

Paleolimnological analysis of Loon Lake, B.C -- Final Report
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Contractor: Dr. Brian Cumming, Assistant Professor
Paleoecological Environmental Assessment and Research Laboratory
Dept. of Biology, Queen's University, Kingston, ON, K7L 3N6,
Ph.: (613) 533-6153; FAX: (613) 533-6617; e-mail:
cummingb@biology.queensu.ca

Supplier: Queen's University, Contact person: Dr. Bruce
Hutchinson, Office of Research Services, Ph.: (613) 533-6081;
FAX: (613) 533-6853

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core.
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 ^{210}Pb output.
Appendix C: Summary of relative abundances of diatom taxa in Loon
Lake.

BACKGROUND

Loon Lake was cored on July 21, 1998 by Rick Nordin and Bob Grace. The core was retrieved using a modified K-B corer (internal diameter ~ 6.35 cm) from the deep basin. On shore the core was sectioned into 0.5-cm intervals into 120-ml plastic containers. These samples were shipped on ice to Queen's University where they were stored in our coldroom at 4°C. Each container was weighed to determine the total wet weight of sediment then subsampled for ^{210}Pb , diatom and pigment analyses. Twenty intervals (every 2 cm) were subsampled for diatom and pigment analyses, and sixteen intervals for ^{210}Pb analysis. Subsamples for analysis of pigments were sent to Prof. Leavitt at University of Regina. Prepared samples for ^{210}Pb analysis (see below) were sent to MYCORE Ltd.

METHODS

^{210}Pb Dating and Percent Organic Matter

The wet weight of the sediment was determined for all the subsections of the core. Sixteen subsamples of wet sediment from each core were weighed and oven-dried (24 hr at 105°C) and reweighed to determine percent water and dry weight of the sediment. Samples that were submitted for ^{210}Pb analysis were ground to a fine dust by use of a pestle and redried overnight at 105°C. The weight of this dried sediment was recorded to four decimal places after it was put in a tared plastic digestion

tube for determination of ^{210}Pb activity that was shipped to MYCORE Ltd.

Percent organic matter for each of the 16 ^{210}Pb samples was determined using standard loss-on-ignition methods (Dean, 1974). A known quantity of dried sediment (recorded to four decimal places) was heated to 550°C for 2 hours. The difference between the original weight of the sediment and the weight of sediment remaining after ignition was used to estimate the percent of organic matter in each sediment sample.

^{210}Pb activities were estimated from determination of 209-Po and a tracer of known activity by alpha spectroscopy. Unsupported ^{210}Pb is calculated by subtracting supported ^{210}Pb (the baseline activity determined from bottom samples of the core) from the total activity at each level. The sediment chronology and sedimentation rates were calculated using the constant rate of supply (CRS) model (Appleby and Oldfield, 1978) from the estimates of ^{210}Pb activities and estimates of cumulative dry mass (Binford, 1990). See Appendix B for summaries of ^{210}Pb analyses by MYCORE (B-1), summary of ^{210}Pb calculations (B-1,2), and output from the CRS model (B-3).

Diatom Preparation and Enumeration

Slides for diatom analysis were prepared using standard techniques (Cumming, Wilson, Smol and Hall, 1995). Briefly, a small amount of wet sediment was suspended in a 50:50 (molar) mixture of sulfuric and nitric acid in a 20-ml glass vial for 24 hr. prior to being submersed at 70°C in a hot water bath for 5 hr. The remaining sediment material was settled for a period of 24 hr, at which time the acid above sample was removed. The sample was rinsed with distilled water and allowed to settle once again for 24 hrs. The procedure was repeated approx. 10 times until the sample was acid free (litmus test). The samples were settled onto coverslips in a series of four 100% dilutions, which when dry, were mounted onto glass slides using a high-resolution mounting media called Naphrax[®]. For each sample, at least 400 diatom taxa were enumerated under oil immersion at 1000X magnification using an objective with a numerical aperture of 1.3. These analyses were based on the references of Krammer and Lange-Bertalot (1986, 1988, 1991a,b), Patrick and Reimer (1966, 1975) and Cumming et al. (1995).

Cluster Analysis

Cluster analysis, which groups similar diatom assemblages, was run on the taxa represented in Fig. 2. Cluster analysis on the diatom assemblage composition was constrained to the depth of the core samples to provide an unbiased assessment of changes in diatom assemblages through time. A squared chord was used to determine similarity between samples in the cluster analysis (Fig.2). Zones were placed based on these analyses to represent distinct groups in diatom assemblages through time (dashed lines on Fig. 2).

Environmental Reconstructions from diatom assemblages

Inferences of total phosphorus downcore were based on a total phosphorus model based on the 111 freshwater lakes from the 219 lakes sampled by Wilson, Cumming & Smol (1996). This model is based on estimates of taxa optima from weighted-averaging regression on non-transformed relative percentage data. The coefficient of determination (r^2) of this model is 0.66, and the jackknifed r^2 is 0.47. This model is superior to the earlier models developed by Reavie, Hall & Smol (1995) for several reasons including its better predictive ability and the larger number of samples which provide more analogs for downcore reconstructions.

The total phosphorus inferences (Fig. 1E) were critically assessed to determine: 1) if they tracked the main direction of variation in the diatom species assemblages (Fig. 1D); and 2) to assess if the assemblages encountered downcore are well represented in the modern-day samples (Fig. 1F). If the diatom-based phosphorus reconstruction matches the main direction of variation in the diatom assemblages downcore, then we can be fairly confident that the diatoms are tracking changes correlated to phosphorus. If the directions of variation do not match, then the diatom-inferred phosphorus reconstructions do not fully represent the changes, if any occurred, in diatom species composition downcore. Presumably, other environmental variables, or interactions between environmental variables, are contributing to the changes in diatom assemblages.

The main direction of variation in the diatom assemblages downcore in Loon Lake was determined from the first axis scores from a principal components analysis (PCA) ordination using a covariance matrix and non-transformed species abundance data. A PCA was chosen to represent the main direction of variation in this core since only minor changes in diatom assemblages occurred and thus a linear ordination technique would more effectively capture changes in this core than an approach based on unimodal techniques.

The reliability of the downcore total phosphorus inferences assumes that the diatom assemblages encountered downcore are well represented in our modern diatom assemblages. To determine if appropriate analogs existed for the core samples, we determined which samples in our present-day dataset of 111 lakes most resembled each of the downcore samples. This determination was based on a squared chord dissimilarity coefficient between all species found in the core samples. The best match between downcore and modern samples was compared with the distribution of best match between modern samples. Any downcore sample that was more dissimilar than 80% of the modern distribution were deemed to be a 'poor analog'. Similarly, any downcore sample that was more dissimilar than 95% of the modern distribution were deemed to have 'no analog' in our present-day dataset. If the downcore assemblages have good representation in modern samples, more confidence can be placed in the reconstruction. If modern analogs do not exist or are poor, then caution must be placed in

reconstructions from these downcore samples.

RESULTS AND DISCUSSION

²¹⁰Pb Profile, Sedimentation Rates and Organic Matter

The ²¹⁰Pb profile from Loon Lake shows a slight decrease in activity at the top of the core (Fig. 1A). The two most likely explanations for this pattern in the ²¹⁰Pb profile are: 1) an increase in sedimentation rate that could cause a dilution of the ²¹⁰Pb activity; or 2) slight sediment mixing. Given that there are some changes in organic matter (Fig. 1C) and some changes, although minor, in the relative abundances of diatoms in this part of the core (Fig. 2), we can conclude that the observed ²¹⁰Pb profile in the core is likely not solely attributed to mixing. The inferred increase in sedimentation rate from approximately 1965 to 1970 (Fig. 1B) corresponds to a sharp decrease in percent organic matter (Fig. 1C, * note time scales on figures 1B & C are different). This suggests that there was increased inputs of inorganics into the basin that may have been associated with erosional events that increased sedimentation rates. Since 1970 percent organic matter has progressively increased by 20-30%. Increases in organic matter can be attributed to several factors including increased in-lake production of organic matter, increased inwash of organic matter, or decreases in the load of inorganic matter of the lake.

Diatom Assemblage Changes and Analyses

Approximately 46 diatom taxa were encountered in the sediment core from Loon Lake (Appendix C-1). The dominant taxa throughout the core are *Stephanodiscus parvus* and *Stephanodiscus minutulus*, both of which are indicative of meso- to eutrophic conditions (Fig. 2). Other taxa which reach relatively high abundances include *Asterionella formosa*, *Fragilaria crotonensis*, *Nitzschia paleacea* and *Stephanodiscus medius*. Both *S. parvus* and *S. minutulus* can be classified as generalists to the total phosphorus gradient (i.e. occurs in high abundance over a wide range of TP values), in comparison to *A. formosa* and *F. crotonensis* which have a narrower distribution of high abundances along the TP gradient (information from the 111 B.C. freshwater lake calibration set).

Cluster analysis suggests the changes in diatom assemblages through time can be divided into three zones (Fig. 2). *S. parvus* is dominant throughout all three zones, whereas *S. minutulus* decreases in Zone A. *F. crotonensis*, *A. formosa* and *Stephanodiscus hantzschii* increase in abundance in Zones A and B, whereas *Cyclotella bodanica* var. *leminica* virtually disappears in Zone A. *N. paleacea* fluctuates in abundance throughout the core, whereas *Stephanodiscus medius* only reaches high abundances during Zone B. The higher abundances of *S. medius* corresponds to the period of higher sedimentation rates and lower organics (see above section), giving further evidence that a significant change to the lake system occurred during this period. Historical

information on development around Loon Lake at this time could provide some insight into the mechanism of these changes.

Even though there are changes in the diatom assemblages, inferred total phosphorus (TP) has not changed significantly since 1880 (Fig. 1E). This is not surprising since *S. parvus* is dominant throughout the core and the other taxa present are also meso- to eutrophic taxa, with the exception of *S. hantzschii* which is a hypereutrophic taxon. *S. hantzschii* has increased since approximately 1950 (Zone B), but only very slightly. This change is coincident with a decrease in the mesotrophic taxon *C. bodanica* var. *leminica* (Zone A).

PCA axis 1 scores (Fig. 1D) accounts for 70% of the variation in diatom taxa in this core. The primary change in the PCA axis 1 scores occurs between Zones B and A, corresponding to the substantial decrease in *S. minutulus*. The correlation between the reconstructed TP and the main direction of variation in taxa (represented by PCA axis 1 scores) is insignificant when all 20 points are considered, which suggests that the changes seen in the diatom assemblages are probably not solely related to changes in total phosphorus since 1880. All samples have good analogs (Fig. 1F), and thus this is not a factor in contributing to the poor correspondence between inferred TP and the main direction of variation in taxa. Another factor that may be influencing the observed changes in the diatoms includes changes in salinity or lake depth.

References:

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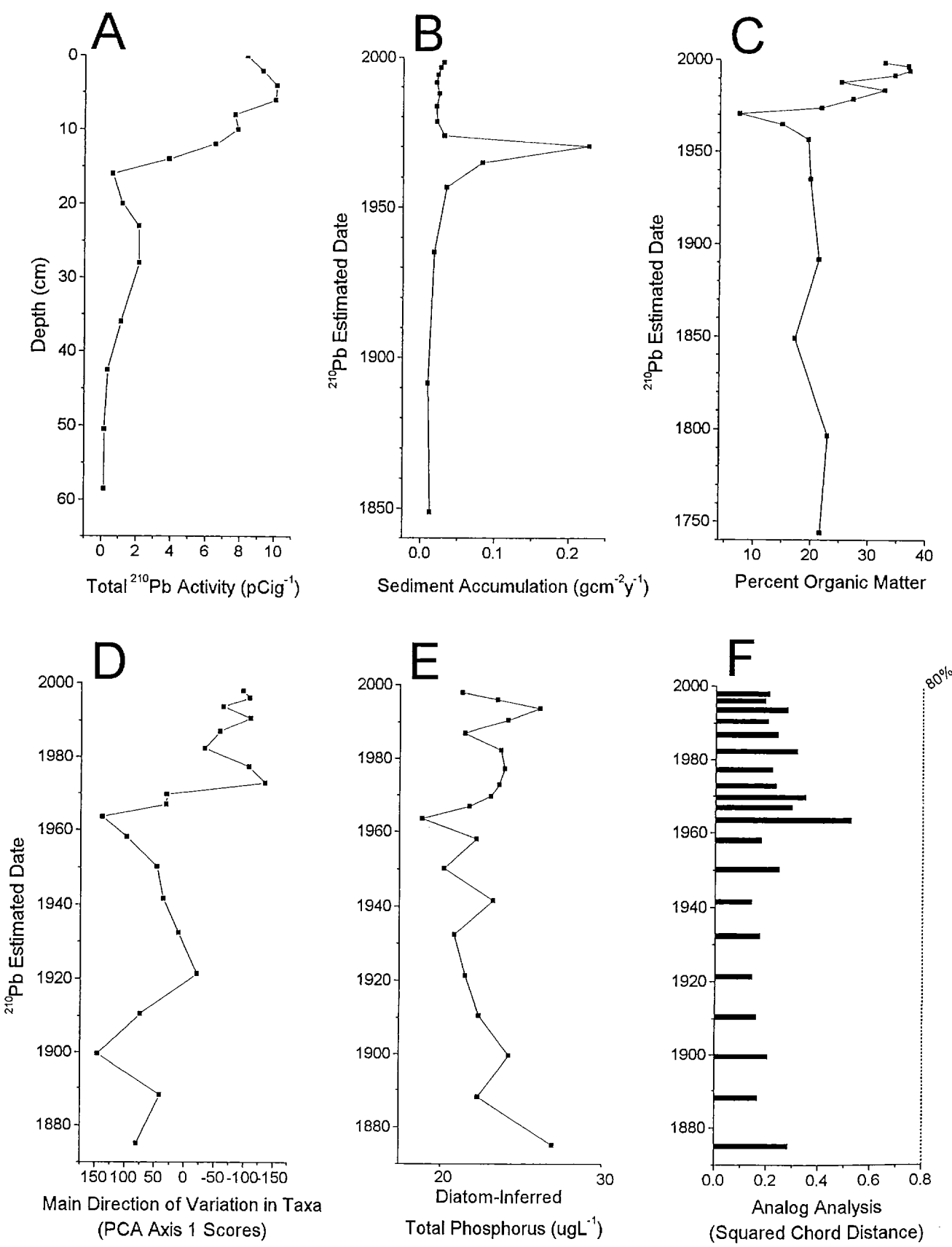
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Figure Captions

Figure 1. Summary diagram for the sediment core from Loon lake showing: A) total ^{210}Pb activity from which the chronology of the core is based; B) the sediment accumulation rate; C) the change in the percent of organic matter in the core; D) the main direction of variation in the diatom assemblage data; E) diatom-based estimated late-summer total phosphorus; and F) analog analysis showing the dissimilarity between present-day and downcore samples (any sample that has a squared chord distance > 0.8 was determined to be a poor analog, whereas any sample with a squared chord distance greater than 1.1 was determined to have no analog in the modern dataset).

Figure 2. Diatom stratigraphy of the diatom taxa that were present in at least ~2% relative abundance in the sediment core from Loon Lake, B.C. (see Appendix C for a complete list of taxa and the relative percentage data). The diatom taxa are arranged in order of increasing late-summer total phosphorus optima which is indicated in parentheses for those taxa with known optima. The dotted lines separate the stratigraphy into three zones that were identified by a cluster analysis on the diatom assemblage composition that was constrained to the depth of the core samples.

Loon Lake, British Columbia



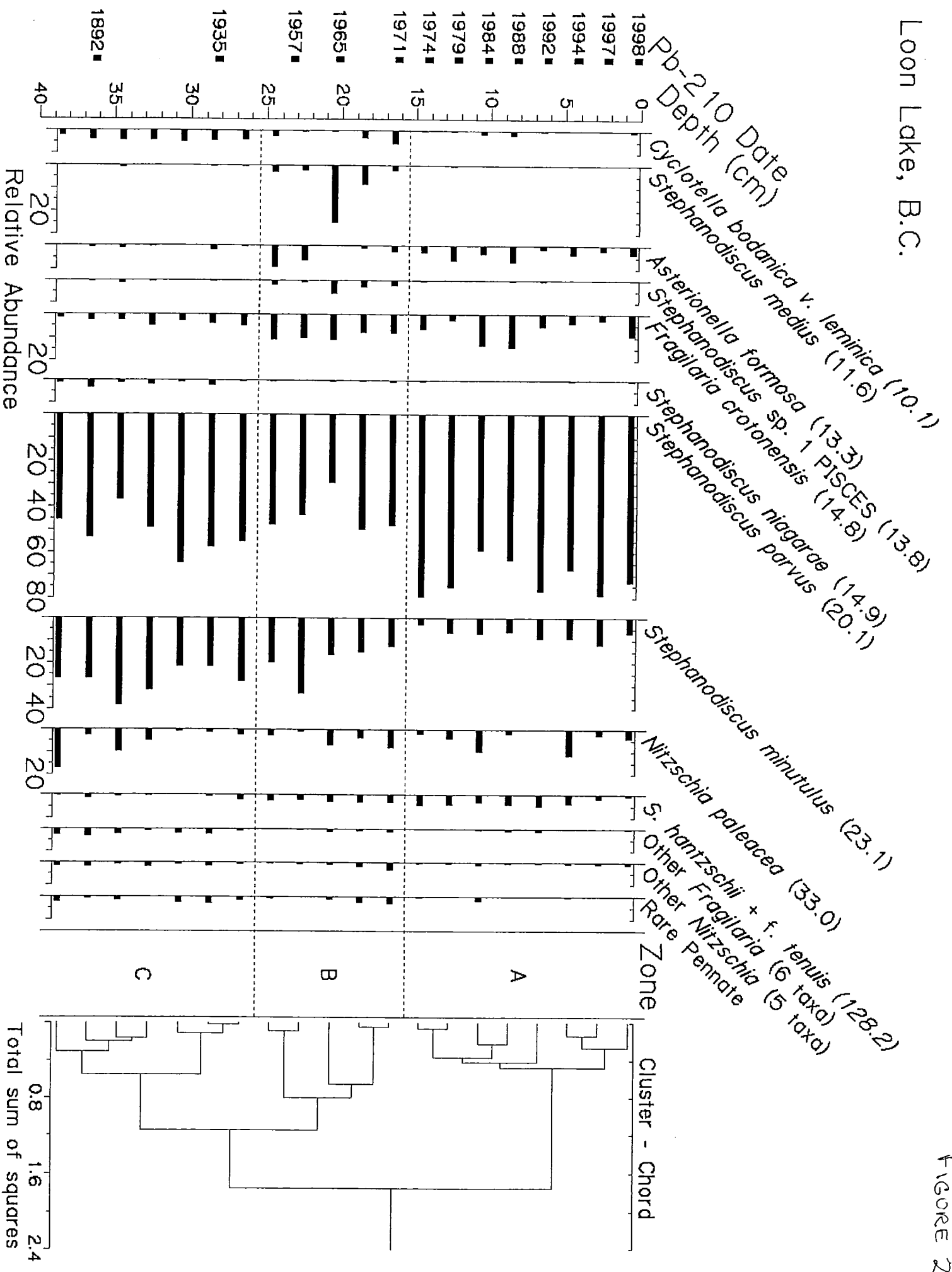


FIGURE 2

Loon Lake - Summary File

Pb210 and LOI summary

Diatom analyses summary

INTTOP (cm)	INTBOT (cm)	Pb210ACT (pCi/g)	LOI(550C) (%organics)	Estimated AD-DATE (g/cm2/yr)	SED RATE (g/cm2/yr)	Depth TOP(cm)	Depth BOT(cm)	Estimated AD-DATE	logTP	TP (ug/L)	Logsalinit	salinity (mg/L)	PCA AX1	11Lakes minimum sq. chord
0.0	0.5	8.3944	32.68	1998.4	0.0297	0.5	1	1998.0	1.324	21.09	2.136	136.8	-97	0.2079
2.0	2.5	9.2693	36.81	1996.7	0.0254	2.5	3	1996.1	1.362	23.01	2.121	132.1	-108	0.1912
4.0	4.5	10.0923	37.04	1994.3	0.0217	4.5	5	1993.6	1.408	25.59	2.233	171.0	-64	0.2758
6.0	6.5	10.0285	34.47	1991.6	0.0200	6.5	7	1990.7	1.374	23.66	2.083	121.1	-110	0.2016
8.0	8.5	7.6733	25.15	1987.9	0.0235	8.5	9	1986.8	1.327	21.23	2.098	125.3	-58	0.2397
10.0	10.5	7.8350	32.67	1983.6	0.0201	10.5	11	1982.3	1.366	23.23	2.223	167.1	-33	0.3138
12.0	12.5	6.5274	27.13	1978.5	0.0207	12.5	13	1977.3	1.37	23.44	2.118	131.2	-107	0.2204
14.0	14.5	3.8523	21.68	1973.8	0.0307	14.5	15	1972.9	1.364	23.12	2.092	123.6	-135	0.2319
16.0	16.5	0.6026	7.37	1970.5	0.2249	16.5	17	1969.8	1.355	22.65	2.226	168.3	31	0.3472
20.0	20.5	1.1940	14.80	1964.9	0.0823	18.5	19	1967.0	1.332	21.48	2.15	141.3	32	0.2949
23.0	23.5	2.1371	19.37	1956.7	0.0336	20.5	21	1963.5	1.28	19.05	2.148	140.6	139	0.5242
28.0	28.5	2.1348	19.79	1935.1	0.0172	22.5	23	1958.1	1.34	21.88	2.124	133.0	98	0.1772
36.0	36.5	1.1033	21.35	1891.5	0.0092	24.5	25	1950.2	1.304	20.14	2.118	131.2	47	0.2451
42.5	43.0	0.3298	17.14	1848.8	0.0127	26.5	27	1941.6	1.358	22.80	2.154	142.6	36	0.1396
50.5	51	0.1588	22.87	1796.4		28.5	29	1932.4	1.316	20.70	2.135	136.5	10	0.1722
58.5	59	0.1352	21.66	1743.9		30.5	31	1921.5	1.328	21.28	2.134	136.1	-21	0.144
						32.5	33	1910.5	1.343	22.03	2.185	153.1	74	0.1607
						34.5	35	1899.6	1.376	23.77	2.27	186.2	146	0.2061
						36.5	37	1888.2	1.342	21.98	2.149	140.9	41	0.1656
						38.5	39	1875.1	1.423	26.49	2.36	229.1	80	0.283

SUMMARY PB210 ANALYSES BY MYCORE - LOON LAKE

Sample Number	Disc #	Section of Core Top	Section of Core Bottom	Sample Weight used (mg)	209 Po Counts	210 Po 210 Po Counts	210 Po Meas (Bq/g)	210 Po (Bq/g)	Precision 1 STD (%)
1	441	0.0	0.5	156	3817	286	0.300	0.309	6.0
2	442	2.0	2.5	351	3269	636	0.331	0.341	4.3
3	443	4.0	4.5	238	4678	659	0.360	0.371	4.2
4	444	6.0	6.5	338	4883	940	0.358	0.369	3.6
5	445	8.0	8.5	507	3254	787	0.274	0.282	4.0
6	446	10.0	10.5	435	4484	905	0.280	0.288	3.6
7	447	12.0	12.5	559	4316	937	0.232	0.240	3.6
8	448	14.0	14.5	736	3533	596	0.137	0.142	4.4
9	449	16.0	16.5	1270	3906	203	0.024	0.027	7.2 repeat
10	450	20.0	20.5	978	5468	249	0.021	0.022	6.5
11	451	23.0	23.5	1032	3114	217	0.043	0.047	7.0 repeat
12	452	28.0	28.5	845	11052	764	0.042	0.044	3.7
13	453	36.0	36.5	840	2235	257	0.066	0.074	6.6 repeat
14	454	42.5	43.0	827	9696	1266	0.075	0.079	3.0
15	455	50.5	51.0	1077	1733	143	0.059	0.065	8.7 repeat
16	456	58.5	59.0	1053	4343	457	0.075	0.079	4.9
					6506	289	0.039	0.041	6.0
					4368	104	0.012	0.012	9.9
					8267	44	0.006	0.006	15.2
						69	0.005	0.005	12.1

SUMMARY PB210 CALCULATIONS FOR DETERMINING DATES - LOON LAKE

Section of Core Top	Section of Core Bottom	Date	Po Sample	Extrac	Date of coring	Time since coring (days)	Decay Corr. to Extrac (Bq/g)	Decay Corr. to Coring (Bq/g)	Sample Weight used (g)	Std dev (Bq/g)
0.0	0.5	98	10	1	98	72	0.3087	0.3106	0.156	0.0071
2.0	2.5	98	10	1	98	72	0.3409	0.3430	0.361	0.0081
4.0	4.5	98	10	1	98	72	0.3711	0.3734	0.238	0.0071
6.0	6.5	98	10	1	98	72	0.3688	0.3711	0.338	0.0070
8.0	8.5	98	10	1	98	72	0.2822	0.2839	0.507	0.0073
10.0	10.5	98	10	1	98	72	0.2881	0.2899	0.435	0.0064
12.0	12.5	98	10	1	98	72	0.2400	0.2415	0.559	0.0059
14.0	14.5	98	10	1	98	72	0.1417	0.1425	1.270	0.0050
16.0	16.5	98	10	1	98	72	0.0271	0.0273	1.270	0.0022
18.0	18.5	98	10	1	98	72	0.0222	0.0223	1.270	0.0016
20.0	20.5	98	10	1	98	72	0.0472	0.0473	0.978	0.0032
23.0	23.5	98	10	1	98	72	0.0439	0.0442	0.978	0.0016
28.0	28.5	98	10	1	98	72	0.0739	0.0743	1.032	0.0047
36.0	36.5	98	10	1	98	72	0.0785	0.0791	0.845	0.0023
42.5	43.0	98	10	1	98	72	0.0654	0.0658	0.845	0.0051
50.5	51.0	98	10	1	98	72	0.0406	0.0408	0.840	0.0034
58.5	59.0	98	10	1	98	72	0.0121	0.0122	0.827	0.0022
		98	10	1	98	72	0.0068	0.0069	1.077	0.0011
		98	10	1	98	72	0.0050	0.0050	1.053	0.0009

YOU ARE ANALYZING CORE C1

FROM LAKE Loon Lake

THE DATA ARE:

INTTOP	INTBOT	PB210ACT	UNSUPACT	RHO	PERCORG	CUMMASST	CUMMASSB	SDACT
0.0	0.5	8.39440	8.24740	0.01640	0.330	0.0000	0.0082	0.1927
2.0	2.5	9.26930	9.12230	0.03340	0.370	0.0424	0.0591	0.2178
4.0	4.5	10.09230	9.94530	0.02270	0.370	0.1041	0.1154	0.1918
6.0	6.5	10.02850	9.88140	0.03420	0.340	0.1666	0.1837	0.1902
8.0	8.5	7.67330	7.52630	0.04650	0.250	0.2590	0.2823	0.1986
10.0	10.5	7.83500	7.68800	0.04830	0.330	0.3592	0.3834	0.1718
12.0	12.5	6.52740	6.38040	0.05430	0.270	0.4499	0.4771	0.1594
14.0	14.5	3.85230	3.70530	0.06560	0.220	0.5630	0.5958	0.1354
16.0	16.5	0.60260	0.45560	0.27290	0.070	0.8246	0.9610	0.0430
20.0	20.5	1.19400	1.04690	0.13230	0.150	1.6020	1.6681	0.0427
23.0	23.5	2.13710	1.99010	0.14480	0.190	1.9046	1.9771	0.0610
28.0	28.5	2.13480	1.98780	0.07410	0.200	2.3159	2.3530	0.0918
36.0	36.5	1.10330	0.95630	0.06910	0.210	2.8768	2.9114	0.0595
42.5	43.0	0.32980	0.18280	0.06320	0.170	3.2653	3.2969	0.0294
50.5	51.0	0.15880	0.00000	0.11130	0.230	3.8961	3.9517	0.0248
58.5	59.0	0.13520	0.00000	0.16760	0.220	4.8149	4.8987	0.0167

STANDARD DEVIATION OF SUPPORTED PB-210 = 0.0166

Pb-210 dates for Lake Loon Lake

core C1

INTTOP	INTBOT	MIDINT	TTOP	SDTTOP	TBOT	SDTBOT	SEDRATE	SDSEDRT	SUMTOP
0.0	0.5	0.2	0.00	0.19	0.28	0.19	0.0297	0.0047	7.9023
2.0	2.5	2.2	1.59	0.19	2.24	0.19	0.0254	0.0044	7.5217
4.0	4.5	4.2	4.01	0.20	4.53	0.20	0.0217	0.0037	6.9745
6.0	6.5	6.2	6.55	0.21	7.40	0.21	0.0200	0.0036	6.4445
8.0	8.5	8.2	10.16	0.22	11.15	0.22	0.0235	0.0045	5.7596
10.0	10.5	10.2	14.42	0.23	15.62	0.24	0.0201	0.0038	5.0438
12.0	12.5	12.2	19.39	0.26	20.71	0.26	0.0207	0.0041	4.3201
14.0	14.5	14.2	24.29	0.28	25.36	0.29	0.0307	0.0060	3.7093
16.0	16.5	16.2	27.83	0.30	28.43	0.30	0.2249	0.0268	3.3220
20.0	20.5	20.2	33.31	0.31	34.12	0.32	0.0823	0.0108	2.8004
23.0	23.5	23.2	40.77	0.36	42.92	0.38	0.0336	0.0060	2.2204
28.0	28.5	28.2	62.41	0.56	64.57	0.58	0.0172	0.0052	1.1317
36.0	36.5	36.2	105.24	1.18	109.01	1.30	0.0092	0.0047	0.2982
42.5	43.0	42.7	148.50	3.28	150.99	3.51	0.0127	0.0093	0.0775

Execution terminated : 0

C:\pb210>

