Assessment of ^{210}Pb data from Canadian lakes using the CIC and CRS models

L. J. Turner · L. D. Delorme

Abstract Much discussion has centered around which ^{210}Pb dating method should be used, the constant initial concentration (CIC) model or the constant rate of supply (CRS) model. In this study, the activity data from 22 lacustrine sediment cores from the Canadian prairies were used to compare the determination of sediment accumulation using the two models. Other relative and absolute dating techniques have been used to calibrate the methodology. For half of the core sites examined, the mass sedimentation rate was constant, and thus both the CIC and CRS models were found to be valid. For the other half, variability was observed in the CRS mass accumulation rate trend. The validity of the CIC model for these cores was dependent on the degree of variability of the mass sedimentation rate. Where the variability is moderate to high, the CRS model may be more satisfactory. Caution should be exercised when using chronological data determined with the CRS model, however, as the accuracy of chronology in the lower reaches of a profile is questionable.

Key words ^{210}Pb dating · Chronology · Sedimentation rate · Accumulation rate

Introduction

Geochronology of sediments has important applications to limnology including studies of accelerated eutrophication, recent history of heavy metal pollution, influx rates for contaminants, regional erosion rates, salt marsh accretion, and sediment budgets (Benninger and others 1975; Evans and Rigler 1980, 1983; McCafferty and Thomson 1980; Battarbee and others 1985; Christensen and Goetz 1987). Chronology has historically been based on qualitative methods such as stratigraphy and palynology (Krishnaswamy and others 1971). Recent utilization of radiochemical techniques has proven successful for dating sediments on a time scale spanning the last 100–150 years.

Goldberg (1963) developed a radiometric method of dating glacial materials based on the decay of naturally occurring ^{210}Pb. Krishnaswamy and others (1971) were the first to attempt to calculate sedimentation rates for lake sediments using ^{210}Pb, as well as three other radionuclides (^{137}Cs, ^{32}Si, and ^{55}Fe). ^{210}Pb is now commonly used to determine sedimentation rates in coastal marine, estuarine, lacustrine, and marsh environments (Koide and others 1972, 1973; Armentano and Woodwell 1975; Appleby and others 1979; Benninger and others 1979; Battarbee and others 1985). Results obtained using ^{210}Pb techniques have been found to be in agreement with those obtained using other methods such as ^{137}Cs and palynology (Bruland and others 1975; Robbins and Edgington 1975; Robbins and others 1978).

This paper compares the results obtained from applying the constant initial concentration (CIC) and constant rate of supply (CRS) models to the ^{210}Pb activity data from lacustrine sediment cores collected from the Canadian prairies for paleoenvironmental research. A time framework is always necessary for this type of research. The ^{210}Pb method extends the chronology back some 100 years beyond the historical limnological and climatic records. Palynological data of *Ambrosia* sp. and ^{137}Cs data are included as a validity check for the ^{210}Pb method.

Sample collection

Between 1984 and 1986 sediment cores were collected from 22 Canadian prairie lakes (Fig. 1) as part of a paleoenvironmental study (National Water Research Institute 1988). Site locations and sampling dates are listed in Table 1.

Cores were taken using a modified lightweight corer (Williams and Pashley 1978) with a core tube diameter of 10.2 cm. On extrusion, the outer portion of each core was removed using a stainless steel ring, leaving a diameter of 7.9 cm. Cores were immediately subsectioned into 1-cm-

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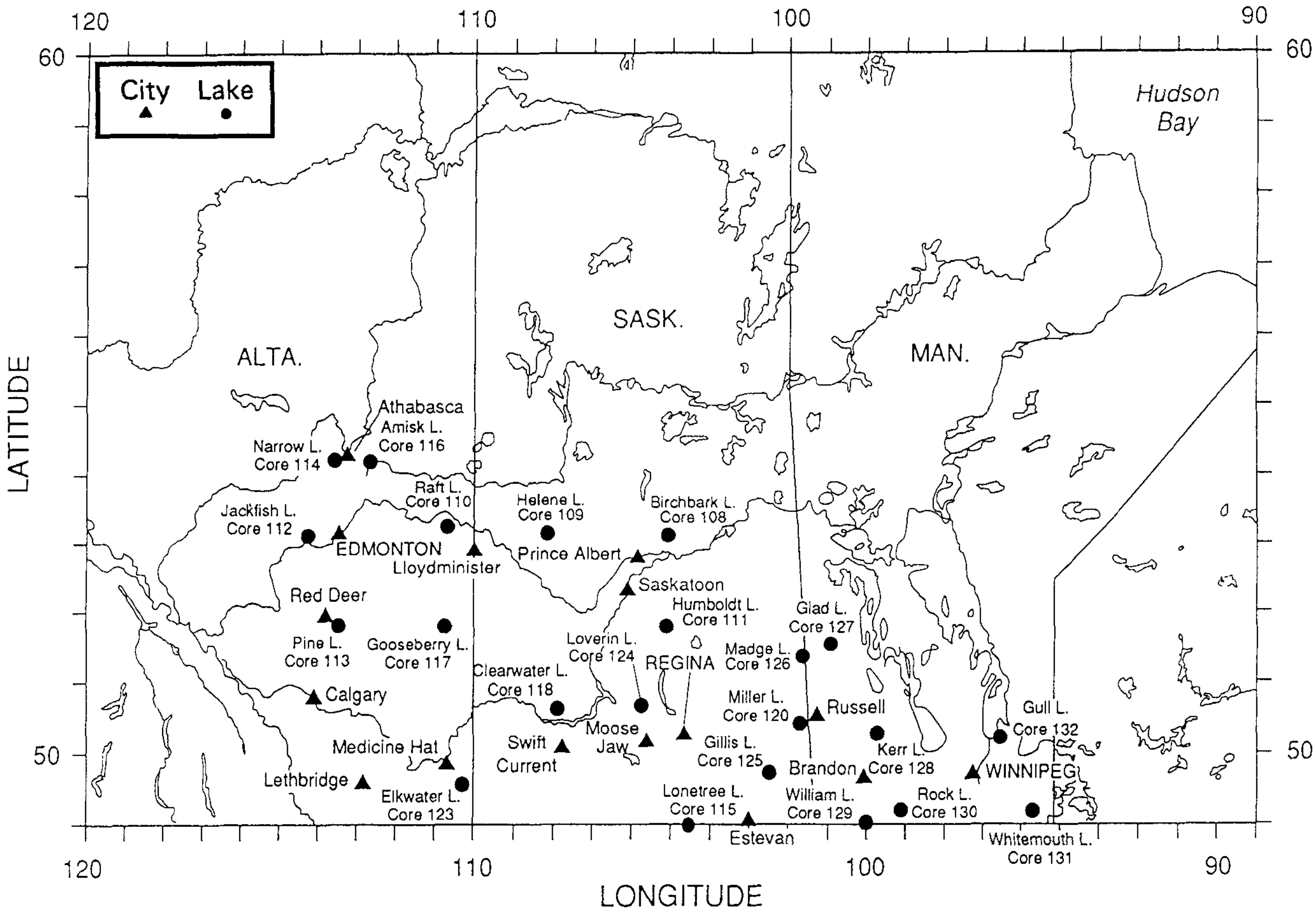

Fig. 1
Location of prairie coring sites

thick contiguous samples, then transported to Burlington, Ontario, where they were weighed, freeze-dried, and then reweighed. These weights were used to calculate the porosity and uncompacted depth for each core section following the equations outlined by Delorme (1991).

Analytical techniques

^{210}Pb in the lake sediments was determined via alpha spectrometric measurements of its granddaughter ^{210}Po ($\alpha = 5.31$ MeV, $t_{1/2} = 138$ d) assumed to be in secular equilibrium with ^{210}Pb. Homogeneous portions of a set of samples from each core were treated using a variation on the Eakins and Morrison (1978) polonium distillation procedure (Turner 1990). All samples were assayed in an alpha spectrometer equipped with silicon surface barrier detectors (active area 500 mm^2). ^{208}Po ($\alpha = 5.11$ MeV) was used as an internal yield tracer.
System checks such as monthly monitoring of alpha spectrometer sample chambers and standard disks ensure the quality of the spectra is maintained. Several samples per core were chosen to have the analyses for ^{210}Po repeated to ensure the reproducibility of results. Blanks were run through the same analytical procedures as samples to ensure there was no contamination from analytical reagents.

Sedimentation rate calculations

The models that are used to calculate sedimentation rates in this study are the CIC (constant initial concentration of unsupported ^{210}Pb) model of Robbins and Edgington (1975) and Matsumoto (1975) and the CRS (constant rate of supply of unsupported ^{210}Pb) model of Appleby and Oldfield (1978).
The CIC model assumes a constant initial concentration of unsupported ^{210}Pb and a constant sedimentation rate over the period of time for which the unsupported ^{210}Pb is measurable. The method requires either measurements of sediment porosity to correct for compaction or cumulative dry weight. The CRS model assumes a constant rate of supply of unsupported ^{210}Pb. The model considers a variable sedimentation rate and sediment compaction. Both models assume a constant flux of unsupported ^{210}Pb to the sediment/water interface. Various mathematical formulations of both models have been introduced to account for a variety of processes affecting ^{210}Pb depositional patterns.

Table 1
Core site coordinates and sample collection dates

Core[a]	Lake	Province	Sampling date	Latitude	Longitude
116	Amisk Lake	Alberta	6/02/85	54.60°N	112.66°W
108	Birchbark Lake	Saskatchewan	5/27/85	53.52°N	105.11°W
118	Clearwater Lake	Saskatchewan	6/05/85	50.87°N	107.92°W
123	Elkwater Lake	Alberta	6/12/86	49.67°N	110.22°W
125	Gillis Lake	Saskatchewan	6/16/86	49.86°N	102.43°W
127	Glad Lake	Manitoba	6/19/86	51.84°N	100.91°W
117	Gooseberry Lake	Alberta	6/03/85	52.12°N	110.75°W
132	Gull Lake	Manitoba	6/27/86	50.41°N	96.52°W
109	Helene Lake	Saskatchewan	5/28/85	53.54°N	108.20°W
111	Humboldt Lake	Saskatchewan	7/19/84	52.13°N	105.13°W
112	Jackfish Lake	Alberta	5/30/85	53.49°N	114.23°W
128	Kerr Lake	Manitoba	6/21/86	50.49°N	99.70°W
115	Lonetree Lake	Saskatchewan	7/19/84	49.02°N	104.52°W
124	Loverin Lake	Saskatchewan	6/13/86	49.84°N	105.63°W
126	Madge Lake	Manitoba	6/18/86	51.64°N	101.65°W
120	Miller Lake	Saskatchewan	6/17/86	50.63°N	101.67°W
114	Narrow Lake	Alberta	6/01/85	54.62°N	113.60°W
113	Pine Lake	Alberta	5/31/85	52.11°N	113.46°W
110	Raft Lake	Alberta	5/29/85	53.62°N	110.71°W
130	Rock Lake	Manitoba	6/24/86	49.21°N	99.13°W
131	Whitemouth Lake	Manitoba	6/25/86	49.27°N	95.70°W
129	William Lake	Manitoba	6/23/86	49.04°N	99.98°W
137[b]	Hamilton Harbour	Ontario	7/03/87	43.28°N	79.80°W
038[b]	Lake Athabasca	Alberta	03/92	59.03°N	110.22°W

[a] LDD laboratory assigned core numbers
[b] Not shown in Fig. 1

For the CIC model, the activity of ^{210}Pb in a sediment core is described as follows:

$$A_{Tx}=(A_{Uo})e^{-\lambda/t}+A' \quad (1)$$

where A_{Tx} is the total activity of ^{210}Pb in the sample in picocuries per gram dry wt at an uncompacted depth x, and age t, A' is the activity of ^{210}Pb in the sample supported by ^{226}Ra in $pCi\cdot g^{-1}$ dry wt (represented by constant ^{210}Pb activities attained at depth), A_{Uo} is the unsupported activity of ^{210}Pb at the sediment/water interface in $pCi\cdot g^{-1}$ dry wt, and λ is the radioactive decay constant for ^{210}Pb ($0.693/22.26\ yr^{-1}=0.0311\ yr^{-1}$). Since $A_{Ux}=A_{Tx}-A'$ then:

$$A_{Ux}=(A_{Uo})e^{-\lambda t} \quad (1a)$$

where A_{Ux} is the unsupported activity of ^{210}Pb in the sample in $pCi\cdot g^{-1}$ dry wt at uncompacted depth x. Equation 1 can be simplified:

$$\ln(A_{Tx}-A')=\ln(P/\omega)-(\lambda/S_0)x \quad (2)$$

where S_0 is the sedimentation rate in centimeters per year at the sediment/water interface, P is the flux of ^{210}Pb at the sediment water interface in picocuries per square centimeters per year, and ω is the mass sedimentation rate in grams per square centimeter per year.
A graphical solution for P/ω (the y intercept) and λ/S_0 (the slope of the line) is possible from a plot of x vs $\ln(A_{Tx}-A')$. As λ is known, then S_0 can be calculated.

The time t in years since the sample was deposited is given by:

$$t=[\ln(A_{Tx}-A')-\ln(P/\omega)]/(-\lambda)=x/S_0 \quad (3)$$

For the CRS model, Eq. 1 takes the following form:

$$B(x)=B(0)e^{-\lambda t} \quad (4)$$

where $B(x)$ represents the total residual or cumulative unsupported ^{210}Pb beneath sediments of depth x, and $B(0)$ represents the total residual unsupported ^{210}Pb in the sediment column.

$$B(x)=\int_x^\infty \rho_x * A_{Ux}dx=\int_x^\infty A_{Ux}d\omega \quad (5)$$

where ρ_x is the dry mass/unit wet volume of the sample (grams per cubic centimeter) at depth x, and ω_t is the dry mass sedimentation rate ($g\cdot cm^{-2}\cdot yr^{-1}$) at time t.

$$B(0)=\int_0^\infty \rho_0 * A_{Uo}dx=\int_0^\infty A_{Uo}d\omega \quad (6)$$

The age of layer at depth x is thus:

$$t=-(1/\lambda)*\ln[B(x)/B(0)] \quad (7)$$

where $B(x)$ and $B(0)$ are calculated by direct numerical integration of the ^{210}Pb profile (the plot of unsupported activity versus cumulative dry weight).

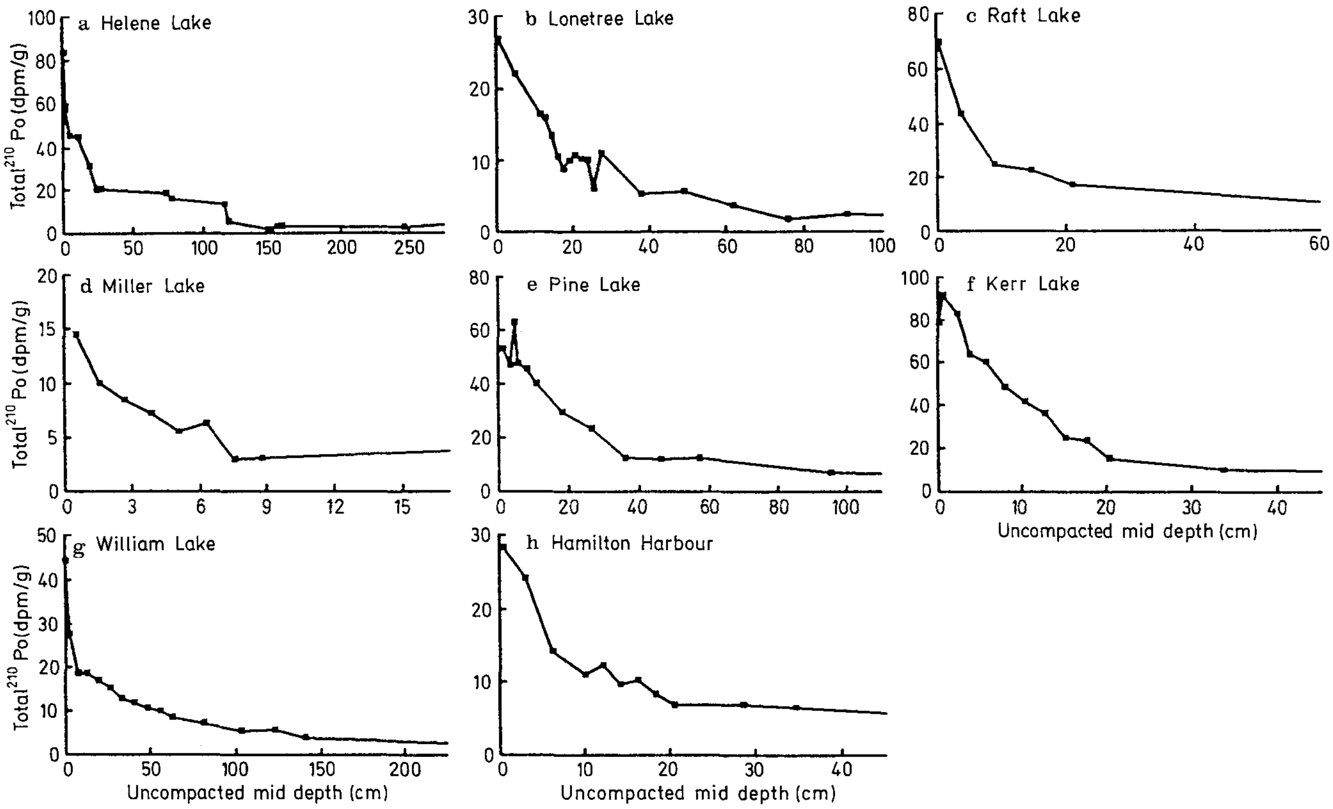

Fig. 2a–h
Distribution of uncompacted mid-depth with total ^{210}Po activity in disintegration per minute per gram for the prairie lakes and Hamilton Harbour. Activity data corresponding to a depth equivalent of 150 years are shown. Data from older sections of the cores are not shown

^{210}Pb analysis results

Figure 2 depicts the ^{210}Po activity profiles of seven of the prairie lake cores and one Ontario lake core with depth. The profiles are scaled to a depth equivalent of 150 years [inclusion of the lower core (background) data in the figures would make it difficult to view the decay profile clearly]. These profiles give a general idea of the variability from location to location that can be seen in the alpha counts.

As expected for conditions of continuous ^{210}Pb deposition and sediment accumulation, the ^{210}Po activity decreases with depth until reaching a constant background value. Although smoother profiles, such as those depicted by cores from Raft Lake, Miller Lake, and William Lake (Fig. 2c, d, g) are common, distorted ^{210}Po profiles are not uncommon to lacustrine sediments. The ^{210}Po concentration of the first sample in the Kerr Lake core profile (Fig. 2f) is lower than the second. This may indicate a core in which the top sample is not in secular equilibrium with ^{210}Pb or may indicate sediment mixing. The profile of the Pine Lake (Fig. 2e) core sediments is more drastically distorted at the top. This may be interpreted as resulting from physical/biological mixing of the upper layers of sediment (Bruland and others 1975; Robbins and Edgington 1975; Robbins and others 1977; Benninger and others 1979).

Figures 3a–h are semilog plots of uncompacted mid-depth (x) vs unsupported activity [$(\ln(A_x - A'))$] for each core in Fig. 2 (CIC model). Sedimentation and atmospheric flux rates derived for all cores from the CIC and CRS models discussed previously are listed in Table 2.

CIC and CRS model results

Validations

The validity of the dating method (not the chronology of the site) was checked by examining the distribution of ragweed pollen (*Ambrosia* sp.) in a core from Ontario. The Hamilton Harbour core was collected by Dr. N. A. Rukavina (Rukavina 1988), the pollen profile interpreted by Harper and Delorme (1988), and ^{210}Pb dated by Turner and Delorme (1988). The start of the *Ambrosia* sp. pollen rise is reflected at a depth of 59.6 cm as estimated by the point-of-change procedure (Esterby and El-Shaarawi 1981a, b; Harper and Delorme 1988). A discussion of this procedure as it relates to this core is given in Turner and Delorme (1994).

McAndrews and Boyko (1972) have indicated that the rise of *Ambrosia* sp. pollen, in the Great Lakes Basin, started around 1850 AD. McAndrews (1976), based on counts of laminae in Crawford Lake, 17 km northwest of Hamilton Harbour, established a date of 1850 for the rise

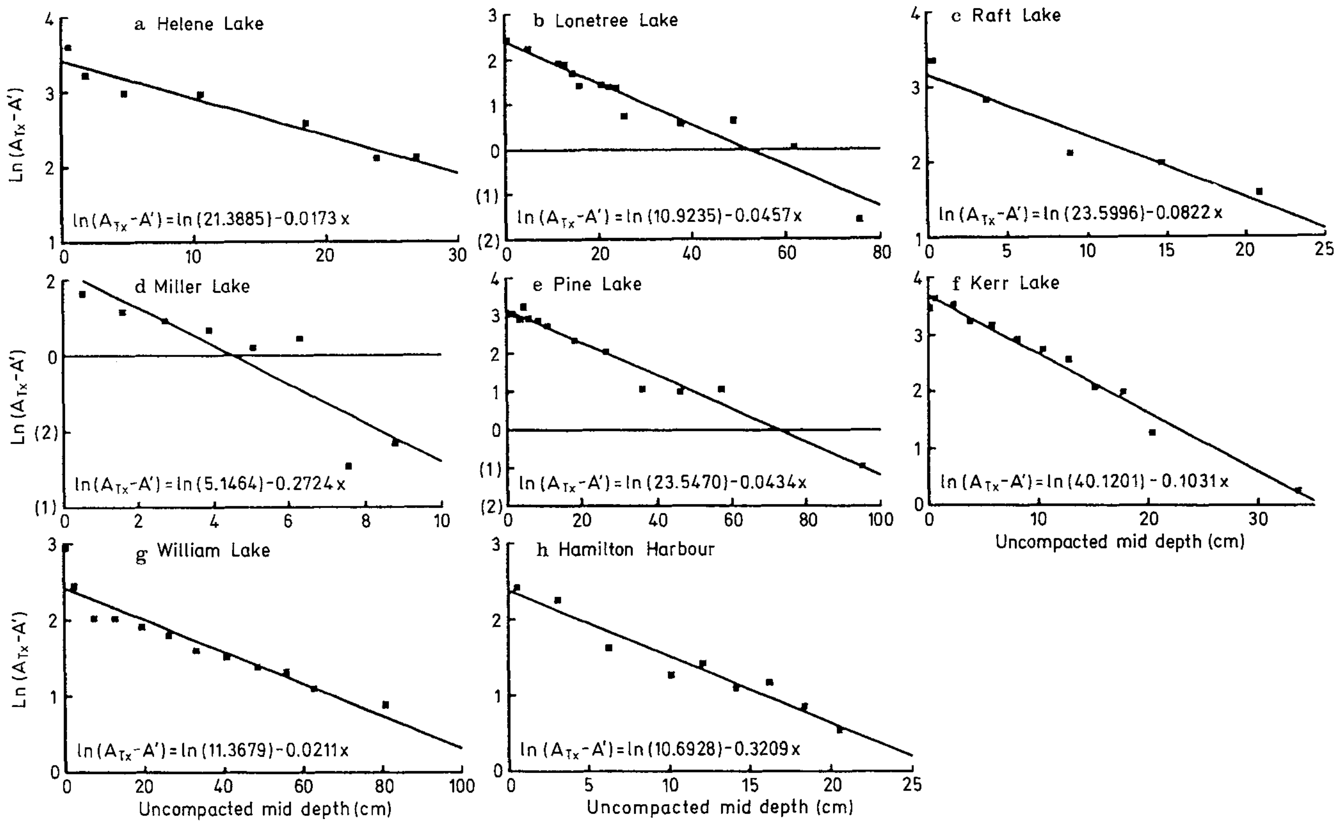

Fig. 3a–h
Distribution of uncompacted mid-depth with unsupported ^{210}Po activity [($\ln(A_{Tx}-A')$)] for prairie lakes and Hamilton Harbour, where A_{Tx} is the total activity of ^{210}Pb in a sample (picocuries per gram dry wt.) and A', is the activity of ^{210}Pb supported by ^{226}Ra (picocuries per gram dry wt.)

in *Ambrosia* sp. pollen in this area. McCarthy (1986), from the analyses of sediments from Grenadier Pond (40 km east of Hamilton Harbour), reports a date of 1830 AD for the abrupt rise of *Ambrosia* sp. The start of *Ambrosia* sp. around 1822 AD from Hamilton Harbour (Turner and Delorme 1988) appears to be a suitable representation for the start of the *Ambrosia* sp. in this part of Ontario.

The validity of the dating method was checked radiometrically by examining the ^{137}Cs profile in a core from Alberta. A core collected from Lake Athabasca by Dr. R. Bourbonniere (Turner 1992) was ^{210}Pb dated by Turner and Delorme (1988) and analyzed for ^{137}Cs by Dr. R. J. Flett (unpublished results).

Nuclear testing led to the appearance of the artificial isotope ^{137}Cs in the atmosphere. When ^{137}Cs is adsorbed onto undisturbed sediments, the resulting activity profile reflects the isotope's fallout history. The initiation of ^{137}Cs fallout occurred around 1952 and peaked around 1963 (Robbins and Edgington 1975). This provides a distinct chronological marker that can be used to confirm ^{210}Pb dates. However, due to the evident mobility of ^{137}Cs in sediments, this isotope must be used with caution. ^{137}Cs activity measured for the Lake Athabasca core starts at 15 cm and reaches a maximum at 10 cm. These depths are dated to 1952 and 1962 by the CIC model, 1958 and 1968 by CRS model. These results indicate reasonable agreement.

Atmospheric flux

The concentration of atmospheric ^{210}Pb and thus the mean flux value varies with latitude (Jaworski 1966). Flux is partly dependent on regional meteorological factors (Appleby and Oldfield 1983). Flux is also influenced by local geology. Sites in close proximity to uranium-bearing rocks/tills show high ^{210}Pb atmospheric flux rates [Mirror Lake, New Hamsphire, USA, at 1.6 pCi cm^{-2} yr^{-1} (Von Damm and others 1979), Trout Lake, Wisconsin, USA, at 2.9 pCi cm^{-2} yr^{-1} (Koide and others 1972), and Lake Superior at 4.2 pCi cm^{-2} yr^{-1} (Evans and others 1981)]. Measurements of the flux of ^{210}Pb to the earth surface by Moore and Poet (1976) range from 0.24 to 0.91 pCi cm^{-2} yr^{-1} for northern temperate zones. Atmospheric flux rates listed in Table 2 range from 0.03 to 2.39 pCi cm^{-2} yr^{-1}. Atmospheric flux rates determined from the CIC and CRS models are in fair agreement.

Mass sedimentation rate

The assumption of a constant rate of accumulation (inherent to the CIC model) was tested by examination of the mass sedimentation rates obtained using the CRS model. Plots of mass sedimentation rate versus the cumulative dry weight are given for several cores in Fig. 4. Data from half of the cores tested (e.g., Miller Lake and

Table 2
Specific gravity and sedimentation rates for cores studied

Lake	Mean Specific gravity (g cm^{-3})[a]	CIC			CRS	
		Sedimentation rate (cm yr^{-1})	Mass sedimentation rate (g cm^{-2} yr^{-1})	Atmospheric flux (pCi cm^{-2} yr^{-1})	Avg. mass sedimentation rate (g cm^{-2} yr^{-1})	Atmospheric flux (pCi cm^{-2} yr^{-1})
Amisk Lake	2.201 ± 0.248	0.40	0.02	0.26	0.02 ± 0.003[bc]	0.24
Birchbark Lake	1.845 ± 0.127	0.08	0.01	0.03	0.01 ± 0.001[c]	0.03
Clearwater Lake	2.386 ± 0.107	1.46	0.26	2.39	0.37 ± 0.354[d]	1.73
Elkwater Lake	2.496 ± 0.077	1.30	0.27	1.61	0.28 ± 0.109[d]	1.66
Gillis Lake	2.218 ± 0.110	0.29	0.04	0.54	0.04 ± 0.011[d]	0.53
Glad Lake	2.355 ± 0.223	0.31	0.01	0.05	0.01 ± 0.002[c]	0.04
Gooseberry Lake	2.590 ± 0.103	0.31	0.05	0.67	0.04 ± 0.016[d]	0.62
Gull Lake	1.976 ± 0.135	0.20	0.01	0.08	0.01 ± 0.004[c]	0.08
Helene Lake	2.009 ± 0.155	1.80	0.05	0.49	0.04 ± 0.015[d]	0.42
Humboldt Lake	2.224 ± 0.007	0.72	0.05	0.76	0.05 ± 0.017[d]	0.65
Jackfish Lake	2.007 ± 0.156	0.73	0.14	0.99	0.13 ± 0.013[d]	0.96
Kerr Lake	2.025 ± 0.116	0.30	0.02	0.26	0.02 ± 0.002[c]	0.27
Lontree Lake	2.380 ± 0.007	0.68	0.11	0.50	0.11 ± 0.021[d]	0.52
Loverin Lake	2.561 ± 0.007	0.73	0.10	0.70	0.11 ± 0.038[c]	0.66
Madge Lake	2.230 ± 0.174	0.67	0.04	0.13	0.05 ± 0.017[c]	0.17
Miller Lake	1.863 ± 0.105	0.11	0.03	0.06	0.03 ± 0.003[c]	0.06
Narrow Lake	1.909 ± 0.071	0.17	0.01	0.08	0.01 ± 0.002[c]	0.09
Pine Lake	2.240 ± 0.118	0.72	0.06	0.62	0.07 ± 0.014[c]	0.63
Raft Lake	2.284 ± 0.099	0.38	0.05	0.46	0.07 ± 0.020[d]	0.59
Rock Lake	2.381 ± 0.064	0.31	0.06	0.24	0.08 ± 0.025[d]	0.24
Whitemouth Lake	2.038 ± 0.146	0.15	0.01	0.07	0.01 ± 0.003[c]	0.07
William Lake	2.078 ± 0.167	1.47	0.05	0.26	0.05 ± 0.009[c]	0.26
Hamilton Harbour	2.486 ± 0.242	0.36	0.10	0.44	0.11 ± 0.012	0.45

[a] Mean specific gravity data from Holloway and Delorme (1984, 1985a, b, 1987)
[b] The standard deviation is based on the total number of mass sedimentation rates determined from the core. Large standard deviation (Clearwater Lake) may indicate change(s) in the sedimentation rate and/or changes in lithology
[c] Displays constant mass sedimentation rate
[d] Displays variable mass sedimentation rate

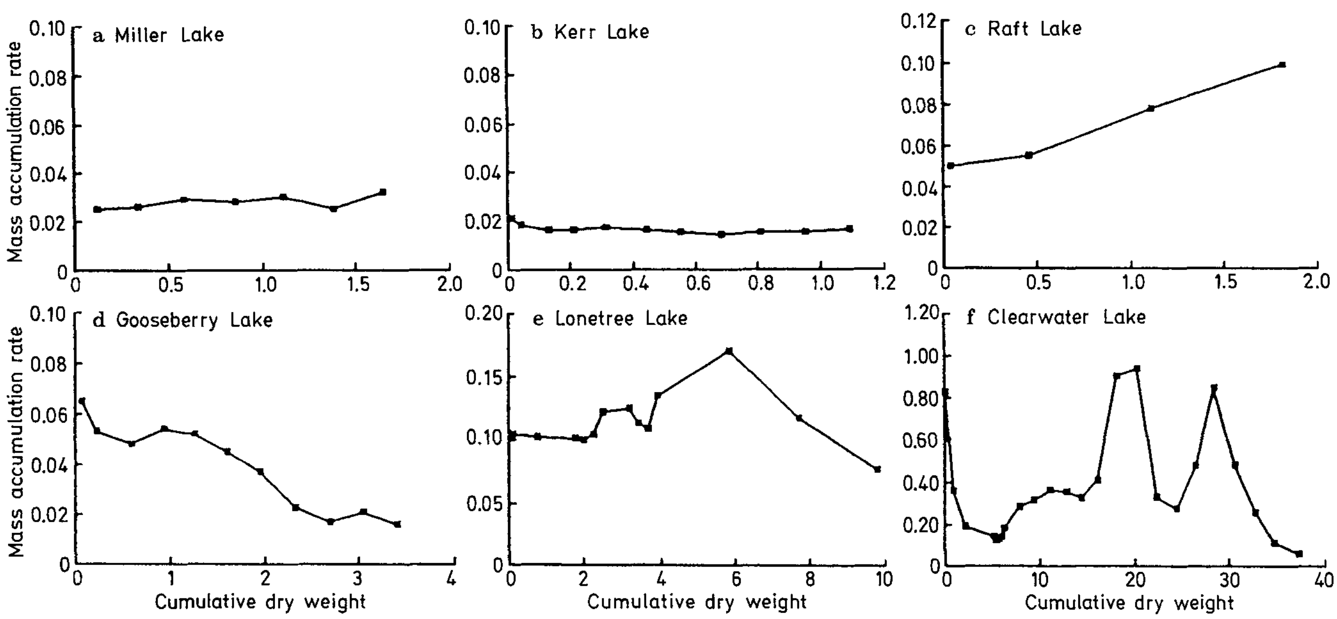

Fig. 4a–f
Plot of mass sedimentation rate (grams per square centimeter per year) versus the cumulative dry weight (grams per square centimeter)

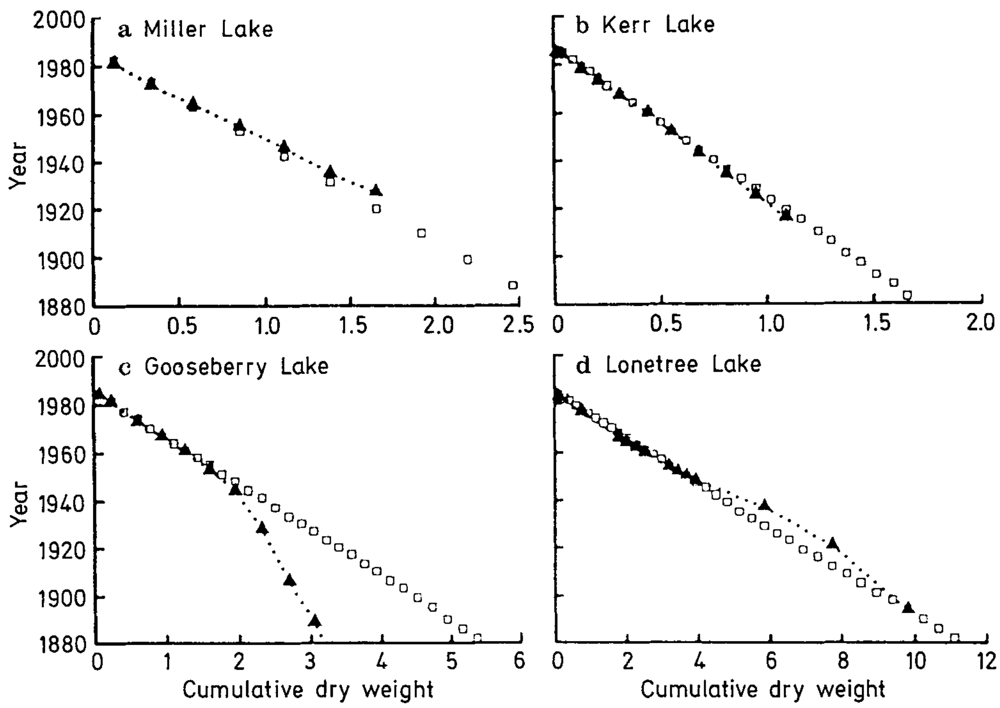

Fig. 5a–d
Plot of year determined from CIC (squares) and CRS (triangles) models versus the cumulative dry weight (grams per square centimeter)

Kerr Lake, Fig. 4a and b) support the assumption of constant sedimentation rate. The other half of the cores illustrate regimes of changing sedimentation rates. In one case (Raft Lake, Fig. 4c) mass sedimentation was observed to decrease as the sediments became younger. In three cases (e.g., Gooseberry Lake, Fig. 4d) mass sedimentation rate increased with decreasing age. In the rest of the cores (e.g., Lonetree Lake and Clearwater Lake, Fig. 4e and f) mass sedimentation rate was completely variable.
The mass sedimentation rates averaged from the CRS data for each core are given in Table 2. Data for all cores except Clearwater Lake are in good agreement with the mass sedimentation rates derived from the CIC model.

Chronology

^{210}Pb chronologies calculated for several cores using the CIC and CRS models are illustrated in Fig. 5. For over half of the cores analyzed (e.g., Miller and Kerr lakes, Fig. 5a and b), there is good agreement between the CIC and CRS chronologies. For some cores, there is agreement between the dates for the most recent sediments only. For example, the CIC and CRS sediment section ages for Gooseberry Lake (Fig. 5c) match down to approximately 1940, after which the CRS model overestimates age in comparison to the CIC model. For two cores (e.g., Lonetree Lake, Fig. 5d) there is agreement between the uppermost and bottommost sections of the core with a slight disagreement in between.

Discussion

In a sedimentary environment characterized by a constant accumulation rate, it does not matter which model (CIC or CRS) is used for analysis. Under the conditions of constant accumulation rate, the CIC and CRS models will produce the same results. Examples of this situation have been illustrated by half of the cores studied. For these cores, plots of mass sedimentation rate determined using the CRS model indicate a reasonably constant accumulation rate, and the chronologies determined from each model are in agreement.
In sedimentary environments where the constancy of the accumulation rate is in question, the CIC and CRS model data will not fully agree. Plots of CRS mass sedimentation rate data indicate that the accumulation rate for some of the cores is variable. Examination of the trends in mass accumulation rate give visible indications (e.g., Clearwater Lake, Fig. 4f) of where variations in sedimentation occur in a profile and thus provide information on the sedimentation history that could be important when studying other physical or chemical aspects of a core site. For example, oddities in organic contaminant or metal profiles (peaks representing increases or dips representing decreases) might be partially explained by variations in sediment accumulation rate (concentration or dilution of the contaminant).
Chronologies for cores with questionable accumulation rate constancy do not agree throughout the whole profile. Often, agreement is found down to a certain depth, after which the data diverge. Similar behavior can be observed in the data of Oldfield and others (1978) and Appleby and others (1990).

For the situations in which data diverge towards the bottom of the core, it is difficult to tell whether the divergence is true (the calculated chronological data truly differ) or an artifact of the models. If the sediment accumulation rate is variable, then the assumption of constant sedimentation rate inherent in the CIC model is inappropriate and the chronology would be expected to disagree. The extent of the disagreement would depend on the range of variability. It is possible, however, that divergence of data may merely be a reflection of increasing error in the CRS data with depth, especially in cases where the variability of the sedimentation rate is low. Error in CRS dates becomes large for dates nearing 100 years because of the uncertainty involved in estimating the small amount of ^{210}Pb contained in older sediment (Appleby and others 1988).

Which model is more appropriate to use depends upon the information known (or not known) about a given situation. We believe the best approach is to calculate both models and compare the results. The calculations for both models are easily done and neither model requires special additional data.

Discrepancies between CRS and CIC results should be checked with independent dating techniques (i.e., pollen analysis, ^{137}Cs). There have been situations when both the CIC and CRS models have been found to incorrectly estimate age when compared to dates acquired by independent dating methods. Davis and others (1984) interpret disagreement between CRS-derived ^{210}Pb chronology and ^{137}Cs chronology in some of their New England and Scandinavian cores as mobility of ^{137}Cs and/or ^{210}Pp.

Table 3 summarizes the geographical and physical limnology settings of the lacustrine habitats. Based on a visual inspection of Table 3, there is no direct link between sedimentation rate and the listed local and regional geographical attributes. The rate of sedimentation at a particular core site is controlled by local conditions. The cores that displayed variable mass sedimentation rates were located in lakes where shoreline erosion scarps were observed (Gooseberry, Humboldt, and Lonetree lakes), in lakes that were part of a river system (Rock lake), at sites near a stream (Elkwater, Raft Lake), and in lakes where surrounding land was under cultivation (Clearwater Lake). Cores that displayed constant mass sedimentation rates throughout their profiles were often located at sites in embayments protected from the influence of streamflow.

In general, a core site close to a source of sediments, such as a stream, river, or slope wash, will likely have a higher and more variable sedimentation rate. Closed basins are not as affected by sediment discharge from intermittent streams. Local relief will affect the amount of sediment received from slope wash. The presence of well-anchored land vegetation surrounding the pond or lake will lessen the effect of slope wash. Agricultural practices also may increase sediment load into these basins.

Table 3
Local and regional geographical attributes for study sites

Lake	Basin type	CIC sed rate (cm yr^{-1})	Water depth (m)	Distance from shore (m)	Lat.	Long.	Vegetation association	Relief
Amisk Lake	open	0.40[a]	7.5	150	54.60	112.66	forest	moderate
Birchbark Lake	closed	0.08[a]	2.0	100	53.52	105.11	forest	low
Clearwater Lake	closed	1.46[b]	6.0	50	50.87	107.92	prairie	moderate
Elkwater Lake	open	1.30[b]	3.7	75	49.67	110.22	forest	high/moderate
Gillis Lake	closed	0.29[b]	3.9	75	49.86	102.43	forest	moderate
Glad Lake	closed	0.31[a]	6.5	45	51.84	100.91	forest	moderate
Gooseberry Lake	closed	0.31[b]	2.7	50	52.12	110.75	prairie	low
Gull Lake	closed	0.20[a]	3.7	90	50.41	96.52	parkland	moderate
Helene Lake	closed	1.80[b]	3.0	1000	53.54	108.20	forest	moderate
Humboldt Lake	closed	0.72[b]	5.0	300	52.13	105.13	parkland	low
Jackfish Lake	closed	0.73[b]	13.5	300	53.49	114.23	forest	moderate
Kerr Lake	open	0.30[a]	3.0	90	50.40	99.70	parkland	moderate
Lonetree Lake	closed	0.68[b]	6.0	150	49.02	104.52	prairie	low
Loverin Lake	closed	0.73[a]	6.8	75	49.84	105.63	prairie	low
Madge Lake	closed	0.67[a]	3.7	38	51.64	101.65	forest	moderate
Miller Lake	open dam	0.11[a]	2.5	23	50.63	101.67	parkland	low
Narrow Lake	open	0.17[a]	10.0	50	54.62	113.60	forest	moderate
Pine Lake	open	0.72[a]	4.7	100	52.11	113.46	parkland	moderate
Raft Lake	closed	0.38[b]	3.0	300	53.62	110.71	parkland	moderate
Rock Lake	open	0.31[b]	2.4	30	49.21	99.13	prairie	high
Whitemouth Lake	open	0.15[a]	1.4	90	49.27	95.70	forest	low
William Lake	closed	1.47[a]	2.1	31	49.04	99.98	forest	moderate

[a] Displays constant mass sedimentation rate
[b] Displays variable mass sedimentation rate

Caution should be used in assuming a sedimentation rate is representative of a lake or pond. There are many variables, as noted above, that play an important role in the transport and accumulation of sediments. These variables can change the sedimentation rate significantly within a distance of a few meters. More research is required to understand the variability in sedimentation rates of a series of cores in a lake, research also is needed to understand the relationship of grain size and mineralogy on the effects of ^{210}Pb adsorption.

Conclusions

A constant initial concentration (CIC) model and a constant rate of supply (CRS) model were used to assess ^{210}Pb data from 22 cores. Mean sedimentation rates for these sites ranged from 0.08 to 1.80 cm yr^{-1} (0.01–0.26 g cm^{-2} yr^{-1}). Half of the sites exhibited a constant mass accumulation rate throughout the activity profile. The other half exhibited a range of variability in mass accumulation rate. Examination of the trends in mass accumulation rate provides information on the sedimentation history that could be important when studying other physical or chemical aspects of a core site (i.e., organic contaminant and metal profiles).

In those cores where there are no visible changes in lithology, the CIC and CRS models predict sedimentation rates that are very similar for about 100 years. Below this point, the CRS model predicts dates that can be widely divergent from values of the CIC model. Since the error in the CRS calculations increases with depth in the profile, this divergence may partly be an artifact of the model itself. Caution should be exercised when using chronological data determined with the CRS model, as the accuracy of chronology in the lower reaches of a profile is questionable.

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