Zone 2)	NSS	NSS	NSS	NSS	NSS	NSS	NSS	NSS	NSS	NSS
% Silt (Zone 1)	NSS	NSS	NSS	SS	NSS	NSS	NSS	SS	NSS	NSS
% Clay (Total)	SS	NSS	NSS	NSS	SS	NSS	NSS	NSS	SS	NSS
% Clay (Zone 3)	NSS	NSS	NSS	NSS	NSS	NSS	NSS	NSS	NSS	SS
% Clay (Zone 2)	NSS	NSS	NSS	NSS	NSS	NSS	NSS	NSS	NSS	NSS
% Clay (Zone 1)	NSS	NSS	NSS	NSS	NSS	NSS	NSS	SS	SS	NSS

Note::
The significance level was set at 0.05 for the analysis of variance. The null hypothesis states that there is a statistically significant relationship between the parameter and the indicated zone. Therefore, a rejection of the null hypothesis indicates that there is not a statistically significant relationship (ie. there is no correlation).

SS	- Statistically significant
NSS	- Not statistically significant

6.0 LINKS WITH PARALLEL STUDIES

While there was no parallel studies being conducted, it has been recommended that further studies examine the linkages between the changes in diatom composition in the early 1800s and possibly the shorter duration of ice cover (a possible result of climate change) and/or the drop in lakewater pH (the changing of a lakes chemical balance). It has also been suggested that more work should be done in conjunction with traditional knowledge on ice phenology.

7.0 TRAINING ACTIVITIES AND RESULTS

There was no training planned nor carried out for this phase of the project because the analysis work is highly specialized in terms of equipment and knowledge.

8.0 EXPENDITURES AND SOURCE OF FUNDS

Expenditures are not reported in our online reports.

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APPENDIX A: DATING AND DIATOM ANALYSIS

Paleolimnological assessment of Slipper Lake,
Northwest Territories

A report prepared for Department of Indian Affairs and Northern Development (DIAND),
Water Resources Division, Yellowknife, NWT
February, 1998

Contract number: ORS-097-101

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BACKGROUND

Limnological studies in northern regions are of interest for numerous reasons including the response of these sensitive ecosystems to natural climatic and environmental change, and to anthropogenic disturbances (Rouse et al. 1997). Moreover, the changes in climate predicted for the next few decades to centuries is expected to proceed at a much faster rate than the slow, long-term orbitally forced climatic changes of the past (Rind 1993). It is important, therefore, to establish the background conditions of a system, so that interpretations of change in the recent past can be placed into a larger context. In addition, long-term data are needed to determine natural variability. The lack of dependable long-term instrumental data has resulted in the development of a suite of climatic and environmental "proxies" (Smol et al. 1995). Proxy data are biotic or abiotic indicators that respond to changes in the environment, making them ideal indicators of past environmental conditions. Proxy data allow for a full historical and paleoecological record to be examined.

Various proxy methods have been developed to explore the responses of boreal forest environments to past episodes of climatic and environmental change (e.g. pollen analysis, dendrochronology, stable isotopes, diatoms, chironomids, plant macrofossils, and chrysophyte cysts). Long-term environmental trends are best evaluated through these paleo-records, such as the sediment cores retrieved from the bottom of lakes and ponds. There is a great deal of uncertainty as to the magnitude and rate of global environmental change, emphasizing the importance of obtaining detailed paleoecological records. These records are important to better understand the natural variability and mechanisms of environmental change.

Diatoms (Bacillariophyceae) are microscopic unicellular algae that have been extensively used in paleolimnological studies. They are characterized by the presence of siliceous cell walls (valves) that are taxonomically distinguished by their size, shape, and ornamentation. The siliceous nature of frustules result in excellent preservation in lake sediments. The short life spans and fast immigration rates of diatoms enable them to respond quickly to environmental change (Dixit et al. 1992). They are ecologically diverse, highly abundant, and their autecological characteristics have been well documented (e.g. Krammer Lange-Bertalot 1986-1991; Hustedt 1927-1966). Collectively, these attributes make diatoms particularly sensitive bioindicators of environmental change. Diatom taxonomy and their ecological preferences have been studied for many geographic regions (especially in Europe). However, studies of this kind in Canadian Arctic regions near treeline are very few (e.g. Kling and Håkansson 1988; Pienitz et al. 1995; Pienitz and Smol 1993).

High latitude diatoms are able to adapt to environmental conditions controlled by often harsh climates. For example, small-celled, benthic species of the genus *Fragilaria* are typically found in small, shallow arctic lakes and ponds. Their small size may be governed by the length of the growing season, solar radiation, and available nutrients (Smol 1983). Centric diatoms and larger pennate diatoms are more common in forested regions where climate, nutrients, ice cover, and length of the growing season may sustain more diverse habitats and thus a greater species richness.

Other water chemistry variables (e.g. DOC, pH, alkalinity) can also influence diatom community composition. In oligotrophic systems, dissolved organic carbon (DOC) concentrations are mainly a reflection of the coniferous litter and the percentage of wetlands in the catchment area. Diatoms are known to covary with changes in DOC concentrations (Pienitz and Smol 1993) and have strong potential to be used as an indicator of arctic treeline position.

Paleolimnological studies of lakes located at or near treeline provide valuable information on past environmental change. The biota contained within the sediments of these lakes (e.g. diatoms) can be used as proxy data to make inferences about environmental and climatic change in these northern regions (e.g. Pienitz and Smol 1993; Pienitz et al. 1995).

Diatoms that exist at higher latitudes are able to adapt to environmental conditions controlled by the often harsh climates found in these regions. In general, the cells of diatoms found in more northern regions are small in size as growth rates may be governed by the length of the growing season, amount of solar radiation, amount of available nutrients and availability of silica (Smol 1988; Pienitz 1993). Centric diatoms and larger pennate diatoms are more common in the more southern, forested regions, where climate, nutrients, and length of the growing season are more amenable to sustain more diverse habitats and thus a greater species richness (Pienitz 1993).

Many of the lakes in North America have been affected by anthropogenic activity causing deterioration in water quality. Canada's Northwest Territories is no exception. Extensive mining of valuable ores in Ontario and the Northwest Territories is a prime example of extensive human disturbance on natural aquatic ecosystems. Contamination of aquatic ecosystems around mining sites in the Northwest Territories has prompted assessment of the water quality of this region.

In order to accurately assess the magnitude and extent of these anthropogenic disturbances, an understanding of the natural or background conditions of a system is essential. Paleolimnological approaches can be used to provide these data (Dixit et al. 1992; Dixit and Smol 1994).

RATIONALE FOR STUDY

The aim of this study is to determine the historical environmental conditions of Slipper Lake (110°50'07", 64°35'65"). Slipper Lake is a "pristine" arctic tundra lake that is relatively deep (17.0 m), circumneutral pH (6.4), with a surface area of 1.9 km^2. Slipper Lake is the lowest lake in the drainage basin of the BHP Diamond Mine before it enters Lac du Gras (a larger lake). The BHP Diamond Mine is located northeast of Slipper Lake and will be fully operational by 1998. This open-pit mine is expected to affect, among other things, turbidity levels in lakes and streams within the BHP Diamond Mine discharge system. Therefore, the goal of this project is to collect a sediment core prior to the mine becoming fully operational. This background information will aid in effective ecosystem management and biomonitoring in the future. Studies of these kind are very rare at present, and Slipper Lake will provide a unique opportunity to track the effects of a large open-pit mining operation in the catchment. In addition, these longer records provide us with an excellent opportunity to observe natural variability in fossil data for these systems.

FIELD PROCEDURES

Two gravity cores were retrieved from the middle of Slipper Lake near the deepest part of the lake (14.0 m) on March 26, 1997. They were taken at approximately 15 m apart.
Slipper Lake Core 1 was retrieved using a modified KB gravity corer (10 cm diameter) and was 45.5 cm long. This core was extruded on the site in 0.5 cm intervals for the top 6.5 cm and at 1.0 cm intervals for the remainder of the core. Slipper Lake Core 2 (17.5 cm) was retrieved using a

mini-Glew (1991) modified KB-type gravity corer equipped with a 4.0 cm inside diameter core tube. This core was extruded, using a Glew (1988) extruder, in 0.5 cm intervals for the entire length. Prior to subsampling, the sediment was placed in Whirlpak® bags and placed in a cooler. At PEARL, subsamples of sediment were taken for diatom preparation and ^{210}Pb dating.

LABORATORY PROCEDURES

Sediment samples were processed using standard procedures for diatom preparations, outlined in Smol (1983). In brief, a subsample of 0.5 to 1.0 gram of wet sediment from each of the sediment samples (core intervals) was placed in glass scintillation vials with a 10% HCl solution to loosen up the sediment and to remove any $CaCO_3$. Samples were then digested with strong acids [50:50 molar ratio of concentrated nitric acid (H_2NO_3) to concentrated sulphuric acid (H_2SO_4)] to digest the organic sediment matrix. The resulting diatom slurries were then pipetted onto coverslips in four different dilutions and allowed to slowly evaporate on a slide warmer set at 35°C. These coverslips were then mounted on microscope slides with Naphrax®, a mounting medium of high refractive index (R.I. = 1.74). For each sample, a minimum of 400 diatom valves were identified and enumerated along transects of the coverslip using a Leitz Dialux 20 microscope (1250 X magnification with differential interference contrast optics, N.A. 1.30). Taxonomy and diatom identifications were made to the lowest taxonomic level possible (usually variety level). Taxonomic diagnostics follows numerous sources, including Hustedt (1927 - 1966), Patrick and Reimer (1966, 1975), Foged (1981), PIRLA Diatom Iconograph (Camburn et al. 1984 - 1986), Krammer and Lange-Bertalot (1986 - 1991), Hein (1990), and

Cumming et al. (1995a). A total of 25 intervals were counted for Slipper Lake Core 1 and 21 intervals for Slipper Lake Core 2.

Pb-210

For ^{210}Pb analyses, sediment subsamples (approx. 30 g) of selected intervals were weighed, oven-dried (24 hr at 110 °C) and ground in a mortar. Samples were reweighed to determine dry weight and submitted to Mycore Ltd. The dating models were run at PEARL. ^{210}Pb dating is calculated from determinations of ^{210}Po, a decay product of ^{210}Pb. Quantitative measurements were made using alpha spectroscopy (Cornett et al. 1984). Unsupported ^{210}Pb was calculated by subtracting supported ^{210}Pb (the baseline ^{210}Pb activity naturally present in the sediments) from total activity at each level. Dates were then determined from unsupported isotopes using the constant rate of supply (C.R.S.) model (Appleby & Oldfield 1978); a computer program designed by Binford (1990) was used to perform these calculations. **^{210}Pb dating is limited to ~150 years before present, so extrapolations beyond this period were made based on calculated sediment accumulation rates for the lowest intervals of the core.**

RESULTS AND DISCUSSION

Pb-210 and Replicate Cores

The Pb-210 profile from Slipper Lake increases in ^{210}Pb concentration from bottom to surface sediments in each core (Fig. 1 a & b), hence we are confident that relatively undisturbed sedimentary profiles have been obtained. Replicate cores for Slipper Lake have similar depth/time relationships (e.g. ca. 1900 occurs at approximately 2.5 cm depth in each core), suggesting excellent reproducibility of paleolimnological investigations within this lake. They are sufficiently similar that a single core would probably have been adequate to describe the lake's recent ecological history. However, replicate cores provide us with extra QA/QC measures for both the coring/extrusion procedure and the enumeration/identification procedure. Furthermore, assessment of significant changes in sedimentation rates are best assessed on multiple cores due to variations in sediment deposition in a lake basin. Both Slipper Lake Core 1 and Core 2 show typical exponential ^{210}Pb profiles (Figure1 a&b), as would be expected if accumulation rate remained relatively constant (Binford 1990).

Pb-210 dating becomes unreliable after 120 -150 years due to the relatively short half-life of ~22 years for Pb-210. Therefore, dates beyond 1847 can only provide rough estimates as to the timing of historical events.

Comparisons of Core 1 and Core 1

As explained above, replicate cores provide extra measures of QA/QC of the data. Both cores retrieved from Slipper Lake show nice profiles (both ^{210}Pb and diatom stratigraphies) indicating that sediment mixing is not a problem. Both diatom stratigraphies (Figs. 2a and 2b) show very similar trends through time and cluster analyses have divided these cores into very similar depth/time zones, again suggesting that a single sediment core can sufficiently represent the overall trends that have occurred through time in and around the lake (Charles et al. 1991).

Qualitative Assessment of Diatoms

A total of 206 diatom taxa were identified in the Slipper Lake cores. Twenty of the most common diatom taxa were presented in the stratigraphic profiles (Fig. 1 & 2; common species were included in the profile if they occurred at ³4% in any interval). Cluster analysis divides these cores into three zones, and depicts the most obvious changes in the diatom assemblage composition through time. Each zone will be described separately.

Zone I (45.5 - 13.0 cm in core 1; 17.5 - 13.5 cm in core 2).

This zone is dominated by heavily silicified tychoplanktonic centric diatoms belonging to the genus *Aulacoseira*. This genus represents between 20 and 56 % of the diatom taxa, with *A. lirata* being the most abundant. Small-celled, benthic pennate *Fragilaria* species are also prevalent, representing between 18 and 40 % of the diatom taxa. Subdominant taxa include *Achnanthes marginulata* and *Navicula pseudoscutiformis*.

Zone II (13.0 - 4.75 cm in core 1; 13.5 - 5.25 cm in core 2).

This zone depicts a rise in *Aulacoseira lirata*, reaching its maximum abundance at 38 % circa 1820 (5 cm core 1; 4cm core 2). *Fragilaria pinnata, F. construens* var. *venter, F. brevistriata*, and *Navicula pseudoscutiformis* are replaced by *Cymbella gaeumannii*, *Nitzschia perminuta* and *Tabellaria flocculosa*.

Zone III (4.75 - 0.0 cm in core 1; 5.25 - 0.0 cm in core 2).

In this zone *Aulacoseira* continues to be strongly represented, but shows a decrease in both *A. lirata* (11% by 1997) and *A. perglabra* (3% by 1997). *Fragilaria construens* var. *venter* disappears altogether from the record and a clear shift towards *Cyclotella stelligera* complex begins circa 1850-1860 (4.0 cm core 1; 3.5 cm core 2). Small *Navicula* species (*N. submuralis* and *N. schmassmannii*), *Achnanthes* species (*A. curtissima, A. carrissima*, and A. *marginulata*), and *Nitzschia perminuta* become more prevalent.

The presence of more alkaliphilous benthic taxa, such as *Fragilaria construens* var. *venter* and *F. brevistriata* at the bottom of the core (Zone I), are more prominent and virtually disappear circa 1820-1850 (5cm). There is a shift towards slightly more acidic conditions in Zone II as is characterized by the maximum expansion of acidophilous *Aulacaseira lirata* (circa 1820s), the appearance of more acidophilous benthic taxa such as *Cymbella gaeumannii* and *Achnanthes marginulata*, and a decrease in alkaliphilous benthic *Fragilaria* taxa. A major change in the diatom flora occurs in Zone III (circa 1830;~ 5cm) where the *Cyclotella stelligera* complex replaces *Aulacoseira lirata* in dominance. Conditions also seem to become increasingly acidic in Zone III, reflected in the diatom assemblage composition being more prominently represented by small benthic acidophilous taxa including *Achnanthes marginulata, A. carrissima*, *Cymbella gaeumannii* and small benthics such as *Navicula schmassmannii* and *N. submuralis*.

Some of the heavily silicified *Aulacoseira* taxa are known to be indicative of deeper, well mixed waters in tundra regions that have a lower pH range (~5.5-6.5) and oligotrophic waters. *Fragilaria virescens*, an acidophilous taxa, is prominent throughout the core.

SUMMARY

Slipper Lake has been a clean water ("pristine") oligotrophic deep water lake throughout the several centuries of history recorded in the two cores. This is reflected by the diatom composition. *Achnanthes* and *Cymbella* taxa, according to van Dam et al. (1994), are intolerant to most pollution, and are generally important components of the diatom flora in pristine areas such as subarctic regions.

Increases in *C. stelligera* and the strong presence of *A. lirata* in Zone II and III could be interpreted as evidence for less ice cover (seasonally open water conditions), and/or more turbulent mixing of the water column from early 1800s to present (Smol 1988). Seasonally open and turbulent waters are generally required by the heavily silicified *Aulacoseira* spp. to be sustained in the euphotic zone. Meanwhile, the relative abundance of *Fragilaria* spp. at the bottom of the core may be indicative of longer ice cover or perhaps less nutrients or both.

Changes throughout the core are gradual, shifting from an oligotrophic system near the bottom of the core, to a more acidic environment in the middle of the core and then to a perhaps more open water system towards the top of the core. Changes in Zones II and III may be may be related to climatic warming.

GENERAL CONCLUSIONS AND REMARKS

- High resolution sediment cores were collected from Slipper Lake. ^{210}Pb indicated that the cores were not disturbed by mixing processes. Diatoms were abundant and well preserved.
- The data composition of Slipper Lake over the last several centuries is indicative of a clean water "pristine" environment, with very gradual changes in taxonomic composition.
- The bottom of the core (from 45.5 - 13.0 cm) contained a very stable diatom assemblage consisting of small benthic taxa that compete well in nutrient-poor, cold water conditions, together with a very stable abundance of heavily silicifed tychoplanktonic taxa that compete well in nutrient-poor oligotrophic conditions.
- There is a clear change in the diatom composition from the early 1800s (circa 1800 to 1840) to the present, suggesting a change to more open water conditions, and likely shorter duration of ice-cover, and a drop in lakewater pH. This slow steady change in diatom assemblage composition is reminiscent of high arctic ponds studied by Douglas et al. (1994). Similar to Slipper Lake, diatom floristic composition in these Cape Herschel ponds was very stable throughout the length of the core, with a distinct change in diatom composition within the last century. Here too, *Fragilaria* species dominated and remained stable in the earlier sediments, dropping off and being replaced near the top of the core. These gradual changes may be indicating warm (less ice-covered) conditions.
- This study shows that high resolution paleolimnological studies can be conducted in arctic lakes, such as those near the mining activities in the Northwest Territories.

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Table 1. Slipper Lake Core 1 and Core 2 Analytic Activity of Pb-210

#	interval (cm)	Sample wt (mg)	209 P wt (mg)	Counting time (sec)	209 Po Counts	210 Po Counts	209 Po cps	210 Po cps	Carrier Yield (%)	210 Po Measured (Bq/g)	Decay Corr. to Extractn (Bq/g)	Precision 1 std dev (%)
SLIPPER LAKE CORE 1												
1	0.0 - 2.0	1.408	0.104	19492	1069	1503	0.055	0.07711	43	0.608	0.611	4.0
2	2.5 - 3.0	1.062	0.097	19578	844	429	0.043	0.02191	36	0.272	0.273	5.9
3	3.5 - 4.0	1.248	0.104	19665	1130	340	0.057	0.01729	45	0.147	0.147	6.2
4	5.5 - 6.0	0.840	0.104	19760	1528	171	0.077	0.00865	61	0.081	0.081	8.1
5	8.5 - 9.5	0.972	0.103	21606	1392	154	0.064	0.00713	51	0.069	0.069	8.5
6	11.5 - 12.5	1.280	0.104	21651	800	162	0.037	0.00748	29	0.096	0.097	8.6
7	14.5 - 15.5	1.461	0.103	21701	1410	264	0.065	0.01217	51	0.077	0.078	6.7
SLIPPER LAKE CORE 2												
1	0.0 - 1.0	0.973	0.103	21719	1106	1004	0.051	0.04623	40	0.562	0.565	4.4
2	1.0 - 1.5	0.430	0.104	39103	2703	369	0.069	0.00944	44	0.193	0.223	5.5
3	1.5 - 2.0	0.410	0.104	38223	2139	241	0.056	0.00631	44	0.167	0.169	6.8
4	2.0 - 2.5	0.444	0.103	39015	2340	190	0.060	0.00487	38	0.110	0.127	7.5
5	2.5 - 3.0	0.517	0.102	38297	2261	218	0.059	0.00569	47	0.111	0.112	7.1
6	3.5 - 4.0	0.471	0.102	38934	5014	337	0.129	0.00866	83	0.085	0.099	5.6
7	5.0 - 5.5	0.425	0.106	22490	1276	68	0.057	0.00302	35	0.078	0.084	12.4
8	6.5 - 7.0	0.584	0.104	22260	3004	245	0.135	0.01101	85	0.085	0.092	6.6

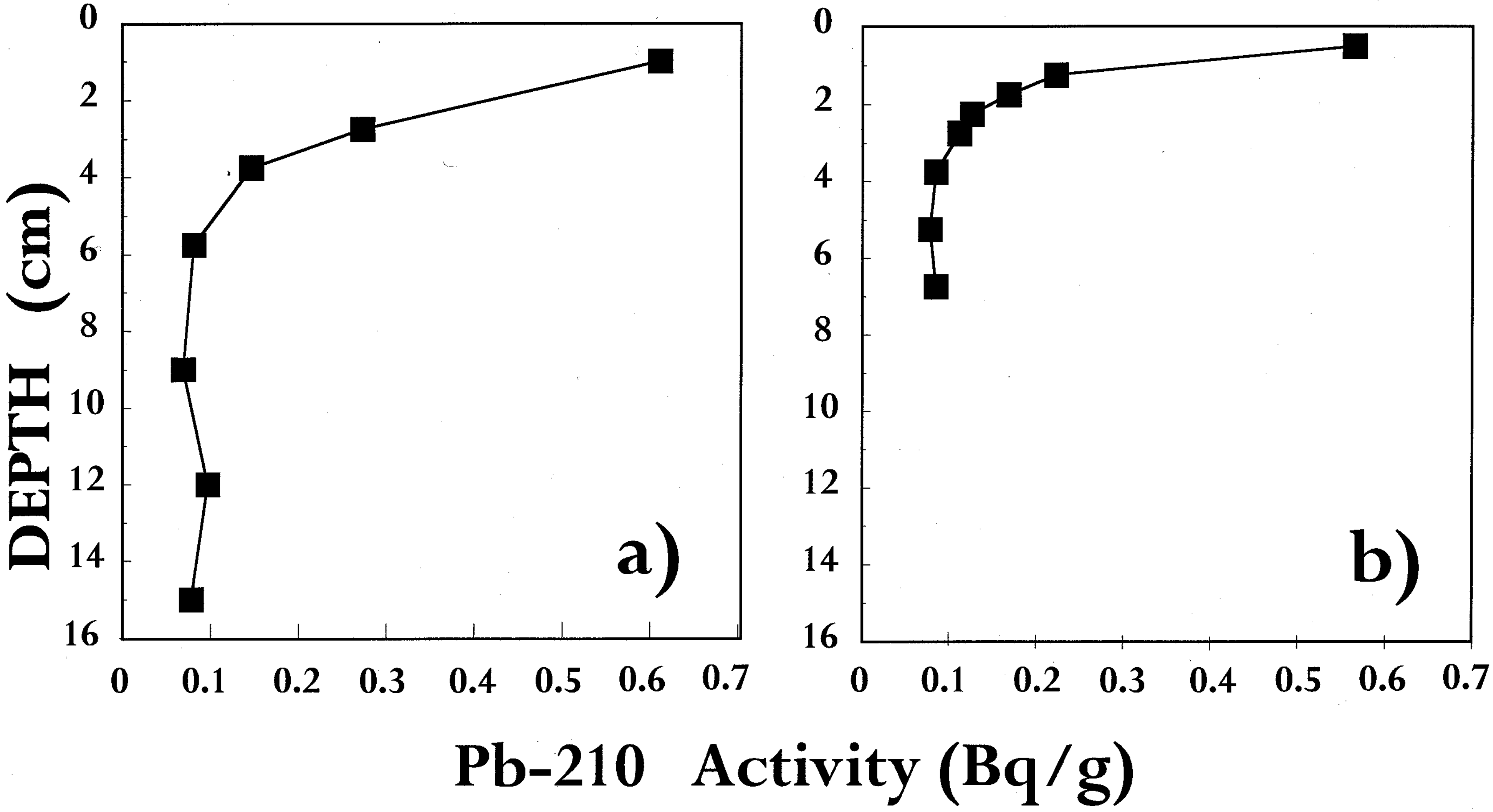

Figure 1. Pb-210 profiles for Slipper Lake Core 1 (a) and Slipper Lake Core 2 (b).

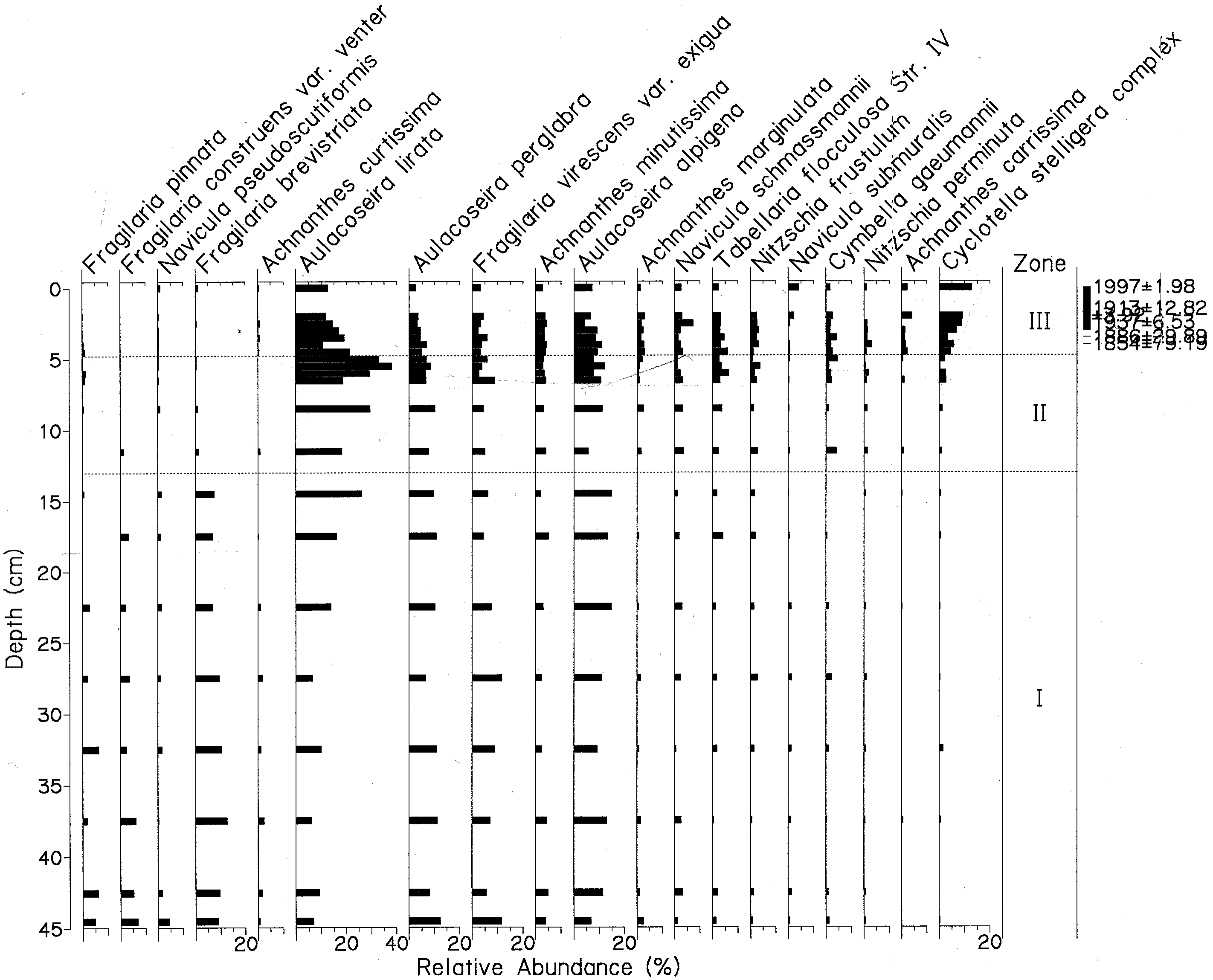

Figure 2a. Diatom stratigraphy for Slipper Lake, Core 1 (full core)

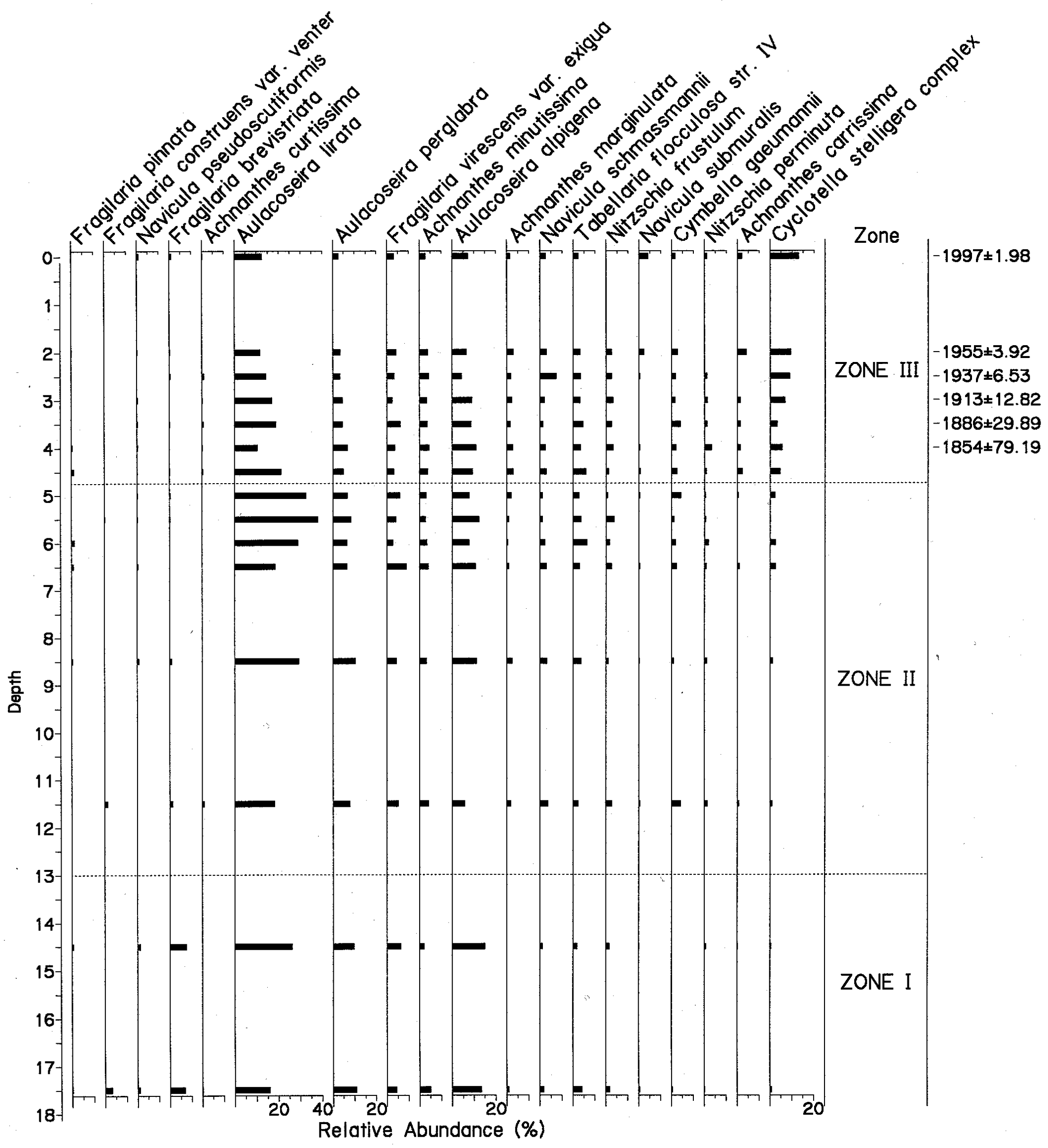

Figure 2b. Slipper Lake Core 1 showing the top 17.5 cm.

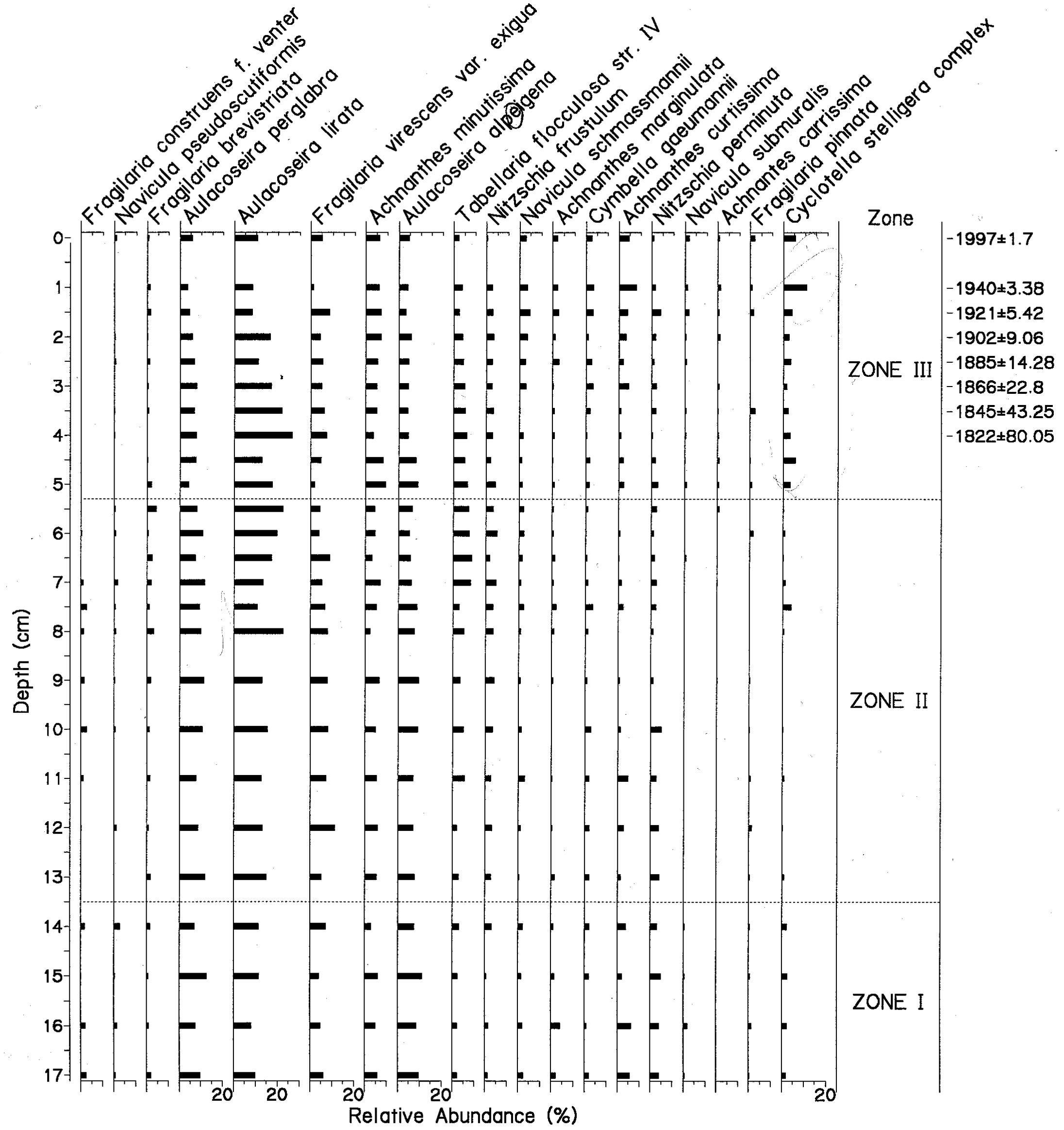

Figure 2c. Diagram Stratigraphy for Slipper Lake Core 2.

APPENDIX B: METAL AND GRAIN SIZE ANALYSIS

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TAIGA ENV. LAB. FACT SHEET

METHOD: Metals in Sediment; 1998

BASED ON REFERENCE: EPA 200.8

KEY WORDS: Sediment, Freeze-dry, Grind to < 125 um, Nitric Acid Digestion, ICP-MS

SUMMARY OF METHOD:

Sediments are mixed, sub-sampled and freeze-dried. Dried sediment is ground by mechanical pestle and mortar to pass through a 125 um (120 mesh) sieve. Approximately 0.25 g of sieved sediment is digested with either 5 mL of conc. UltraPure Nitric Acid or 2 mL of 1:1 Nitric Acid and 5 mL 1:4 Hcl acid (if antimony is required) using reflux digestion tubes and a hot block set at 85 C for 30 min.

The digest is diluted to volume and analyzed by ICP-MS according to EPA Method 200.8. Results are reported in ng/g. Replicate samples are run for precision and Certified Reference Materials are used for accuracy assessment.

METAL ANALYSIS

Parameter	Lab	Depth	Silver	Aluminum	Barium	Beryllium	Bismuth	Cadmium	Cobalt
Detection Limit			0.2	0.01	0.2	0.2	0.2	0.2	0.2
Units		cm	ug/g	wt %	ug/g	ug/g	ug/g	ug/g	ug/g
SL970101	970111	0	0.2	1.7	169	0.9	0.9	0.4	51.3
SL970102	970112	2.0	0.2	2.2	170	0.8	0.9	0.4	31.4
SL970103	970113	2.5	0.2	2.0	156	0.8	0.9	0.4	32.9
SL970104	970114	3.0	0.2	2.1	151	0.5	0.9	0.3	32.4
SL970105	970115	3.5	0.3	2.4	155	0.5	0.9	L0.2	24.0
SL970106	970116	4.0	0.3	2.4	157	0.7	1.0	L0.2	22.9
SL970107	970117	4.5	0.2	2.7	158	0.8	1.0	L0.2	24.5
SL970108	970118	5.0	0.3	2.3	136	0.8	0.9	L0.2	34.5
SL970109	970119	5.5	0.3	1.9	118	0.5	0.8	L0.2	35.8
SL970110	970120	6.0	0.2	1.5	88	0.5	0.7	L0.2	27.1
SL970111	970121	6.5	0.2	1.8	103	0.8	0.8	L0.2	19.7
SL970112	970122	7.5	0.3	2.2	127	1.1	1.2	L0.2	20.1
SL970113	970123	8.5	0.4	2.8	155	1.1	1.4	0.3	16.9
SL970114	970124	9.5	0.3	2.9	167	1.1	1.4	0.4	15.3
SL970115	970125	10.5	0.3	2.5	160	0.9	1.4	0.5	13.6
SL970116	970126	11.5	0.3	2.6	171	1.0	1.1	0.6	15.4
SL970117	970127	12.5	L0.2	2.5	170	0.9	1.1	0.3	14.5
SL970118	970128	13.5	0.3	2.5	173	1.1	1.0	L0.2	11.6
SL970119	970129	14.5	0.2	2.6	178	1.2	1.1	L0.2	12.4
SL970120	970130	15.5	L0.2	2.6	179	1.3	1.0	L0.2	11.2
SL970121	970131	16.5	0.2	2.0	172	0.9	1.0	0.4	12.3
SL970122	970132	17.5	0.2	2.5	171	1.3	1.1	0.6	11.4
SL970123	970133	18.5	0.2	2.7	185	0.8	1.1	0.7	13.4
SL970124	970134	19.5	L0.2	2.6	178	1.3	1.0	L0.2	13.0
SL970125	970135	20.5	0.2	2.5	168	2.0	1.0	0.4	13.4
SL970126	970136	21.5	L0.2	2.6	179	1.1	1.2	0.6	13.1
SL970127	970137	22.5	0.3	2.4	162	1.2	1.2	0.5	14.8
SL970128	970138	23.5	0.3	2.7	180	0.8	1.2	L0.2	16.1
SL970129	970139	24.5	0.2	2.7	175	0.9	1.1	0.3	14.6
SL970130	970140	25.5	0.2	2.3	171	1.3	1.2	0.5	17.5
SL970131	970141	26.5	0.3	2.0	141	1.5	1.3	0.4	19.1
SL970132	970142	27.5	0.3	2.5	166	1.0	1.2	0.2	17.0
SL970133	970143	28.5	0.2	2.1	149	1.9	1.0	L0.2	14.9
SL970134	970144	29.5	0.2	2.4	172	0.8	1.0	0.4	13.5
SL970135	970145	30.5	0.2	2.3	162	1.2	0.9	0.3	13.1
SL970136	970146	31.5	L0.2	2.4	173	1.3	0.9	0.4	13.8
SL970137	970147	32.5	L0.2	2.2	164	1.0	0.9	0.3	12.5
SL970139	970148	34.5	L0.2	2.1	155	1.6	0.9	0.3	14.2
SL970140	970149	35.5	L0.2	2.2	150	0.7	1.0	0.2	14.0
SL970141	970150	36.5	L0.2	2.2	150	0.7	1.0	0.2	16.1
SL970142	970151	37.5	0.2	2.1	150	1.2	1.1	0.3	18.0
SL970143	970152	38.5	L0.2	2.0	151	1.5	1.1	0.3	19.5
SL970144	970153	39.5	0.2	2.3	154	1.3	1.0	0.3	19.0
SL970145	970154	40.5	0.2	2.0	148	1.3	1.1	0.3	20.4
SL970146	970155	41.5	0.2	2.5	171	1.6	1.1	0.3	21.8
SL970147	970156	42.5	L0.2	2.3	148	0.8	1.2	0.3	35.4
SL970148	970157	43.5	L0.2	2.3	162	1.2	1.2	0.3	44.0
SL970149	970158	44.5	0.2	2.8	181	1.5	1.4	0.4	32.0

Parameter	Lab	Depth	Chromium	Cesium	Copper	Iron	Lithium	Manganese	Molybdenum
Detection Limit			0.4	0.2	0.2	0.02	0.2	0.2	0.2
Units		cm	ug/g	ug/g	ug/g	wt%	ug/g	ug/g	ug/g
SL970101	970111	0	46.9	4.0	62.7	13.40	34.3	14700	5.3
SL970102	970112	2.0	53.4	4.4	65.4	7.81	45.8	6150	3.5
SL970103	970113	2.5	57.3	4.9	66.7	5.94	46.0	3270	2.7
SL970104	970114	3.0	57.2	4.9	62.0	5.61	46.3	2260	2.4
SL970105	970115	3.5	57.7	5.1	61.6	5.73	48.8	1910	1.8
SL970106	970116	4.0	60.7	5.4	65.2	5.26	50.1	1610	1.7
SL970107	970117	4.5	58.6	5.1	62.2	5.49	49.0	1340	1.5
SL970108	970118	5.0	54.4	4.9	59.0	9.11	42.0	1760	2.5
SL970109	970119	5.5	43.6	3.5	58.7	18.90	29.6	2660	6.0
SL970110	970120	6.0	34.4	2.5	53.6	26.50	20.0	2270	7.1
SL970111	970121	6.5	42.2	3.4	52.8	18.70	28.7	1660	4.1
SL970112	970122	7.5	69.6	6.7	81.3	9.85	48.8	938	2.4
SL970113	970123	8.5	79.7	7.5	99.1	5.21	55.0	890	1.9
SL970114	970124	9.5	78.1	7.3	108.0	7.41	48.9	988	2.9
SL970115	970125	10.5	75.5	6.6	102.0	5.01	57.3	825	2.5
SL970116	970126	11.5	76.8	7.5	91.0	3.65	57.0	689	3.0
SL970117	970127	12.5	75.1	6.6	86.2	3.83	56.5	651	2.7
SL970118	970128	13.5	72.2	6.8	73.6	4.17	53.8	582	2.4
SL970119	970129	14.5	73.7	6.6	76.6	4.20	59.4	546	2.5
SL970120	970130	15.5	73.5	6.5	74.9	4.04	59.5	506	2.6
SL970121	970131	16.5	75.8	6.7	78.9	3.42	62.7	472	2.3
SL970122	970132	17.5	74.9	6.5	82.6	3.98	62.3	479	3.3
SL970123	970133	18.5	80.0	6.7	89.3	2.90	63.8	530	3.7
SL970124	970134	19.5	78.9	6.2	81.9	3.66	66.3	474	4.0
SL970125	970135	20.5	77.7	6.4	84.8	3.47	61.6	454	4.1
SL970126	970136	21.5	80.3	8.2	88.7	3.96	57.4	465	4.9
SL970127	970137	22.5	73.9	7.1	84.2	3.74	58.7	425	4.4
SL970128	970138	23.5	75.3	6.7	93.0	4.29	55.5	478	3.9
SL970129	970139	24.5	76.1	6.2	87.6	4.12	59.8	425	3.0
SL970130	970140	25.5	79.2	6.7	87.1	3.17	58.9	421	3.7
SL970131	970141	26.5	84.6	6.8	92.5	3.24	61.8	352	4.2
SL970132	970142	27.5	76.6	6.4	83.0	3.79	60.4	392	3.6
SL970133	970143	28.5	73.9	6.3	84.5	3.22	60.3	359	3.6
SL970134	970144	29.5	73.2	6.5	78.9	3.59	58.7	400	3.4
SL970135	970145	30.5	71.7	6.0	75.5	3.58	58.4	367	3.1
SL970136	970146	31.5	73.1	6.1	75.7	3.73	59.8	390	3.2
SL970137	970147	32.5	72.7	5.8	72.1	3.34	60.7	342	3.1
SL970139	970148	34.5	73.7	5.8	76.3	3.35	64.4	351	3.0
SL970140	970149	35.5	68.5	5.8	68.9	3.63	55.6	328	3.0
SL970141	970150	36.5	70.6	5.8	73.0	3.54	55.0	315	3.0
SL970142	970151	37.5	76.7	5.8	83.9	3.75	61.0	336	3.4
SL970143	970152	38.5	69.4	5.8	78.1	3.68	58.9	352	3.4
SL970144	970153	39.5	72.0	5.9	81.8	4.01	58.3	349	3.5
SL970145	970154	40.5	71.3	6.4	81.5	3.57	60.2	320	3.5
SL970146	970155	41.5	72.2	6.2	80.5	4.21	61.4	375	3.5
SL970147	970156	42.5	74.9	6.8	88.0	4.36	61.5	342	4.1
SL970148	970157	43.5	76.0	6.2	95.6	4.54	64.2	389	4.3
SL970149	970158	44.5	78.7	6.9	106.0	5.27	65.6	445	3.8

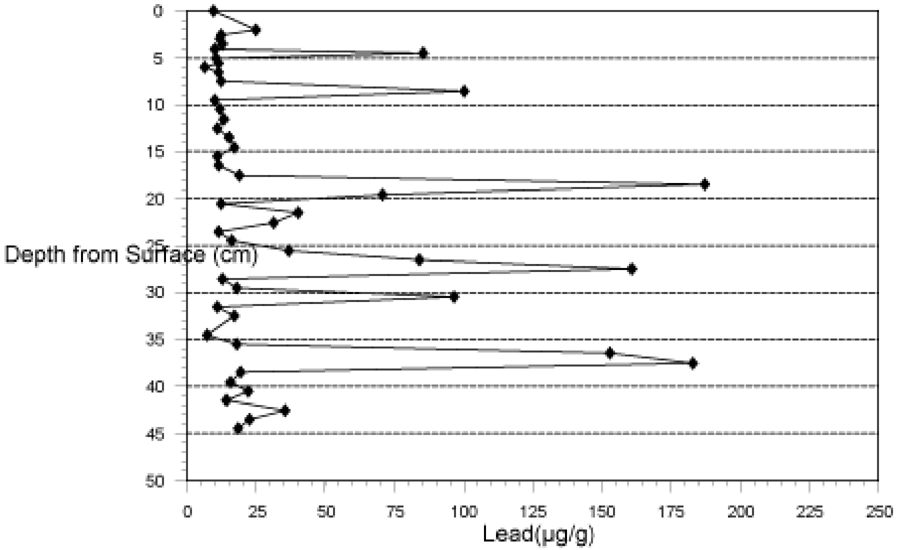
Parameter	Lab	Depth	Nickel	Lead	Rubidium	Antimony	Selenium	Strontium	Titanium
Detection Limit			0.2	0.2	0.2	0.2	2	0.2	0.2
Units		cm	ug/g	ug/g	ug/g	ug/g	ug/g	ug/g	ug/g
SL970101	970111	0	53.1	9.6	31.8	L0.2	L2	16.9	817
SL970102	970112	2.0	51.1	24.6	38.9	L0.2	L2	16.6	967
SL970103	970113	2.5	55.7	12.4	39.7	L0.2	L2	14.6	988
SL970104	970114	3.0	52.9	12.0	38.8	L0.2	L2	13.4	825
SL970105	970115	3.5	49.1	12.6	41.9	L0.2	L2	12.9	998
SL970106	970116	4.0	50.7	10.0	43.2	L0.2	L2	13.1	1030
SL970107	970117	4.5	50.7	85.3	41.4	L0.2	L2	11.8	1070
SL970108	970118	5.0	45.0	10.3	39.3	L0.2	L2	11.4	859
SL970109	970119	5.5	35.1	11.4	30.0	L0.2	L2	10.1	899
SL970110	970120	6.0	27.6	6.5	22.3	L0.2	L2	9.6	671
SL970111	970121	6.5	31.5	11.3	28.1	L0.2	L2	10.1	856
SL970112	970122	7.5	45.0	12.4	41.0	L0.2	L2	13.1	950
SL970113	970123	8.5	53.6	100.0	51.4	L0.2	L2	15.2	1000
SL970114	970124	9.5	49.1	10.0	45.9	L0.2	L2	14.7	1190
SL970115	970125	10.5	55.3	11.9	47.9	L0.2	L2	14.9	1090
SL970116	970126	11.5	64.7	13.0	48.0	L0.2	L2	15.1	1040
SL970117	970127	12.5	62.1	10.8	47.1	L0.2	L2	14.7	960
SL970118	970128	13.5	54.0	14.9	44.8	L0.2	L2	13.6	790
SL970119	970129	14.5	54.8	17.1	46.2	L0.2	L2	13.9	1110
SL970120	970130	15.5	54.9	10.9	46.0	L0.2	L2	13.2	1160
SL970121	970131	16.5	59.5	11.3	48.3	L0.2	L2	15.4	833
SL970122	970132	17.5	63.3	18.9	49.9	L0.2	L2	15.7	1050
SL970123	970133	18.5	68.9	187.0	47.7	L0.2	L2	15.3	860
SL970124	970134	19.5	66.4	70.8	47.6	L0.2	L2	16.5	789
SL970125	970135	20.5	62.6	12.5	49.5	L0.2	L2	17.3	903
SL970126	970136	21.5	58.4	40.2	53.7	L0.2	L2	18.6	1020
SL970127	970137	22.5	64.8	31.4	47.9	L0.2	L2	17.1	1010
SL970128	970138	23.5	63.0	11.6	46.5	L0.2	L2	17.1	835
SL970129	970139	24.5	63.4	16.0	47.6	L0.2	L2	18.1	937
SL970130	970140	25.5	69.2	37.0	50.5	L0.2	L2	18.7	999
SL970131	970141	26.5	73.8	84.0	55.6	L0.2	L2	21.4	846
SL970132	970142	27.5	63.2	161.0	50.0	L0.2	L2	20.0	959
SL970133	970143	28.5	61.8	12.6	47.8	L0.2	L2	18.9	929
SL970134	970144	29.5	63.2	17.7	46.9	L0.2	L2	18.8	919
SL970135	970145	30.5	59.6	96.4	46.9	L0.2	L2	18.0	957
SL970136	970146	31.5	59.3	11.0	46.3	L0.2	L2	18.3	837
SL970137	970147	32.5	61.4	17.0	47.3	L0.2	L2	18.7	979
SL970139	970148	34.5	64.7	7.2	44.4	L0.2	L2	16.8	998
SL970140	970149	35.5	56.8	17.7	45.0	L0.2	L2	16.9	946
SL970141	970150	36.5	60.3	153.0	47.1	L0.2	L2	18.3	860
SL970142	970151	37.5	67.8	183.0	45.5	L0.2	L2	17.8	963
SL970143	970152	38.5	62.9	19.1	44.5	L0.2	L2	19.5	823
SL970144	970153	39.5	67.8	15.6	47.3	L0.2	L2	16.8	997
SL970145	970154	40.5	68.6	22.1	47.6	L0.2	L2	17.7	965
SL970146	970155	41.5	68.0	14.3	46.4	L0.2	L2	17.6	1010
SL970147	970156	42.5	74.3	35.6	47.3	L0.2	L2	18.1	948
SL970148	970157	43.5	82.9	22.3	46.4	L0.2	L2	17.7	810
SL970149	970158	44.5	80.9	18.5	53.2	L0.2	L2	20.0	993

Parameter	Lab	Depth	Thallium	Uranium	Vanadium	Zinc	Arsenic	Mercury
Detection Limit			0.2	0.2	0.2	1	0.1	0.005
Units		cm	ug/g	ug/g	ug/g	ug/g	ug/g	ug/g
SL970101	970111	0	0.4	7.3	42.3	94	48.8	0.190
SL970102	970112	2.0	0.4	7.5	46.9	87	33.5	0.190
SL970103	970113	2.5	0.5	7.9	46.4	91	19.3	0.170
SL970104	970114	3.0	0.4	7.8	45.2	88	17.3	0.150
SL970105	970115	3.5	0.4	8.0	48.0	85	15.4	0.140
SL970106	970116	4.0	0.4	8.3	50.0	93	15.8	0.130
SL970107	970117	4.5	0.4	8.0	48.7	98	13.2	0.130
SL970108	970118	5.0	0.3	8.2	45.9	81	47.9	0.088
SL970109	970119	5.5	0.3	7.0	38.2	79	11.8	0.079
SL970110	970120	6.0	0.2	6.4	32.5	73	231.0	0.078
SL970111	970121	6.5	0.2	6.8	35.9	70	187.0	0.079
SL970112	970122	7.5	0.3	9.4	59.3	77	78.7	0.081
SL970113	970123	8.5	0.5	11.3	66.0	91	15.1	0.076
SL970114	970124	9.5	0.4	11.8	73.0	94	18.2	0.086
SL970115	970125	10.5	0.5	10.7	67.5	102	14.8	0.080
SL970116	970126	11.5	0.5	10.2	64.8	99	5.1	0.067
SL970117	970127	12.5	0.4	9.6	62.8	107	13.3	0.063
SL970118	970128	13.5	0.4	9.7	60.3	107	11.5	0.062
SL970119	970129	14.5	0.4	9.9	63.1	111	14.4	0.061
SL970120	970130	15.5	0.3	10.1	64.6	92	14.0	0.056
SL970121	970131	16.5	0.4	9.4	64.0	99	10.9	0.052
SL970122	970132	17.5	0.5	10.0	65.4	103	11.7	0.051
SL970123	970133	18.5	0.5	10.4	69.4	142	15.8	0.047
SL970124	970134	19.5	0.4	10.2	70.9	136	14.7	0.052
SL970125	970135	20.5	0.5	10.4	67.7	114	14.5	0.049
SL970126	970136	21.5	0.6	12.1	74.4	145	17.8	0.044
SL970127	970137	22.5	0.5	11.2	67.0	132	16.8	0.049
SL970128	970138	23.5	0.4	11.8	68.5	157	11.2	0.051
SL970129	970139	24.5	0.4	10.6	69.9	120	15.8	0.058
SL970130	970140	25.5	0.6	11.7	68.8	110	19.5	0.054
SL970131	970141	26.5	0.6	12.7	75.2	92	17.3	0.065
SL970132	970142	27.5	0.5	11.1	69.9	117	14.0	0.066
SL970133	970143	28.5	0.4	11.0	67.2	97	15.0	0.073
SL970134	970144	29.5	0.4	10.2	65.1	103	16.1	0.060
SL970135	970145	30.5	0.4	9.9	65.1	96	18.9	0.064
SL970136	970146	31.5	0.5	10.0	66.4	97	17.9	0.053
SL970137	970147	32.5	0.4	9.5	65.0	87	17.1	0.055
SL970139	970148	34.5	0.4	9.1	67.2	88	17.6	0.049
SL970140	970149	35.5	0.4	9.5	62.2	107	16.9	0.047
SL970141	970150	36.5	0.4	9.5	65.8	126	21.4	0.051
SL970142	970151	37.5	0.6	9.8	75.4	116	20.8	0.051
SL970143	970152	38.5	0.5	10.1	65.4	111	20.2	0.053
SL970144	970153	39.5	0.6	10.3	68.2	116	21.0	0.059
SL970145	970154	40.5	0.5	10.7	67.7	112	25.0	0.061
SL970146	970155	41.5	0.5	11.0	67.7	129	25.7	0.056
SL970147	970156	42.5	0.4	11.6	70.8	116	24.6	0.061
SL970148	970157	43.5	0.4	12.1	73.8	124	25.3	0.059
SL970149	970158	44.5	0.4	13.2	77.0	152	25.8	0.070

GRAIN SIZE ANALYSIS INFORMATION

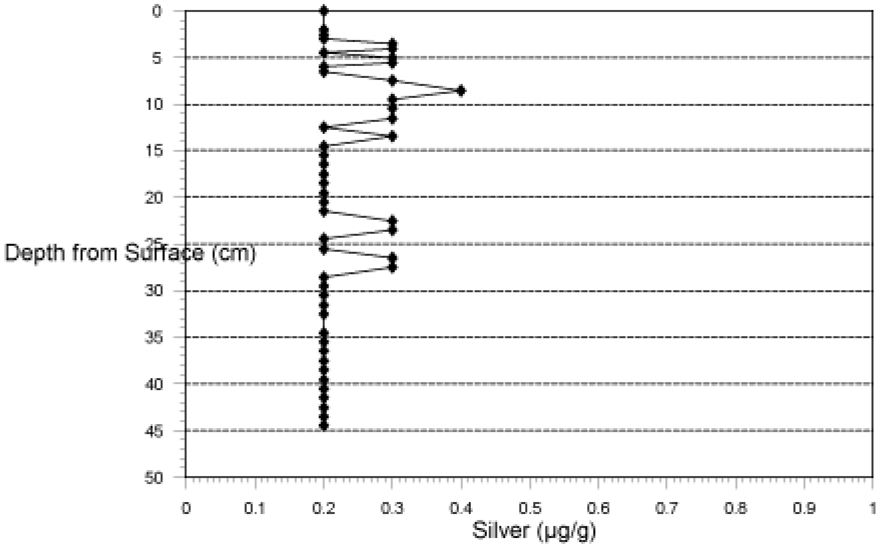
Parameter	Lab	Depth	OrganicMatter	% Sand	% Silt	% Clay	D50
Detection Limit							
Units		cm	%	%	%	%	µm
SL970101	970111	0	19.0	7.9	80.0	12.1	17.69
SL970102	970112	2.0	14.9	5.7	82.4	11.9	16.96
SL970103	970113	2.5	14.4	0.3	91.0	8.8	14.79
SL970104	970114	3.0	15.6	0.0	87.8	12.1	11.95
SL970105	970115	3.5	13.7	0.0	85.8	14.2	11.56
SL970106	970116	4.0	13.7	24.0	68.5	7.5	25.04
SL970107	970117	4.5	12.2	1.9	79.2	18.9	11.10
SL970108	970118	5.0	13.5	3.7	77.8	18.5	11.78
SL970109	970119	5.5	16.3	2.2	73.9	23.9	9.80
SL970110	970120	6.0	15.7	5.7	72.9	21.4	12.50
SL970111	970121	6.5	14.0	9.4	67.7	22.9	11.22
SL970112	970122	7.5	11.5	1.9	75.2	22.9	10.04
SL970113	970123	8.5	10.6	10.0	66.2	23.8	10.80
SL970114	970124	9.5	13.1	2.9	66.2	30.9	7.99
SL970115	970125	10.5	12.2	5.3	75.9	18.8	11.98
SL970116	970126	11.5	11.6	2.1	80.4	17.5	12.20
SL970117	970127	12.5	12.1	3.0	75.3	21.7	10.34
SL970118	970128	13.5	8.2	0.6	76.5	22.9	9.48
SL970119	970129	14.5	6.8	0.9	76.1	23.0	11.26
SL970120	970130	15.5	9.9	5.1	73.4	21.5	11.01
SL970121	970131	16.5	9.9	24.0	66.0	10.0	22.70
SL970122	970132	17.5	10.6	4.5	81.9	13.6	15.39
SL970123	970133	18.5	10.2	12.0	76.0	12.0	17.69
SL970124	970134	19.5	11.2	5.3	81.6	13.1	15.21
SL970125	970135	20.5	11.9	11.7	77.0	11.2	17.83
SL970126	970136	21.5	12.0	25.9	65.2	8.9	23.61
SL970127	970137	22.5	13.8	4.6	74.1	21.2	10.34
SL970128	970138	23.5	11.9	3.5	75.1	21.4	10.04
SL970129	970139	24.5	11.4	20.0	70.4	9.6	20.83
SL970130	970140	25.5	11.4	21.2	68.2	10.6	11.38
SL970131	970141	26.5	11.3	4.5	75.2	20.3	10.60
SL970132	970142	27.5	10.4	6.3	72.9	20.8	10.80
SL970133	970143	28.5	11.5	3.4	76.2	20.4	10.61
SL970134	970144	29.5	9.7	10.9	73.4	15.7	13.97
SL970135	970145	30.5	9.8	25.3	67.2	7.5	26.16
SL970136	970146	31.5	10.7	26.2	63.2	10.6	22.47
SL970137	970147	32.5	9.8	13.6	72.8	13.6	16.24
SL970138	970148	34.5	9.7	11.8	70.8	17.3	12.92
SL970139	970149	35.5	9.1	16.0	70.7	13.3	16.76
SL970140	970150	36.5	10.4	11.9	72.6	15.5	14.25
SL970141	970151	37.5	9.7	14.2	70.8	15.1	14.91
SL970142	970152	38.5	9.9	18.7	69.4	11.9	18.62
SL970143	970153	39.5	9.9	11.0	72.2	16.8	13.25
SL970144	970154	40.5	10.0	21.5	65.6	12.9	18.24
SL970145	970155	41.5	9.6	27.3	63.1	9.6	24.58
SL970146	970156	42.5	10.1	17.6	68.9	14.5	15.44
SL970147	970157	43.5	10.0	17.6	68.9	13.5	16.06
SL970148	970158	44.5	9.7	26.1	64.9	8.9	24.28

SLIPPER LAKE SEDIMENT PROFILE

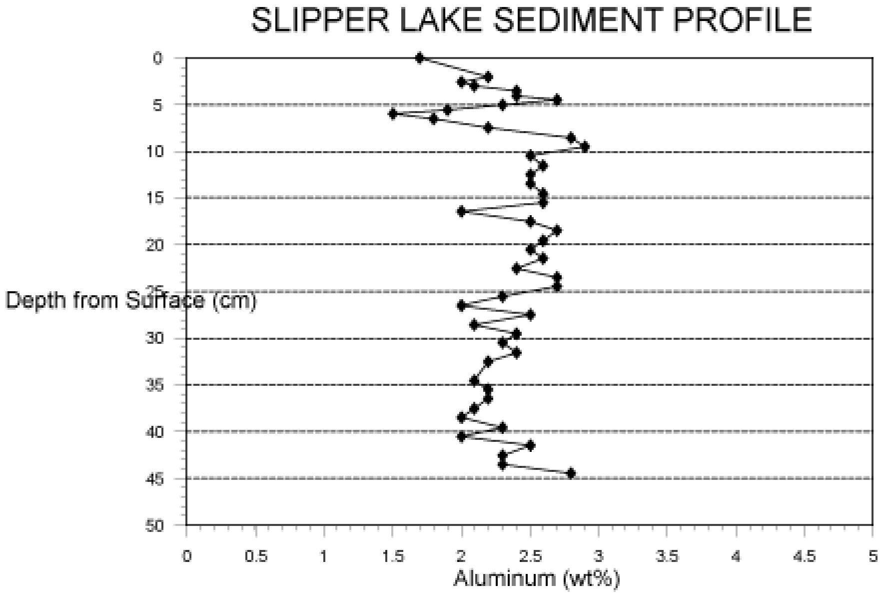


Detection Limit is 0.2 µg/g

SLIPPER LAKE SEDIMENT PROFILE

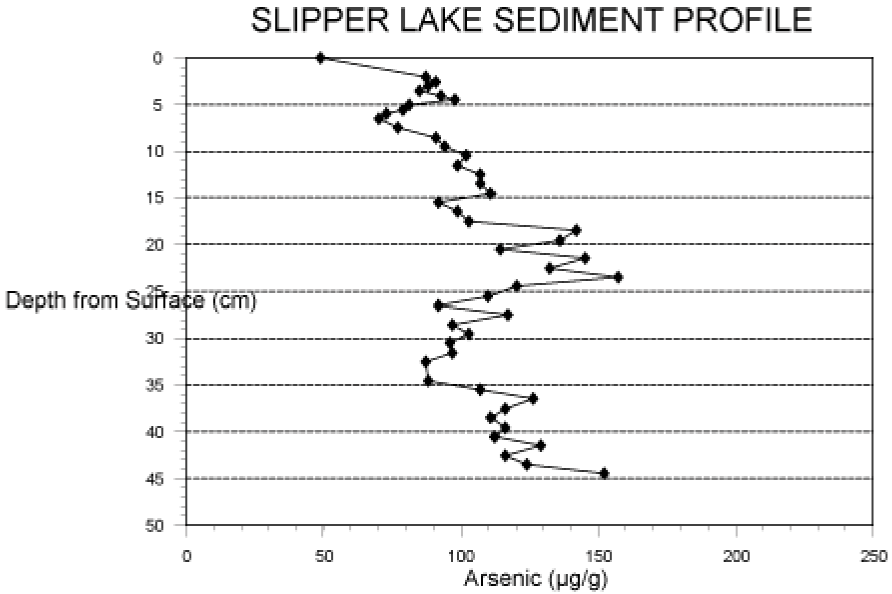


Detection Limit is 0.2 µg/g



SLIPPER LAKE SEDIMENT PROFILE

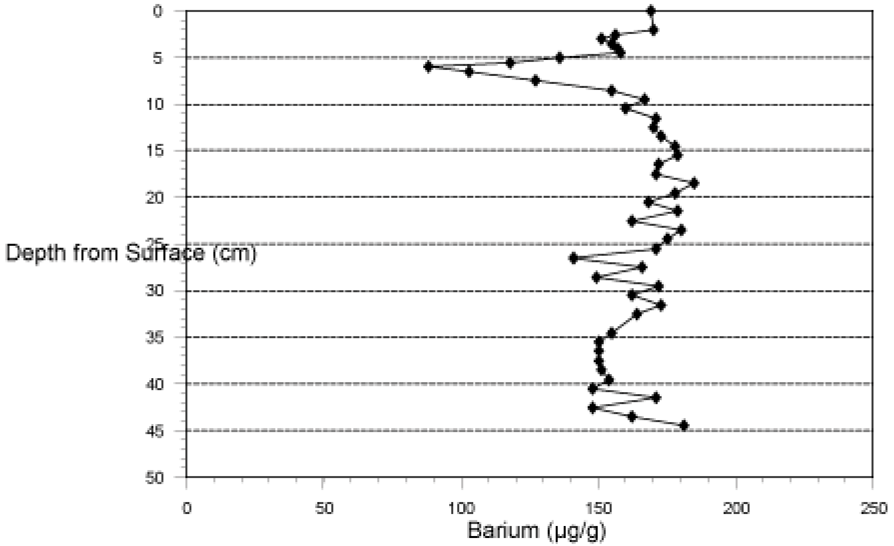
Detection Limit is 0.01 wt%



SLIPPER LAKE SEDIMENT PROFILE

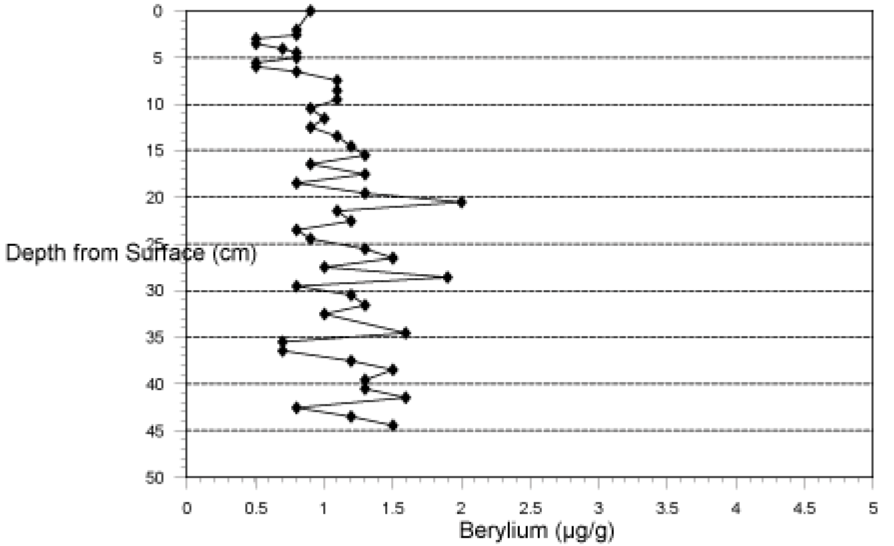
Detection Limit is 0.1 µg/g

SLIPPER LAKE SEDIMENT PROFILE

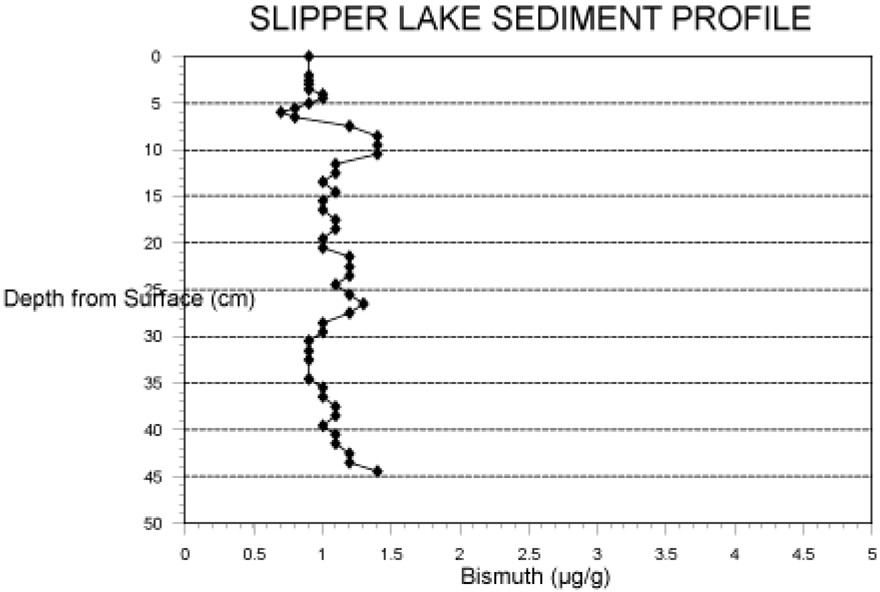


Detection Limit is 0.2 µg/g

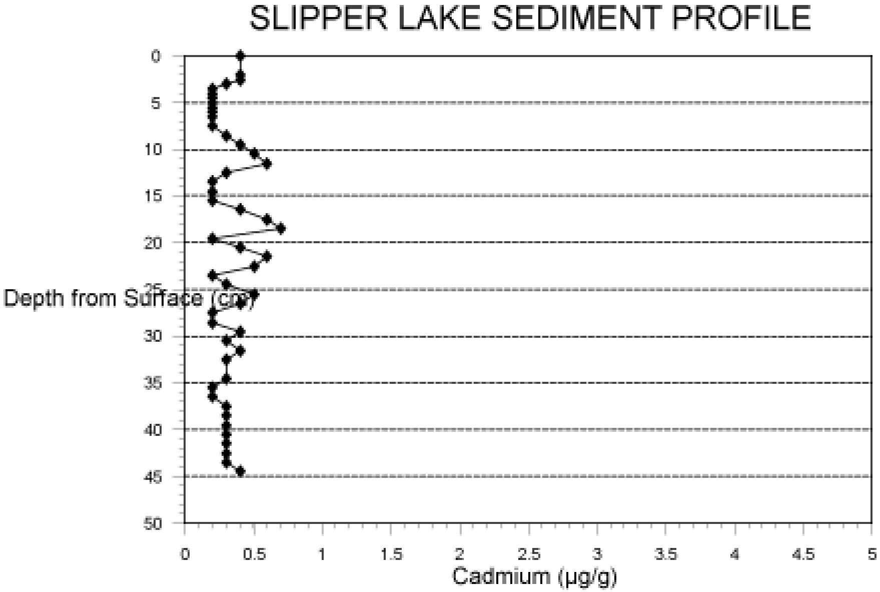
SLIPPER LAKE SEDIMENT PROFILE



Detection Limit is 0.2 µg/g



Detection Limit is 0.2 µg/g



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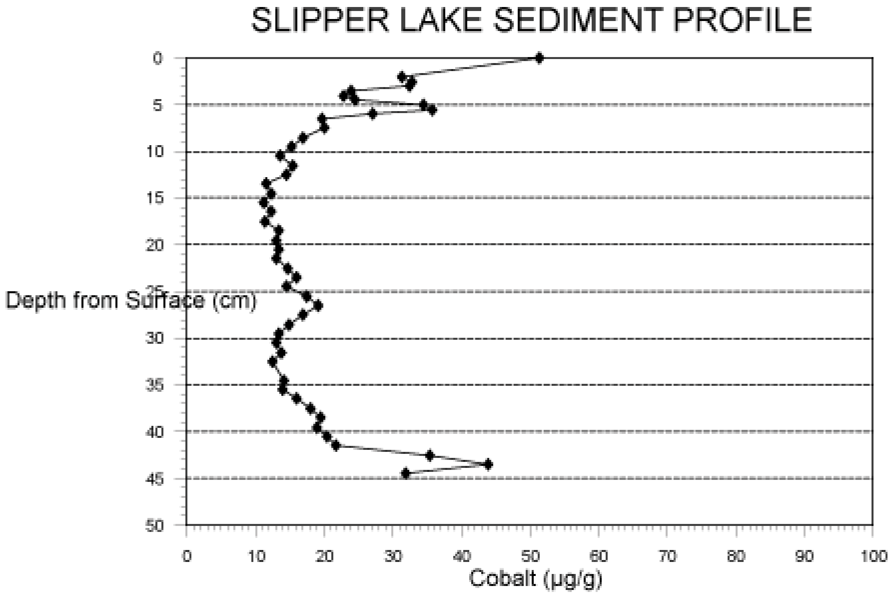
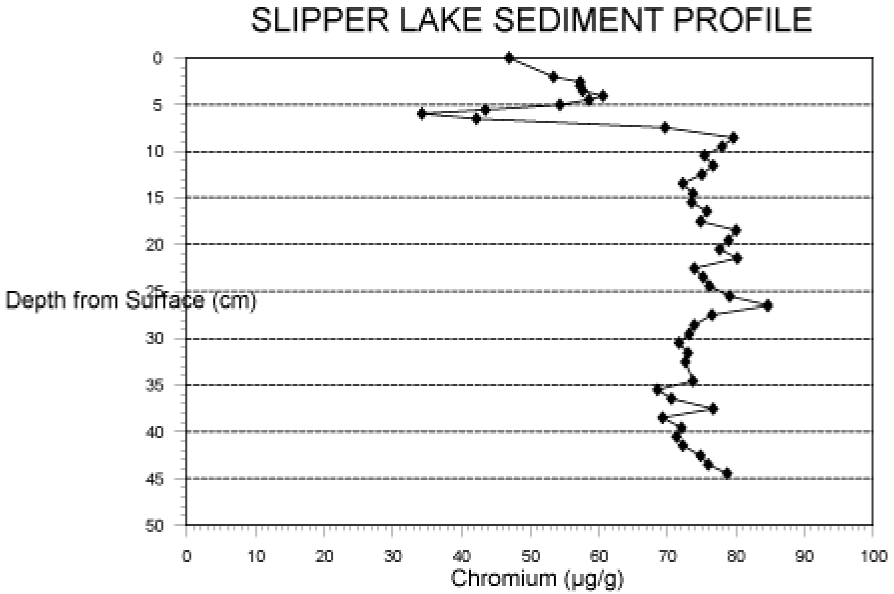
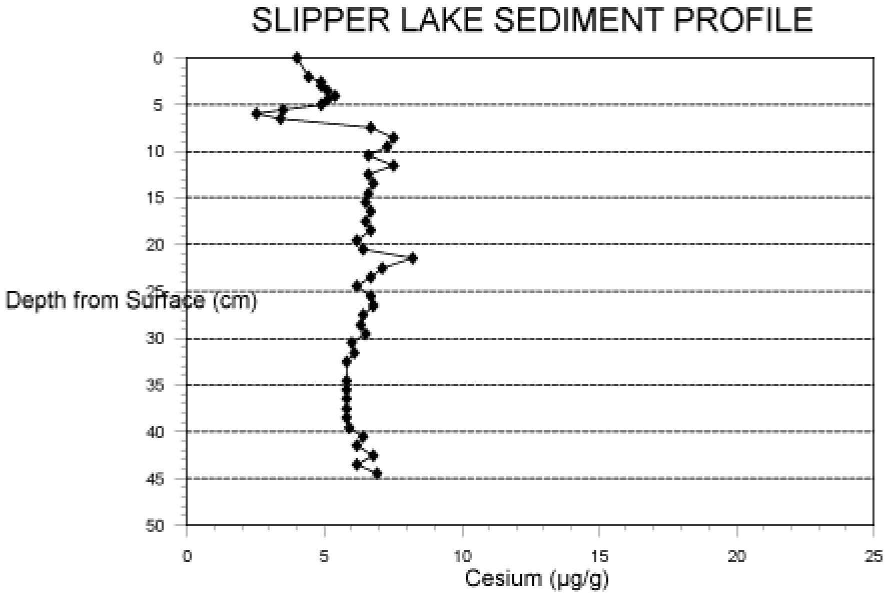


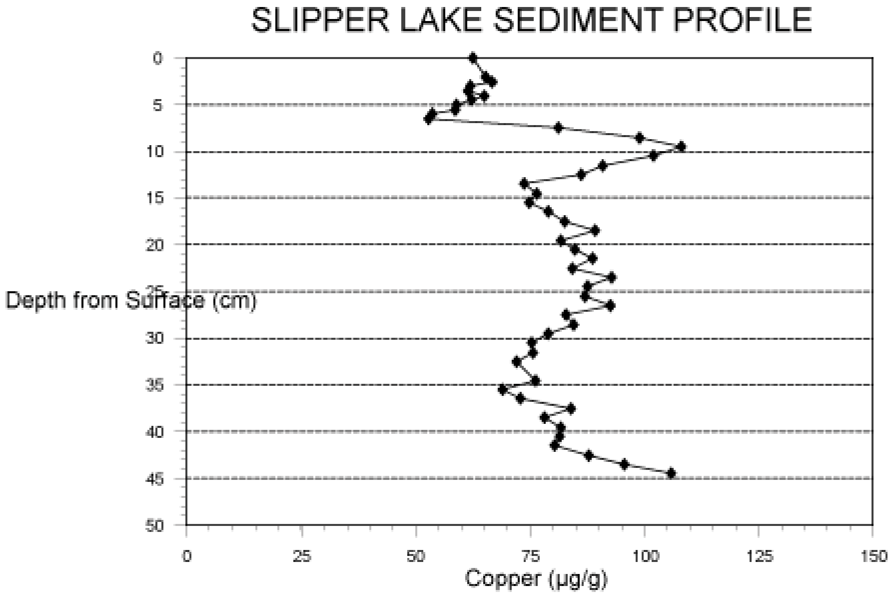
Detection Limit is 0.2 µg/g



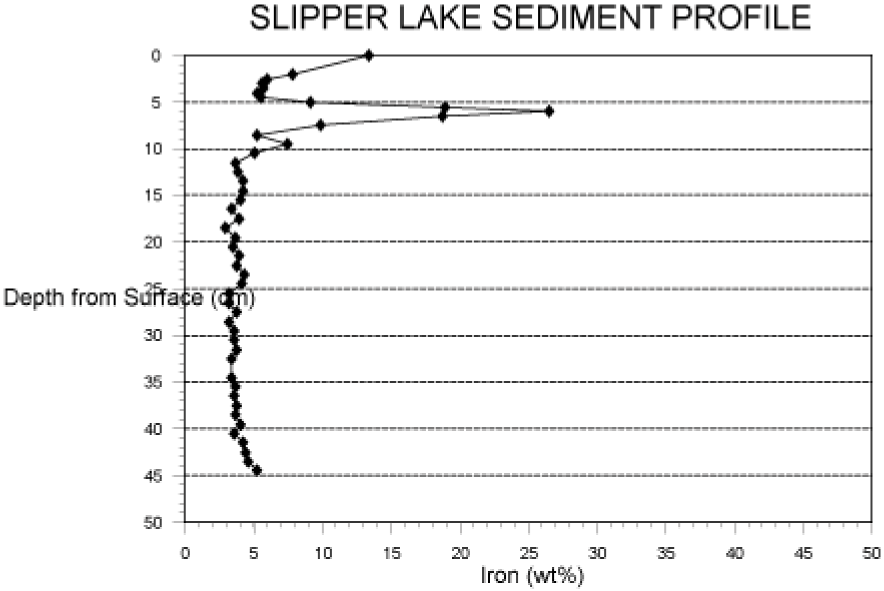
Detection Limit is 0.4 µg/g



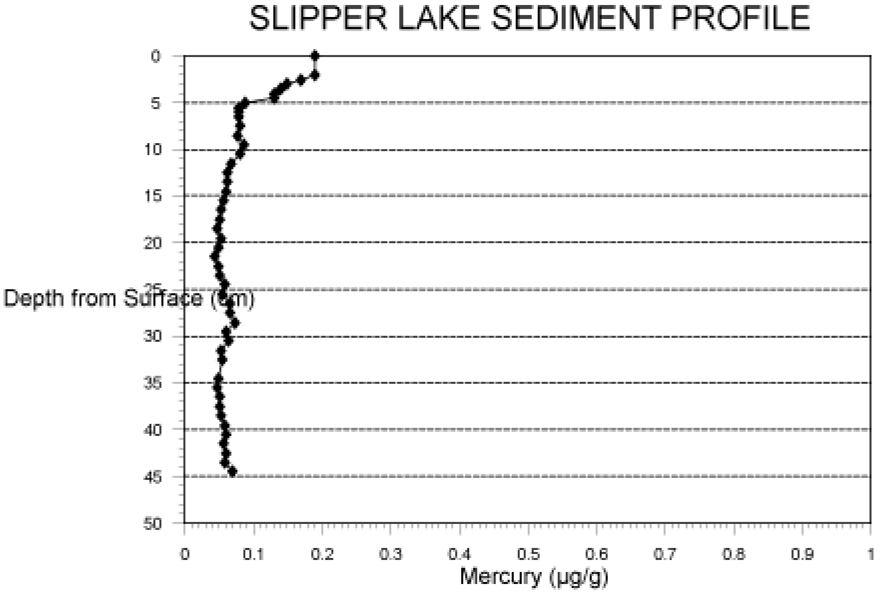
Detection Limit is 0.2 µg/g



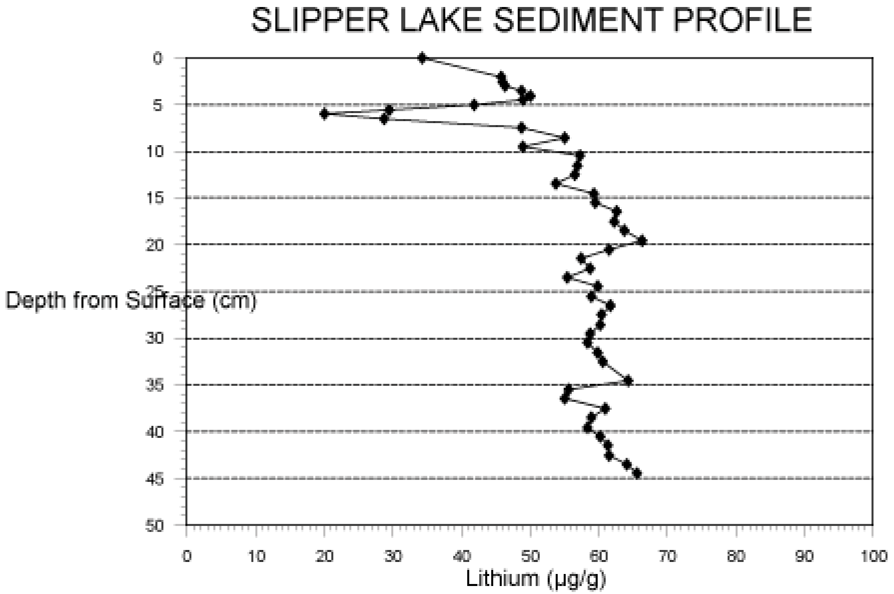
Detection Limit is 0.2 µg/g



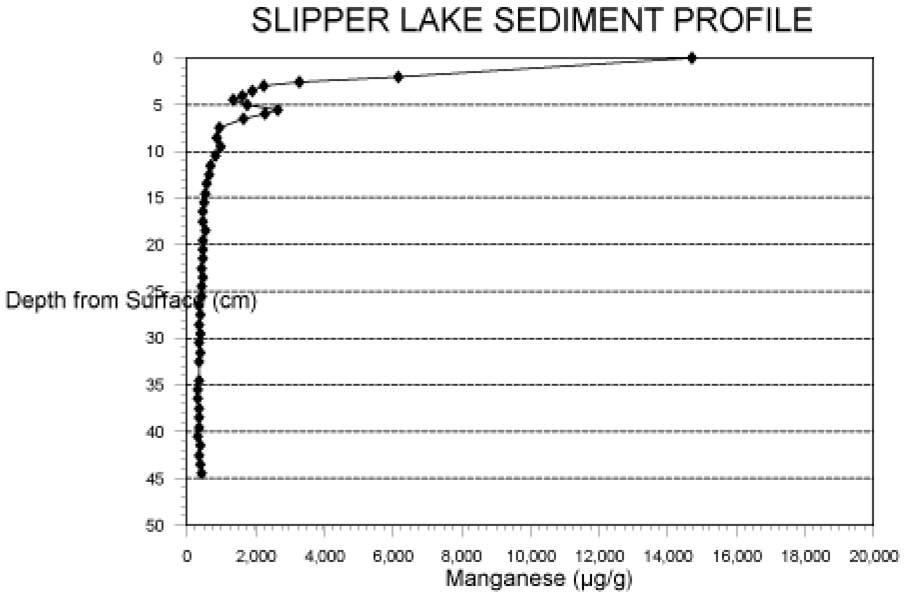
Detection Limit is 0.02 wt%



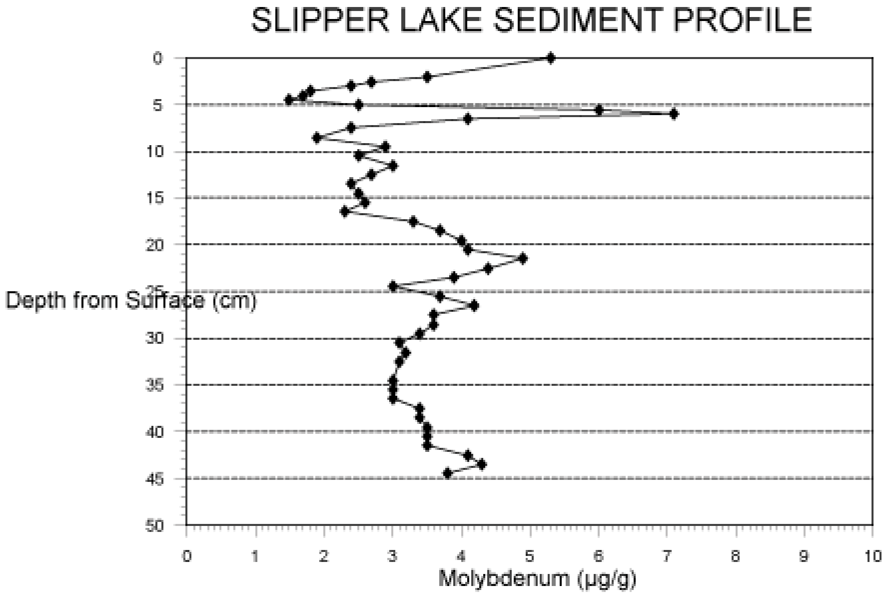
Detection Limit is 0.005 µg/g



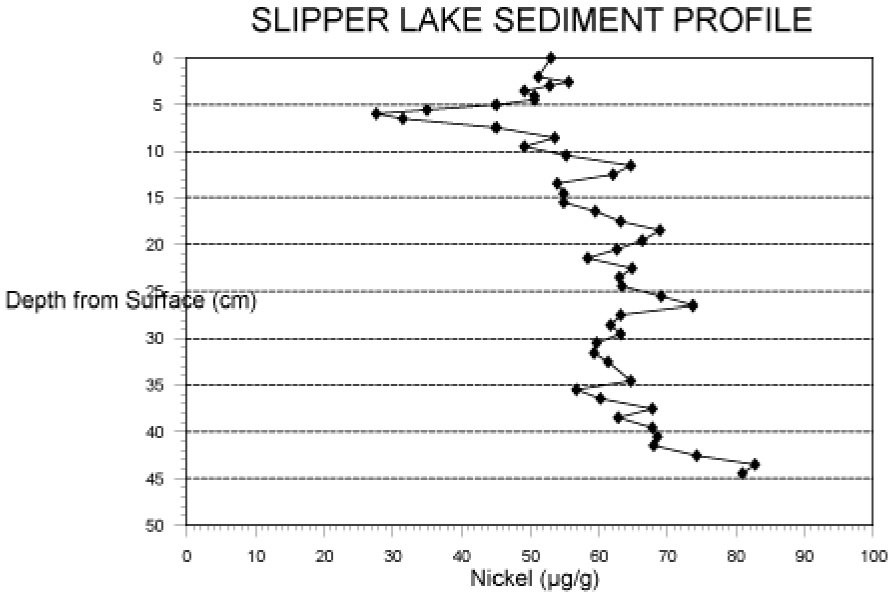
Detection Limit is 0.2 µg/g



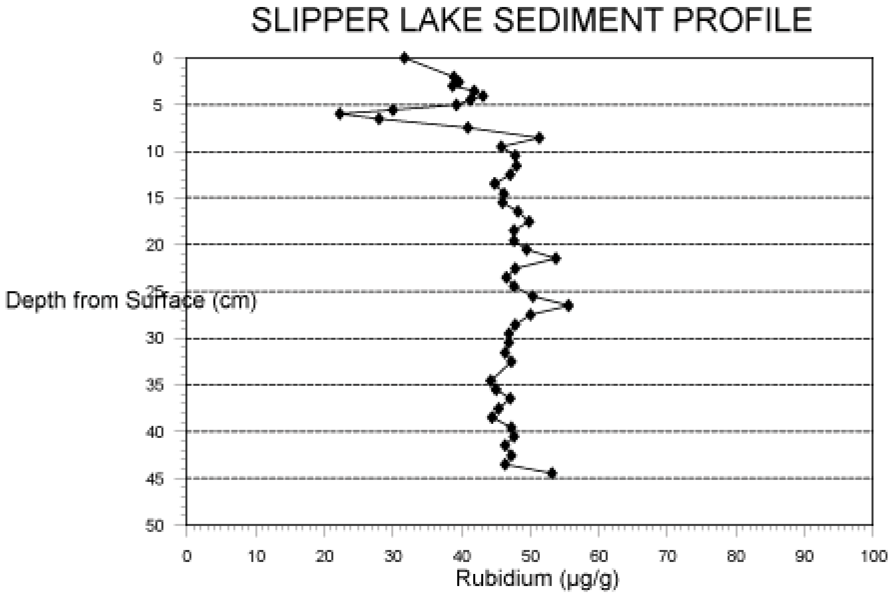
Detection Limit is 0.2 µg/g



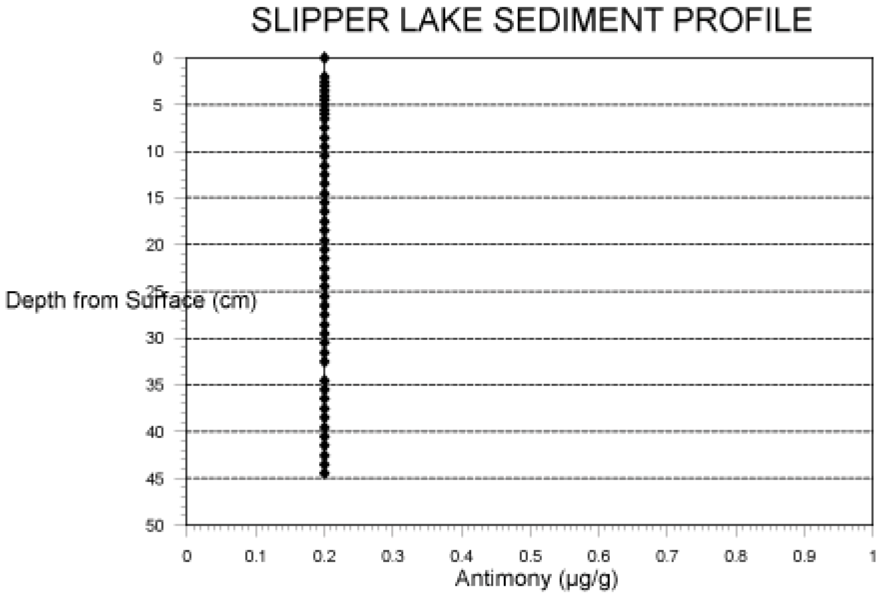
Detection Limit is 0.2 µg/g



Detection Limit is 0.2 µg/g

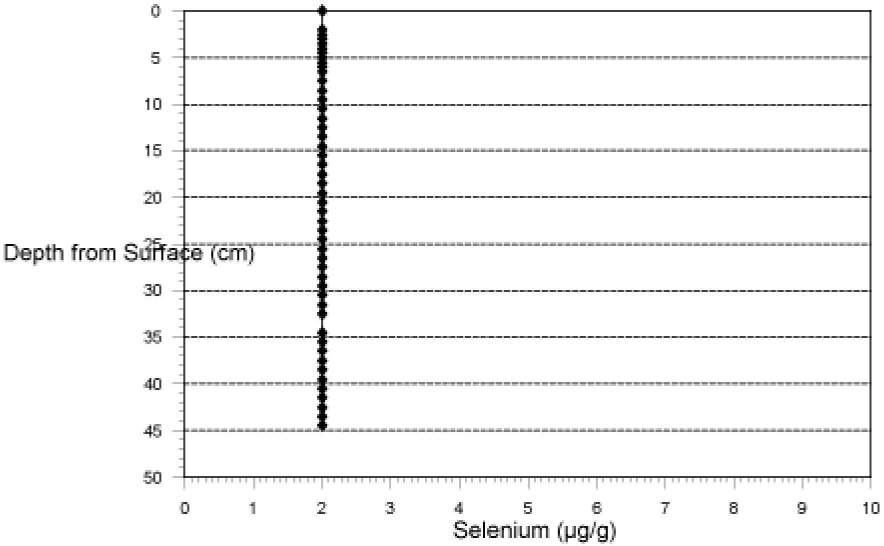


Detection Limit is 0.2 µg/g



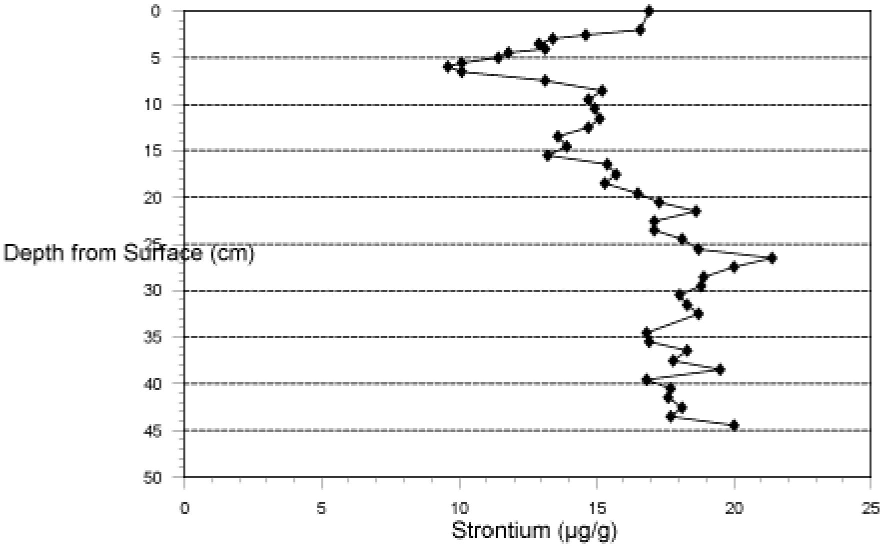
Detection Limit is 0.2 µg/g

SLIPPER LAKE SEDIMENT PROFILE

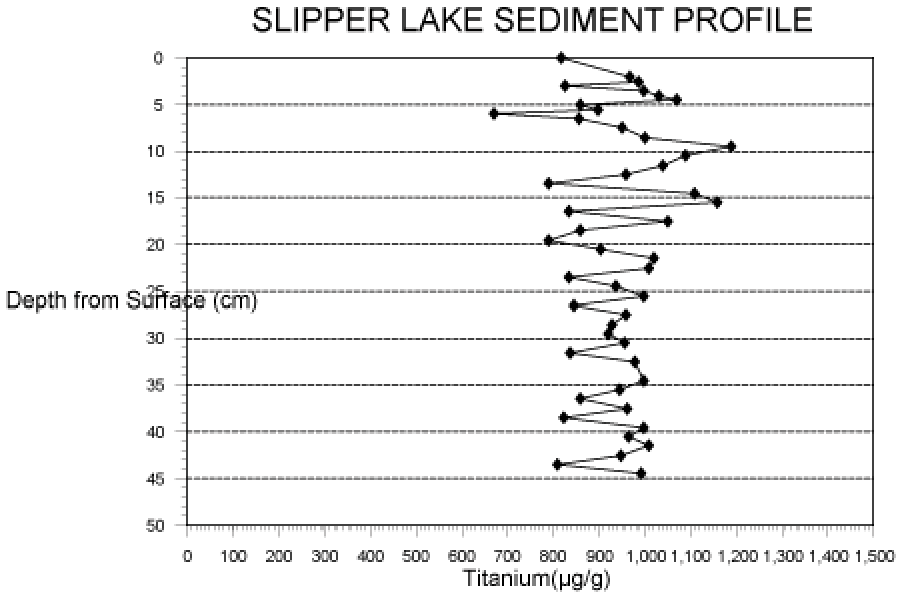


Detection Limit is 2 µg/g

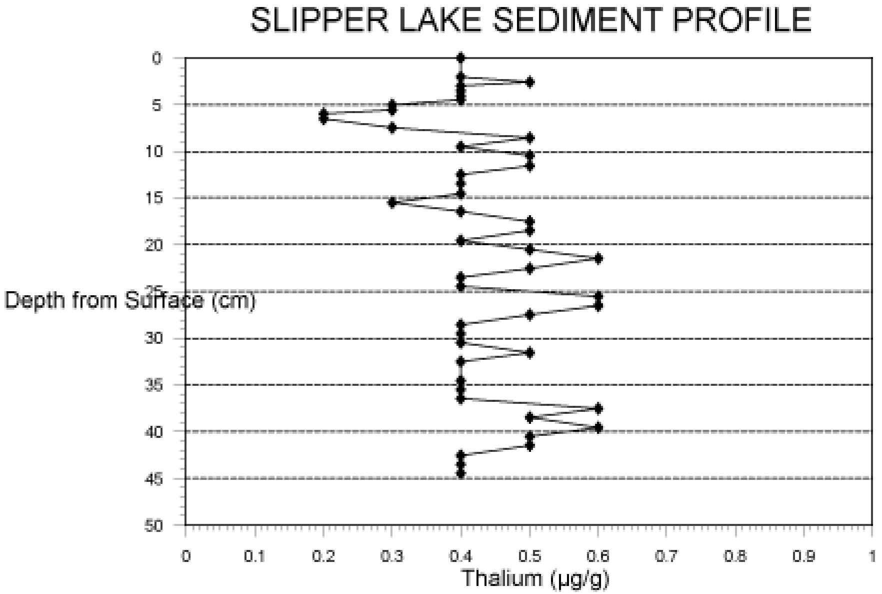
SLIPPER LAKE SEDIMENT PROFILE



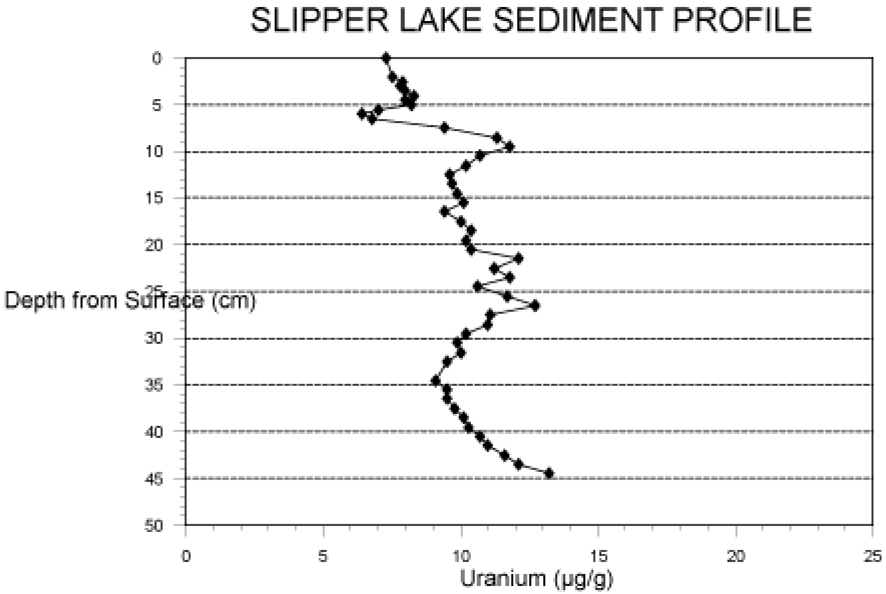
Detection Limit is 0.2 µg/g



Detection Limit is 0.2 µg/g



Detection Limit is 0.2 µg/g



Detection Limit is 0.2 µg/g