# MEASUREMENT OF SEDIMENT ACCUMULATION
# AND PHOSPHORUS RETENTION
# USING LEAD-210 DATING

by

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requirements for the degree of Doctor of Philosophy
at McGill Univeristy

# PREFACE

The format of this thesis is similar to most in that various sections of work are presented as individual chapters. As part of the work two chapters are presented as published papers. Only the table and figure numbers have been changed from the original papers.

The contents of chapter six, as published in Environmental Science and Technology, may initially seem out of character with the content of the rest of this thesis. It has been included in its present form because in addition to fulfilling the data requirements of work presented in chapter seven on calculating whole lake sediment accumulation rates, it represents an important contribution to the field of environmental contamination analysis. As such it fulfills one of the objectives of this work, by demonstrating that sediments are a viable medium in which to make whole lake measurements.

# ABSTRACT

Lead-210 dating was used to measure rates of sediment accumulation in three lakes in the Haliburton area of Ontario. Approximately twenty cores were analyzed in each lake. The rates of accumulation were correlated with lake depth at the sample site. This relationship was used to calculate accumulation of sediment over the whole lake area. The retention of phosphorus (P) in the sediments of each lake was calculated using the whole lake sediment accumulation, and mean P concentrations in the sediments. This P retention compared favourably with that previously measured by mass balance methods.

Total anthropogenic lead was measured in each lake. In a proposed method for simplifying the measurement of the average accumulation of the bulk sediments, the amount of anthropogenic lead in a core was used as an indicator of sediment movement. Predictions of average accumulation based on a single dated sediment core compared well with whole lake measurements.

# RESUMÉ

Les taux d'accumulation des sédiments dans trois lacs de la région de Haliburton, Ontario, ont été measurés par datation au plomb-210. Environ vingt carottes ont été analysées dans chaque lac. Il existe une étroite corrélation entre les taux d'accumulation et la profondeur du lac à la location d'échantillonnage. Cette rel-tion permet de calculer l'accumulation des sédiments pour le lac en entier. La rétention du phosphore (P) dans les sédiments de chaque laac a été calculée a partir de l'accumulation totale de sédiments dans le lac et de la concentration moyenne de P dans les sédiments. Cette mesure de rétention de P se compare assez étroitement a celle mesurée en calculant l'apport moins la perte de P.

Le plomb anthropogénique total a été measuré pour chaque lac. Dans une méthode proposée pour simplifier la measure de l'accumulation moyenne de sédiments, la quantité de Pb anthropogénique présente dans chaque carotte a été utilisée comme indicateur du movement des sédiments. Les prédictions de taux moyens d'accumulation basées sur une seule carotte sedimentaire datée, se comparent bien avec les mesures des taux d'accumulation pour les lacs en entier.

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# CHAPTER ONE:

# INTRODUCTION

The material which accumulates at the bottom of lakes stores within it a great deal of information potentially useful to limnologists. To those studying paleoecological and paleolimnological processes, the lake sediments hold a record of past changes in the lake and its drainage basin (Davis 1969; Webb 1973; Adams and Duthie 1976). Similarly, those studying recent environmental changes such as increased atmospheric emissions of pollutants, look to the sediments to provide baseline data from previous years (Bortleson and Lee 1972; Kemp et al. 1978). Sediments can function as either a sink or a source of elements in the lake water. In a mass balance analysis, the rate at which an element is lost to the sediments must be quantified. However, those examining oxygen depletion in lake hypolimnia view the sediments as a source of respirable organic matter (Hargrave 1972). In answering many limnological questions the rate at which the sediments are accumulating must be known.

One area where quantification of sediment accumulation is particularly important is in modelling of lake trophic status. This problem provided the impetus for the current study. In attempting to formulate a model that would predict the trophic status of lakes, early workers such as Piontelli and Tonolli (1964) and Vollenweider (1969) chose to use the mass balance of phosphorus (see Dillon 1974a). In using such an approach, one required component was the loss of phosphorus to the lake bottom. It has long been recognized that the net fraction of phosphorus deposited in the sediments was a necessary input to trophic status models such as Vollenweider's (1969) and Dillon and Rigler's (1974). But for reasons of simplicity the fractional difference between input and output of phosphorus (ie. retention) was substituted for the sedimentation constant (Kirchner and Dillon 1975, Larsen and Mercier 1976, Ostrofsky 1978). These two are not always identical. In cases where a nutrient is lost from the sediment through mineralization or diagenesis, the difference between catchment and aeolian inputs and outlow losses may overestimate the actual storage if changes in lake water concentration are not considered. In addition, there are situations where all inputs can not be measured adequately. For example, where cottage development of lakes has taken place, nutrient input from sewage disposal systems can not be quantified. In this instance actual measurement of total sediment phosphorus provides the only valid estimate of P storage.

The sampling and analysis of lake sediments can be quite complex. Because of this, an interesting situation has arisen. Often, workers have chosen to model sediment parameters rather than make direct measurements even though the model predictions are largely untested. For example Cornett and Rigler (1979) chose to model P retention as an input to an oxygen deficit model, rather than measure it. This method was used for simplicity even though the errors associated with predictions of the models they used can be large. In those studies in which sedimentological data have been collected, generally they are not sufficiently detailed to give confident estimates of whole lake accumulation rates. Whether one's concern is phosphorus storage, organic carbon flux to the lake bottom, or an historical or paleoecological interpretation of change through time, a central problem is the quantification of the average rate at which the bottom sediments are accumulating.

To determine this average rate, one must have a reliable method of measuring the sediment accumulation rate at a given location. Then using this technique, the variation in accumulation rates over the lake bottom, if any, must be taken into account. Only then can statements be made about whole lake phenomena.

## Historical Background

Over the years, many methods for measuring sediment accumulation rates have been proposed. Each has some merit and some applicability. The method must be chosen to suit the problem at hand. The first and most direct method of measuring sediment accumulation involves placing a container on the bottom of the lake and collecting the material which falls into it. Kleerkoper (1952) and Thomas (1955) were early proponents of the sediment trap method. Gardner (1977) has given an extensive review of sediment trap studies. Unfortunately, it is not certain that the quantity of material found in a trap is representative of the fallout over the trap. Various confounding effects such as turbulence (Golterman 1973) and trap size (Kirchner 1975) have been examined, but no conclusive evidence of the validity of trap results has come to light. Some of the material falling to the lake bottom will ultimately be returned to the water column either through resuspension (particulates) or mineralization (solutes). It was found by Fuhs (1973) that the amount of phosphorus trapped by containers overestimated the P retention measured as input minus output by about ten times. This was also found by Nicholls (1976). This overestimation may be due to resuspension of bottom material or to cycling of mineralized phosphorus. Given the difficulty in interpreting trap collection data, I rejected sediment traps as a method of measuring bulk sediment accumulation for the purposes of this study.

This leaves a second category of measurements. These involve taking a sample of the sediment which has been deposited and calculating the date at which various events occurred or the age of sediment from a series of depths. The sediment sample is usually referred to as a core. The best opportunity for this type of dating occurs in meromictic lakes. Annual laminae, identifiable from colour changes in the sediment, are deposited (Tippet 1964). The annual layers remain undisturbed and may be counted visually. By measuring the number of laminations per unit depth or mass, one derives the rate at which the sediments are accumulating. This technique has been employed by Boyko (1973), Ludlam (1969) and by many others. While this technique is extremely useful in meromictic lakes, the sediments of most temperate North American lakes are subject to disturbances such as wave action and benthic burrowing which obliterate any laminations which might occur. This leaves either event marking, a variety of long term methods or radiochemical dating.

Event dating requires that some change has occurred in the past which has left a recognizable mark on the sediments of a lake. For example, a volcanic eruption may leave an ash layer in the sediments. If the time of the eruption is known, and an observed ash layer can be attributed unequivocally to that eruption, a sediment accumulation rate can be calculated by measuring the amount of material above the marker layer and dividing by the number of years since its deposition. The result will be an average accumulation rate for many years. This is not suitable if changes in the lake basin are suspected. Kimmel (1978) used volcanic ash from an eruption 1360 years ago as a marker in Castle Lake, California. Obviously, this method is not available in all lakes. Other markers that have been used include pollen horizons, particularly ragweed (Kemp et al. 1978, Birks et al. 1976) and chestnut (Anderson 1974); charcoal from forest fires (Swain 1973), lead from automobile gasoline (Edgington and Robbins 1975), and fallout from bomb tests such as $^{137}Cs$ (Pennington 1973, Ritchie et al. 1973). Each of these techniques suffers from the fact that it is not able to detect changes in accumulation rate since the time of deposition of the marker. The shorter the time since its deposition, the better the estimate will be for modern accumulation rates. Some long term techniques that have been used, but which are not useful for measurement of modern accumulation rates include remanent magnetism and thermoluminescence (Roberts and Graves 1972; Huntley and Johnson 1976). These techniques have more applicability to the slow accumulation rates of marine sediments than to lacustrine deposits.

Most radiochemical dating techniques involve the utilization of a radioactive isotope which has been laid down at a continuous rate through time in the sediments. Once deposited the isotope decays according to its half-life and by measuring its remnant activity, one can estimate the age of a sample from a particular depth in the sediment core. Geochronological methods using radiochemical dating have been developed extensively and are outlined in many reviews and texts (eg. Schwarcz 1978; Faure 1977). These have been used primarily to examine ages of rock formations, but a few methods have been applied to lake sediments. Urry (1948) examined the possibility of using radium-226 dating in clay deposits. Carbon-14 has been utilized more than any other isotope for lacustrine deposits (Likens and Davis 1975, Skreenivasa and Duthie 1973). A problem with both of these isotopes, when examining recent sediment accumulation, is the length of their half-lives ( $^{14}C$ - 5620 yr, $^{226}Ra$ - 1622 yr). Radiochemical dating gives accumulation rates for time periods of a few half-lives of the isotope used. To extrapolate to modern accumulation rates using $^{14}C$ or $^{226}Ra$, one must assume constant accumulation over the last few thousand years. In some cases this assumption is clearly unwarranted and in most others it is dubious.

In order to measure recent accumulation rates, one must employ a natural isotope with a short half-life which is also immobile in the sediments. There are not many isotopes which fit these criteria but lead-210 (half-life = 22.26 yr.) was proposed by Koide et al.(1972) and Krishnaswami et al. (1971). In the last ten years it has become the most popular method of dating recent lacustrine deposits and is the method of choice for this study.

Lead-210 is a natural decay product of the uranium-238 series (Fig. 1a). Uranium in the earth's crust decays through a series of daughters to radon-222, which is a noble gas. This gas emanates out of the earth's crust into the atmosphere. In the atmosphere, the radon decays quickly to lead-210 which is a solid and attaches onto particles in the air. These particles bearing $^{210}$Pb are washed out of the atmosphere by precipitation and if they fall on a lake's surface they sink to the bottom and are incorporated into the sediments. The $^{210}$Pb decays through time and the change in activity of $^{210}$Pb with depth into the sediment is used to calculate the rate at which the bulk sediments have accumulated.

Koide et al.(1972) compared the accumulation rate predicted by $^{210}$Pb dating with counting of annual laminae in a core from the Santa Barbara Basin, California and found good agreement. Appleby et al. (1979) have compared laminae and $^{210}$Pb in a Finnish lake. Robbins et al.(1978) compared $^{210}$Pb, $^{137}$Cs, and pollen chronologies and found reasonable agreement between the methods. This is minimal testing of the method given the number of researchers currently using $^{210}$Pb dating. It would seem that more testing is in order. Lead-210 has been used in marine situations (Koide et al. 1972; Nozaki et al. 1977), in salt marshes (Armentano and Woodwell 1975), in peat bogs (Oldfield et al. 1979) and primarily in lacustrine situations (Bruland et al. 1975; Robbins and Edgington 1976; Farmer 1978; Krishnaswami et al.

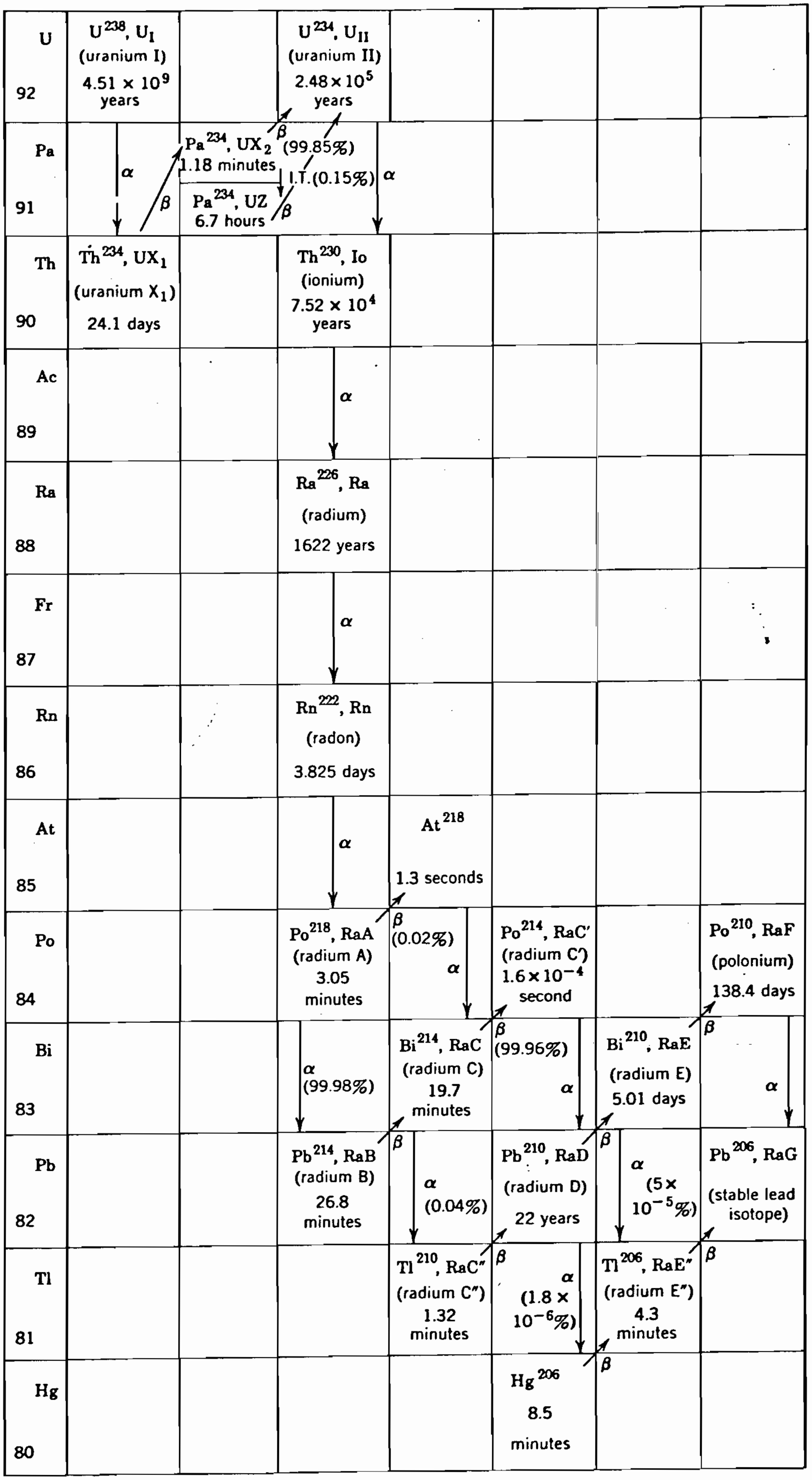

U 92
$U^{238}$, $U_I$
(uranium I)
4.51 × $10^9$ years
$U^{234}$, $U_{II}$
(uranium II)
2.48 × $10^5$ years
Pa 91
α
β
$Pa^{234}$, $UX_2$
1.18 minutes
β
(99.85%)
I.T.(0.15%)
α
$Pa^{234}$, UZ
6.7 hours
β
Th 90
$Th^{234}$, $UX_1$
(uranium $X_1$)
24.1 days
$Th^{230}$, Io
(ionium)
7.52 × $10^4$ years
Ac 89
α
Ra 88
$Ra^{226}$, Ra
(radium)
1622 years
Fr 87
α
Rn 86
$Rn^{222}$, Rn
(radon)
3.825 days
At 85
α
$At^{218}$
1.3 seconds
Po 84
$Po^{218}$, RaA
(radium A)
3.05 minutes
β
(0.02%)
α
$Po^{214}$, RaC′
(radium C′)
1.6 × $10^{-4}$ second
$Po^{210}$, RaF
(polonium)
138.4 days
Bi 83
α
(99.98%)
$Bi^{214}$, RaC
(radium C)
19.7 minutes
β
(99.96%)
α
$Bi^{210}$, RaE
(radium E)
5.01 days
β
α
Pb 82
$Pb^{214}$, RaB
(radium B)
26.8 minutes
β
α
(0.04%)
$Pb^{210}$, RaD
(radium D)
22 years
β
α
(5 × $10^{-5}$%)
$Pb^{206}$, RaG
(stable lead isotope)
Tl 81
$Tl^{210}$, RaC″
(radium C″)
1.32 minutes
β
α
(1.8 × $10^{-6}$%)
$Tl^{206}$, RaE″
(radium E″)
4.3 minutes
β
Hg 80
$Hg^{206}$
8.5 minutes
β

Fig. 1a. The Uranium Series
(from Friedlander et al. 1964).

1971). Robbins (1978) has given an extensive review of the literature on $^{210}$Pb dating and has outlined in detail the theory behind the method. Krishnaswami and Lal (1978) have also reviewed the subject.

The second aspect which must be taken into account when one attempts to quantify sediment accumulation in a lake, is spatial variation in deposition rates over the lake bottom. In an ideal situation, there would be no variation from one location to the next and a single sample would provide an adequate estimate of the average condition for the lake. Unfortunately there exist considerable data to suggest that such a situation is rarely, if ever, met.

Wilson (1936, 1938, 1945) undertook extensive sampling of Winona and Tippecanoe Lakes in Indiana and Douglas Lake in Michigan. In each he found considerable variation in the rates at which the sediment was accumulating over the bottom. There was a general trend towards higher rates in the deeper parts of the lakes than in the shallows. Tutin (1941) emphasized the potential for bottom slope and wind action to transport sediment in lakes. Wieckowski (1969) demonstrated without any doubt that sediment in four Polish lakes was accumulating more rapidly in deep areas than in shallow. Others have provided data which lend support to this general conclusion. R.B. Davis et al.(1969) and M.B. Davis et al.(1973) both found more pollen accumulating per unit time in the centre of lakes than at the edges.

Despite these general findings, many workers have continued to make the erroneous assumption that the accumulation rate measured in a single sediment core from a lake bottom adequately represents the average condition for the lake. Birch et al. (1980) and Kipphut (1978) are two recent examples.

Although workers like Wilson (1945) and Wieckowski (1969) identified the phenomenon of "sediment focusing" as it has since been called (Likens and Davis 1975), they were unable to offer any solutions to the real problem of how one quantifies this spatial variation. A few people have attempted such a quantification. De March (1978) studied a high Arctic lake (Char Lake). He used deposition since last glaciation and by systematically sampling the sediments over the entire lake bottom, was able to calculate whole lake accumulation. Of course the use of deposition since glaciation necessitates the assumption of no changes in the accumulation rate over the last 5000 years if the results are to be used in interpretation of recent limnetic events. Kimmel (1978) tried the same technique using volcanic ash layers. Despite the high degree of variability in his data, it is possible to calculate a whole lake accumulation rate from his results. These two studies are a valuable beginning, but do not provide nearly enough data to allow generalizations to be made about sediment acccumulation. It is to be hoped that given sufficient data, a simple model could be developed for the prediction of whole lake sediment accumulation.

## Objectives

The long-term objectives of my research are many. Some are easily achievable and some will only be realized with many years work. The primary objective of this study was to demonstrate that it is possible, in a variety of lakes, to measure sediment accumulation rates at a number of locations and from these data, confidently calculate an average accumulation rate. This would be accomplished using the best dating technique available.

A secondary objective was to use the whole lake acccumulation and sediment phosphorus analyses of sediment to provide measurements of phosphorus storage in sediments to compare with phosphorus retention as measured by the mass balance method. A long term objective of this work is to provide the data for the formation of a model to predict whole lake sediment accumulation from simple measurements of lake properties. Such a model would be useful since history has shown that most limnologists are unwilling or can not afford the time to undertake detailed sedimentological studies. A simple predictive model for sediment accumulation would alleviate the need for this type of work.

# CHAPTER TWO:

# METHODS

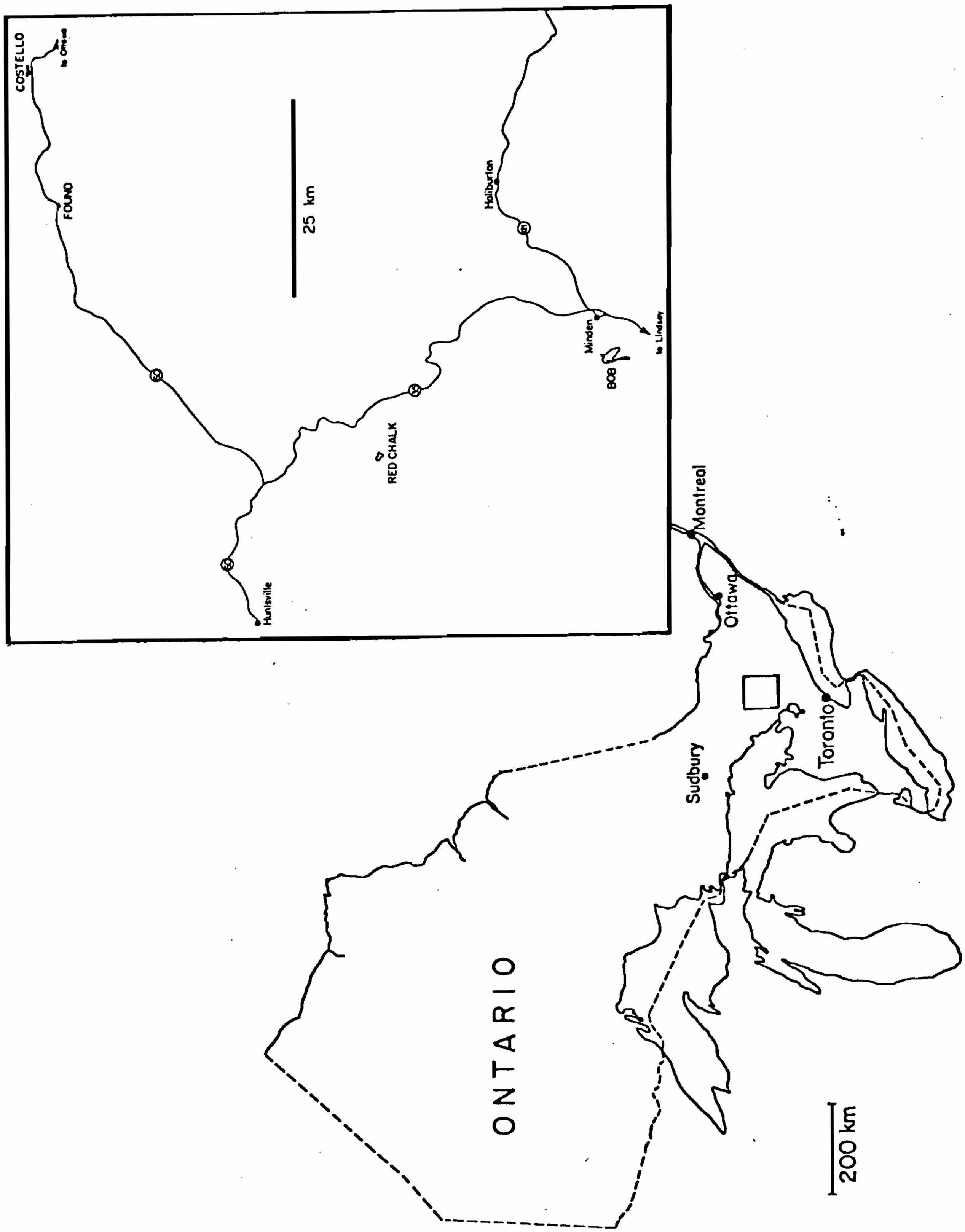
## Study Area

Three lakes were chosen as study sites for whole lake sediment accumulation measurements. In view of the desired objective, to compare sediment P with mass balance measurements, existing phosphorus input - output budgets were a prerequisite. There exists in the Haliburton region of Ontario (Fig. 2a) a series of about 30 lakes within 70 km of Huntsville, Ontario that have been monitored for phosphorus (Dillon 1974b, Scheider 1974, Cross 1977, Scheider et al. 1979). From these lakes, three were selected for the sediment accumulation studies. They were chosen to provide variation in both morphology and morphometry of the lakes and their basins.

Bob Lake (44° 54' N latitude, 78° 47' W longitude) is a 230 ha lake. Its catchment covers an area of 31.8 km$^2$. Much of the shoreline is developed by recreational cottages. One major inflow drains about 61% of the basin. Bob Lake was studied in detail by Cross (1977) and Dillon (1974b).

Red Chalk Lake is a 44 ha lake about 50 km north of Bob Lake. Its catchment and geology are similar to Bob. The catchment is 4.05 km$^2$ in size. There are three unoccupied cottages on its shores. This lake is currently under study by the Ontario Ministry of the Environment as part of its

Fig. 2a. Southern Ontario and study area


COSTELLO
to Ottawa
FOUND
25 km
Haliburton
Minden
BOB
to Lindsay
RED CHALK
Huntsville
Montreal
Ottawa
Toronto
Sudbury
ONTARIO
200 km

Lakeshore Capacity Study (Scheider et al. 1979). Morphometry of Red Chalk Lake (45°11' N latitude, 78°56' W longitude), presented in Fig. 2b, and chemical data have been provided by them.

Costello Lake lies about 50 km east of Red Chalk Lake in Algonquin Provincial Park (45°35' N latitude, 78°20'W longitude). Its surface area is 34 ha and its catchment is 11.5 km$^2$. It is a shallow lake with a very regular bottom (Fig. 2c). It has no cottages in its catchment. Morphometry and chemical data for Costello Lake are from the work of Scheider (1974).

The lakes were selected to give a wide range in a variety of parameters including maximum depth, surface area, and the ratio of catchment area to lake area (Ad/Ao). Table 2a gives a comparison of these parameters for the study lakes.

In addition to the lakes on which whole lake sediment measurements were made, sediment cores were analyzed from two lakes in which the sediments are thought to be undisturbed by normal mixing processes. Found Lake is a small meromictic lake about 15 km from Costello Lake (Scheider 1974). Although laminae are not apparent visually in the sediments, the meromixis should prevent sediment disturbance. Lucerne Lake is a large deep lake in Switzerland (Bloesch 1974,1977) which is not meromictic but in which the sediments are laminated. These cores were used

Fig. 2b. Morphometry of Red Chalk Lake (Ministry of the Environment of Ontario, unpublished data)

# RED CHALK

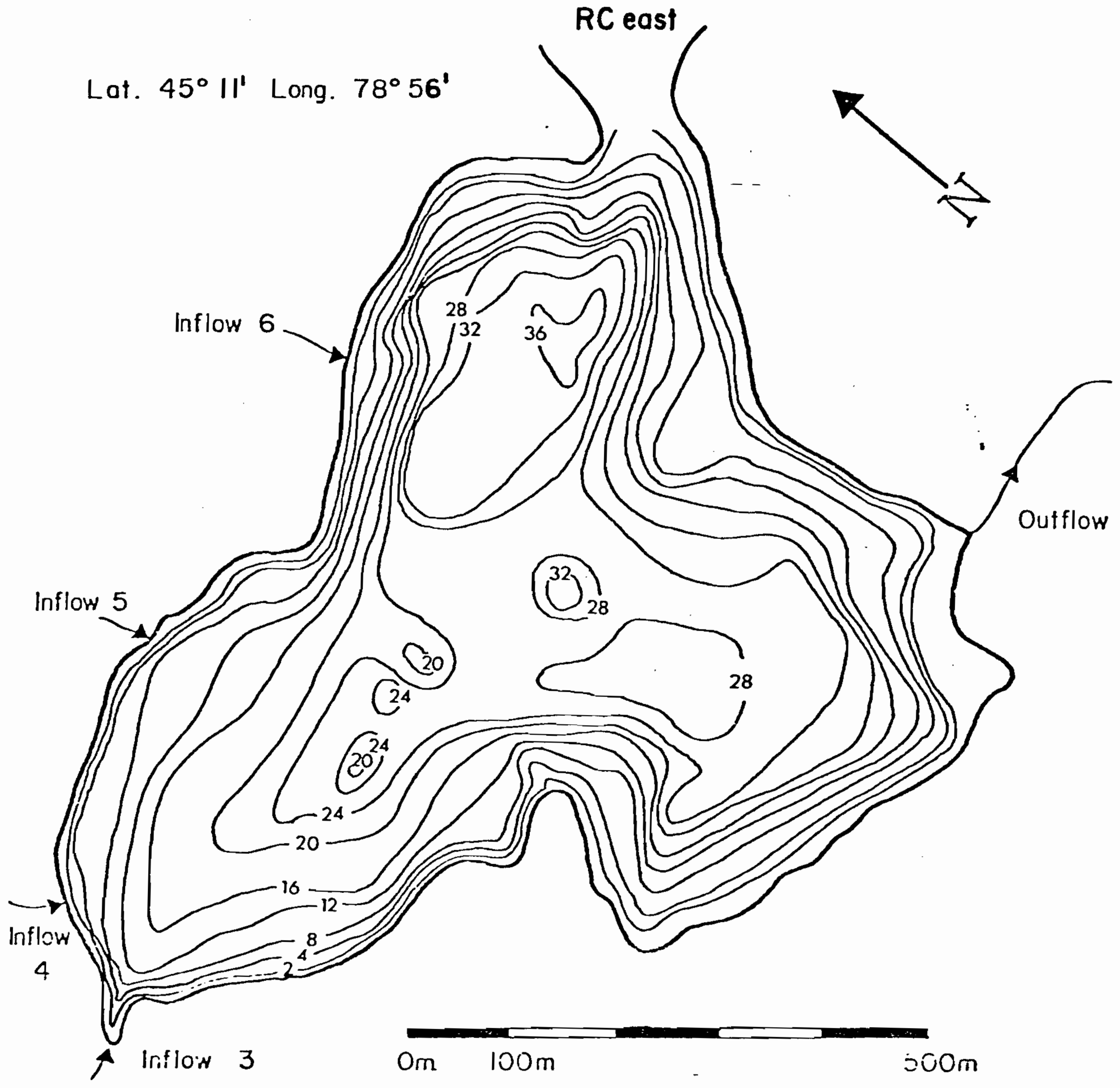
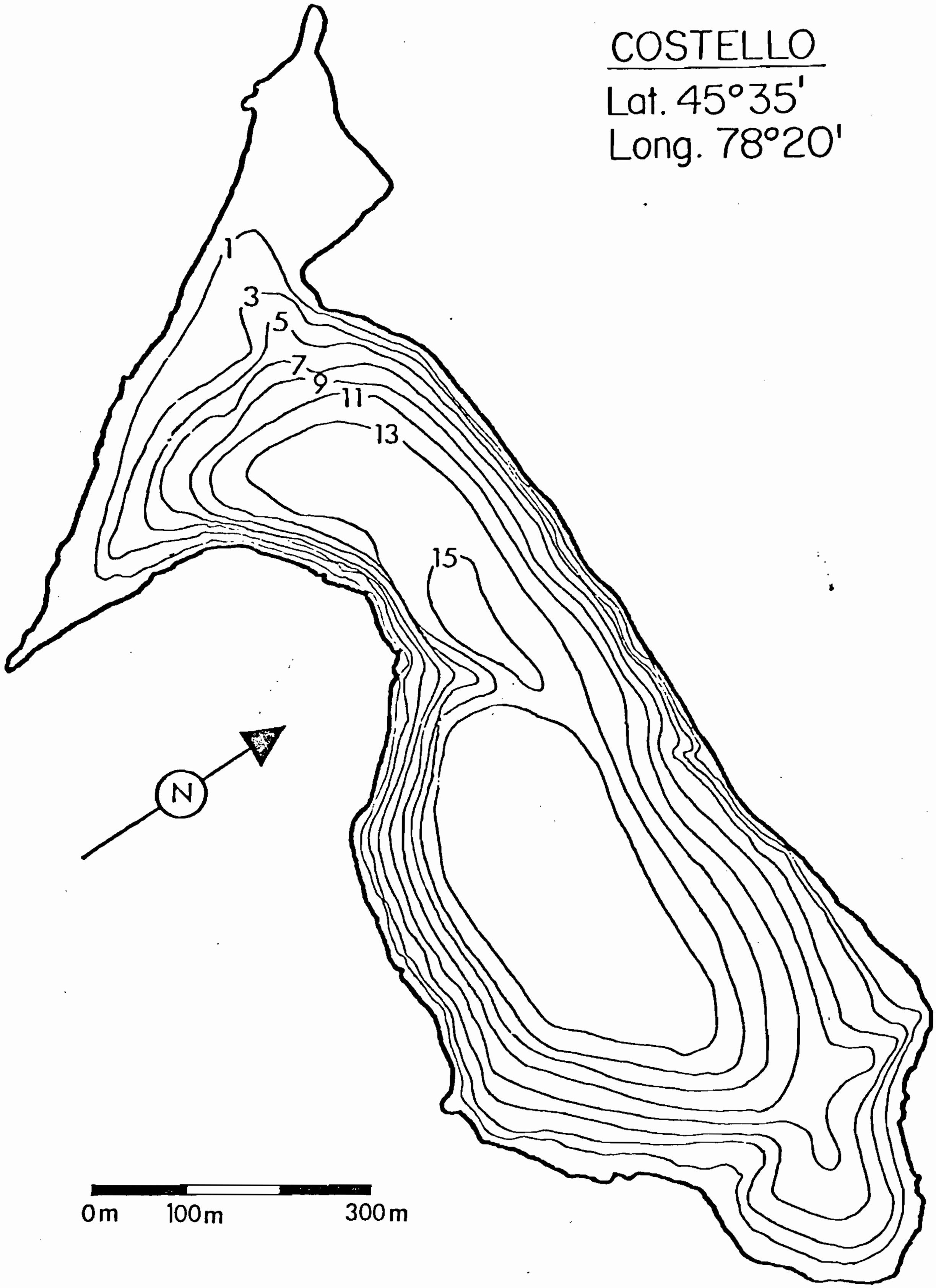

RC east
Lat. 45° 11' Long. 78° 56'
N
Inflow 6
Inflow 5
Inflow 4
Inflow 3
Outflow
2
4
8
12
16
20
24
20
24
24
20
28
32
36
32
28
28
28
0m
100m
500m

Fig. 2c. Morphometry of Costello Lake
(from Scheider 1974)


COSTELLO
Lat. 45°35'
Long. 78°20'
1
3
5
7
9
11
13
15
N
0m
100m
300m

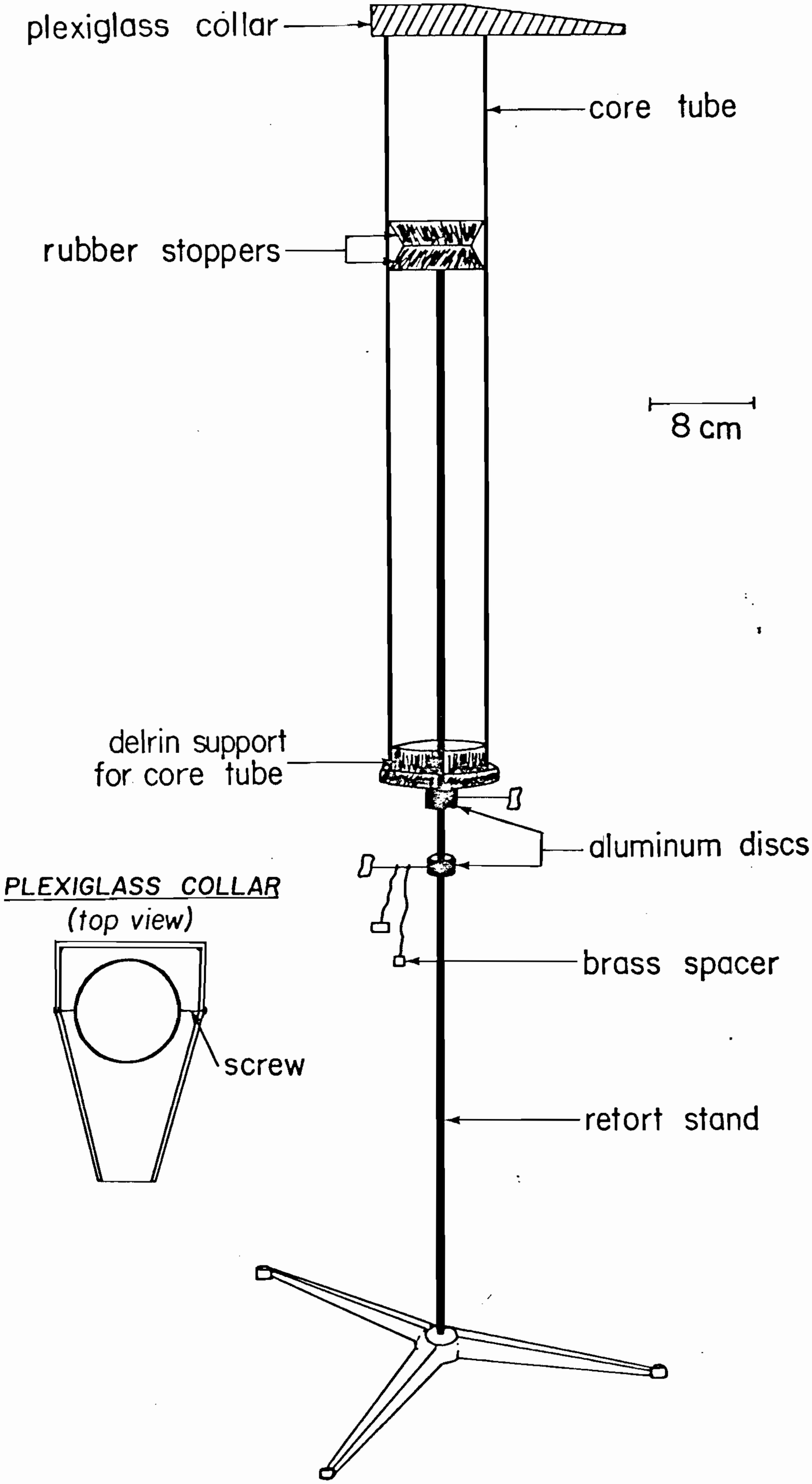
as a test of the lead-210 dating method.

## Sample Collection

The sediment cores from Bob Lake were collected by P.M. Cross (1977) using a K-B corer (Brinkhurst et al. 1969) fitted with core tubes of 5 cm inner diameter (I.D.). Following collection these cores were extruded into 2 cm sections (Fig. 2d) and frozen until analyzed further. Because of the hardness of the bottom material, no samples could be obtained with the K-B corer in areas where the water depth was less than 16.5 m. I attempted to collect shallower cores using a piston corer of the design described by Davis and Doyle (1969). With this device, four cores were collected at depths less than 16.5 m, but no samples could be obtained in areas shallower than 11.5 m.

Because of the hardness of the bottom material in shallow regions and the fact that shallow regions comprise a large fraction of a lake bottom it was decided that samples from this area would have to be collected by SCUBA divers. Thus in Red Chalk and Costello Lakes, cores were collected by divers in depths from the shoreline to the limit of visibility for diving (Red Chalk - 17 m, Costello - 13 m). Cores from depths greater than these limits were collected by K-B corer, modified, to increase sample size by using a 7 cm I.D. coring tube. In addition there has been some suggestion in the literature that core diameter can affect

Fig. 2d. Extruder for sectioning sediment cores (modified from Cross 1977)


plexiglass collar
core tube
rubber stoppers
8 cm
delrin support for core tube
aluminum discs
PLEXIGLASS COLLAR
(top view)
brass spacer
screw
retort stand

the efficiency with which bottom material is recovered. As size of the tube used decreases, more material is excluded by the shearing effect of the edge of the core tube (Hongve and Erlandsen 1979). The increase in core tube size was designed to counteract such a problem.

Approximately twenty-five cores were collected from each of Red Chalk and Costello Lakes. Sample sites for Red Chalk Lake are presented in Fig. 2e and for Costello Lake in Fig. 2f. Each core was sectioned immediately into 1 cm slices to 10 cm and either 1 or 2 cm slices thereafter, to within about 5 cm of the bottom of the core. This generally provided sample material to a depth of 20 cm. Each section was frozen within a few hours of sectioning until required for chemical analysis.

## Analytical Methods

Five parameters were measured on the sediment cores. Some sections were not analyzed for all five parameters (Appendix II). Measurements made were wet mass,dry mass, lead-210,total lead and total phosphorus. Methodologies for wet and dry masses and phosphorus concentration are outlined in chapter four.

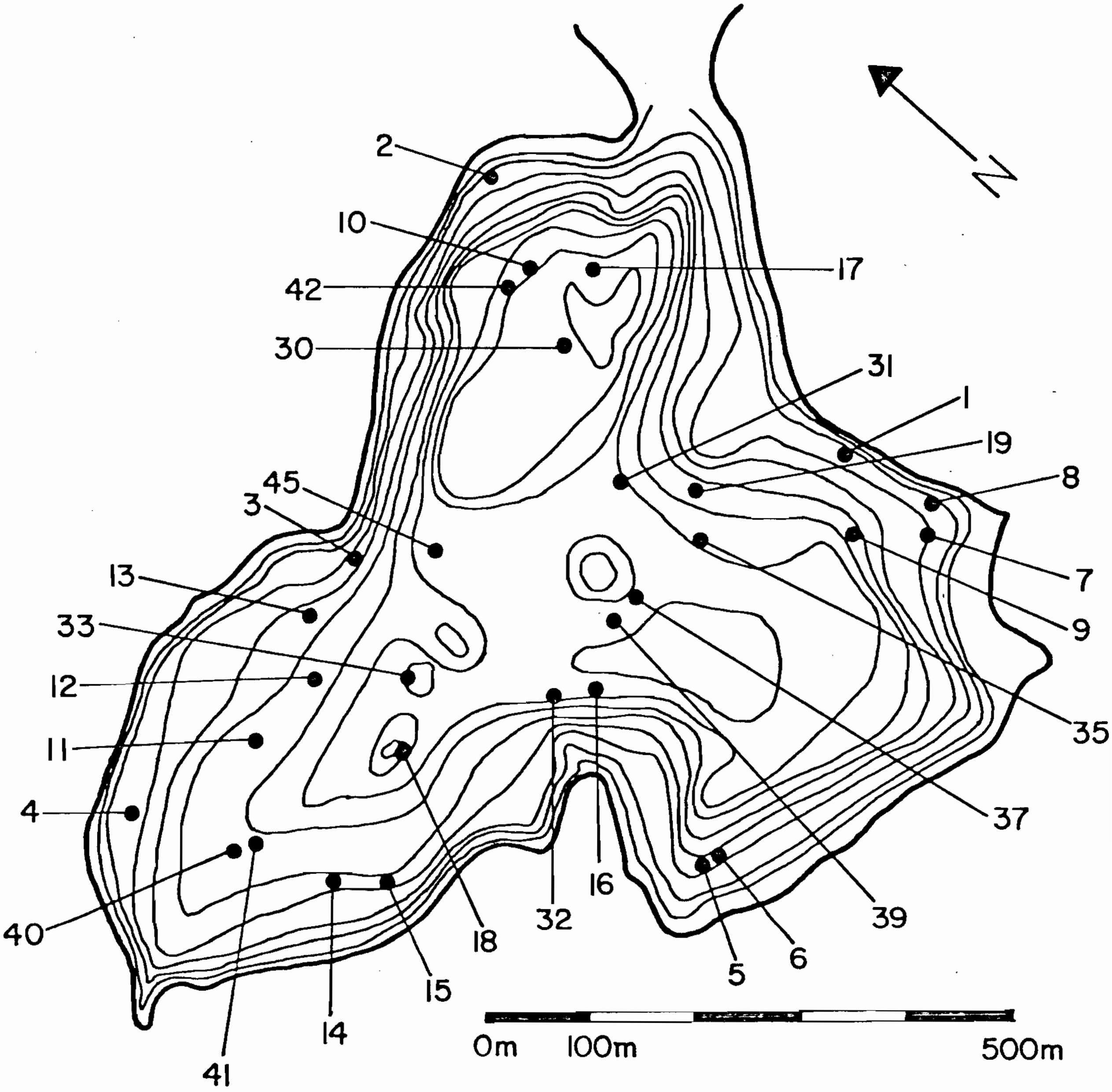
## Total Lead

Total lead was determined using the method of Bronson (1975). Since the method is not commonly used, it will be

| LAKE | AREA ($km^2$) | MEAN DEPTH (m) | MAX.DEPTH (m) | VOLUME ($m^3*10^6$) | WATERSHED AREA ($km^2$) | WATERSHED: LAKE AREA RATIO |
|---|---|---|---|---|---|---|
| Bob | 2.28 | 17.8 | 65.0 | 40.63 | 31.8 | 13.9 |
| Red Chalk | 0.44 | 16.7 | 38.0 | 7.33 | 4.1 | 9.23 |
| Costello | 0.34 | 8.4 | 17.5 | 2.89 | 11.5 | 33.74 |

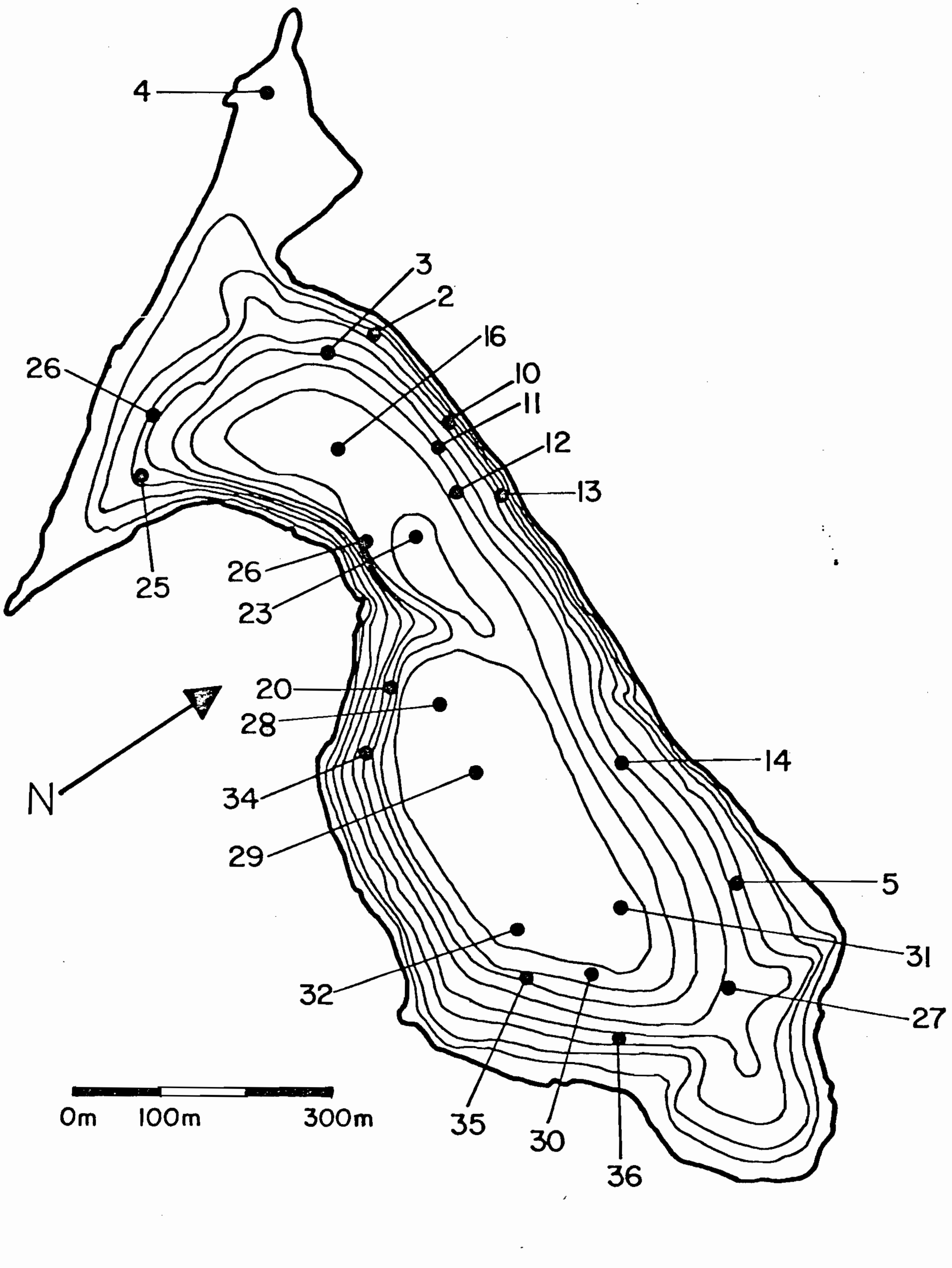
Table 2a. Morphometric characteristics of the three study lakes.

Fig. 2e. Sampling sites in Red Chalk Lake



2
10
17
42
30
31
1
19
8
45
3
7
13
9
33
35
12
11
37
4
16
32
18
39
40
6
5
15
14
41
N
0m
100m
500m

Fig. 2f. Sampling sites in Costello Lake


4
3
2
16
10
11
12
13
26
25
26
23
20
28
34
29
14
5
31
32
35
30
36
27
N
0m
100m
300m

outlined here. This technique was chosen from many that have been developed (Agemian and Chau 1975, Ediger 1973) because it is currently being used by the Ontario Ministry of the Environment. Since they are collecting comparable data in the vicinity of my study area, the use of the same methods facilitates data comparison. While there is probably some mineral lead not extracted by this digestion, the amount remaining in mineral lattices should be constant from sample to sample in a single core. Furthermore, the lead not extracted probably is not of any environmental significance.

Aliquots of 0.5 to 1.0 gram of dry sediment were placed in 5 ml of concentrated $HNO_3$ (sp. gr. 1.42) and 10 ml of concentrated HCl (sp. gr. 1.18). Care must be taken upon addition of the acids as foaming will occur from the breakdown of organics in the sediment. If attention is not given to this problem, material will foam over the top of the digestion flask resulting in an underestimation of the actual lead concentration. This problem can be overcome by "resting" the sediment in the acids for about 1 hour before heating.

The acid - sediment mixture was heated at 70°C until dry (usually overnight). To the dried sediment 15 ml of 1.5N HCl was added and the contents warmed to precipitate hydrated silica. The solution was centrifuged to remove particles which were too large to be aspirated through the nebulizer of the atomic absorption spectrophotometer. The digestate, once separated from the residue, was analyzed for Pb using a Perkin-Elmer model 403 analyzer. Cores from Bob Lake were read using the 217 nm spectral line and corrected for background interference by subtracting the reading at the 220 nm non-absorbing line. Following these analyses, the machine was equipped with a deuterium background corrector. Red Chalk and Costello sediments were analyzed using the 283 nm spectral line and deuterium background correction.

### Lead-210

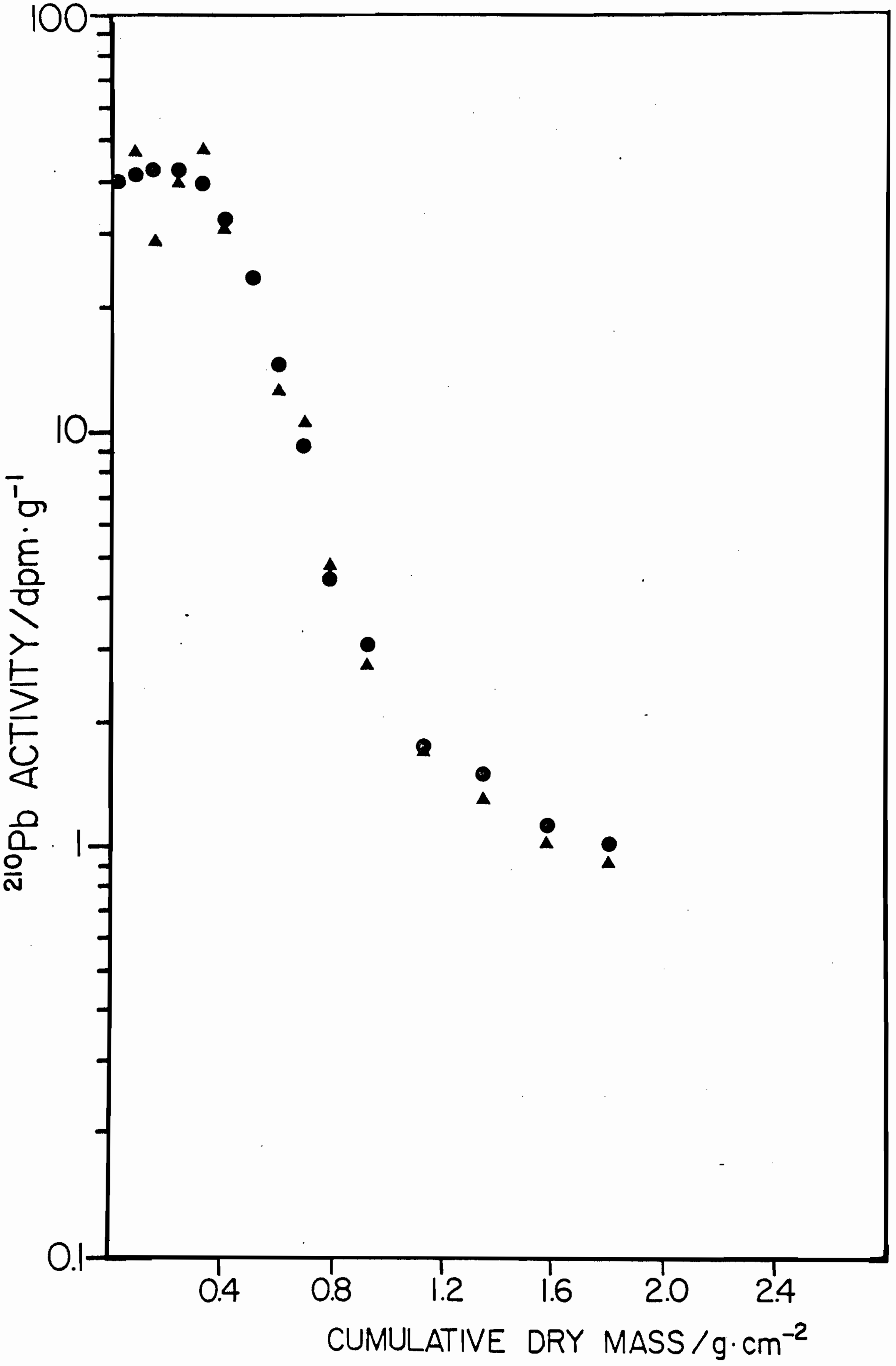
Lead-210 is a weak beta emitter ($e_{max}$=0.61 Mev). As a result, most people choose to measure lead-210 activity via either the bismuth-210 daughter ($\beta\ e_{max}$=1.16 Mev) or the polonium-210 granddaughter ($\alpha\ e_{max}$=5.31 Mev). Samples from Found Lake and a few cores from Bob Lake were analyzed using the bismuth-210 method of Koide et al. (1972). While the method is quite useful, the alpha spectrometric polonium-210 method offers certain advantages over beta counting. First recovery of the isotope from the sediment is never complete and thus yield must be determined. The $^{210}$Po method utilizes $^{208}$Po as a yield tracer whereas the $^{210}$Bi method uses stable Pb and gravimetric analysis as a yield tracer . The radiochemical tracer is more sensitive. Second, alpha counting is virtually background-free whereas special effort must be taken to reduce beta background to the point where sample activities and background are approximately equal (anti-coincidence circuitry, extra lead shielding, etc.). This lower background of alpha counting decreases counting time and increases accuracy for samples of very low activity. It also helps to extend the time period over which the dating technique can be used. For these reasons the alpha $^{210}$Po method was used for lead-210 determinations in most of the cores from Bob Lake and in all cores from Red Chalk and Costello Lakes.

The alpha method used was a modification of that described in detail by Eakins and Morrison (1978). Their method involves the distillation of $^{210}$Po and tracer $^{208}$Po from the sediment followed by plating on silver planchettes. Modifications were made to decrease the handling time per sample and allow large numbers of samples to be processed at one time. Eakins and Morrison (E & M) recommended pretreatment of the dry sediment with concentrated hydrochloric acid to remove excess carbonate. I found this unnecessary because my sediments are generally low in carbonate and simply added the $^{208}$Po yield tracer to the dry sediment. Once the polonium is distilled from the sediment, it must be removed from the condenser with concentrated nitric acid. This nitric must be exchanged for hydrochloric acid before proper plating will occur on the silver. E & M suggest repeated boiling down of the solution combined with addition of concentrated hydrochloric acid. This requires constant attention for if the solution evaporates to a very small volume at high temperature, spattering will result and polonium will be lost. I found it simpler to dry the beaker containing $HNO_3$ and polonium overnight at a very low heat. This required no attention and had no apparent effect on the recovery which was generally greater than 70%. My samples were plated on 1 cm squares of silver rather than 3.2 cm discs to reduce the cost. Silver planchettes were coated with liquid rubber on one side and then placed in the plating solution unstirred except for the natural convection caused by heating of the solution. These modifications are small but they significantly reduce the time required for analysis to the extent that one person can easily process upwards of fifty samples per week. The method is quite reproducible, as can be seen in the results of duplicate analysis of a core in Fig. 2g.

## Calibration of Polonium-208 Tracer

$^{208}Po$ was added to each sample of sediment in the analysis of lead-210. To report the results of these measurements in terms of absolute activity (dpm/g dry mass) it is necessary that the absolute activity of the polonium-208 tracer be measured. I produced my own $^{208}Po$ by irradiation of bismuth foil in the McGill cyclotron (p,2n reaction). The absolute activity of the $^{208}Po$ was determined by calibrating it against a $^{210}Po$ standard source supplied by Amersham Corporation. A known activity of $^{210}Po$ was

Fig. 2g. Duplicate lead-210 analyses of core 13 from Red Chalk Lake


100
10
1
0.1
0.4
0.8
1.2
1.6
2.0
2.4
$^{210}$Pb ACTIVITY / dpm·g$^{-1}$
CUMULATIVE DRY MASS / g·cm$^{-2}$

plated on silver along with a known volume of $^{208}$Po. Since the absolute activity of the $^{210}$Po calibration source was known, the yield and counting efficiency of the $^{210}$Po could be calculated. By applying this factor to the observed activity of the $^{208}$Po, its absolute activity can be calculated. This method is preferable to the normal procedure of drying out standard aliquots on planchettes. Self absorption and geometric influences on the counting are eliminated. The activity of the $^{208}$Po solution was checked periodically through time to check on loss to container walls, solution evaporation etc. Table 2b gives results and an estimate of error from the absolute activity of $^{208}$Po solution used.

| ACTIVITY OF $^{208}$Po YIELD TRACER (dpm/0.5 ml) | 1 $\sigma$ STANDARD COUNTING ERROR (dpm/0.5 ml) |
|---|---|
| 34.11 | 1.31 |
| 34.61 | 1.19 |
| 35.08 | 1.07 |
| 35.78 | 0.83 |
| 38.47 | 1.23 |
| 38.59 | 0.80 |

average = 36.11 dpm/0.5 ml

Table 2b. Determinations of absolute activity of polonium-208 yield tracer.

# CHAPTER THREE:

# LEAD-210 DATING IN UNDISTURBED SEDIMENTS

At the outset of this work, only one test of the validity of $^{210}$Pb dating had been reported in the literature. This was the study of Koide et al. (1972) in the Santa Barbara Basin off the coast of California. The sediments in this area are laminated and yearly layers are visible. Thus a comparison could be made between the accumulation rate predicted by $^{210}$Pb dating and by counting the yearly laminae. Since the agreement between the two methods was very good, most workers have taken this test as sufficient validity of the lead-210 dating technique. Subsequently, laminated sediments in Finland have been dated with $^{210}$Pb with some success (Appleby et al. 1979), although these authors used a method of calculation not generally accepted by others (Robbins 1978; Edgington and Robbins 1979). Brunskill (pers. comm.) has examined one assumption of the $^{210}$Pb method; that of constant input of $^{210}$Pb to the sediments through time . He has found that year to year variation in $^{210}$Pb flux to a given bottom location varies by less than 25%. Thus some testing has been done but many of the assumptions of the method remain untested.

As outlined earlier, both Found Lake and Lake of Lucerne produce apparently undisturbed sediments. In these situations the theory of $^{210}$Pb dating would predict a perfect negative log-linear relationship between $^{210}$Pb activity in the sediment and depth. In neither of the lakes examined can yearly increments be visually counted so the absolute accumulation rate predicted by dating can not be independently checked. However the closeness of fit to log-linearity can be tested. This is important since normal dimictic lakes usually exhibit surface disturbance the exact cause of which is debated. The validity of the method is dependent on the assumption that lead-210, once deposited in the sediments, is chemically immobile. In other words, surface mixed layers are a result of physical mixing and not of migrations of elemental lead. This assumption would be falsified if a mixed layer were to be found in physically undisturbed sediments. For this reason sediments from Found and Lucerne Lakes were dated.

Fig. 3a and 3b show the results of lead-210 dating on two cores from Found Lake. Core A was collected with a K-B corer and a core tube of 5 cm I.D. Core B was collected with a Williams corer (Williams and Pashley 1979) and a core diameter of 10 cm. Both cores show the expected log-linear relationship in the surface region of the core. In core B there is deviation from linearity in the section closest to the sediment - water interface. This phenomenon has been reported by others (Koide et al. 1972, Eakins and Morrison 1978). The sediments in this region are very young and since secular equilibrium between $^{210}$Pb and $^{210}$Po requires 2.5

Fig. 3a. Lead-210 analysis of Found Lake core A

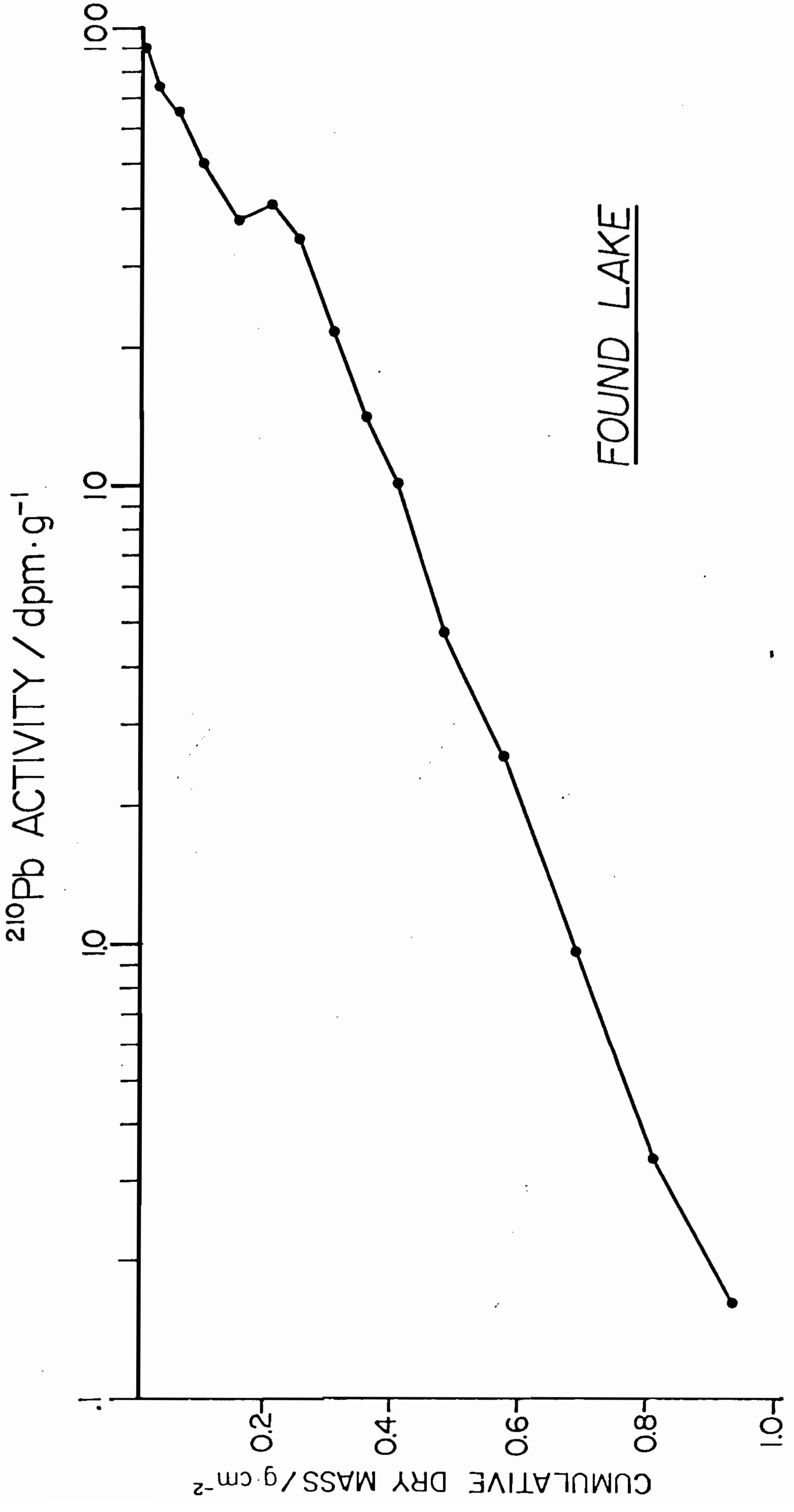
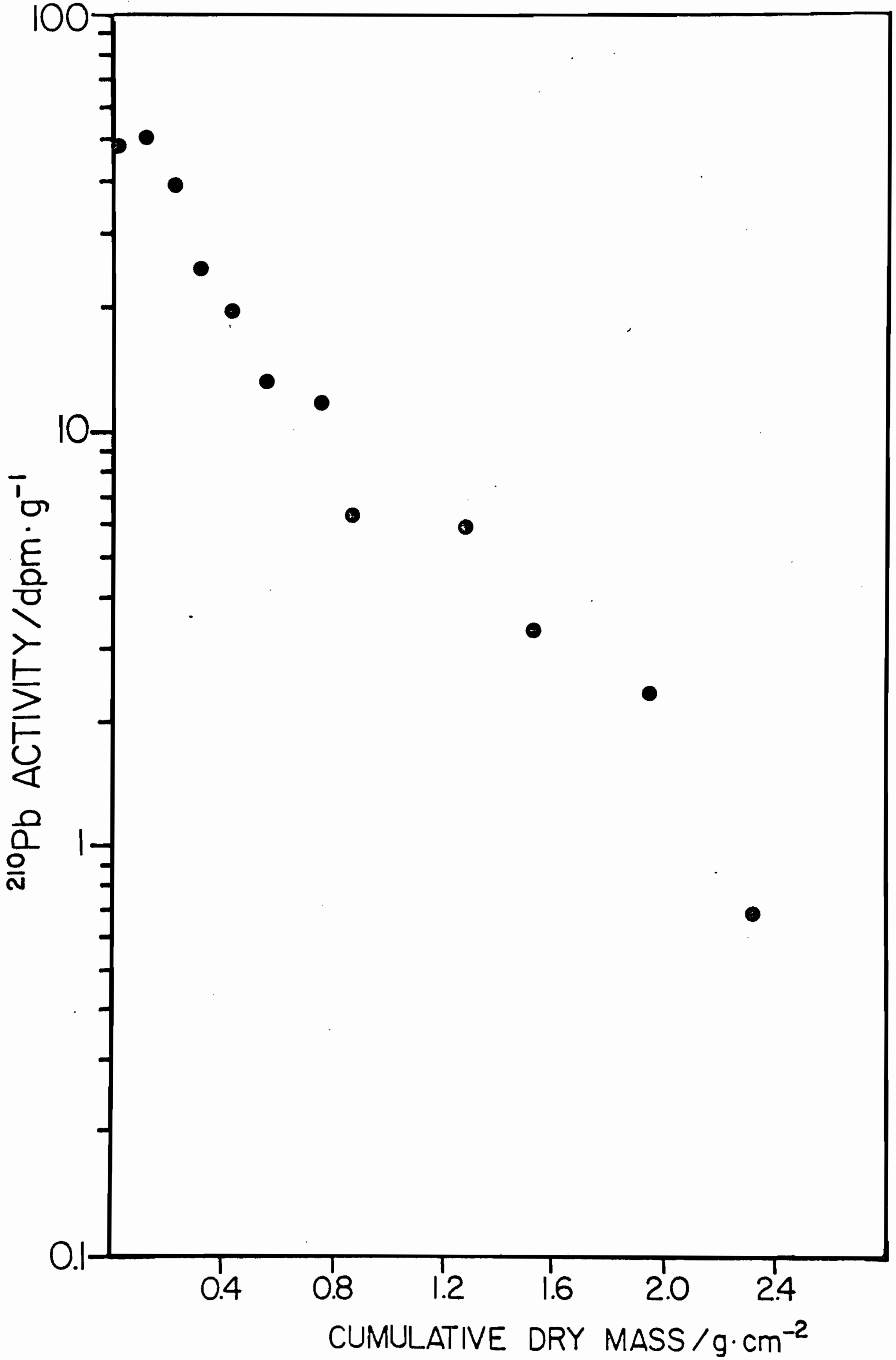

FOUND LAKE
$^{210}Pb$ ACTIVITY / dpm·g$^{-1}$
100
10
1.0
.1
CUMULATIVE DRY MASS / g·cm$^{-2}$
0.2
0.4
0.6
0.8
1.0

Fig. 3b. Lead-210 analysis of Found Lake core B

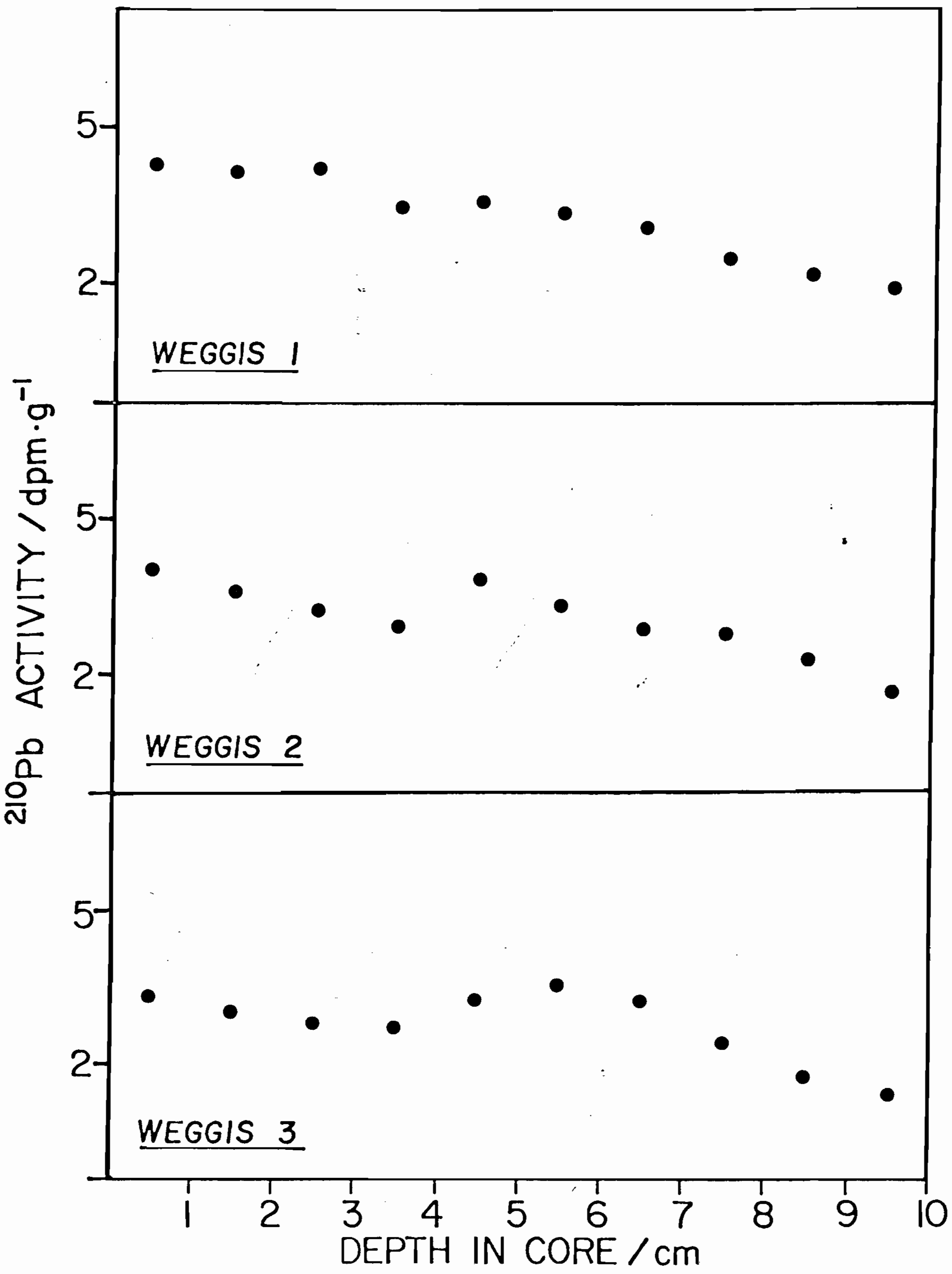

100
10
1
0.1
0.4
0.8
1.2
1.6
2.0
2.4
$^{210}$Pb ACTIVITY / dpm · g$^{-1}$
CUMULATIVE DRY MASS / g · cm$^{-2}$

years to be achieved, it is possible that the $^{210}$Po activity is underestimating the $^{210}$Pb activity. Although this is certainly a plausible explanation this phenomenon requires further exploration.

Fig. 3c illustrates the results of three replicate cores taken from the Weggis region of Lake of Lucerne. All cores were obtained with an Ambuhl corer (Ambuhl and Buhrer 1975), by J. Bloesch of the Swiss Institute of Technology in September 1979. The accumulation rates in these cores are quite high and the $^{210}$Pb concentrations quite low. Consequently, the slope of activity versus depth is not very steep and the interpretation of these cores is not as clear as those from Found. Each core exhibits the expected log-linearity at the surface. No mixed layers were found in any of the cores from either lake. Thus these results do not falsify any assumptions of the $^{210}$Pb dating method.

There is an interesting aspect to each of these $^{210}$Pb profiles. In each case there is a deviation from log-linearity at some depth in the profile. These deviations probably are the result of slumping of the sediments or influx of large amounts of basin material. Landslides are known to have occurred on the shores of Lucerne (Staub 1977) In undisturbed sediments these perturbances are obvious and present no real problem. While these lakes are certainly more prone to slumping because of their steep bottom slopes, such events probably occur in most if not all lakes. In a

Fig. 3c. Lead-210 analyses on three replicate cores from Lake of Lucerne, Switzerland


5
2
WEGGIS 1
5
2
WEGGIS 2
5
2
WEGGIS 3
210Pb ACTIVITY / dpm·g-1
1
2
3
4
5
6
7
8
9
10
DEPTH IN CORE / cm

dimictic lake these slumps would be mixed into the active surface layer and not readily visible. Thus rates calculated from cores with mixed layers will be an average of the sediment accumulation locally and any material added through slumping.

# CHAPTER FOUR:

# MEASUREMENT OF WHOLE LAKE SEDIMENT ACCUMULATION AND PHOSPHORUS RETENTION USING LEAD-210 DATING

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running head: $^{210}$Pb sediment accumulation and P retention

## ABSTRACT

Lead-210 dating was used to measure rates of sediment accumulation in 15 cores from Bob Lake, Ontario. The rate of accumulation was highly correlated with sample depth. This relation allowed the calculation of accumulation of sediments over the whole lake area. Phosphorus (P) retention was calculated from mean concentration of P in the sediments and the whole lake accumulation of sediment. Retention of P calculated in this way was similar to retention calculated from previously measured input and output of P.

Key words: Lead-210 dating, sediment accumulation, phosphorus retention.
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# INTRODUCTION

Knowledge of the net accumulation of materials in the sediments of a lake is potentially useful for modelling nutrient concentrations in the water (Vollenweider, 1969; Dillon and Rigler 1974), for establishing the rate of return from the sediments for some substance for which influx is known (Schindler et al. 1976), and for testing the validity of energy flow data (Rigler 1978). This information would be equally useful outside the field of limnology as, for example, to geomorphologists concerned with regional erosion rates.

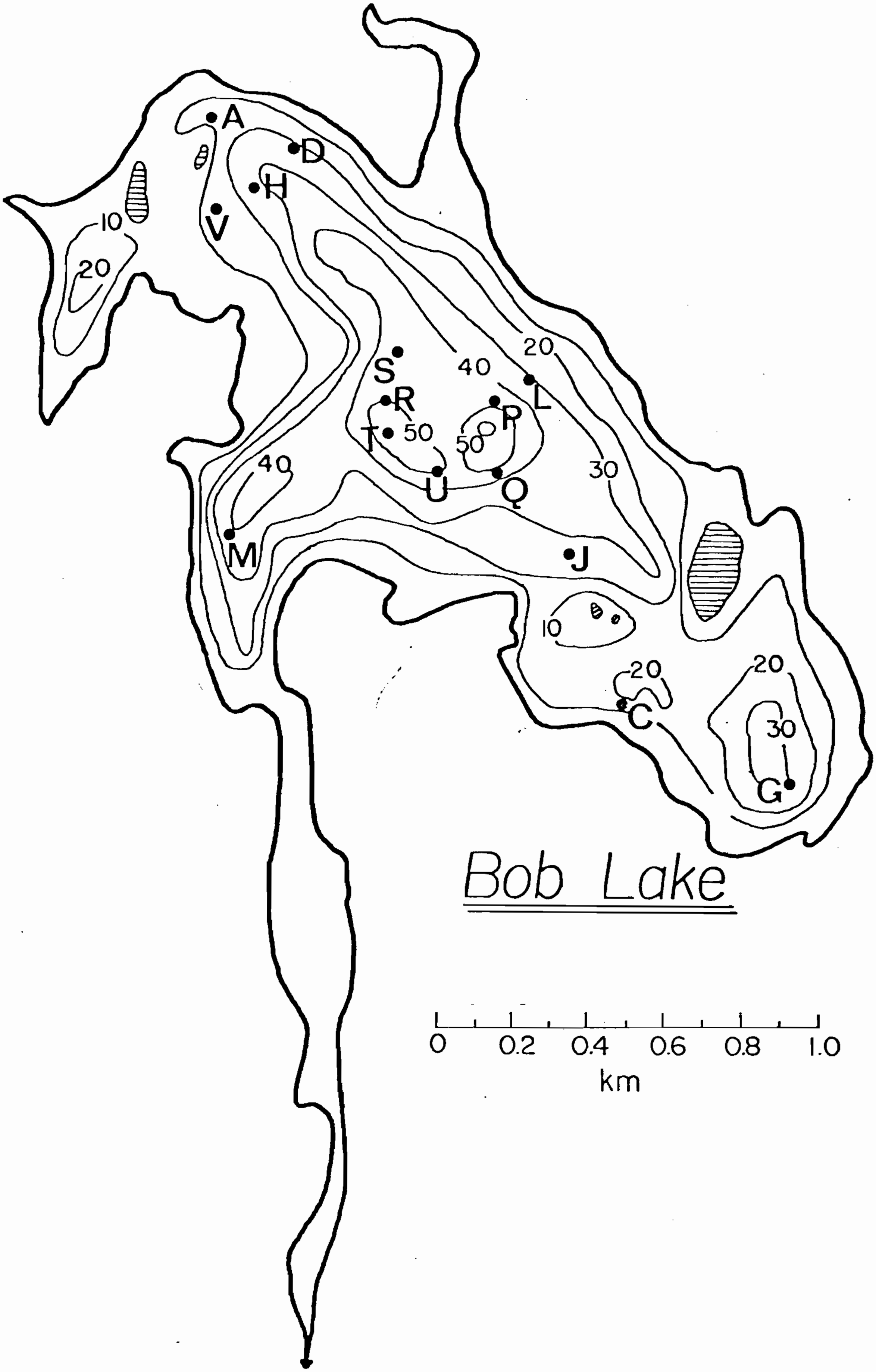
Despite their obvious value, data on the net accumulation rate of sediments for a whole lake basin have rarely been gathered (Wilson 1936; de March 1978; Kimmel 1978), presumably because of the difficulty of such measurements and uncertainty about their validity.

Problems arise from two sources. First, valid results depend on a reliable method of measuring the rate at which sediments are accumulating at a particular location. Second, sediments accumulate at different rates at different parts of a lake. (de March 1978; Kimmel 1978). Consequently many samples must be taken at various sites in the lake if a good estimate of average sedimentation is to be obtained. Our research was addressed to these two difficulties.

Several studies have suggested that depth in the lake may be the most important factor governing spatial variation in sediment accumulation rates (Wilson 1936; Wieckowski 1969; Davis et al. 1971; Lehman 1975). If this were true, a random sampling pattern, stratified with respect to depth, should give a good estimate of average sediment accumulation. However, two studies have suggested that factors other than depth can have an important influence. de March (1978) examined sediment accumulation in Char Lake, a polar lake with dense moss beds at intermediate depths. He found that, presumably because of trapping of sediments by the moss beds, sedimentation was higher there than at shallower or deeper sites and at sites of equal depth where moss did not grow. Kimmel (1978), studying Castle Lake, concluded that depth explained only 30% of the variation in rates of sediment accumulation. Other factors, steepness of slope being an important one, accounted for much of the remaining variability. Castle Lake is unusual in that it is highly sheltered from prevailing winds and has an exceptionally steep sloping bottom. Edgington and Robbins (1976) have shown non-morphometric patterns of sediment deposition in Lake Michigan. They propose wind driven currents as the mechanism for the observed deposition but given the size of Lake Michigan many more samples would be required than the few taken by Edgington and Robbins before any firm conclusions could be drawn. Our hypothesis was that in a more morphometrically - typical, temperate lake, depth would be the main factor causing variation in the rate of sediment accumulation. Thus we chose Bob Lake in southern Ontario (44°54' N., 78°47' W.); a 2.26 $km^2$ lake with a maximum depth of 60 m. Morphometry is shown in Fig. 4a. We predicted that in this lake depth would be the most important variable influencing sediment accumulation rates.

Theoretically, the best method for measuring present accumulation is one, such as the $^{210}Pb$ method, which depends on decay of a short-lived isotope. Markers such as volcanic ash layers (deposited at approximately 3370 BP) used by Kimmel, and marine sediments (approximately 6600 BP) used by de March (1978), or long-lived isotopes such as $^{14}C$ (Likens and Davis, 1975) integrate sediment accumulation

Fig. 4a. Morphometry and sampling locations in Bob Lake. Depth contours are in tens of metres.


A
D
H
V
10
20
S
40
20
L
R
P
T
50
50
U
Q
30
40
M
J
10
20
C
20
30
G
Bob Lake
0
0.2
0.4
0.6
0.8
1.0
km

over too long a period to be used with confidence to measure present accumulation rate. Other possible methods for dating recent accumulation include $^{232}Th/^{228}Th$ ratios (Koide et al. 1973) and low frequency echo sounding (d'Anglejan and Brisebois 1974, King 1966). Even the interpretation of lead-210 results has been questioned (Robbins 1978; Appleby and Oldfield 1978). Controversy arises from the generally made assumption of constant rate of accumulation of the sediments. Where varved sediments are produced, as in meromictic lakes, $^{210}Pb$ dating and varve counts can be compared to establish the validity of the accumulation rate predicted by the $^{210}Pb$ dating (Koide et al. 1972; Appleby et al. 1979). In general there is good agreement between accumulation rates calculated by the two methods. Examination of the flux of $^{210}Pb$ to the varved sediments of Fayetteville Green Lake reveals year to year variation of less than 25% (G.J. Brunskill, Department of Fisheries and Oceans, Winnipeg, 1979, personal communication) in keeping with the assumption of constant flux of $^{210}Pb$ to the sediments. In dimictic lakes these tests of the model are not feasible. Making the assumption that the method gives valid results in dimictic lakes, we have chosen to test the applicability of lead-210 dating to the measurement of whole lake accumulation by applying it to a lake for which phosphorus budgets had been thoroughly measured. Bob Lake, previously studied by Dillon and Rigler (1974), and Cross (1977) was suitable on this count also. From their studies we could obtain an estimate of annual accumulation of P in the sediments. This estimate could then be compared with an independent estimate derived from $^{210}Pb$ dating of the sediments and their P content.

# METHODS

The coring sites in Bob Lake are shown in Fig. 4a. Sediment cores were taken with a K-B corer (Brinkhurst et al. 1969) in 1975 and 1976 by P.M. Cross (1977). Cores were sectioned into 2-cm slices with 24 h of being collected, sealed by polycarbonate vials and frozen until analyzed for $^{210}$Pb and P. Of the 50 cores collected by Cross, 15 were selected to represent most areas and depths of the lake. None was taken at depths less than 10 m because the bottom materials there were too hard to be sampled by the K-B corer.

The sediment samples were massed, dried at 105°C for 24 h and remassed. Initially $^{210}$Pb was measured by the method described by Koide et al. (1972). In this method the beta-emitting daughter (bismuth-210) of $^{210}$Pb in secular equilibrium is assayed. This method, although satisfactory, was too slow. Consequently, in most cores, we assayed $^{210}$Po, the grand-daughter of $^{210}$Pb. The polonium-210 was extracted from the dry sediments by the volatilization technique of Eakins and Morrison (1978), and deposited on silver discs according to Flynn (1968). All $^{210}$Po samples were assayed in a Canberra alpha spectrometer equipped with Princeton Gamma Tech surface barrier detectors (active area 300 mm$^2$). The isotope $^{208}$Po, produced in the McGill University cyclotron by irradiation of bismuth foil, was added to the dry sediments as a yield indicator to measure the efficiency with which $^{210}$Po was extracted and plated. The absolute activity of the $^{208}$Po was calibrated against a $^{210}$Po source supplied by Amersham Corporation. In general recovery of the $^{208}$Po was above 60%.

Total phosphorus in the sediments was measured by the method of Andersen (1976). Dry sediment was ashed at 550°C for 6 h, the residue was massed and dissolved in dilute HCl. A subsample was then diluted to 50 ml and phosphorus in it determined colorimetrically (Strickland and Parsons 1968).

## CALCULATION OF ACCUMULATION RATES FROM LEAD-210 ACTIVITY

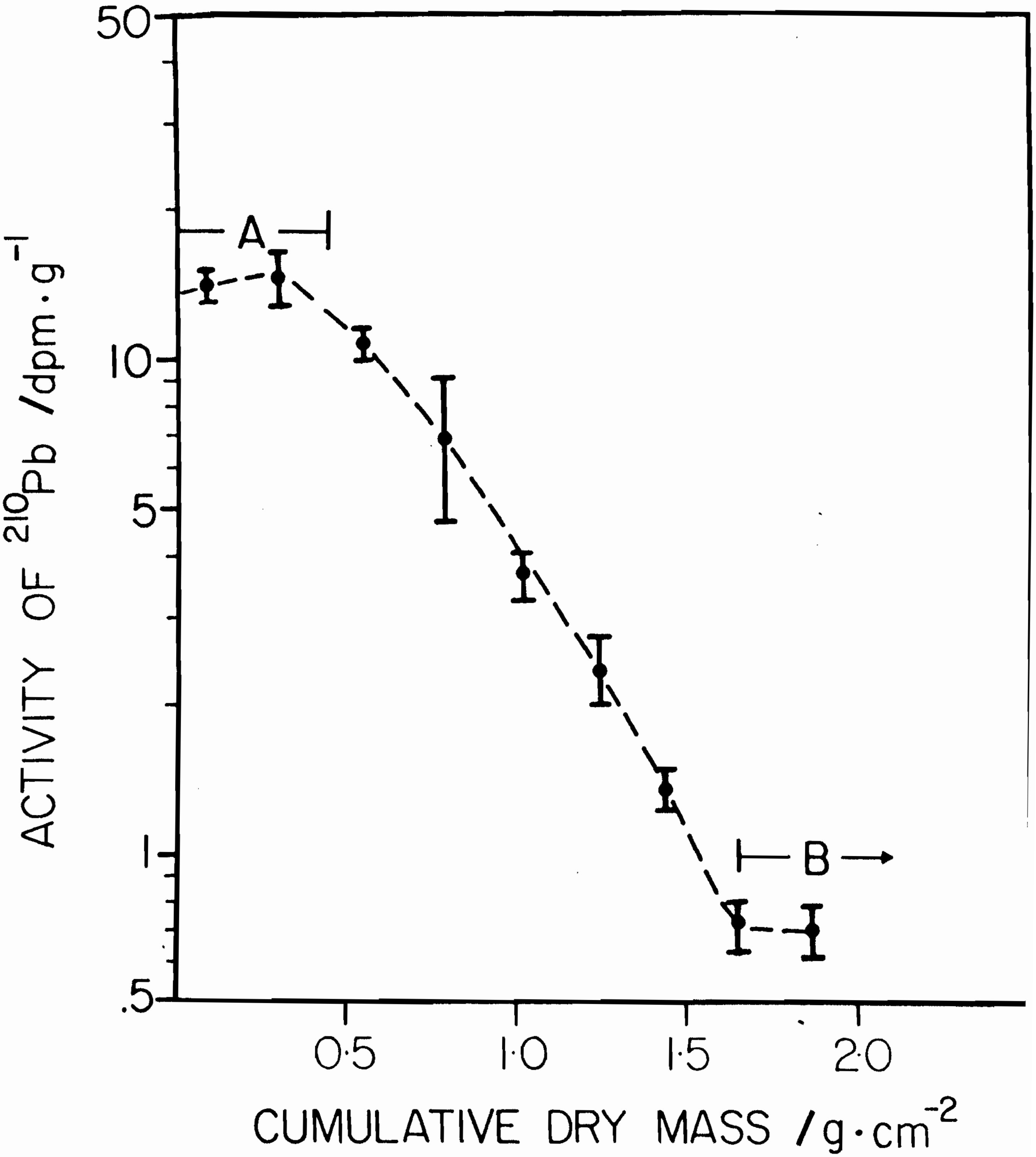
Since there has been some dispute as to the proper method of interpreting $^{210}$Pb profiles in sediments (Robbins 1978; Appleby and Oldfield 1978) we will describe our method and the assumptions involved in it. We assume that over the last century the sediments in Bob Lake have accumulated at a constant rate. We assume that profiles deviate from a simple log-linear relation near the surface (shown as A in Fig. 4b) because activity of benthic organisms and water currents mix the surface sediments. Deviation from log-linearity far below the surface (B in Fig. 4b) is a result of $^{210}$Pb continually being produced at all depths by decay of in situ parent radium. Further we assume that the radium content of dry sediments is constant with depth. Finally, we assume that the flux of $^{210}$Pb to the sediment surface has been constant through time.

Provided these assumptions are valid the $^{210}$Pb content of the sediments will decrease exponentially with depth to an asymptote of the concentration C, where C is the supported $^{210}$Pb level. Thus below the mixed layer, the concentration of $^{210}$Pb ($C_w$) at depth w is described by:

$$(1) \qquad C_w = Co\, e^{-kw} + C$$

where: $C_w$ is the concentration of $^{210}$Pb measured in dpm $g^{-1}$ dry wt, w is the depth measured as g dry mass per $cm^2$, Co is the surface concentration of $^{210}$Pb, and C is the concentration of supported $^{210}$Pb in

Fig. 4b. A typical lead-210 profile from Bob Lake. Data are for core L. Error bars are 1 σ counting errors.


50
10
5
1
.5
ACTIVITY OF $^{210}$Pb /dpm · g$^{-1}$
A
B
0·5
1·0
1·5
2·0
CUMULATIVE DRY MASS /g · cm$^{-2}$

the sediments. Depth is expressed as cumulative dry mass to avoid the problems caused by compaction of the sediment through time (Robbins 1978). The slope of the regression of $\ln(C_w - C)$ on w gives the constant (k) of decrease of unsupported $^{210}$Pb with depth expressed as $g^{-1}\ cm^2$, and the sediment accumulation rate (r) in $g.cm^{-2}.yr^{-1}$ is given by:

(2) $$r = \lambda/k$$

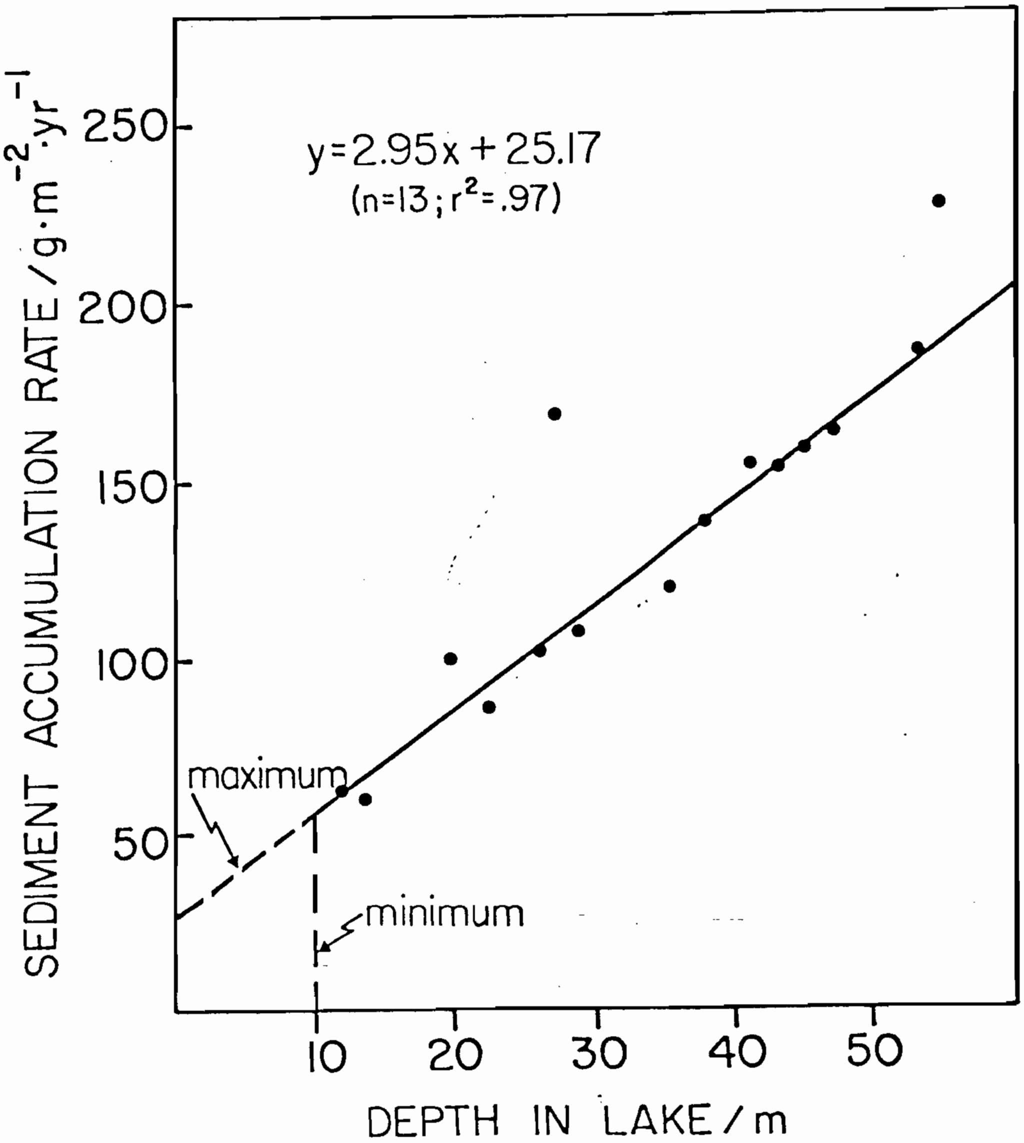
where $\lambda$ is the decay constant of $^{210}$Pb ($0.03114\ yr^{-1}$).

To derive k a linear regression was calculated through the three points of highest activity in the section in which unsupported radioactivity decreased exponentially with depth. This procedure was adopted because the plot usually deviated from linearity as zero activity was approached. This deviation could merely indicate that C is consistently overestimated. By neglecting data where $C_w \simeq C$, we have minimized effects of this possible error. A similar unexplained deviation from linearity can be seen in the data of Schubel and Hirschberg (1977).

## RESULTS

Calculated rates of sediment accumulation are plotted against depth in the lake at which the cores were taken in Fig. 4c. It shows a strong correlation between sediment accumulation rate and depth. It also shows that two sites are anomalous. There is nothing distinctive about the location of the two anomalous cores (G and U in Fig. 4a). Although there are many possible explanations for such anomalous rates of accumulation, we can not presently discern the actual cause of these results.

Fig. 4c. The relation between sediment accumulation rate and lake depth in Bob Lake


y=2.95x + 25.17
(n=13; $r^2$=.97)
SEDIMENT ACCUMULATION RATE / $g \cdot m^{-2} \cdot yr^{-1}$
250
200
150
100
50
maximum
minimum
10
20
30
40
50
DEPTH IN LAKE / m

Improper coring can result in sediment mixing and an overestimation of the actual accumulation rate. Core U shows some evidence of corer induced mixing as defined by Kipphut (1978). It is also possible that there are small areas where morphometry or water movement enhance deposition, although the evidence would suggest these sites occupy a very small percentage of the lake bottom. Our assumption is that cores G and U are not representative of the accumulation rates for the depths from which the samples were taken and will not be included in the following calculations.

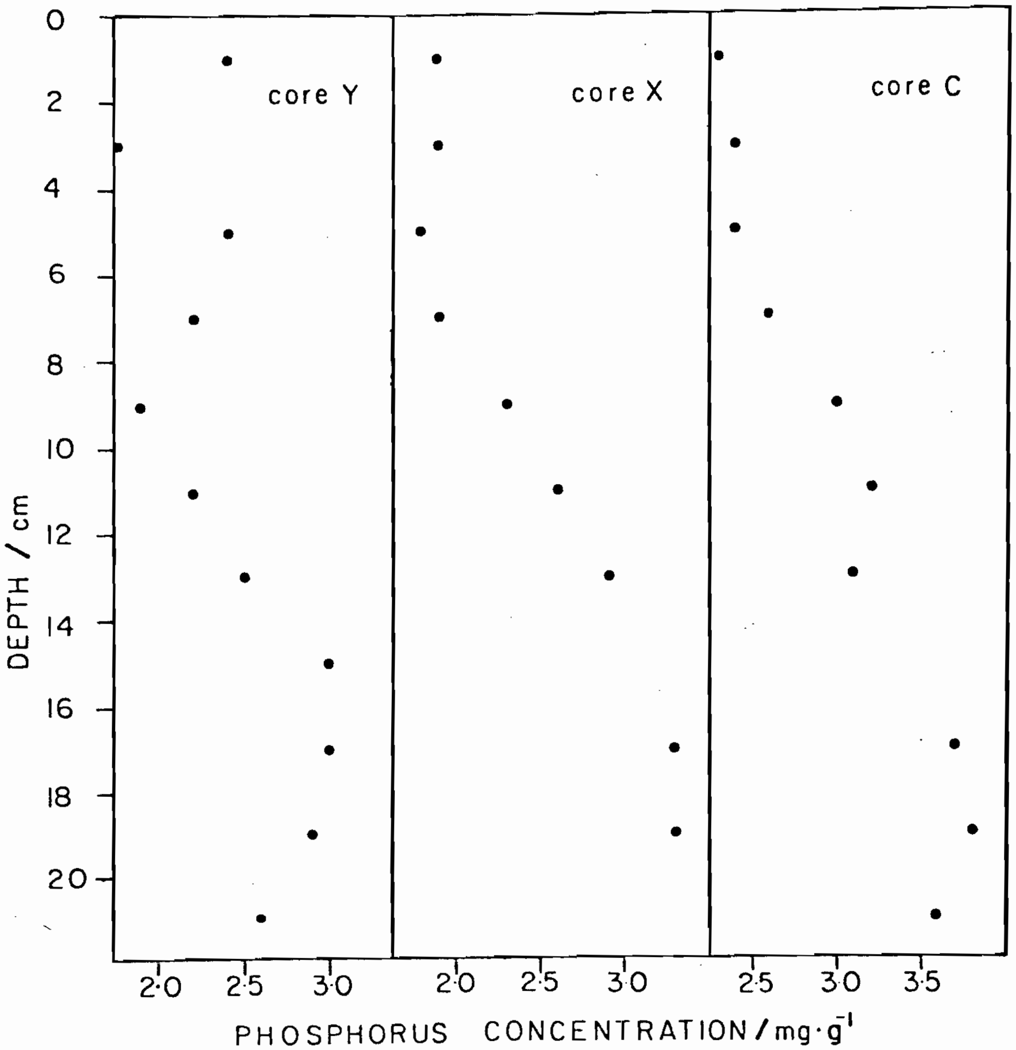
For the remaining 13 sites the regression of the sediment accumulation in g $m^{-2}$ $yr^{-1}(y)$ on sample depth in metres (x) is:

(3) $$y = 2.95\ x + 25.17\ (n=13, r^2=0.97)$$

Thus, depth alone explained 97% of the variation between sites in the rate of sediment accumulation. With the inclusion of sites G and U in the regression 82% of the variation is accounted for.

Three typical profiles of phosphorus concentration in Bob Lake sediments are shown in Fig. 4d. The profiles vary from uniform concentration with depth to slightly increasing concentration with depth. As with the $^{210}$Pb profiles depth has been calculated as a cumulative weight to eliminate the effects of compaction. We have chosen to use the surficial concentration (0-2 cm) as the one most representative of recent sedimenting material. Although processes such as diagenesis can alter concentration profiles in sediments there is no evidence (such as a large increase towards the sediment surface) for these processes in Bob Lake. In the absence of information to the the contrary we feel that the surficial section of sediment offers the best estimate of current sediment phosphorus in our lake. The P

Fig. 4d. Typical phosphorus profiles from three Bob Lake cores



core Y
core X
core C
DEPTH / cm
0
2
4
6
8
10
12
14
16
18
20
2·0
2·5
3·0
2·0
2·5
3·0
2·5
3·0
3·5
PHOSPHORUS CONCENTRATION / mg·g$^{-1}$

concentration in this section will be used in subsequent calculations and these data are given in Table 4a.

Table 4a shows that although the horizontal variation in P concentration of surface sediment is not large, there is a trend to higher P concentration at deeper depths in the lake. A linear regression of P concentration on depth showed a significant correlation. 55% of the variation in P concentration was explained by depth. Thus we felt that a simple average of all samples was not sufficient and chose to use the regression equation:

(4) $P = 0.018\ d + 1.75\ (n=23,\ r^2=0.54)$

where P is phosphorus concentration in $mg.g^{-1}$ and d is depth in meters, in the calculation of lake retention of P.

## CALCULATION OF WHOLE LAKE RATES

To calculate the total accumulation of sediments in Bob Lake we must make an assumption about the sediment accumulation at water depths less than 10 m because the bottom material in this region, which represents 39% of the lake bottom, was too hard to be cored. Evidence from cores collected by divers in similar areas of lakes in the vicinity of Bob Lake suggest that this material is primarily sand and gravel and that the water content of sediments in the shallows is much lower than in sediments from the centre of the lake (unpublished data). The best we can do for the present is to set upper and lower limits on the accumulation from 0 - 10 m and use these. The lowest limit would result from assuming that zero accumulation occurs at depths from 0 - 10 m. This would be equivalent to assuming that the K-B corer did not work in

| CORE | LAKE DEPTH (m) | PHOSPHORUS (mg $g^{-1}$ dry wt.) |
|---|---|---|
| A* | 11.5 | 1.7 |
| B | 16.5 | 2.0 |
| C* | 19.6 | 2.2 |
| D* | 22.4 | 2.2 |
| E | 22.6 | 2.3 |
| G* | 27.0 | 2.1 |
| I* | 27.8 | 2.3 |
| J* | 28.8 | 2.4 |
| K | 31.6 | 2.7 |
| L* | 35.5 | 2.4 |
| M* | 38.0 | 2.1 |
| N | 39.5 | 2.4 |
| O | 40.5 | 2.5 |
| P* | 41.0 | 2.5 |
| Q* | 43.0 | 2.6 |
| R* | 45.0 | 2.6 |
| S* | 47.0 | 3.0 |
| T* | 52.9 | 2.4 |
| U* | 53.4 | 2.6 |
| V* | 13.5 | 1.9 |
| W | 23.0 | 2.4 |
| X | 27.0 | 1.9 |
| Y | 45.0 | 2.4 |

Table 4a. Surficial phosphorus concentrations for twenty-three cores.

* - Cores for which $^{210}Pb$ dating is available.

this area because no sediments were accumulating. This assumption would underestimate total accumulation. The upper limit would be given by extrapolating the regression equation (3) to zero depth (see Fig. 4c). That this procedure would overestimate total accumulation is supported by the work of Kipphut (1978), and Likens and Davis (1975), which suggested that the bottom of the summer epilimnion is the depth above which no permanent sediments accumulate. This would be approximately 6 m in Bob Lake. The most likely situation between these extremes is that sediment accumulation decreases rapidly between 10 and 5 m.

For all depths the estimated (0 - 10 m) or predicted (10 - 60 m) mean sedimentation rate for each 5-m stratum was applied to the area of the stratum and all strata were summed to give the total sediment accumulation. Expressed per unit of lake surface area, the average sediment accumulation for Bob Lake is between 63 and 78 g dry matter per $m^2$ per year.

Calculations were made using equation 4 to determine the mean P concentration for each stratum. The whole lake P retention was calculated by summation of the products of mean P and mean accumulation rate for each stratum. Using this technique the rate of accumulation of phosphorus in the sediments of Bob Lake falls between 143 and 170 mg $m^{-2}$ $yr^{-1}$.

## DISCUSSION

The results of this study suggest that in medium-sized temperate lakes with a single basin, the measurement of total annual accumulation of sediments by the $^{210}Pb$ dating technique is a feasible process. In

Bob Lake, if we assume that the two anomalous results are due to the coring operation, depth in the lake alone explained 97% of the between-site variation in sediment accumulation rate. If this single relationship can be confirmed in other lakes, future estimates of total annual accumulation of sediments can be derived from a relatively small series of cores provided all samples are good and the upper limit of sediment accumulation is carefully ascertained.

For studies designed to test our simple hypothesis, a sampler such as the K-B corer will be inadequate, because the shallow areas with coarse bottom materials in which it functions poorly constitute a large fraction of the lake basin. Although sediment accumulation is certainly slow in this area, the absence of samples from it introduces uncertainty into the final estimate which in Bob Lake was equal to ± 9%. Probably, if we are to be certain that sampling is adequate, it will have to be done by divers or with devices thoroughly tested by diver-observers. We stress this because sampling, although the least time consuming part of this work, is the part most subject to uncontrolled error.

Despite the fact that we have stressed the weakness of our data, the comparison of our estimate of P accumulation rate in Bob Lake with the estimate obtained by the mass budget method is most encouraging. The first estimate of P retention in Bob Lake was made by Dillon (1974) who measured the major inputs and output over 18 months. He calculated that average retention is 115 mg $m^{-2}$ $yr^{-1}$. Subsequently Cross (1977) repeated the study in greater detail and concluded that P retention is 140 mg $m^{-2}$ $yr^{-1}$. Dillon measured only the major inputs and assumed that the many small, temporary streams entering Bob Lake had a low P export of 2.5 mg $m^{-2}$ yr. Cross sampled these streams and showed that because their P concentration is high as they dry up, they export from 3 to 14.4 mg $m^{-2}$ $yr^{-1}$. We therefore believe that 140 mg $m^{-2}$ $yr^{-1}$ is the better figure with which to compare our range of 143-170 mg $m^{-2}$ $yr^{-1}$.

Considering the number of untested assumptions and potential sources of error in our estimate of P accumulation rate, the similarity between the two results is surprising. In fact the two results are well within the range of error that would be expected from the nutrient budget method. One cause of uncertainty in the results of the nutrient budget method is caused by our inability to measure aeolian loading accurately. It is often a significant fraction of total loading, and estimates of it vary by a factor of two depending on the type of fallout collector used (Gomolka 1975). Also, in a cottaged lake, such as Bob, no method has been developed to measure the input of P from cottages. If cottages do contribute P to the lake it is an input that was unmeasured by Cross (1977) and Dillon (1974). The omission of this input would cause both studies to underestimate true retention. Obviously more careful comparisons are needed before we can have confidence in the accuracy of either method, but we believe that our initial comparison shows that measurements of accumulation rate of sediments for whole lake areas and related element retentions are feasible using lead-210 dating.

# ACKNOWLEDGMENTS

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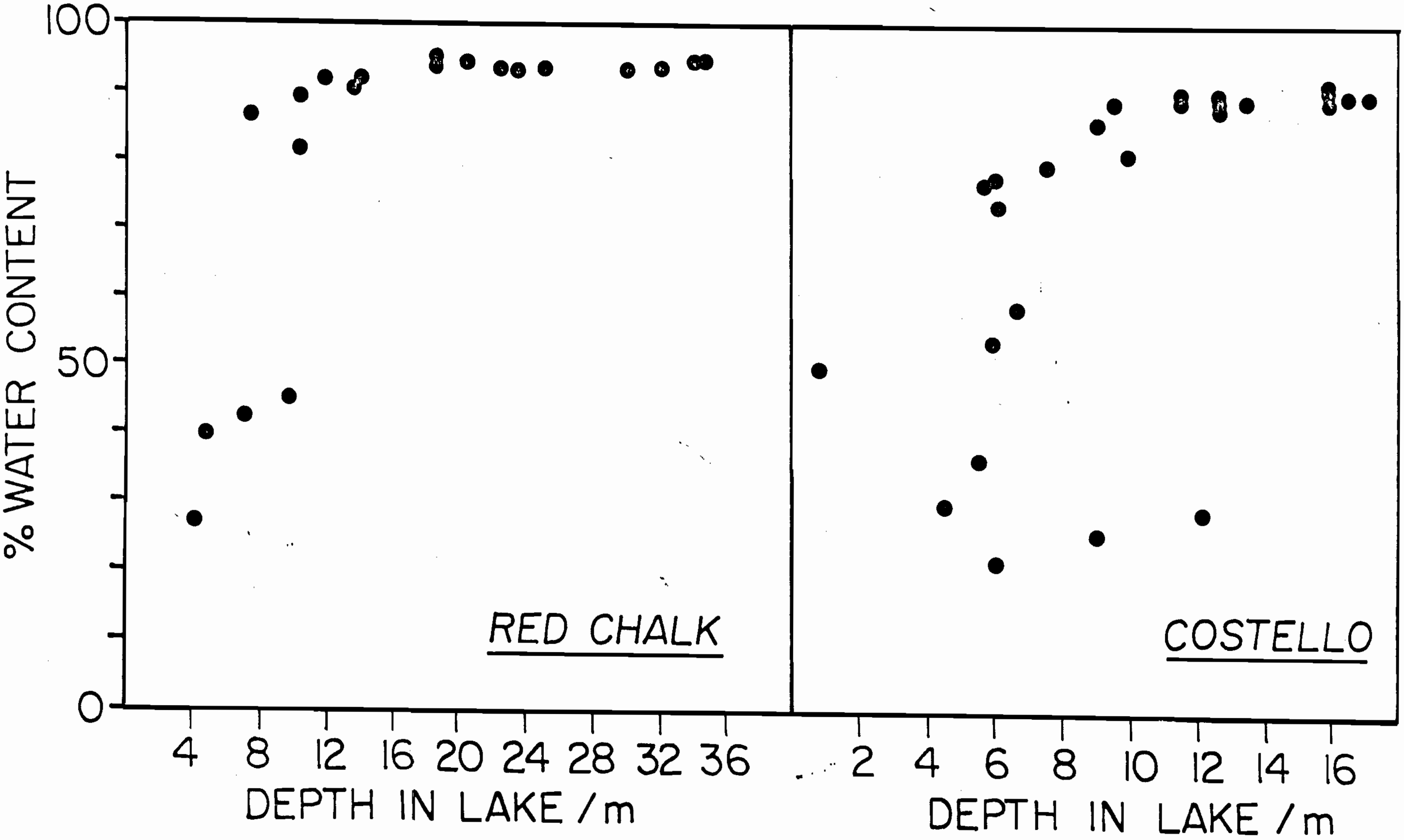
# CHAPTER FIVE:

# THE INFLUENCE OF MORPHOMETRY ON SEDIMENT ACCUMULATION

## Sediment Accumulation in Shallow Water

A major drawback to the results of chapter four is that no samples were collected in shallow regions of Bob Lake. This omission is important in view of the large percentage of the lake's bottom which this area occupies. To overcome the problem a number of cores were collected from areas of shallow water by SCUBA diver in both Costello and Red Chalk Lakes. Results from this work are much the same for both lakes. The depth at which soft sediments begin to accumulate was determined visually in both lakes by divers. In each, the shift in sediment texture from coarse sand to soft gyttja occurred between 9.5 and 12.0 metres. At any given location the boundary was quite distinct. An examination of water content and loss on ignition of sediments from shallow and deep areas provides further evidence for a fundamental change in sediment type in this depth range. Water content is much lower per unit volume in shallows than in sediments from the centre of the lakes. In Fig. 5a, the water content of compacted sediments is shown as a function of lake water depth from which the sediment core was drawn. (Surficial sediments not yet compacted were not included in these calculations). There is a distinct difference in water content above and below the transition

Fig. 5a. Relation between % water content and water depth in cores from Red Chalk and Costello Lakes


% WATER CONTENT
100
50
0
4
8
12
16
20
24
28
32
36
DEPTH IN LAKE / m
RED CHALK
2
4
6
8
10
12
14
16
DEPTH IN LAKE / m
COSTELLO

zone. This change is also evident if one examines loss on ignition (LOI) of these sediments (Fig. 5b). The abrupt change in percent ignitable material occurs in conjunction with the change in water content in both lakes. It is my feeling based on visual inspection of the bottom and on these results, that the upper boundary of recent sediment accumulation in Red Chalk and Costello Lakes occurs between 9.5 and 12 metres.

These conclusions are not, however, supported by measurements of sediment accumulation using lead-210 dating in these regions. Although in some cores no measurable lead-210 is present, most shallow water cores exhibit typical activity versus depth profiles in terms of the shapes of the profiles. Fig. 5c is an example. This core (core 8) from Red Chalk Lake was taken in 4.3 m of water. The typical surface mixed layer is followed by a good log-linear relationship of activity versus depth. (Depth is expressed in units of cumulative mass to eliminate compactive effects; see chapter four, and Robbins 1978). The only unusual aspect to the profile is the extremely low activity. In other cores from deep areas of the lake, typical surface activities range from 50 to 180 dpm/g dry mass. When the accumulation rate is calculated for this core, the result is 631 g/m$^2$/yr. This is over four times the maximum rate observed in the centre of the lake. The high accumulation is primarily a function of the extremely high

Fig. 5b. Relation between loss on ignition and water depth in cores from Red Chalk and Costello Lakes

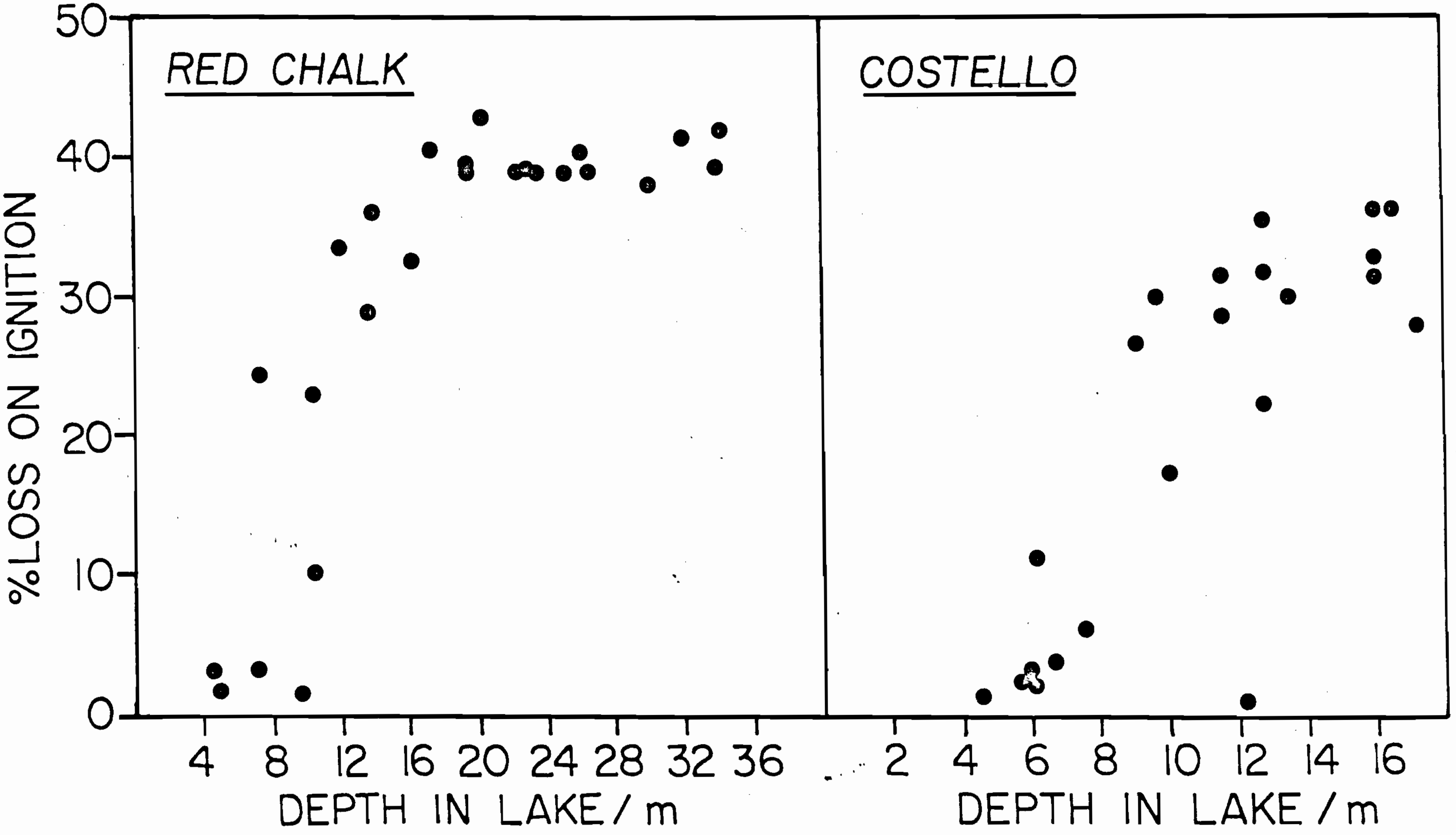
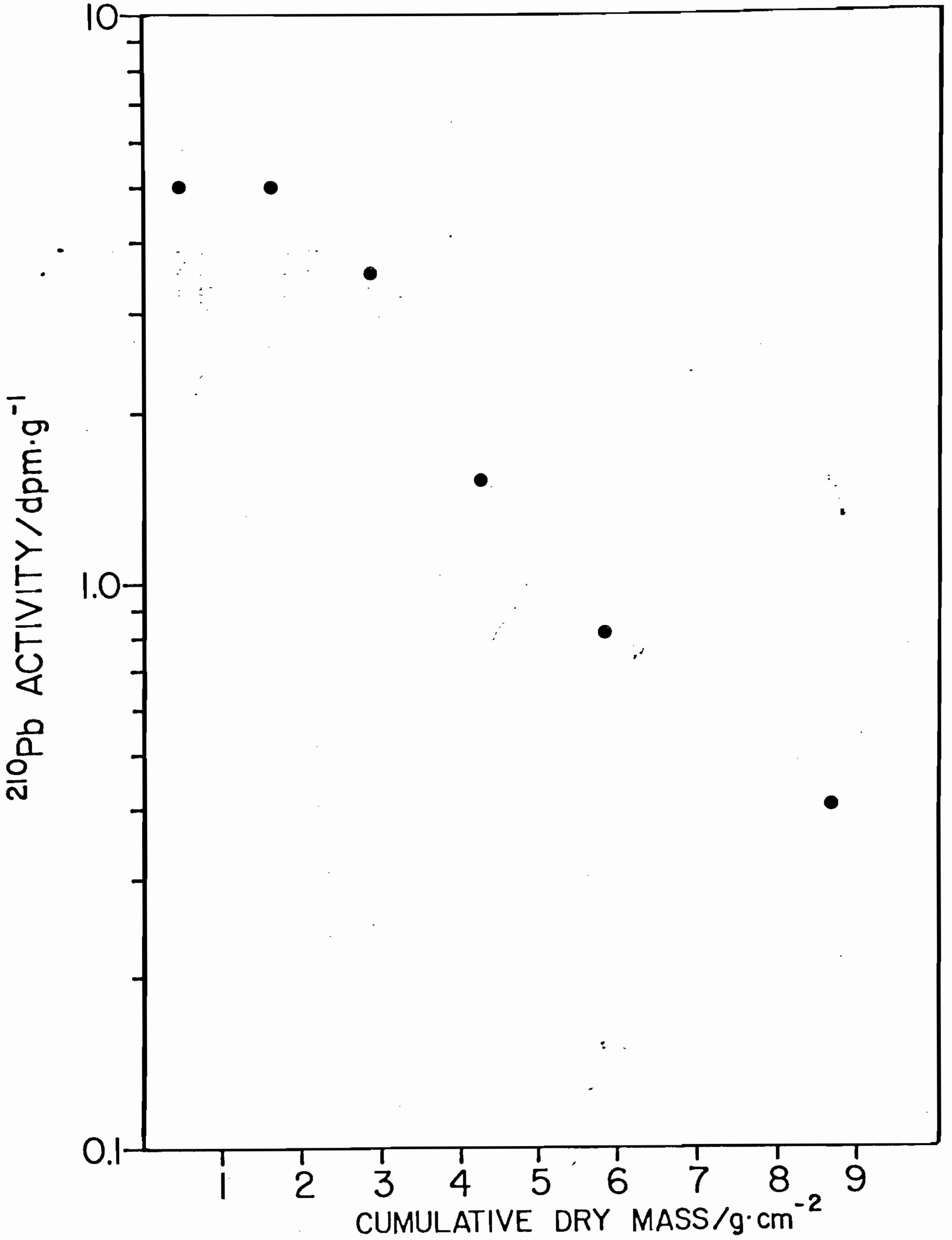

RED CHALK
COSTELLO
%LOSS ON IGNITION
0
10
20
30
40
50
4
8
12
16
20
24
28
32
36
DEPTH IN LAKE / m
2
4
6
8
10
12
14
16
DEPTH IN LAKE / m

Fig. 5c. Lead-210 activity in Red Chalk Lake core 8


10
1.0
0.1
$^{210}$Pb ACTIVITY/dpm·g$^{-1}$
1
2
3
4
5
6
7
8
9
CUMULATIVE DRY MASS/g·cm$^{-2}$

density of the material in these regions. There are two possible conclusions from these results. First, if the lead-210 dating is correct, massive amounts of sandy-gravely material are accumulating in the shallow regions of lakes each year. Second, it is possible that the result is caused by an artifact and that lead-210 dating does not give meaningful results in this type of sediment. While it is not possible at present to eliminate either of these hypotheses, I feel that the second option is most likely correct. The very low deposition rate of lead-210 in the shallows may indicate that it does not associate with large sized particles and thus the $^{210}$Pb dating method is not applicable to coarse sediment types. Moreover, if the rates of accumulation measured in the shallows were correct, large quantities of large sized material should build up in these regions. This would ultimately lead to instability and some of this material would be washed down into the deeper areas. In the detailed investigation of the bottom deposits of three lakes, large particles of the shallow water type have never been found in sediments from areas of the lake where soft gyttja accumulates. For these reasons I assume that no measurable sediment accumulates in the shallow regions. Although accumulation rates calculated for the shallow cores are given in Tables 5a and 5b, they are not used in the remaining calculations.

It has previously been suggested (Kipphut 1978) that no

| CORE | STATION DEPTH (metres) | ACCUMULATION RATE ($g/m^2/yr$) | n VALUE FOR REGRESSION | "$r^2$" |
|---|---|---|---|---|
| 2 | 4.6 | 955.0 | 4 | 0.844 |
| 4 | 0.8 | 104.7 | 4 | 0.968 |
| 5 | 5.8 | 429.0 | 6 | 0.984 |
| 10 | 6.7 | 440.0 | 4 | 0.980 |
| 11 | 10.0 | 54.7 | 3 | 0.925 |
| 12 | 11.6 | 78.7 | 5 | 0.974 |
| 13 | 7.6 | 67.9 | 4 | 0.913 |
| 16 | 16.0 | 131.8 | 9 | 0.989 |
| 20 | 11.6 | 85.6 | 10 | 0.992 |
| 23 | 16.5 | 175.7 | 10 | 0.958 |
| 24 | 12.8 | 107.4 | 8 | 0.994 |
| 27 | 9.7 | 298.0 | 3 | 0.999 |
| 28 | 16.0 | 102.0 | 7 | 0.942 |
| 29 | 16.0 | 125.9 | 8 | 0.971 |
| 30 | 13.5 | 104.0 | 7 | 0.967 |
| 31 | 12.8 | 77.9 | 6 | 0.894 |
| 32 | 17.2 | 130.0 | 6 | 0.983 |
| 35 | 12.8 | 96.6 | 7 | 0.985 |

Table 5a. Sediment accumulation rates from various Costello Lake core

| CORE | STATION DEPTH (metres) | ACCUMULATION RATE ($g/m^2/yr$) | n VALUE FOR REGRESSION | "$r^2$" |
|---|---|---|---|---|
| 1 | 4.9 | 629.0 | 4 | 0.946 |
| 6 | 10.0 | 150.0 | 5 | 0.965 |
| 7 | 7.3 | 282.0 | 6 | 0.929 |
| 8 | 4.3 | 631.0 | 4 | 0.988 |
| 10 | 31.9 | 87.7 | 11 | 0.900 |
| 13 | 13.7 | 53.6 | 5 | 0.979 |
| 14 | 14.0 | 41.9 | 3 | 0.999 |
| 15 | 11.9 | 38.1 | 5 | 0.950 |
| 16 | 25.0 | 59.9 | 5 | 0.998 |
| 17 | 34.0 | 84.2 | 8 | 0.992 |
| 19 | 18.5 | 44.3 | 3 | 0.999 |
| 30 | 34.5 | 94.6 | 5 | 0.998 |
| 31 | 30.0 | 128.3 | 8 | 0.993 |
| 32 | 22.5 | 71.0 | 5 | 0.996 |
| 33 | 23.5 | 74.5 | 7 | 0.992 |
| 35 | 17.5 | 43.0 | 5 | 0.900 |
| 37 | 26.7 | 97.2 | 8 | 0.990 |
| 39 | 23.0 | 32.1 | 5 | 0.998 |
| 40 | 19.5 | 64.4 | 7 | 0.989 |
| 41 | 19.5 | 62.9 | 5 | 0.998 |
| 45 | 26.1 | 60.3 | 8 | 0.995 |

Table 5b. Sediment accumulation rates for various cores from Red Chalk Lake.

permanent sediments accumulate above the bottom of the epilimnion. This seems reasonable because the epilimnetic bottom is continuously exposed to water movement which could sweep it clear of any fine sediment. This generality bears further examination since it is far easier to measure the depth of the epilimnion than to undertake a detailed survey of the lake bottom to determine the upper limit of sediment accumulation. Fig. 5d and 5e present isotherms for Red Chalk and Costello Lakes during the stratified period. Quite clearly, Kipphut was correct in that no sediments accumulate in areas less than the depth of the epilimnion. In Costello and Red Chalk Lakes, however, the upper limit of sediment accumulation is much deeper than the bottom of the epilimnion and use of this generalization would lead to an erroneous calculation of whole lake accumulation. If we assume an average upper limit of 10 m in each lake, the bottom of the thermocline is probably a better estimate of this boundary in these two lakes. This generality bears further testing in other types of lakes such as shallow or weakly stratified ones.

## Lead-210 Dating and Whole Lake Accumulation

Raw data for the specific activity of lead-210 in each sediment core section analyzed are presented in Appendix II. For each core, the sediment accumulation has been calculated in a manner similar to that outlined in chapter

Fig. 5d. Isotherms for Red Chalk Lake, 1978 and 1979 (Ministry of the Environment of Ontario, unpublished data)

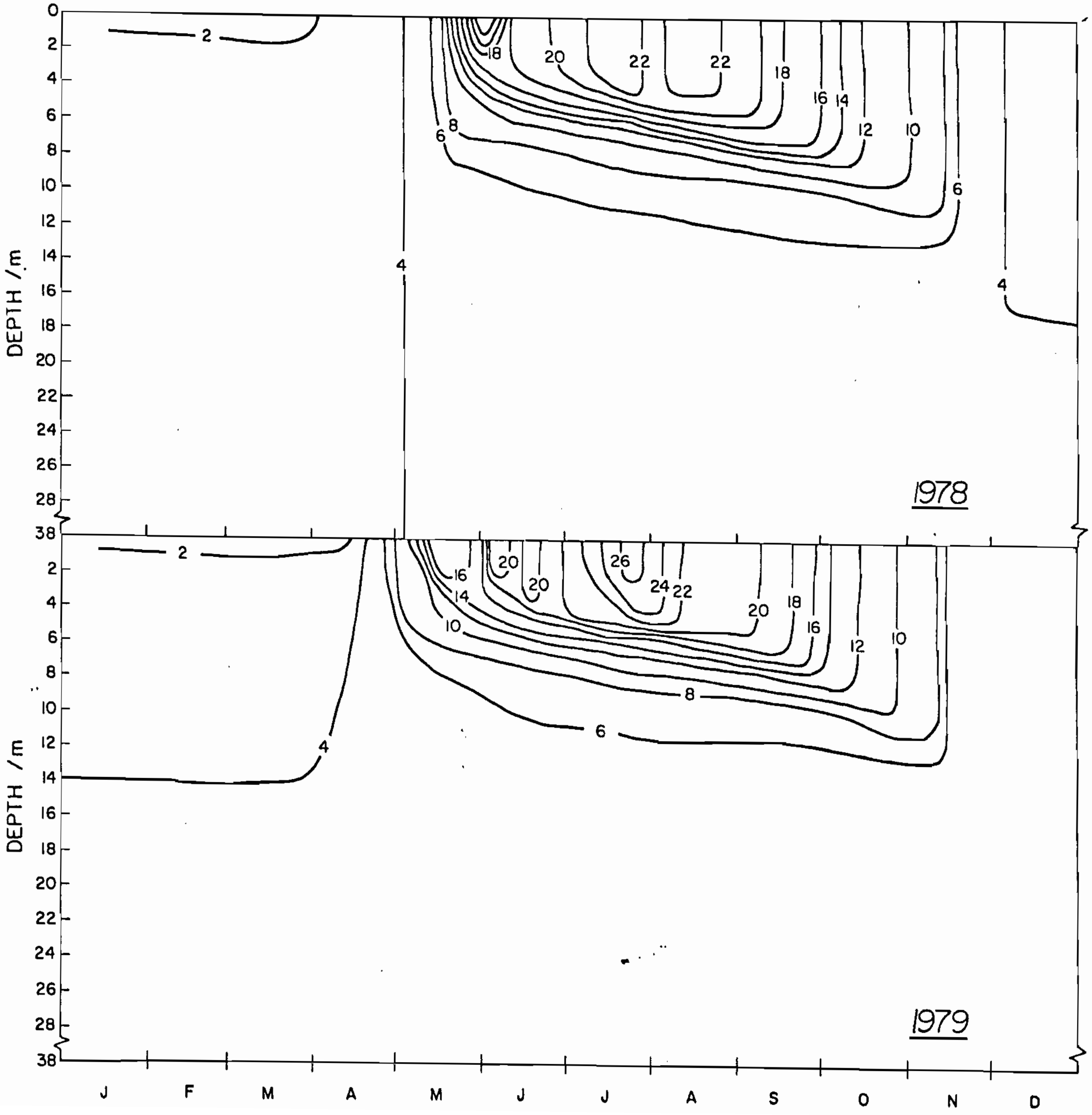
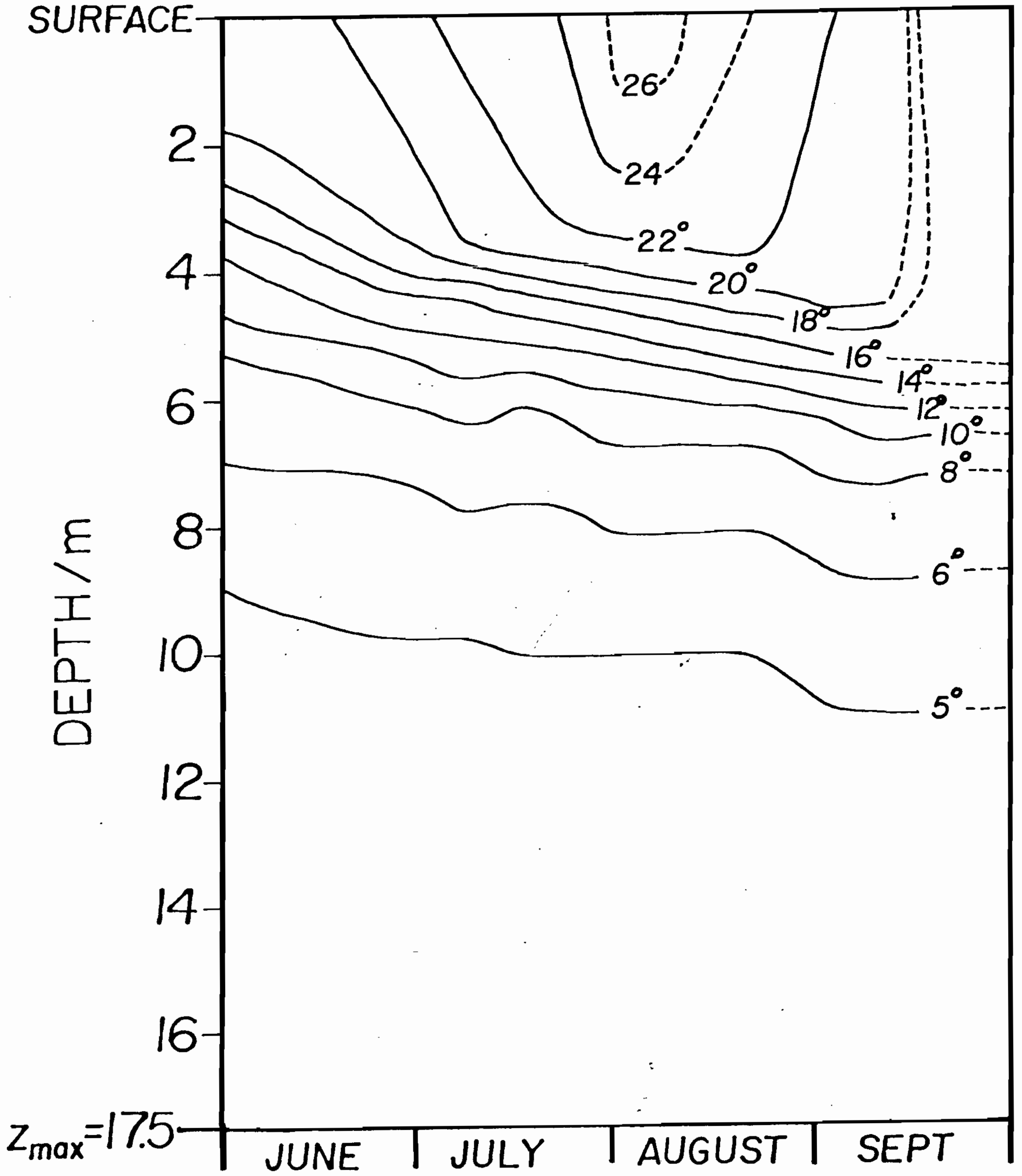

DEPTH /m
0
2
4
6
8
10
12
14
16
18
20
22
24
26
28
38
2
4
18
20
22
22
18
16
14
12
10
8
6
6
4
1978
2
4
16
20
20
14
10
26
24
22
20
18
16
12
10
8
6
1979
J
F
M
A
M
J
J
A
S
O
N
D

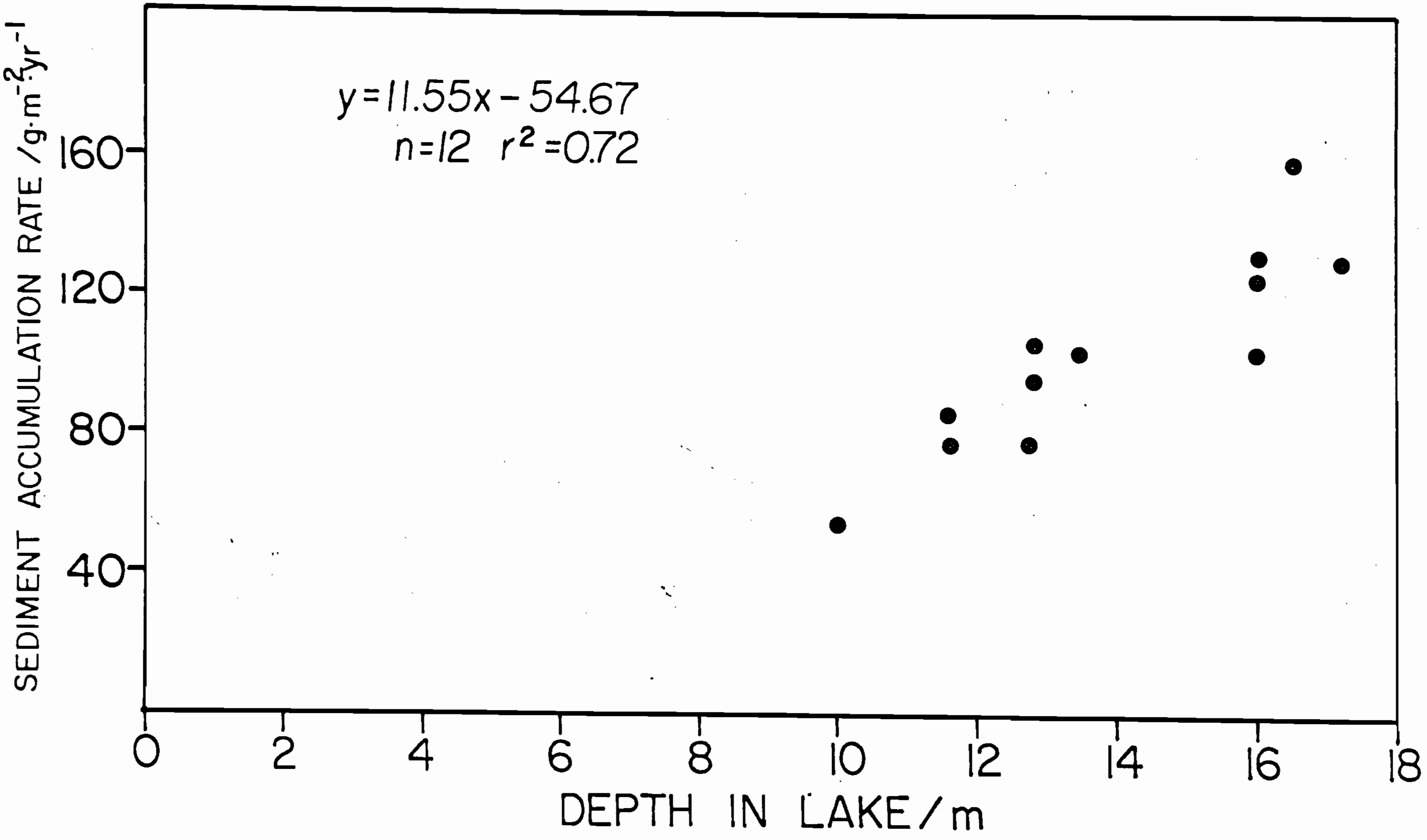
Fig. 5e. Isotherms for Costello Lake, 1959
(R.R. Langford, unpublished data)


SURFACE
2
4
6
8
10
12
14
16
$Z_{max}$=17.5
DEPTH / m
JUNE
JULY
AUGUST
SEPT
26
24
22°
20°
18°
16°
14°
12°
10°
8°
6°
5°

four. One difference is that calculations for Bob Lake were made using only the first three or four measurements below the mixed zone. This was done because estimates of radium supported $^{210}Pb$ background were poor. Cores were collected from Red Chalk and Costello in order to obtain deeper sections and a better estimate of supported lead-210 activity. Despite this, many deep water cores did not reach a stable background concentration. In those cores in which an asymptote was not reached, the lowest value among the deep-water cores from a lake was used as the background activity. Sediment cores were sectioned into finer slices and this allowed more analyses to be included in the calculation of accumulation rates. These changes in technique allow more confidence to be placed in the results from Red Chalk and Costello Lakes than those from Bob Lake.

One of the objectives of this section of work was to test the generality of the finding from Bob Lake regarding the dependence of sediment accumulation rate on depth. In Bob Lake, 97% of the variance in accumulation rates was explained by water depth over the sample site. Sediment accumulation rates from various lake depths in Costello Lake are shown in Table 5a. The relationship between accumulation and lake depth is good and is shown in Fig. 5f. Samples from the same water depth but from different areas of the lake compare well. Three samples from 12.8 m ranged between 78 $g/m^2/yr$ and 106 $g/m^2/yr$. This is probably the

Fig. 5f. Relation between accumulation rate and lake depth in Costello Lake


y=11.55x − 54.67
n=12 r² =0.72
SEDIMENT ACCUMULATION RATE /g·m⁻²yr⁻¹
160
120
80
40
0
2
4
6
8
10
12
14
16
18
DEPTH IN LAKE/m

type of variation to be expected in a shallow lake such as Costello.

To calculate the whole lake sediment accumulation, I chose to use a regression analysis similar to that used in Bob Lake. I assumed no recent sediment accumulation over the lake bottom where water is less than 10 m in depth. All cores from areas deeper than 10 m were used in the calculation of whole lake accumulation with the exception of core 14. This core, from 12 m, exhibited little change in activity with depth (see Appendix II). It was composed of gravel and was taken from the deepest location at which no soft sediment could be found. In Costello Lake the regression of sediment accumulation rate on depth explained 72% of the variation. The best fit equation of the least squares linear regression on samples taken between 10 and 17.5 m was:

$$Y = 11.55\,X - 54.67 \qquad n = 12 \quad r^2 = 0.72 \qquad (5\text{-}1)$$

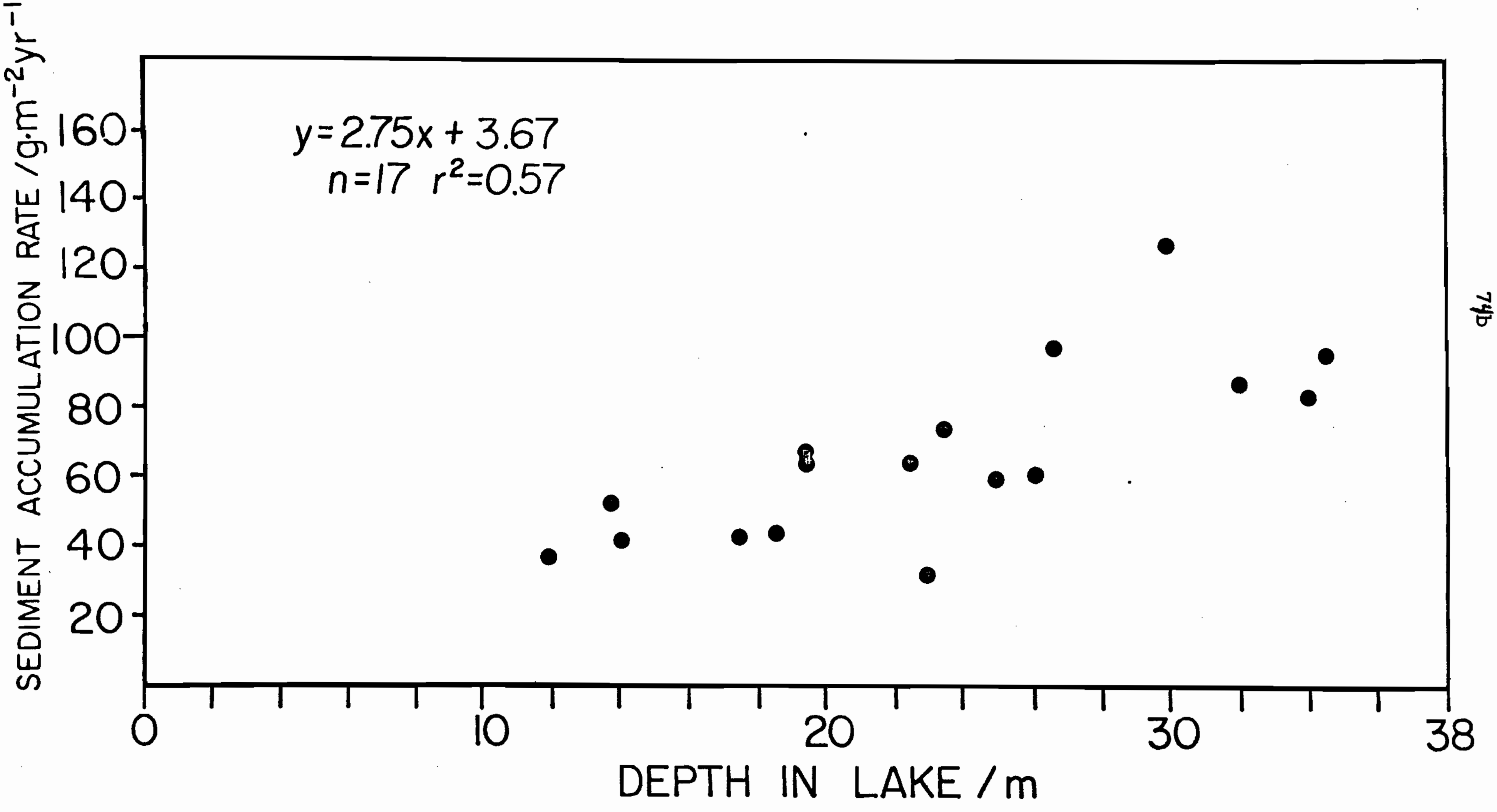
The lake bottom was divided into 2 m intervals and the accumulation rate predicted by equation (5-1) for the midpoint of a stratum was applied over the entire 2 m interval. These calculations are detailed in Table 5c. The whole lake sediment accumulation rate in Costello Lake is 47.5 g dry matter/$m^2$/yr.

Accumulation rates for sediment cores from Red Chalk Lake are given in Table 5b. Four cores taken from depths greater than 10 m exhibited uninterpretable lead-210 profiles (cores 9, 11, 12, 18). These will be discussed in more detail later, but are not included in the calculation of whole lake accumulation. The accumulation rates observed are plotted as a function of the lake water depth at the sampling sites in Fig. 5g. While there is a strong relationship, the scatter of points is larger than that observed in either Costello or Bob Lakes. Regressing accumulation rate (Y) on lake depth (X), the best fit equation was:

$$Y = 2.75\ X + 3.67 \qquad n = 17 \qquad r^2 = 0.57 \qquad (5\text{-}2)$$

Only 57% of the variability in accumulation rates can be explained by depth. Part of the remaining variability may be due to the fact that the bottom topography of Red Chalk Lake is much more irregular than either of the previous two lakes examined. Kimmel (1978) suggested that bottom slope may be important in determining accumulation rate in some lakes. Moreover a lake with a highly irregular bottom may be more prone to sediment disturbance because of locally steep areas. This could lead to erosions or slumping. Several cores from Red Chalk, especially those from depths less than 20 m, show signs of these types of disturbances, as defined by Robbins (1978), in their lead-210 profiles . These disturbances can lead to further variation since accumulation rates calculated in this type of core are less

Fig. 5g. Relation between accumulation rate and lake depth in Red Chalk Lake


y=2.75x + 3.67
n=17 r²=0.57
SEDIMENT ACCUMULATION RATE /g·m⁻²yr⁻¹
160
140
120
100
80
60
40
20
0
10
20
30
38
DEPTH IN LAKE /m

certain than for undisturbed cores. The "$r^2$" values shown in Table 5b give an estimate of the approximation to log-linearity realized in each core and hence an estimate of the confidence to be placed in any individual prediction of accumulation rate.

As in Costello, the area of the bottom over which sediments are accumulating was divided into strata and the regression equation used to predict the accumulation rate at the stratum midpoint (Table 5d). Using equation (5-2) the predicted average accumulation in Red Chalk Lake is 45 $g/m^2$ /yr. To check the accumulation rates calculated for Red Chalk and Costello, phosphorus accumulation in the sediments was also determined and compared to that measured by mass balance measurements.

## Phosphorus Accumulation

In Fig. 5h and 5i the phosphorus concentrations of the 0 - 1 cm sections of the sediment cores from Red Chalk and Costello Lakes are presented. There is a highly predictable relationship between phosphorus concentration and depth in each lake. As in Bob Lake, the phosphorus concentration increases towards the deepest area of the lakes. Even over the small range of depths found in Costello Lake, the change in phosphorus concentration is two-fold. A possible explanation of this phenomenon is that in addition to spatial variation in the quantity of accumulating material

| STRATUM<br>(m) | AREA<br>($m^2*10^5$) | MIDPOINT ACCUMULATION<br>($g/m^2/yr$) | TOTAL SEDIMENT ACCUMULATION<br>($g*10^5/yr$) | MIDPOINT P<br>(mg/g) | PHOSPHORUS ACCUMULATION<br>($mg*10^5/yr$) |
|---|---|---|---|---|---|
| 10-11 | 0.14 | 66.6 | 9.32 | 1.37 | 12.77 |
| 11-13 | 0.30 | 83.9 | 25.17 | 1.59 | 40.03 |
| 13-15 | 0.46 | 107.0 | 49.23 | 1.88 | 92.55 |
| 15-17.5 | 0.60 | 133.0 | 79.80 | 2.21 | 176.36 |
| TOTALS | 1.50 | | 163.52 | | 321.71 |

Lake Area = 3.44 * $10^5$ $m^2$
Average Sediment Accumulation = 47.5 $g/m^2/yr$
Average Phosphorus Accumulation = 93.5 $mg/m^2/yr$

Table 5c. Calculations of sediment and phosphorus accumulation in Costello Lake.

| STRATUM<br>(m) | AREA<br>($m^2*10^4$) | MIDPOINT ACCUMULATION<br>($g/m^2/yr$) | TOTAL SEDIMENT ACCUMULATION<br>($g*10^5/yr$) | MIDPOINT P<br>(mg/g) | PHOSPHORUS ACCUMULATION<br>($mg*10^5/yr$) |
|---|---|---|---|---|---|
| 10-12 | 1.63 | 33.9 | 5.53 | 1.22 | 6.75 |
| 12-16 | 4.20 | 42.2 | 17.71 | 1.48 | 26.21 |
| 16-20 | 5.10 | 53.2 | 27.11 | 1.89 | 53.17 |
| 20-24 | 4.60 | 64.2 | 29.52 | 2.30 | 67.89 |
| 24-28 | 8.05 | 75.2 | 60.51 | 2.71 | 163.99 |
| 28-32 | 2.74 | 86.2 | 23.61 | 3.11 | 73.43 |
| 32-36 | 2.70 | 97.2 | 26.23 | 3.52 | 92.35 |
| 36-38 | 0.32 | 105.4 | 3.37 | 3.83 | 12.92 |
| TOTALS | 29.30 | | 193.59 | | 494.79 |

Lake Area = 4.39 * $10^5$ $m^2$
Average Sediment Accumulation = 44 $g/m^2/yr$
Average Phosphorus Accumulation = 112.7 $mg/m^2/yr$

Table 5d. Calculations of sediment and phosphorus accumulation in Red Chalk Lake.

Fig. 5h. Relation between surface (0 - 1 cm) sediment phosphorus concentration and depth in lake in cores from Red Chalk Lake

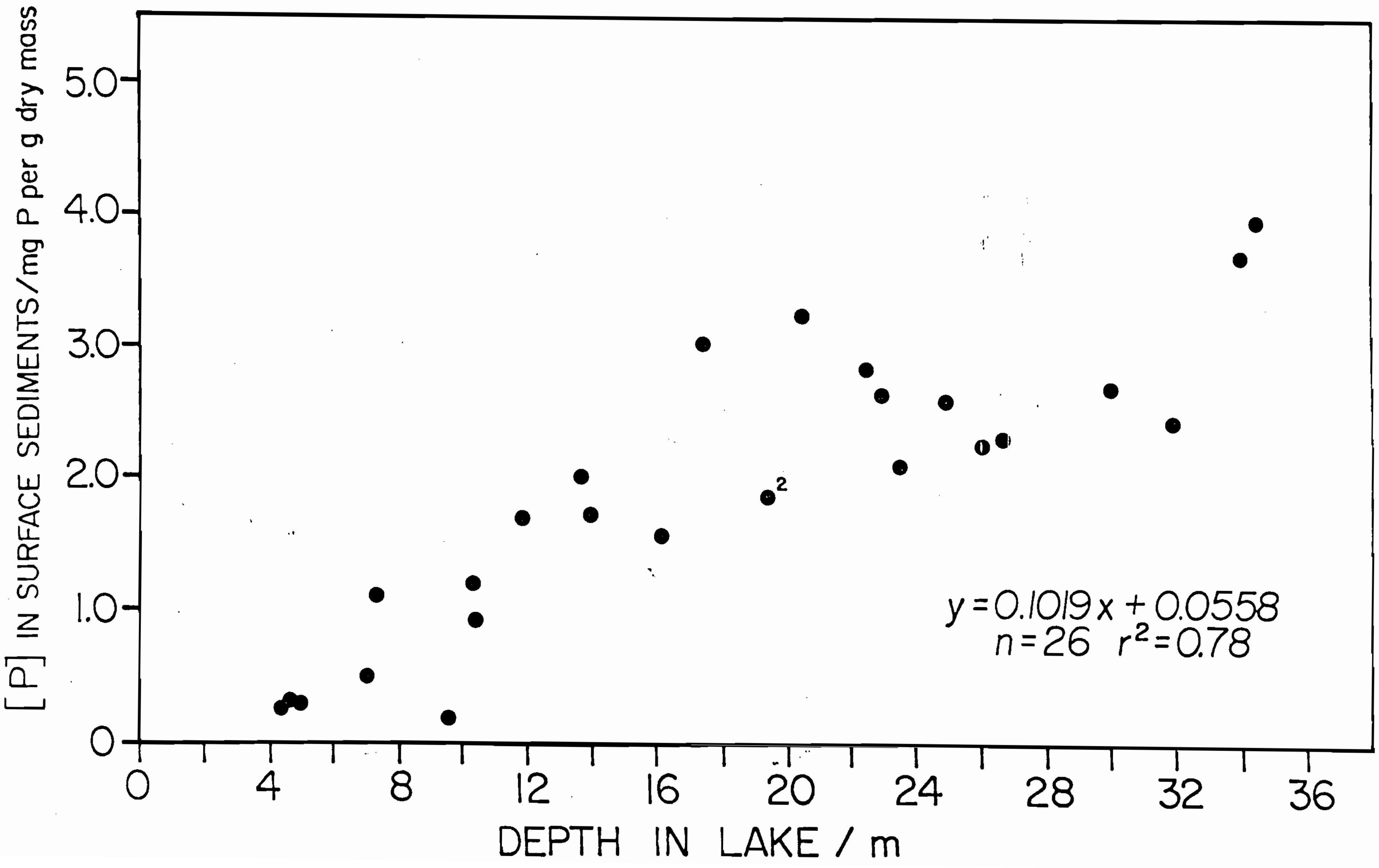
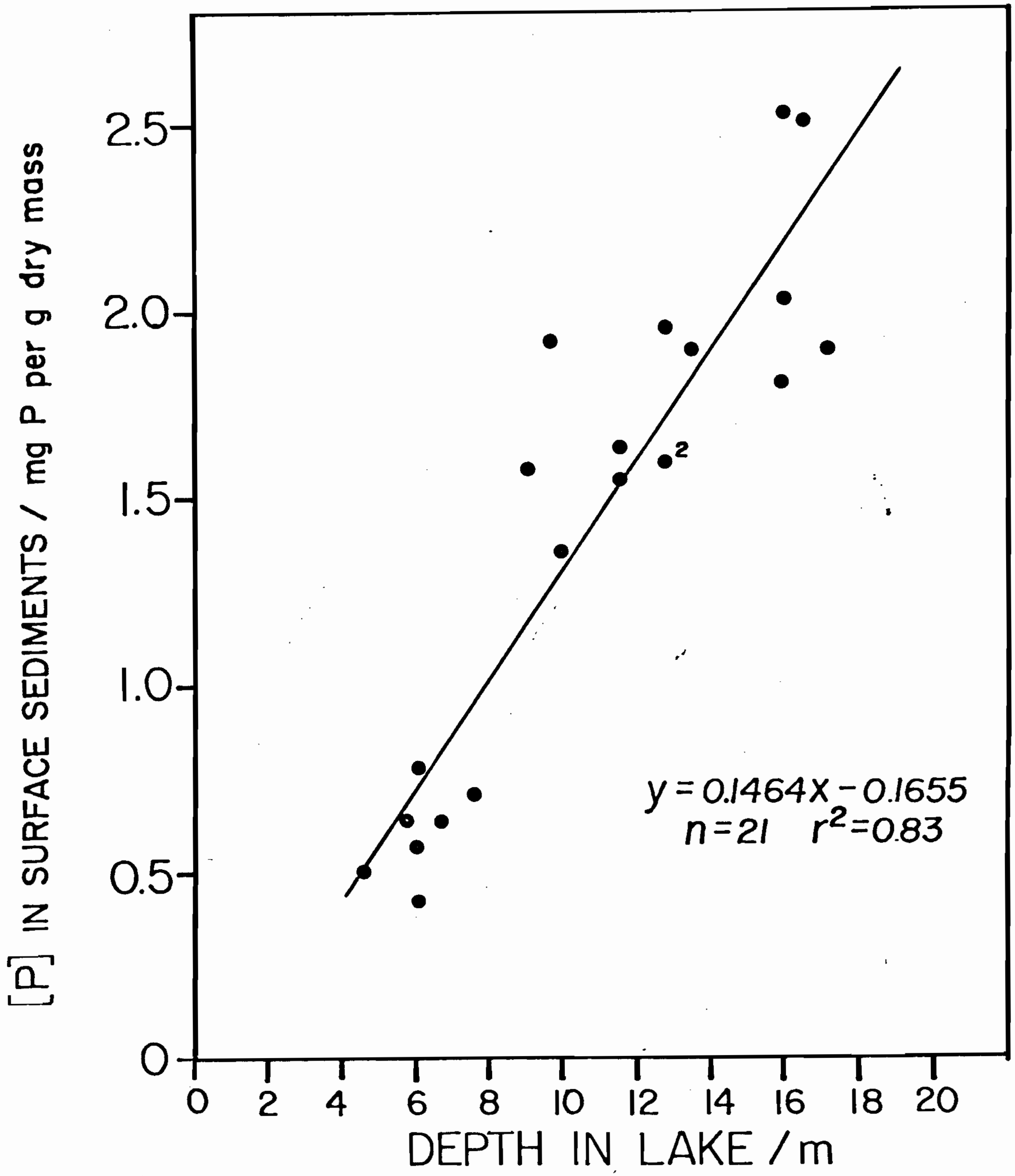

[P] IN SURFACE SEDIMENTS/mg P per g dry mass
5.0
4.0
3.0
2.0
1.0
0
0
4
8
12
16
20
24
28
32
36
DEPTH IN LAKE / m
2
y = 0.1019 x + 0.0558
n = 26 r² = 0.78

Fig. 5i. Relation between surface (0 - 1 cm) sediment phosphorus concentration and depth in lake in cores from Costello Lake


[P] IN SURFACE SEDIMENTS / mg P per g dry mass
2.5
2.0
1.5
1.0
0.5
0
0
2
4
6
8
10
12
14
16
18
20
DEPTH IN LAKE / m
2
y = 0.1464x − 0.1655
n = 21 r² = 0.83

per unit time, there is spatial variation in the quality of material accumulating. In other words, there is a shift in the type of material accumulating over the 10 - 17.5 m range.

It has been suggested by Carignan and Flett (in press) that post-depositional mobility of P in sediments can alter profiles. To determine whether surficial P concentrations in Red Chalk and Costello are representative of recent material, complete profiles for three cores were analyzed from shallow, mid, and deep locations in each lake. Phosphorus profiles from cores 32 and 35 in Costello Lake are similar to those found in Bob Lake in that there is an increase in P concentration with depth into the core (Fig. 5j). Core 34 from 9.1 m, which is the shallowest of the three, exhibits an increase in concentration towards the surface. While it is perhaps tempting to make the assumption that this increase is due to diagenetic movement, this hypothesis can not explain the increase in concentration at lower depths in the core.

Similar fluctuations in concentration are found in Red Chalk profiles (Fig. 5k). There is no consistent pattern in the variation in P concentrations. In view of the variability in profiles within each lake, and in the absence of a theory which could explain them otherwise, I have made the assumption that the phosphorus concentrations observed are indicative of depositional concentrations and therefore

Fig. 5j. Phosphorus profiles in three Costello Lake cores

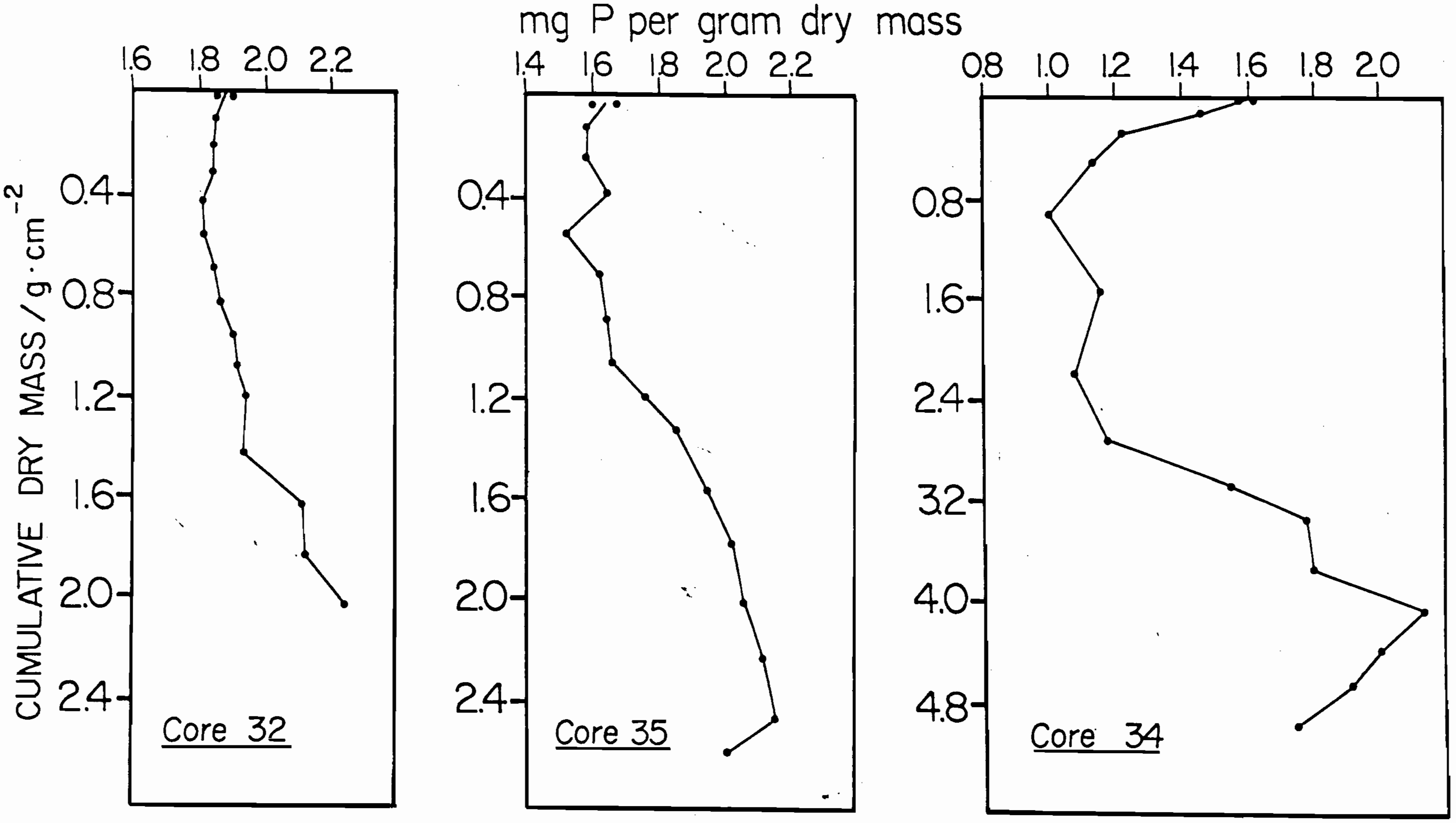
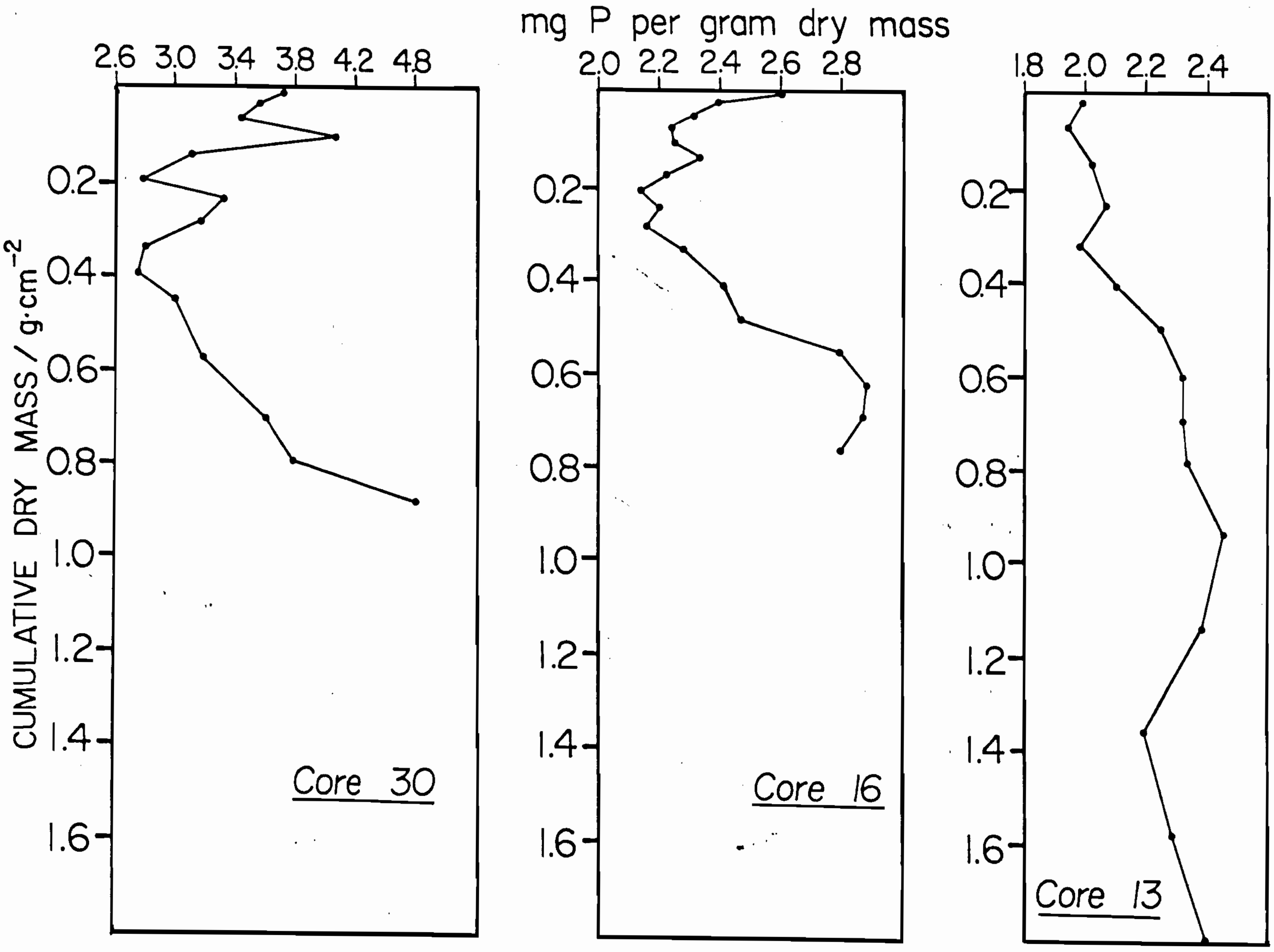

mg P per gram dry mass
CUMULATIVE DRY MASS / g · cm$^{-2}$
1.6
1.8
2.0
2.2
0.4
0.8
1.2
1.6
2.0
2.4
Core 32
1.4
1.6
1.8
2.0
2.2
0.4
0.8
1.2
1.6
2.0
2.4
Core 35
0.8
1.0
1.2
1.4
1.6
1.8
2.0
0.8
1.6
2.4
3.2
4.0
4.8
Core 34

Fig. 5k. Phosphorus profiles in three Red Chalk Lake cores


mg P per gram dry mass
CUMULATIVE DRY MASS / g·cm$^{-2}$
2.6
3.0
3.4
3.8
4.2
4.8
2.0
2.2
2.4
2.6
2.8
1.8
2.0
2.2
2.4
0.2
0.4
0.6
0.8
1.0
1.2
1.4
1.6
Core 30
Core 16
Core 13

the concentration of P in the 0 - 1 cm section of a sediment core is appropriate to the calculation of P retention.

To obtain the P retention, a least squares linear regression equation was fit to the phosphorus and lake water depth data. The regression for each lake (see Fig. 5h and 5i) was used to predict the phosphorus concentrations at the midpoint of each stratum used in the whole lake sediment accumulation calculations. These values were combined with bulk accumulation data to calculate phosphorus storage in the sediment (Tables 5c and 5d). Phosphorus retained in the sediments of Costello Lake is 93.5 $mg/m^2/yr$. In Red Chalk Lake sediment P storage is 113 $mg/m^2/yr$.

An alternate method of determining the appropriate concentration of phosphorus in sedimenting material for P retention calculations, is to collect the falling seston in sediment traps. This was done on three occasions during the stratified seasons in Red Chalk Lake in 1976 (Evans and Dillon, unpublished data). Sediment was collected in traps suspended below the thermocline and located in the middle of the lake. The average concentration of five samples collected over three, two week periods was 2.4 mg P/g dry mass. This compares favourably with the area weighted average concentration of the 0 - 1 cm sections of soft sediments, which is 2.42 mg P/g, and indicates that the use of surficial P concentrations are appropriate.

Scheider (1974) has determined the retention of phosphorus in Costello Lake as the difference between measured inputs and outputs. He found the mass of P retained by the lake to be 86.5 $mg/m^2/yr$. This is quite comparable to the 95 $mg/m^2/yr$ determined by the sediment accumulation method. If one is realistic about the potential errors associated with each method, the two estimates are not significantly different. Thus I feel that the measurement of whole lake sediment accumulation of 48 $g/m^2/yr$ in Costello is quite accurate.

The Ontario Ministry of the Environment has measured input and output of phosphorus in Red Chalk Lake. Although their calculations are provisional at this time and subject to change, the best estimate of P retention is 81 $mg/m^2/yr$ (W. Scheider, Ont. Ministry of Environment, pers. comm.). One problem in this calculation is that the water budget for the lake had a discrepancy of 22% between runoff and outflow discharge. In other words, 22% of incoming water was not measured. The retention given has been corrected for this discrepancy. Since there is some uncertainty about the mass of phosphorus input to the lake and hence the actual retention, it is possible to predict a retention by rearranging the mass balance model developed by Dillon and Rigler (1974) such that:

$$Rp = PQR/\ A(1-R) \quad (\text{in } mg/m^2/yr) \qquad (5\text{-}3)$$

where: A = lake area (in square metres)

Q = outflow water discharge (in cubic metres)

P = lake phosphorus concentration (in mg per cubic metre)

R = fraction of input mass of P retained by the lake

This model assumes no knowledge of the input of phosphorus to the lake except indirectly through the lake P concentration. The discharge through the outflow is as measured by the Ontario Ministry of the Environment (W. Scheider, pers. comm.). R can be estimated from the empirical model of Ostrofsky (1978). This technique of estimating P retention has been used by Cornett and and Rigler (1979). Using values for P, Q, and R of 5.6 ug/l, $3.29 * 10^5 m^3$/yr, and 0.68, respectively, this model predicts a phosphorus retention for Red Chalk Lake of 90 $mg/m^2$/yr. This gives some support to the measured P retention of 81 $mg/m^2$/yr. There is a larger difference between P retention and sediment storage of P in Red Chalk than in the other two lakes. This may indicate that the estimate of bulk sediment accumulation in Red Chalk Lake is somewhat high.

## Discussion

In Bob Lake the concentration of phosphorus in surficial sediment (0-2 cm) varied as a function of depth, with highest concentrations in the deepest areas of the lake. This phenomenon has been reported in Lake Esrom by Kamp-Nielsen and Hargrave (1978) who interpreted it as evidence of sediment focusing. This is a misinterpretation. Changes in concentration of an element reveal nothing about changes in sediment accumulation rates which are changes in mass accumulating per unit time.

The type of material found in deep areas is higher in both phosphorus and nitrogen (Kamp-Nielsen and Hargrave 1978). There is evidence of a slight increase in LOI in Red Chalk and Costello (Fig. 5b) in soft sediments which would indicate a change in organic matter. The most probable mechanism to account for these concentration variations is one of selective particle size distribution. Yuretich (1979) and Thomas et al. (1972) have measured variation in particle size distribution over lake bottoms. Both found that particle size decreases with increasing water depth. If these results can be extrapolated to Red Chalk and Costello Lakes, it might be hypothesized that as particle size decreases, binding capacity for nutrients such as P and N increases. Whatever the mechanism that causes this variation in nutrient concentration, it is apparent that if one desires to quantify sediment phosphorus retention, spatial variation in both bulk accumulation rates and phosphorus concentrations over a lake bottom must be measured.

Although the results of whole lake accumulation calculations support the contentions made in chapter four, that lead-210 dating can be used in a variety of small lakes and that variation in sediment accumulation rates is related to changes lake bottom depth, there are several areas in which require further study. First the upper limit of accumulating sediment is not certain. While it can be established visually, a predictive model for this parameter would be helpful. In addition, since there is variation in the depth of this transition, some error is introduced by the arbitrary fixation of a depth for the purposes of calculating whole lake accumulation. The reason for the extremely high accumulation rates predicted by lead-210 dating in shallow areas of no apparent accumulation requires further study. One possible explanation is that fine particles containing lead-210 may filter down between the relatively large pores created by the packing of sand and gravel. This mechanism could also explain the small but measurable concentrations of organic material (LOI) and phosphorus found in these shallow sediments.

Lead-210 dating in general requires much further work in as wide a variety of situations as possible. There is still an element of subjectivity required in the choosing of data points to be used in an accumulation calculation. No one to date has presented an unambiguous method for rejecting anomalous data points. In addition, in some lakes at least, dating by $^{210}$Pb is confounded by disturbances. In Fig. 5l and 5m , the four uninterpretable lead-210 profiles from Red Chalk are shown. At the time of coring, there was nothing to suggest that these cores were disturbed. These and other cores from depths less than 20 m show some

Fig. 51. Lead-210 profiles for Red Chalk Lake cores 9 and 11

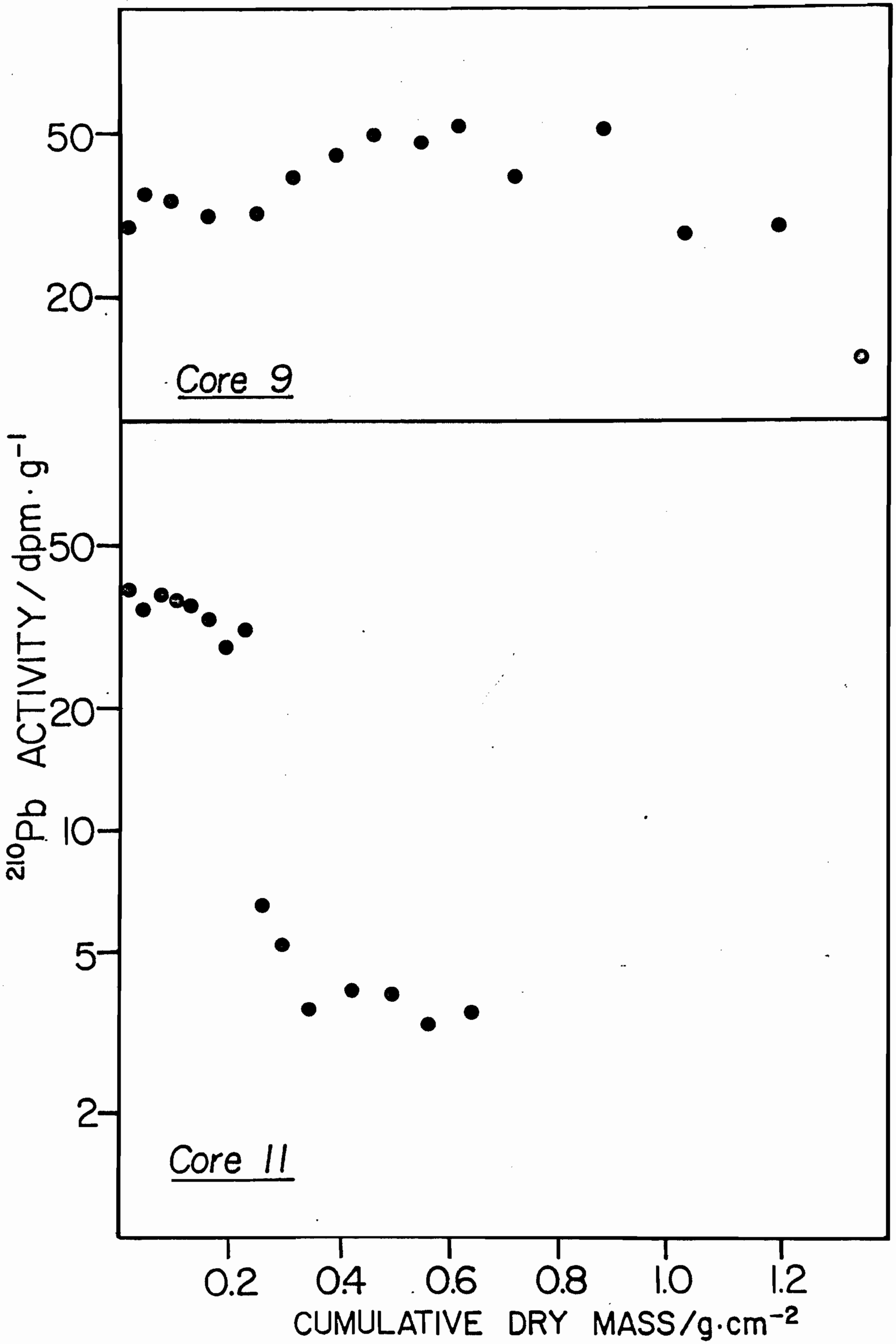
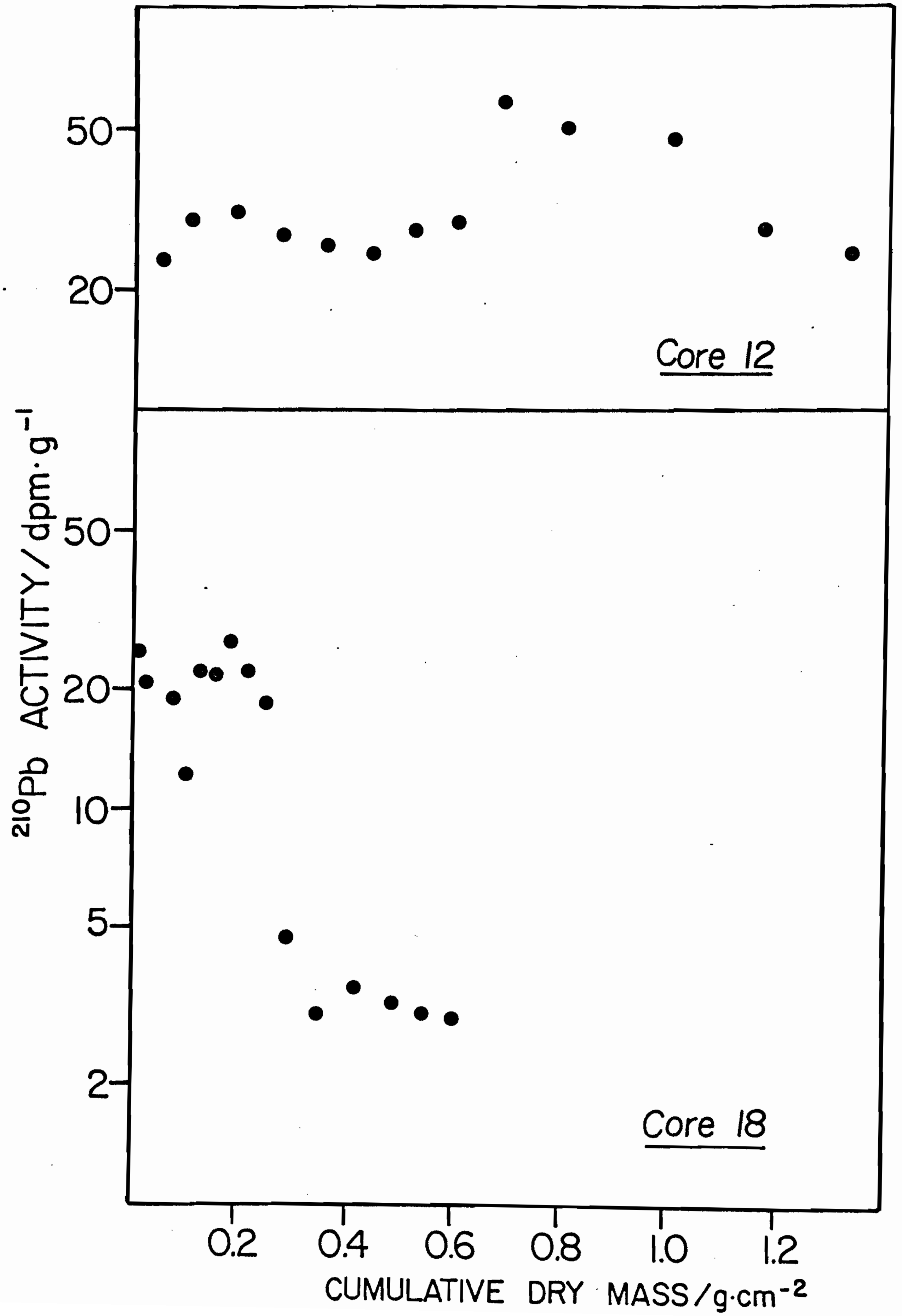

50
20
Core 9
50
20
10
5
2
Core 11
$^{210}$Pb ACTIVITY / dpm · g$^{-1}$
0.2
0.4
0.6
0.8
1.0
1.2
CUMULATIVE DRY MASS / g · cm$^{-2}$

Fig. 5m. Lead-210 profiles for Red Chalk Lake cores 12 and 18


Core 12
Core 18
50
20
50
20
10
5
2
0.2
0.4
0.6
0.8
1.0
1.2
$^{210}$Pb ACTIVITY / dpm·g$^{-1}$
CUMULATIVE DRY MASS / g·cm$^{-2}$

evidence of sediment loss by erosion. This is supported by the anthropogenic Pb data in chapter seven. If sediment is lost by erosion and then resuspended ultimately to fall in the deep areas, it may result in an overestimation of the whole lake rate, since the sediment lost by erosion will be measured twice.

The results of lead-210 dating in Costello and Red Chalk Lakes and the comparison of phosphorus retentions to mass balances support the hypotheses put forward in chapter four. Morphometry strongly influences the variation in sediment accumulation across the bottom of a lake. The relationship of this variation to morphometry can be utilized to simplify measurement of whole lake sediment accumulation. These results suggest that lead-210 dating of a series of sediment cores in a lake will provide meaningful and useful measurements in small temperate lakes.

# CHAPTER: SIX

# CALCULATION OF THE TOTAL ANTHROPOGENIC LEAD IN THE SEDIMENTS OF A RURAL ONTARIO LAKE

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## ABSTRACT

Sediment cores from a rural Ontario lake (Bob Lake lat. 44° 55'N. long. 78° 47'W.) were analyzed for total anthropogenic lead content. A high correlation between deposition of anthropogenic lead and sediment depth facilitated calculation of total fallout of anthropogenic lead in Bob Lake. The total fallout of 820 mg $m^{-2}$ is large for a rural area in comparison to that calculated for the Lake Michigan-Chicago area (390 mg $m^{-2}$).

Lake sediments have been used to reconstruct the historical record of environmental contamination (eg. 1,2,3), in particular, the historical record of lead pollution (4,5). Two principle aims of such studies are the estimation of current atmospheric fallout of anthropogenic lead and the examination of regional differences in atmospheric fallout. In order to use lake sediments to answer these questions two assumptions must be made about the source of sediment lead. If no lead comes in to the lake through the inflows or leaves the lake through the outflow (6), the total amount of lead in that lake may be used to estimate the areal deposition over the lake.

To estimate current atmospheric fallout or to assess regional differences, two data are required. First, the whole lake average lead content fallout must be assessed, and second, the current fallout can only be calculated with a knowledge of the change in fallout through time. Unfortunately, very few studies have yet accomplished both of these aims. The problem encountered most often is the phenomenon of sediment focusing (7,8), where sediments accumulate more rapidly at deep locations of a lake than at shallow sites. Edgington and Robbins (4) pointed out in 1972 the dangers of trying to extrapolate the results of only a few cores over large areas of a lake. Despite this warning, workers continue to use the results of single cores as estimates of whole lake values (9,10).

Peyton et al. (11) have attempted to adequately sample a sediment system for lead content. Their data were complicated by a strong gradient in fallout from a nearby highway. Because of this no simple means of integration over the entire pond area could be made. Edgington and Robbins (4) modeled the distribution of anthropogenic lead in sediment cores from Lake Michigan, in relation to a historical source function for the release of Pb into the atmosphere. This model makes a number of assumptions the validity of which have been debated (12,13). The complexity and size of Lake Michigan necessitates the assessment of whole lake fallout on the basis of only a few cores. We felt that initially work such as that done by Peyton et al. and Edgington and Robbins would be more easily accomplished in a less complicated environment.

As a first step to this process, we have chosen a small temperate lake of simple morphometry in which to calculate the whole lake lead fallout. There has been some suggestion that accumulation of various elements in a lake is depth related (11). Our hypothesis was that the correct choice of lake would allow us to relate total anthropogenic lead per unit area in a particular sample to depth of the lake at the sampling site. This relationship would facilitate an accurate extrapolation from measurements on a series of sediment cores to the total quantity of lead in the sediments of our lake.

If such relationships could be found in a series of simple lakes, regional difference in the accumulation of anthropogenic lead could be compared. These total fallout measurements could then be related to historical investories such as that suggested by Edgington and Robbins (4) to allow calculation of present day flux. This paper represents the first step in a program to adequately test the feasibility of this approach.

## EXPERIMENTAL

Bob Lake is a 230 ha lake lying on the Laurentian Shield in the Haliburton Highlands region of Ontario, Canada ($44^{o}$ 54'N. lat. $78^{o}$ 47'W. long). The lake is about 8 km west of the nearest highway and 200 km northeast of the nearest large city (Toronto). Local sources of lead are small since automobile traffic is light and the few homes occupied out of the recreational season are heated by wood or oil.

Sediment cores were taken with a K-B gravity corer at twenty-two locations by P.M. Cross in 1977 (14). Sample sites are shown in Figure 6a. No cores were taken in areas less than 10 m deep because of the hardness of the bottom material. All cores were sectioned into 2 cm slices within 24 hours after sampling, sealed in plastic vials and frozen until analyzed. The frozen core sections were massed, dried at $105^{o}$C for 24 hours, and remassed, to obtain wet and dry mass.

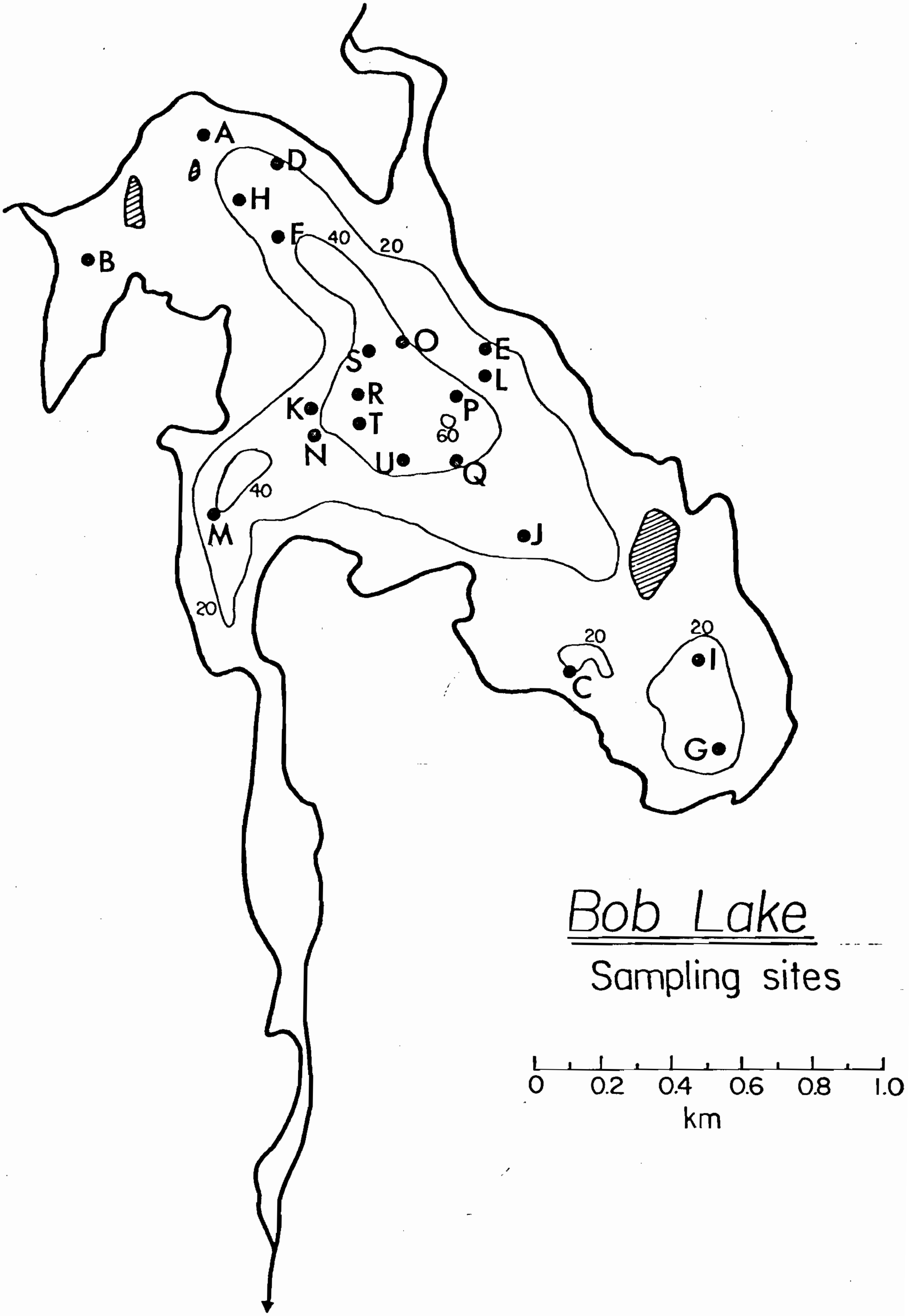
Subsamples of 0.5 to 1.0 g dry mass were digested overnight at $70^{o}$C in a 2:1 mixture of HCl (s.g. 1.18) and $HNO_3$ (s.g. 1.42) (15). The digestate was separated from the residue by centrifugation and analyzed for lead content by atomic absorption spectrometry using a Perkin-Elmer model 403 analyzer.

The total anthropogenic lead in a core was calculated as:

$$\sum_{i=1}^{n} (Pb_i) \times M_i/a \quad (mg/m^2)$$

where $(Pb_i)$ = (Pb) measured in $i^{th}$ section minus (Pb) in deep "background" sections (in mg/g of dry mass).
$M_i$ = dry mass of $i^{th}$ section (in g).
$a$ = area of core taken (in $m^2$).

Fig. 6a. Morphometry of Bob Lake showing sample sites. Contours are in tens of metres.



Bob Lake

Sampling sites

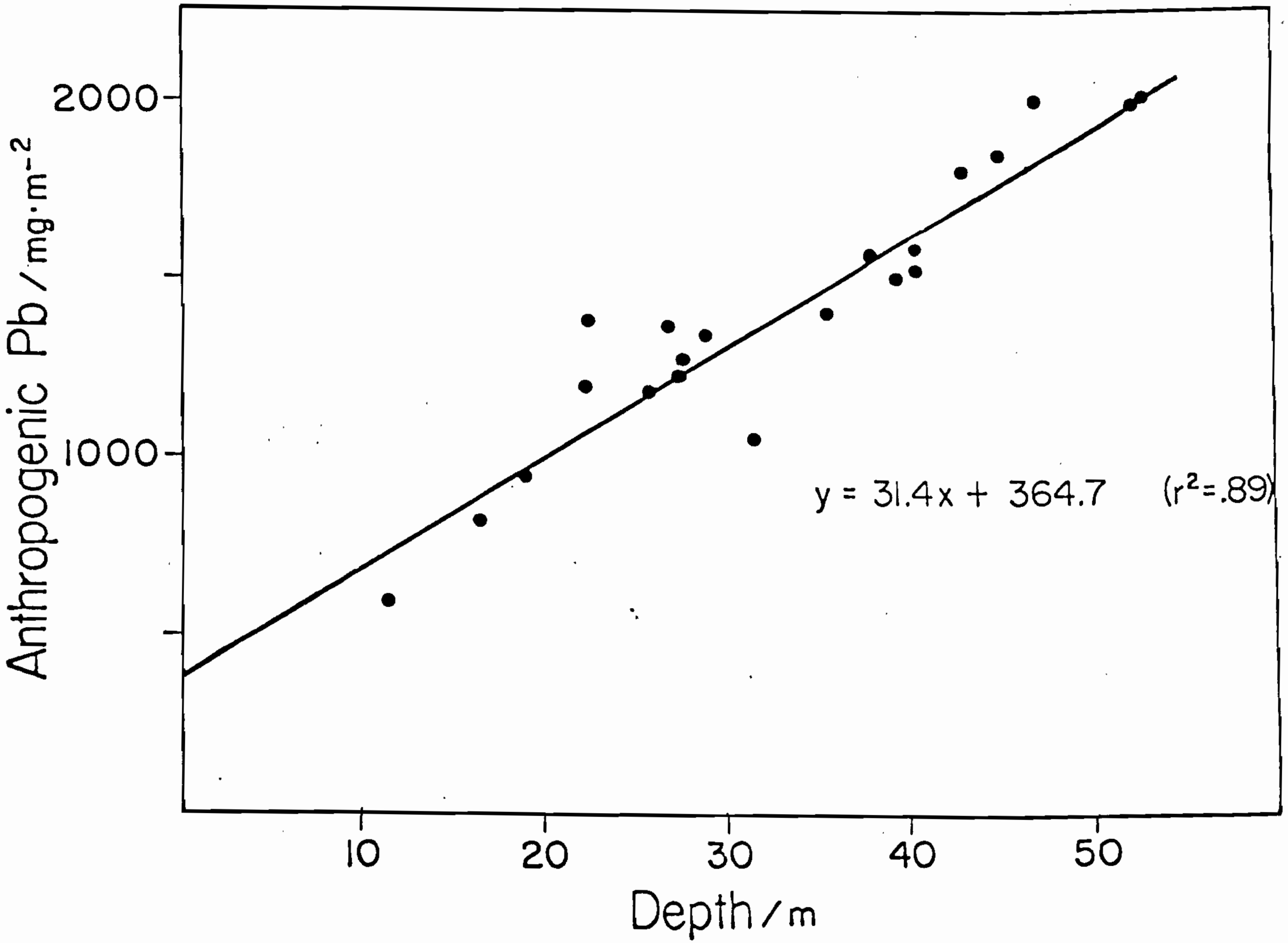
## RESULTS AND DISCUSSION

The total anthropogenic lead is shown as a function of depth at sample site in Fig. 6b. Results are consistent with the hypothesis since a simple linear regression of lead per unit area on depth explains 89% of the variation among sample sites.

Before calculating lead accumulation in Bob Lake, one unknown remains to be considered. This is the effect of the method of extrapolating to depths less than 10 m where no cores were taken. The simplest method would be to extrapolate the linear regression to its zero-depth intercept as shown on Fig. 6b. However, this would probably overestimate the total Pb content because it assumes considerable Pb accumulation at zero depth where little or no sediments accumulate. At the other extreme, one could assume no accumulation at all in areas shallower than 10 m, on the assumption that the bottom materials in this range were too hard to sample because no fresh sediments were accumulating. If Pb accumulation in Bob Lake is calculated from these limiting assumptions it could be as low as 725 mg $m^{-2}$ or as high as 920 mg $m^{-2}$. Several studies have shown that no permenent sediments accumulate above the bottom of the mid summer epilimnion (8,16,17). In Bob Lake this is about six meters. Using this assumption the best estimate of total anthropogenic lead accumulation for Bob Lake is 820 mg $m^{-2}$.

Although such morphometric relationships are probably not common to all lakes, there are sufficient numbers of small lakes of reasonably simple morphometry that could be used in a similar manner. The relationship of lead accumulation with depth in Bob Lake is encouraging enough that similar relationships should be sought in other regions to explore continental

Fig. 6b. The relation between total anthropogenic lead and lake depth at the sample location, in Bob Lake


Anthropogenic Pb / mg·m⁻²
2000
1000
Depth / m
10
20
30
40
50
y = 31.4x + 364.7 (r² = .89)

variation. At present there is very little data to suggest whether 820 mg $m^{-2}$ is a significant amount of lead relative to other areas of North America.

Using the calculated flux for 1972 and the historical source function as given by Edgington and Robbins (4) it is possible to calculate the total anthropogenic lead fallout over Lake Michigan since about 1860. 1972 emissions of lead represented about 3.3% of the total historical inventory (18,19) and 1972 fallout was 13 mg $m^{-2}$. Thus the historical lead accumulation over Lake Michigan would be equal to 390 mg $m^{-2}$. In comparison the Bob Lake fallout represents a significant amount of lead. Unlike Lake Michigan, Bob Lake is situated away from any local sources of lead emmision. More work in remote areas is warranted to test the generality of our findings. Also the assumptions that there is no transport of Pb from the lake catchment or loss from the outflow should be tested by more sensitive analyses of lead concentration in stream water and by measuring total accumulation of Pb in a series of small lakes of simple morphometry with varying ratios of catchment to lake surface area.

## ACKNOWLEDGEMENTS

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# CHAPTER SEVEN:

# A SIMPLIFIED METHOD FOR CALCULATING WHOLE LAKE SEDIMENT ACCUMULATION RATES

Several mechanisms have been suggested to account for the spatial variation in accumulation rates of bulk sediment. Lake morphometry, including depth (this study) and bottom slope (Kimmel 1978), and wind driven currents (Robbins and Edginton 1975) are among the most popular. While it is possible that one or a combination of these factors could be used to calculate the mean sediment accumulation rate from a single or a few field observations, the data do not exist currently to formulate an empirical predictive model. Yet we need a method to calculate a mean rate of sediment accumulation for a whole lake basin without undertaking a major sedimentological study. For this reason I have taken the approach of using an element which will act as a tracer of sediment movement in a lake and allow us to make this calculation from a single sediment core. The strength of this approach is that it makes no assumption about the mechanism which causes sediment redistribution and funnelling.

## Outline of the Method

Let us assume that there exists element X, which is deposited uniformly on a lake's surface and then is incorporated as part of the falling seston. The seston forms the deposits which are accumulating differentially over the lake bottom. Given the assumption that none of this element is lost from the sediment column, the amount of it which has accumulated per unit time at any location will be proportional to the rate at which the bulk sediments are accumulating at that same location. If we know the average input of element X to the lake, per unit time, we can calculate the total accumulation of bulk sediment per unit time by the simple equation:

$$\frac{Xi}{Xavg} = \frac{Ri}{Ravg} \qquad (7\text{-}1)$$

where: Xi = mass of element X/unit area/unit time at location "i"

Xavg = average mass of X/unit area/unit time in lake

Ri = sediment accumulation rate at location "i"

Ravg = average accumulation rate for whole lake

This equation is the basis of my proposed method for calculating the whole lake accumulation rate from a single core.

There are three parameters required to use equation (7-1). First the rate of accumulation of the bulk sediments at some location 'i' must be measured. This can be accomplished using standard dating techniques and the choice will depend on the situation and facilities at hand. In this study lead-210 dating was used. Second, an element X must be chosen which meets the following criteria.

1) The element should be non-diagenetic in the sediments.
2) Its depositional concentration must be uniform over the lake bottom
3) The average input of this element to the lake sediments per unit time must be known or quantifiable.

While there are conceivably several elements which meet these requirements, I have chosen anthropogenic lead as defined in chapter 6. This is simply the total amount of lead observed in a sediment core per unit area minus the background contribution from geologic weathering. Although the chemistry of lead in sediments is not well known, it seems to exhibit the characteristics required. It shows no evidence of post-depositional mobility (Edgington and Robbins 1976). There appears to be no input of Pb from the catchment of a lake (Andren et al. 1978, Benninger et al 1975). If this is correct, all loading will occur through rainfall, and deposition over the lake is most likely uniform. Anthropogenic lead in a sediment core can be measured using standard atomic absorption techniques (Edgington and Robbins 1975, Ediger 1973). Finally, by measuring the total mass of anthropogenic lead in a core, the 'time element' in the left-side of equation (7-1) is taken into account. This is because anthropogenic Pb has been deposited over a discrete time interval (approximately since 1850) which will be the same for all cores in a lake.

The third parameter needed for equation (7-1) is the average input of anthropogenic Pb to the lake. This can be measured empirically as has been done for the Haliburton, Ontario area (chapter 6). The range of applicability and the limitations of this measurement of Pb input will be discussed more thoroughly later. Thus all the variables in equation (7-1) can be measured and in theory the whole lake accumulation rate of the bulk sediments calculated on the basis of a single sediment core.

Although there are few data available to test this new method, the conceptual model involved makes a prediction that is easily tested. For the method to work there must be a constant ratio between the accumulation rate of the bulk sediments and the mass of anthropogenic lead in a series of cores from any lake. If such a constant ratio exists, it is an indication that the lead - sediment interactions are in fact similar to those that I have proposed. Edgington and Robbins (1975) pointed out that this constant ratio was found in the sediments of Lake Michigan. The ratio of anthropogenic lead to accumulation rate of the sediments is quite constant for four cores for which data were provided (Table 7a), although the accumulation rates vary up to eight times. The data from chapters four and six can be used to calculate the same ratios for Bob Lake (Table 7b). These ratios vary between 0.07 and 0.11 with a mean value of 0.09.

In this study I have also measured anthropogenic lead in a series of cores from Costello and Red Chalk Lakes (Appendix II). The ratios of mass of anthropogenic lead to

| CORE | A* | B** | RATIO A/B |
|---|---|---|---|
| 17 | 120. | 455 | 0.26 |
| 29 | 940. | 4505 | 0.21 |
| 31 | 180. | 819 | 0.22 |
| 105 | 150. | 822 | 0.18 |

* $^{210}$Pb Accumulation Rate in $g/m^2/yr$.
** Mass of Anthropogenic Pb in Core in $mg/m^2$.

Table 7a. Calculation of the Ratio of Anthropogenic Lead to Bulk Accumulation in Four Lake Michigan Cores. Data from Edgington and Robbins (1975).

| MEASURED $^{210}$Pb ACCUMULATION (g/m$^2$/yr) | ACCUMULATION RATE ANTHROPOGENIC Pb | PREDICTED WHOLE LAKE RATE (g/m$^2$/yr) |
|---|---|---|
| 62 | .105 | 86 |
| 99 | .105 | 86 |
| 86 | .072 | 59 |
| 102 | .086 | 71 |
| 107 | .080 | 65 |
| 119 | .085 | 70 |
| 138 | .088 | 72 |
| 153 | .097 | 79 |
| 152 | .084 | 69 |
| 157 | .087 | 69 |

Table 7b. Predictions of Whole Lake Sediment Accumulation Rate in Bob Lake.

bulk sediment accumulation rate for cores from Red Chalk are given in Table 7c. As in Bob Lake and Lake Michigan, these ratios are very constant in Red Chalk. In Costello Lake (Table 7d) there is not quite as good agreement among the ratios from various cores. There is a greater than two-fold variation in ratios which will give rise to a similar variation in the prediction of average accumulation rates.These data violate the primary requirement of the model. There must be a mechanism in Costello Lake, not present in the others, which causes either selective loss or gain of lead relative to bulk sediment at a given site. One possible cause is change in pH in the overlying water. In the Haliburton region, lake acidification is a recent problem (Dillon et al. 1978). If the pH in Costello is significantly lower than in the other lakes, lead could be mobilized in the sediments and lost from the lake through the outflow, resulting in variable lead to bulk accumulation ratios.

The relatively lower ratios in Bob Lake reflect a higher loading of lead in Bob than in Michigan (820 $mg/m^2$ cf. 340 $mg/m^2$). This difference in loading of anthropogenic Pb between Michigan and Haliburton indicates one area in which further testing of the model is required. At present I assume that there is no input of Pb from the catchment of a lake or outflow loss. This assumption should be examined carefully since it may be the source of small scale

| Core | a<br>MEASURED $^{210}$Pb ACCUMULATION (g/m$^2$/yr) | b<br>ANTHROPOGENIC LEAD mg/m$^2$ | AVERAGE ACC. PREDICTED (g/m$^2$/yr) | RATIO a/b |
|---|---|---|---|---|
| 13 | 53.6 | 572 | 71.2 | 0.09 |
| 14 | 41.6 | 834 | 37.9 | 0.05 |
| 15 | 38.1 | 710 | 40.8 | 0.05 |
| 16 | 59.9 | 1445 | 31.5 | 0.04 |
| 17 | 84.2 | 1861 | 34.4 | 0.05 |
| 30 | 94.6 | 1883 | 38.2 | 0.05 |
| 31 | 128.3 | 2075 | $<$47.0* | 0.06 |
| 33 | 74.5 | 1469 | 38.5 | 0.05 |
| 37 | 97.2 | 1536 | 48.1 | 0.06 |
| 39 | 32.1 | 1617 | 15.1 | 0.02 |
| 40 | 64.4 | 1051 | 46.6 | 0.06 |
| 41 | 62.9 | 1206 | 39.6 | 0.05 |
| 45 | 60.3 | 883 | 51.9 | 0.07 |

* minimum lead concentration observed in core = 110 ug/g.

Table 7c. Prediction of average lake sediment accumulation rates using average anthropogenic lead mass of 760 mg/m$^2$ in cores from Red Chalk Lake.

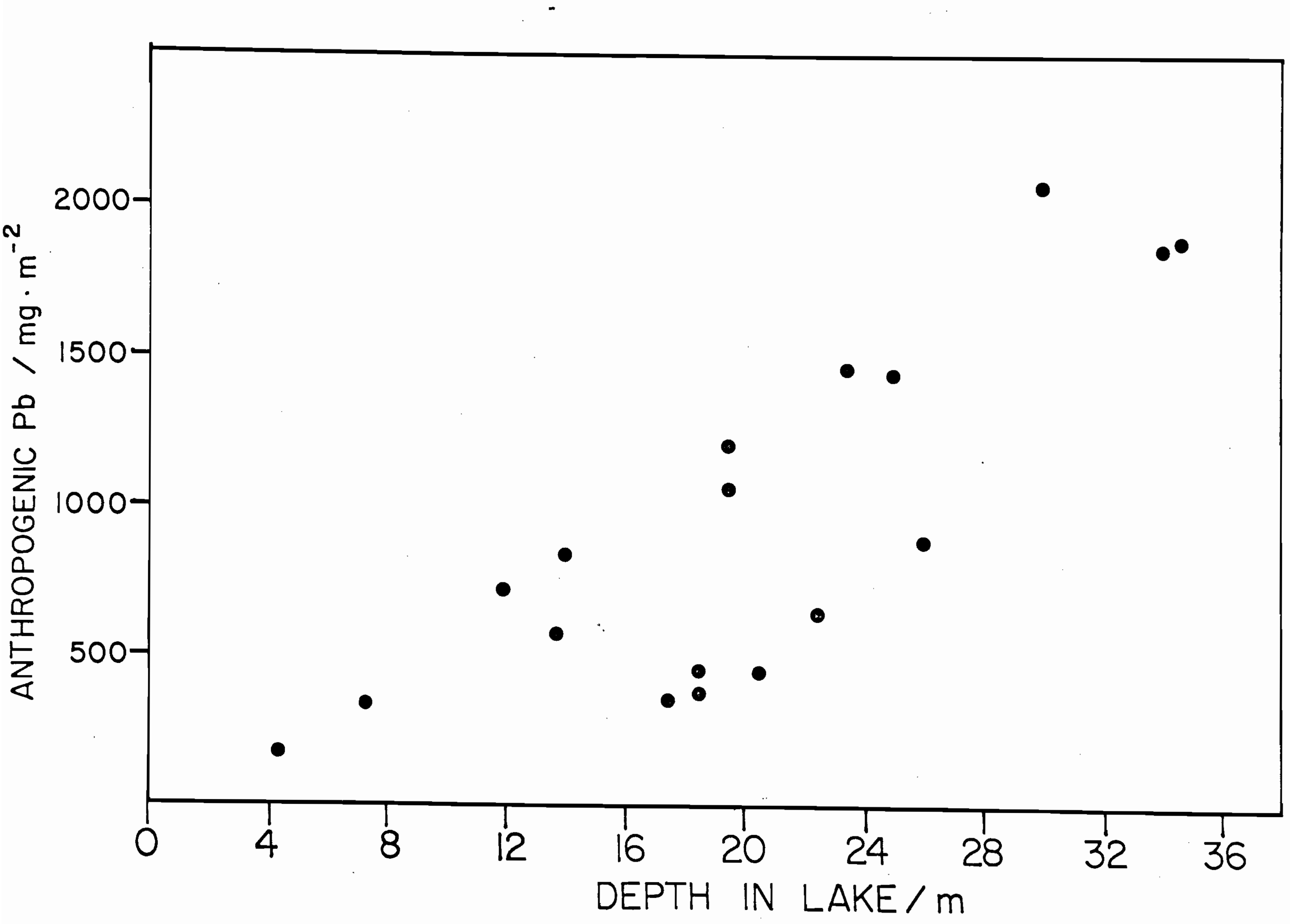
| Core | MEASURED $^{210}$Pb ACCUMULATION (g/m$^2$/yr) [a] | ANTHROPOGENIC LEAD mg/m $^2$ [b] | AVERAGE ACC. PREDICTED (g/m$^2$/yr) | RATIO a/b |
|---|---|---|---|---|
| 11 | 54.7 | 626 | 38.4 | 0.09 |
| 12 | 78.7 | 714 | 48.5 | 0.11 |
| 16 | 131.8 | 783 | 74.1 | 0.17 |
| 20 | 85.6 | 558 | 67.5 | 0.15 |
| 23 | 157.7 | 1127 | 61.6 | 0.14 |
| 24 | 107.4 | 513 | 92.1 | 0.21 |
| 28 | 102.0 | 1147 | 39.1 | 0.09 |
| 29 | 125.9 | 974 | 56.9 | 0.13 |
| 30 | 104.0 | 432 | 105.9 | 0.24 |
| 31 | 77.9 | 305 | 112.4 | 0.26 |
| 32 | 130.0 | 1078 | 53.4 | 0.12 |
| 35 | 96.6 | 613 | 69.3 | 0.16 |

Table 7d. Prediction of average lake sediment accumulation rates using average anthropogenic lead mass of 440 mg/m $^2$ in cores from Costello Lake.

variation in lead loading in an otherwise homogenous region of fallout. Also, I do not know over what distance the fallout of Pb will be constant. Obviously, the larger the area, the more attractive the method becomes, since the fallout figure calculated from a single lake such as Bob, will be applicable to a large number of others. Evidence from five other lakes within 100 km of Bob Lake suggests that there is approximately constant fallout of anthropogenic lead over wide areas. Anthropogenic input of Pb varied in these five lakes between 600 $mg/m^2$ and 900 $mg/m^2$ (P.Dillon, pers.comm., unpublished data). This limited evidence gives me reason to believe that the method will be applicable to large numbers of lakes with minimal new input data. In the Haliburton region of Ontario, for example, whole lake sediment accumulation could be measured on several hundreds of lakes relatively easily. Yet the absence of data similar to that collected from Bob Lake on a continental scale means that, for the present, anthropogenic lead fallout must be measured in new areas of interest before this method can be used.

The anthropogenic lead in each of several cores from Red Chalk Lake is related to the depth from which the core was taken (Fig. 7a). This relationship has been used, as in Bob Lake (chapter 6), to calculate an average accumulation of lead. There are a series of samples which had less anthropogenic lead per unit area than might be expected from

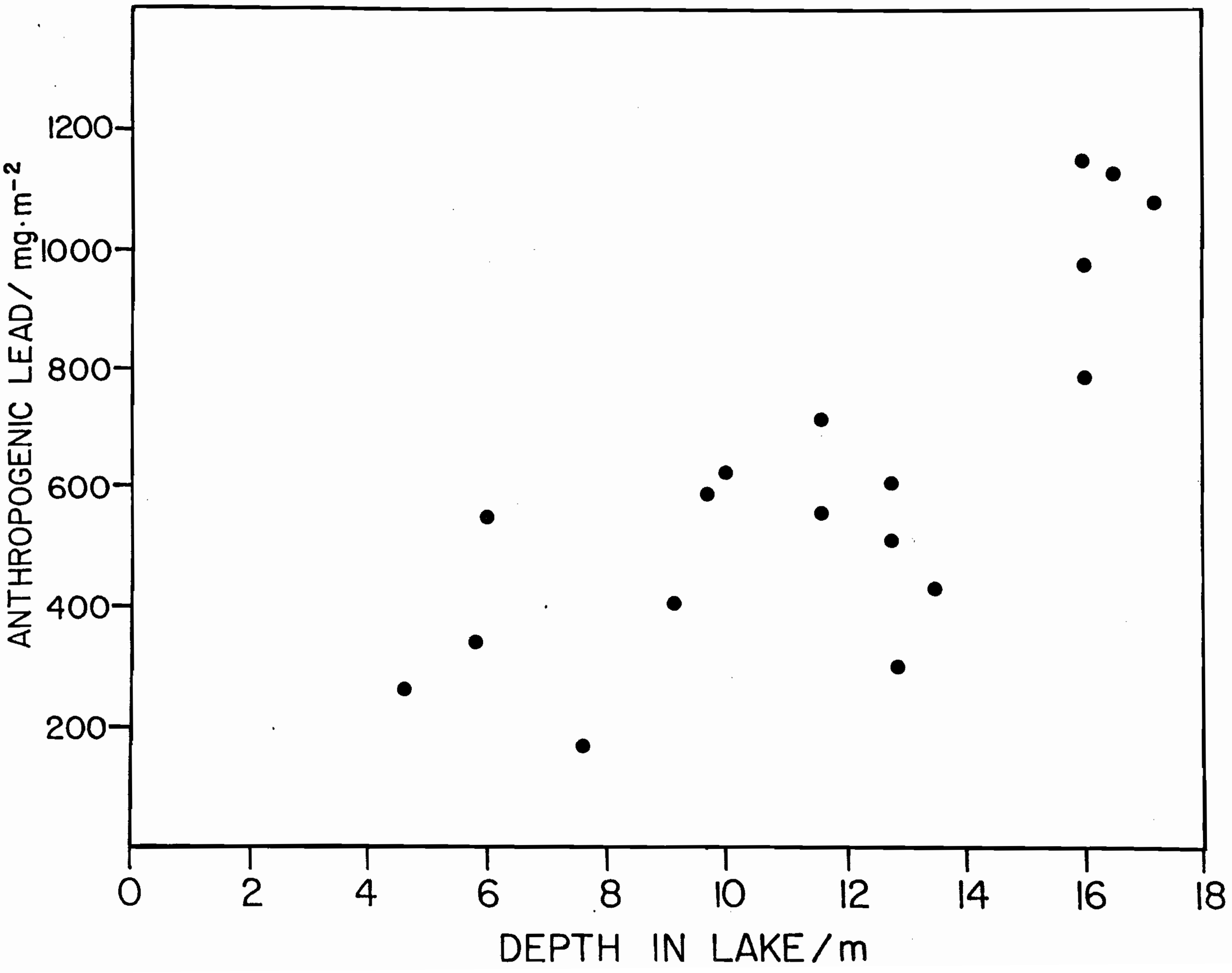
Fig. 7a. Total anthropogenic lead versus lake depth at sample site, in Red Chalk Lake


ANTHROPOGENIC Pb / mg · m⁻²
2000
1500
1000
500
0
4
8
12
16
20
24
28
32
36
DEPTH IN LAKE / m

the trend in the rest of the cores. It is possible, as discussed with respect to lead-210 accumulation rates, that these values should be rejected due to loss of sediment through slumping or erosion. But the lead lost through these events may have become incorporated into deeper sediment. For this reason I have included these seemingly anomalous values in my calculations of anthropogenic lead in Red Chalk Lake. The anthropogenic lead is 760 $mg/m^2$. The Ontario Ministry of the Environment has also measured anthropogenic lead in Red Chalk (P. Dillon pers. comm., unpublished data). They used similar methods and arrived at a value of 772 $mg/m^2$. There is very little difference between the anthropogenic fallout in Bob and Red Chalk Lakes. There is also little difference between the ratios of catchment to lake area for the two lakes. To test for basin input, a lake such as Costello is a better choice because of its large catchment area.

In Fig. 7b, anthropogenic lead from Costello Lake cores is related to depth from which the cores were taken. The average loading in Costello is 441 $mg/m^2$. This is much lower than the values found in either Bob or Red Chalk. If there was any input of lead from the catchment, one would expect Costello to have the highest loading and Red Chalk the lowest. The fact that the results are reversed may be construed as evidence that input from a catchment is not an influencing factor on lead accumulation in lake sediments.

Fig. 7b. Total anthropogenic lead versus lake depth at sample site, in Costello Lake


ANTHROPOGENIC LEAD/ mg·m⁻²
1200
1000
800
600
400
200
0
2
4
6
8
10
12
14
16
18
DEPTH IN LAKE/m

9/11

On the other hand the fact that Pb accumulation is so low in Costello might suggest that lead loss through the outflow of a lake can be significant. This is reasonable in light of two factors. First Costello is no further removed from the other two lakes than are Red Chalk and Bob removed from each other. They should be exposed to the same climatic conditions and approximately the same amount of local automobile traffic. Second, the flushing time for Costello Lake is about 0.85 years compared with approximately 2.5 years for Bob and Red Chalk Lakes. Another possibility, of course, is the pH hypothesis presented earlier. Observations from many more lakes will be required to test these hypotheses.

## Prediction of Whole Lake Rates

For a series of twelve cores in Bob Lake I have tabulated the data required to make a calculation of the average sediment accumulation rate (Table 7b). For each core I can make an estimate of this whole lake average rate which can be compared for internal consistency. If the model has any applicability, the predictions from each core should be approximately the same. The average whole lake accumulation rate was calculated by the equation:

$$Ravg = Ri * \frac{820}{Pbi}$$

where: Ra = average whole lake sediment accumulation rate in $g/m^2/yr$

Ri = observed sediment accumulation rate in core i in $g/m^2/yr$

820 = average fallout of Pb in Haliburton area in $mg/m^2$

Pbi = observed mass of anthropogenic Pb in core i in $mg/m^2$

The predicted average lake accumulation rates range from 59 $g/m^2/yr$ to 86 $g/m^2/yr$ with a mean of 72.2 $g/m^2/yr$. The observed accumulation rates in those same cores ranged from 62 to 157 $g/m^2/yr$. The whole lake rate predicted by the model for each core is reasonably similar, confirming its internal consistency.

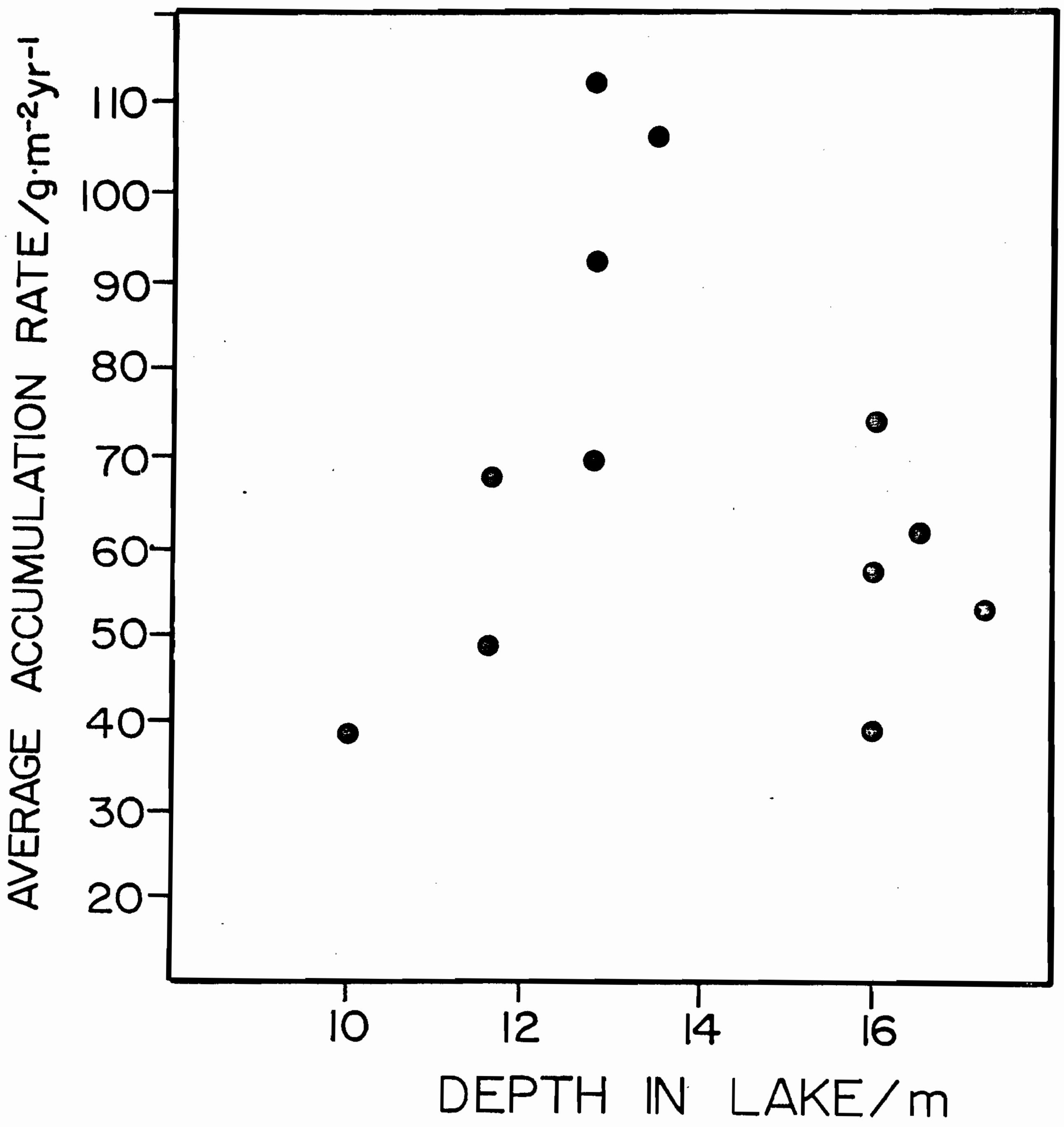
The predicted rates, however, must be compared to an independent estimate of whole lake sediment accumulation. In chapter four, Fig. 4d, the average dry sediment accumulation for Bob Lake was calculated to be between 63 $g/m^2/yr$ and 77 $g/m^2/yr$ with a best estimate of 70 $g/m^2/yr$. The predicted estimates of whole lake average compare favourably with this figure. On the strength of these few data, this technique offers promise for the prediction of whole lake sediment accumulation.

In Red Chalk Lake the use of equation (7-1) results in individual predictions of average whole lake accumulation ranging between 34 and 77 $g/m^2/yr$. The actual anthropogenic lead accumulation of 760 $mg/m^2/yr$ was used in equation

(7-1). Of the 13 cores analyzed, 8 give very similar results. Two cores (13 & 45) give unexplicably high results. Cores 16 and 17 both give lower than average predictions and both these cores were obtained with small diameter (5 cm) core tubes. All others were obtained using 7 cm diameter tubes. It may be fortuitous but the results predicted by these two cores, while low, are very similar. Hongve and Erlandsen (1979) have shown that as core size decreases in gravity cores, proportionately more material is lost in the coring action. Of course such a loss would apply to both accumulation rate and lead content. Despite the results of these two cores, the predictions of most cores are extremely encouraging. The use of almost any core would yield a good estimate of whole lake sediment accumulation rate in comparison to the 45 $g/m^2/yr$ calculated in chapter five.

Predictions of average accumulation rate of bulk sediments for Costello Lake are given in Table 7d. These predictions are not as good as those for the lakes previously examined. As discussed earlier, there is a difference in the lead - sediment interactions in Costello Lake. With a sample size of three lakes it is not possible at this time to sort out the reasons for this. At this stage multiple estimates are needed to detect the presence of anomalous predictions. The error in prediction of average acumulation is not random in Costello Lake (Fig. 7c). Samples from the shallowest and deepest depths of soft

Fig. 7c. Predicted average accumulation rates versus lake depth in Costello Lake


AVERAGE ACCUMULATION RATE/g·m⁻²yr⁻¹
110
100
90
80
70
60
50
40
30
20
10
12
14
16
DEPTH IN LAKE/m

sediment accumulation give reasonable estimates. Those from mid-depth areas give the worst. The deepest area of the lake may be the best location for samples to be used.

In the application of this method, it is not important that the anthropogenic lead is not the same in all lakes. It simply means that we must be able to measure or predict the amount of anthropogenic lead in a particular lake of interest. This study has demonstrated that its measurement is feasible. If some simple dependence such as flushing time can be found, prediction will be possible. What is important, however, is that the ratio of bulk sediment accumulation rate to observed anthropogenic lead in any sediment core be constant within a lake in which the method is to be used. In Costello this ratio varies by a factor of two (Table 7d). This indicates that in Costello the method as outlined here would give variable predictions even with a good estimate of average anthropogenic lead.

In conclusion, the method that I have outlined above offers promise that it will allow the prediction of whole lake sediment accumulation rates with comparatively less work than required by a conventional, detailed sedimentological study. In projects where this detailed study is either not possible or not warranted, it is usable in its present form provided proper caution is exercised. For example, at present a few samples from a range of depths should be taken and the anthropogenic lead to bulk sediment ratios examined for trends. It must be emphasized that much more testing of this method and the assumptions associated with it are required before the technique can be considered generally applicable to a wide variety of situations.

# SUMMARY :

1. Lead-210 dating has been used to measure bulk sediment accumulation rates in approximately twenty cores from each of three lakes in the Haliburton Highlands region of Ontario, Canada.

2. In lead-210 profiles from these dimictic lakes, a region of uniform activity was present at the top of the cores.

3. To test the validity of lead-210 dating, activity vs. depth profiles were measured in the sediments of two lakes with undisturbed sediments. In each there was no evidence of a surface mixed layer which supports the validity of lead-210 dating.

4. In Bob Lake, depth in the lake from which a sample was taken explained 97% of the variation in accumulation rates observed. Accumulation was linearly related to depth with highest rate at the maximum lake depth.

5. The relationship of accumulation rate to depth was used to calculate the average accumulation rate for the whole lake. In Bob this was between 63 and 77 g/m$^2$/yr. The variation was caused by uncertainty in accumulation at

shallow water location. Bulk accumulation was checked by a comparison of phosphorus retained by these sediments to that calculated by mass balance methods.

6. Shallow water accumulation was examined in both Costello and Red Chalk Lakes. The upper limit of soft sediment accumulation occurred between 9.5 and 12 m in each lake. For purposes of calculation, this boundary was arbitrarily set at 10 m. Lead-210 dating indicated apparently high accumulation rates in the absence of any soft sediment in cores from 0 - 10 m. There is no explaination for this at present.

7. Sample depth did not explain as much variation in accumulation rates in Costello and Red Chalk as it did in Bob, 72% and 56% respectively. Despite this, it was possible to calculate an average accumulation rate for each lake. In Red Chalk, this was 45 $g/m^2/yr$ and in Costello it was 48 $g/m^2/yr$.

8. These accumulation rates were checked as in Bob Lake by comparison to phosphorus mass balance measurements. Agreement was good in Costello but sediment phosphorus was slightly higher in Red Chalk than that determined by input minus output.

9. Anthropogenic lead was measured in each study lake. In Bob Lake 820 $mg/m^2$ have accumulated since the start of cultural activities in Haliburton, compared to 760 $mg/m^2$ in Red Chalk and 440 $mg/m^2$ in Costello.

10. The total anthropogenic lead was used as a tracer of sediment movement in a proposed method for simplifying the calculation of the average accumulation rate of the bulk sediments in a lake. This method shows promise but requires testing on many more lakes before it can be accepted as a viable alternative to detailed studies of the sediments.

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# APPENDIX I:
# MORPHOMETRIC DATA

## A. BOB LAKE*

| STRATUM m | AREA OF STRATUM X $10^5$ $m^2$ | VOLUME OF STRATUM X $10^5$ $m^3$ |
|---|---|---|
| 0-5 | 22.82 | 100.92 |
| 5-10 | 17.66 | 79.05 |
| 10-15 | 14.03 | 63.02 |
| 15-20 | 11.23 | 49.74 |
| 20-25 | 8.72 | 38.49 |
| 25-30 | 6.72 | 29.22 |
| 30-35 | 5.01 | 20.49 |
| 35-40 | 3.25 | 12.72 |
| 40-45 | 1.90 | 7.10 |
| 45-50 | 0.99 | 3.40 |
| 50-55 | 0.41 | 1.61 |
| 55-60 | 0.24 | 0.55 |
| 60-65 | 0.02 | 0.03 |

* From Cross (1977)

## APPENDIX I: continued

### B: RED CHALK LAKE*

| STRATUM m | AREA OF STRATUM X $10^5$ $m^2$ | VOLUME OF STRATUM X $10^5$ $m^3$ |
|---|---|---|
| 0-2 | 4.39 | 8.38 |
| 2-4 | 3.98 | 7.73 |
| 4-8 | 3.75 | 14.00 |
| 8-12 | 3.26 | 12.10 |
| 12-16 | 2.77 | 10.20 |
| 16-20 | 2.35 | 8.36 |
| 20-24 | 1.84 | 6.43 |
| 24-28 | 1.38 | 3.80 |
| 28-32 | 0.575 | 1.72 |
| 32-36 | 0.30 | 0.57 |
| 36-38 | 0.03 | 0.02 |

* Courtesy of the Ontario Ministry of the Environment, unpublished data

## APPENDIX I: continued

### C. COSTELLO LAKE*

| STRATUM m | AREA OF STRATUM X $10^5$ $m^2$ | VOLUME OF STRATUM X $10^5$ $m^3$ |
|---|---|---|
| 0-1 | 3.44 | 3.17 |
| 1-3 | 2.91 | 5.50 |
| 3-5 | 2.60 | 4.88 |
| 5-7 | 2.29 | 4.25 |
| 7-9 | 1.97 | 3.61 |
| 9-11 | 1.64 | 3.00 |
| 11-13 | 1.36 | 2.41 |
| 13-15 | 1.06 | 1.63 |
| 15-17 | 0.60 | 0.40 |
| 15-17.5 | 0.00 | 0.00 |

* from Scheider (1974)

# APPENDIX II:
# SEDIMENT CORE DATA

## A. BOB LAKE

### Bob Lake Core A ( 2)

| DEPTH INTERVAL cm | CUMULATIVE MASS g/cm2 | LEAD-210 ACTIVITY dpm/g | COUNTING ERROR % | % DRY MASS | TOTAL LEAD ug/g |
|---|---|---|---|---|---|
| 0-1 | 0.040 | 33.00 | 6.53 | 10.2 | 123.5 |
| 1-2 | 0.138 | 32.08 | 5.27 | 13.3 | 114.7 |
| 2-3 | 0.242 | 26.87 | 5.40 | 14.9 | 110.9 |
| 3-4 | 0.358 | 32.03 | 3.15 | 14.8 | 115.0 |
| 4-5 | 0.475 | 26.66 | 3.35 | 15.4 | 98.9 |
| 5-6 | 0.587 | 12.04* | 6.54 | 15.4 | 38.6 |
| 6-8 | 0.749 | 6.53* | 11.06 | 14.2 | 26.0 |
| 8-10 | 0.953 | 3.33* | 8.73 | 14.4 | 18.0 |
| 10-12 | 1.154 | 2.35* | 10.70 | 13.3 | 19.7 |
| 12-14 | 1.377 | | | 15.0 | 13.7 |
| 14-16 | 1.613 | 1.79 | 8.20 | 14.8 | |

Supported lead-210 activity = 1.70 dpm/g

### Bob Lake Core C (17-6)

| DEPTH INTERVAL cm | CUMULATIVE MASS g/cm2 | LEAD-210 ACTIVITY dpm/g | COUNTING ERROR % | % DRY MASS | TOTAL LEAD ug/g |
|---|---|---|---|---|---|
| 0-2 | 0.115 | 45.14 | 4.70 | 10.8 | 111.0 |
| 2-4 | 0.367 | 41.86 | 3.15 | 12.7 | 110.0 |
| 4-6 | 0.641 | 30.00 | 7.20 | 12.7 | 92.5 |
| 6-8 | 0.911 | 17.25* | 7.90 | 12.0 | 49.1 |
| 8-10 | 1.167 | 8.47* | 5.79 | 11.7 | 33.0 |
| 10-12 | 1.401 | 5.19* | 23.05 | 10.1 | 15.5 |
| 12-14 | 1.611 | 3.94 | 11.05 | 9.4 | 12.0 |
| 16-18 | 2.050 | 1.79 | 11.31 | 11.0 | 5.0 |
| 18-20 | 2.282 | 1.70 | 11.15 | 10.8 | 8.3 |
| 20-22 | 2.500 | 2.54 | 13.30 | 10.7 | 8.2 |

Supported lead-210 activity = 1.65 dpm/g

* Samples used in the calculation of accumulation rate.

## Bob Lake Core D (26-2)

| DEPTH INTERVAL cm | CUMULATIVE MASS g/cm2 | LEAD-210@ ACTIVITY cpm/g | COUNTING ERROR % | % DRY MASS | TOTAL LEAD ug/g |
|---|---|---|---|---|---|
| 0-2 | 0.087 | 29.05 | 4.47 | 8.8 | 162.3 |
| 2-4 | 0.297 | 25.90 | 4.47 | 11.5 | 158.4 |
| 4-6 | 0.549 | 18.36 | 4.47 | 11.8 | 126.8 |
| 6-8 | 0.794 | 10.26* | 4.47 | 11.0 | 75.8 |
| 8-10 | 1.021 | 4.94* | 5.89 | 10.5 | 41.0 |
| 10-12 | 1.233 | 2.41* | 4.47 | 9.6 | 22.8 |
| 12-14 | 1.433 | 1.29* | 4.47 | 9.4 | 20.5 |
| 16-18 | 1.824 | 0.61 | 4.47 | 9.3 | 12.1 |
| 18-20 | 2.018 | 0.59 | 4.47 | 9.3 | 10.7 |
| 24-26 |  | 0.31 | 4.47 | 9.9 |  |

Supported lead-210 activity = 0.31 cpm/g

@ counted using bismuth-210 method...results are in relative counts/min

## Bob Lake Core G (25-4)

| DEPTH INTERVAL cm | CUMULATIVE MASS g/cm2 | LEAD-210 ACTIVITY dpm/g | COUNTING ERROR % | % DRY MASS | TOTAL LEAD ug/g |
|---|---|---|---|---|---|
| 0-2 | 0.110 | 51.83 | 2.49 | 10.2 | 145.7 |
| 2-4 | 0.366 | 44.95 | 3.30 | 13.2 | 136.6 |
| 4-6 | 0.661 | 33.15* | 5.59 | 13.7 | 102.8 |
| 6-8 | 0.932 | 13.28* | 7.89 | 11.4 | 47.0 |
| 8-10 | 1.161 |  |  | 10.0 | 22.6 |
| 10-12 | 1.366 | 4.77* | 10.28 | 9.4 | 16.6 |
| 12-14 | 1.565 | 2.59 | 9.43 | 9.4 | 10.5 |
| 16-18 | 1.997 | 1.66 | 11.10 | 11.2 | 7.1 |
| 18-20 | 2.226 | 1.32 | 10.82 | 10.6 | 14.2 |
| 20-22 | 2.450 | 1.45 | 11.63 | 10.7 | 11.6 |

Supported lead-210 activity = 1.32 dpm/g

### Bob Lake Core I (14-4)

| DEPTH INTERVAL cm | CUMULATIVE MASS g/cm2 | LEAD-210 ACTIVITY dpm/g | COUNTING ERROR % | % DRY MASS | TOTAL LEAD ug/g |
|---|---|---|---|---|---|
| 0-2 | 0.102 | 59.27 | 5.2 | 9.9 | 168.0 |
| 2-4 | 0.333 | 58.99* | 6.6 | 12.1 | 158.1 |
| 4-6 | 0.563 | 38.22* | 6.6 | 11.7 | 108.0 |
| 6-8 | 0.827 | 25.18* | 6.8 | 11.0 | 76.8 |
| 8-10 | 1.059 | 16.53* | 7.3 | 10.9 | 58.7 |
| 10-12 | 1.302 | | | 10.5 | 27.7 |
| 12-14 | 1.502 | 8.45 | 6.0 | 10.0 | 43.8 |
| 16-18 | 1.909 | 3.98 | 7.6 | 9.5 | 10.1 |
| 18-20 | 2.105 | 2.71 | 9.2 | 9.1 | 11.9 |
| 20-22 | 2.298 | 2.13 | 10.4 | 9.5 | |
| 22-24 | 2.501 | 2.03 | 10.7 | 9.9 | |
| 24-26 | 2.715 | 1.75 | 10.5 | 10.7 | |

Supported lead-210 activity = 1.89 dpm/g

### Bob Lake Core J (19-4)

| DEPTH INTERVAL cm | CUMULATIVE MASS g/cm2 | LEAD-210 ACTIVITY dpm/g | COUNTING ERROR % | % DRY MASS | TOTAL LEAD ug/g |
|---|---|---|---|---|---|
| 0-2 | 0.101 | 60.10 | 5.15 | 9.5 | 194.2 |
| 2-4 | 0.330 | 56.38 | 6.57 | 12.0 | 136.3 |
| 4-6 | 0.597 | 49.89* | 3.72 | 12.9 | 142.6 |
| 6-8 | 0.868 | 26.82* | 5.64 | 12.2 | 92.6 |
| 8-10 | 1.119 | 13.07* | 5.64 | 11.5 | 57.6 |
| 10-12 | 1.344 | 8.98* | 13.02 | 10.1 | 28.9 |
| 12-14 | 1.554 | 3.70* | 6.82 | 11.0 | 18.3 |
| 16-18 | 1.965 | 2.69 | 6.99 | 9.8 | 16.5 |
| 18-20 | 2.177 | 2.82 | 7.70 | 10.2 | 0.0 |

Supported lead-210 activity = 2.32 dpm/g

Bob Lake Core L (21-2)

| DEPTH INTERVAL cm | CUMULATIVE MASS g/cm2 | LEAD-210 ACTIVITY dpm/g | COUNTING ERROR % | % DRY MASS | TOTAL LEAD ug/g |
|---|---|---|---|---|---|
| 0-2 | 0.095 | 67.79 | 4.25 | 9.1 | 185.8 |
| 2-4 | 0.312 | 68.32 | 9.8 | 11.3 | 183.0 |
| 4-6 | 0.559 | 51.03* | 7.0 | 11.5 | 140.1 |
| 6-8 | 0.802 | 33.63* | 38.8 | 11.3 | 86.4 |
| 8-10 | 1.035 | 17.91* | 9.25 | 10.5 | 47.7 |
| 10-12 | 1.252 | 11.37* | 16.1 | 9.7 | 30.6 |
| 12-14 | 1.460 | 6.47 | 6.7 | 9.6 | 20.4 |
| 16-18 | 1.667 | 3.57 | 9.9 | 10.3 | 11.0 |
| 18-20 | 1.893 | 3.29 | 9.4 | 10.7 | 11.1 |

Supported lead-210 activity = 3.29 dpm/g

Bob Lake Core M (9-11)

| DEPTH INTERVAL cm | CUMULATIVE MASS g/cm2 | LEAD-210@ ACTIVITY cpm/g | COUNTING ERROR % | % DRY MASS | TOTAL LEAD ug/g |
|---|---|---|---|---|---|
| 0-2 | 0.096 | 28.47 | 4.47 | 10.1 | 195.1 |
| 2-4 | 0.313 | 27.93 | 4.47 | 12.0 | 171.1 |
| 4-6 | 0.549 | 26.50 | 4.47 | 12.1 | 155.3 |
| 6-8 | 0.785 | 22.94 | 4.47 | 11.9 | 154.3 |
| 8-10 | 1.007 | 18.88* | 4.47 | 11.4 | 130.7 |
| 10-12 | 1.217 | 13.86* | 4.47 | 11.0 | 82.7 |
| 12-14 | 1.433 | 9.82* | 4.47 | ---- | 64.1 |
| 16-18 | 1.864 | 6.14 | 4.47 | ---- | 44.5 |
| 18-20 | 2.063 | 5.34 | 4.47 | 10.4 | 37.6 |

Supported lead-210 activity = 4.8 cpm/g

@ counted using bismuth-210 method...results are in relative counts/min

Bob Lake Core P (21-4)

| DEPTH INTERVAL cm | CUMULATIVE MASS g/cm2 | LEAD-210 ACTIVITY dpm/g | COUNTING ERROR % | % DRY MASS | TOTAL LEAD ug/g |
|---|---|---|---|---|---|
| 0-2 | 0.095 | 77.08 | 5.7 | 9.3 | 245.0 |
| 2-4 | 0.310 | 61.23* | 6.9 | 11.0 | 208.0 |
| 4-6 | 0.545 | 40.91* | 6.5 | 10.9 | 126.0 |
| 6-8 | 0.775 | 33.71 | 10.9 | 10.1 | 99.0 |
| 8-10 | 0.991 | | | 9.6 | 68.0 |
| 10-12 | 1.179 | 12.14* | 5.9 | 8.4 | 32.0 |
| 12-14 | 1.355 | 6.02 | 8.9 | 8.5 | 17.0 |
| 16-18 | 1.723 | 3.52 | 11.1 | 9.2 | 9.0 |
| 18-20 | 1.917 | 2.66 | 6.3 | 9.7 | 9.0 |
| 20-22 | 1.123 | 3.17 | 6.5 | 9.9 | 7.0 |

Supported lead-210 activity = 1.94 dpm/g

Bob Lake Core Q (20-4)

| DEPTH INTERVAL cm | CUMULATIVE MASS g/cm2 | LEAD-210 ACTIVITY dpm/g | COUNTING ERROR % | % DRY MASS | TOTAL LEAD ug/g |
|---|---|---|---|---|---|
| 0-2 | 0.095 | 49.74 | 3.48 | 9.3 | 217.6 |
| 2-4 | 0.031 | 47.96 | 3.57 | 10.6 | 161.4 |
| 4-6 | 0.551 | 45.52 | 2.36 | 12.0 | 173.7 |
| 6-8 | 0.810 | 39.26* | 2.74 | 12.2 | 134.2 |
| 8-10 | 1.061 | 25.65* | 4.84 | 11.6 | 97.1 |
| 10-12 | 1.303 | 16.96* | 8.65 | 11.1 | 59.2 |
| 12-14 | 1.531 | 9.53* | 4.34 | 10.3 | 39.7 |
| 16-18 | 1.955 | 4.49 | 5.46 | 9.7 | 25.8 |
| 18-20 | 2.167 | 3.96 | 6.11 | 10.3 | 19.9 |
| 20-22 | 2.394 | 3.98 | 15.43 | 11.0 | |

Supported lead-210 activity = 3.98 dpm/g

Bob Lake Core R (9-5)

| DEPTH INTERVAL cm | CUMULATIVE MASS g/cm2 | LEAD-210 ACTIVITY dpm/g | COUNTING ERROR % | % DRY MASS | TOTAL LEAD ug/g |
|---|---|---|---|---|---|
| 0-2 | 0.104 | 69.44 | 3.88 | 9.6 | 193.4 |
| 2-4 | 0.326 | 51.64 | 5.41 | 11.4 | 171.5 |
| 4-6 | 0.573 | 60.05 | 4.89 | 11.6 | 154.3 |
| 6-8 | 0.826 | 44.88* | 5.96 | 11.7 | 120.2 |
| 8-10 | 1.071 | 27.64* | 7.55 | 11.3 | 86.2 |
| 10-12 | 1.310 | 20.61* | 6.18 | 11.2 | 64.1 |
| 12-14 | 1.539 | 10.52* | 7.72 | 10.4 | 45.0 |
| 16-18 | 1.958 | 6.77* | 6.15 | 9.6 | 17.7 |
| 18-20 | 2.158 | 3.65 | 7.03 | 9.4 | 14.4 |
| 20-22 | 2.358 | 2.41 | 8.33 | 9.7 | 6.3 |
| 22-24 | 2.567 | 2.39 | 8.03 | 10.2 | 0.0 |
| 24-26 | 2.780 | 1.89 | 9.23 | 10.1 | 8.7 |

Supported lead-210 activity = 1.32 dpm/g

Bob Lake Core S (23-4)

| DEPTH INTERVAL cm | CUMULATIVE MASS g/cm2 | LEAD-210 ACTIVITY dpm/g | COUNTING ERROR % | % DRY MASS | TOTAL LEAD ug/g |
|---|---|---|---|---|---|
| 0-2 | 0.092 | 81.78 | 4.86 | 9.0 | 270.0 |
| 2-4 | 0.294 | 59.16 | 6.53 | 10.6 | 242.5 |
| 4-6 | 0.527 | 75.17 | 6.26 | 11.4 | 183.6 |
| 6-8 | 0.771 | 44.74* | 3.83 | 11.4 | 132.2 |
| 8-10 | 1.005 | 29.49* | 4.42 | 10.7 | 103.0 |
| 10-12 | 1.226 | 20.03* | 5.25 | 10.2 | 46.9 |
| 12-14 | 1.430 | 10.73 | 5.30 | 9.3 | 30.0 |
| 16-18 | 1.818 | 3.82 | 8.06 | 9.1 | 22.1 |
| 18-20 | 2.013 | 2.59 | 7.71 | 9.5 | 17.9 |
| 20-22 | 2.206 | 2.08 | 10.65 | 10.2 | 15.0 |

Supported lead-210 activity = 2.08 dpm/g

### Bob Lake Core T (22-6)

| DEPTH INTERVAL cm | CUMULATIVE MASS g/cm2 | LEAD-210 ACTIVITY dpm/g | COUNTING ERROR % | % DRY MASS | TOTAL LEAD ug/g |
|---|---|---|---|---|---|
| 0-2 | 0.090 | 99.20 | 6.87 | 9.0 | 246.2 |
| 2-4 | 0.292 | 76.63 | 5.89 | 10.5 | 178.8 |
| 4-6 | 0.523 | 64.06 | 7.09 | 10.9 | 167.0 |
| 6-8 | 0.761 | 51.29* | 4.25 | 11.1 | 142.5 |
| 8-10 | 0.991 | 34.77* | 4.29 | 10.6 | 116.0 |
| 10-12 | 1.208 | 25.89* | 4.95 | 10.3 | 88.4 |
| 12-14 | 1.425 | 17.59* | 6.23 | 10.3 | 62.5 |
| 16-18 | 1.834 | 11.34 | 4.21 | 9.1 | 67.0 |
| 18-20 | 2.018 | 6.57 | 4.48 | 8.5 | 30.0 |
| 20-22 | 2.208 | 3.87 | 5.52 | 9.4 | 0.0 |

Supported lead-210 activity = 2.40 dpm/g

### Bob Lake Core U (7-5)

| DEPTH INTERVAL cm | CUMULATIVE MASS g/cm2 | LEAD-210 ACTIVITY dpm/g | COUNTING ERROR % | % DRY MASS | TOTAL LEAD ug/g |
|---|---|---|---|---|---|
| 0-2 | 0.082 | 73.02 | 7.71 | 7.9 | 146.5 |
| 2-4 | 0.269 | 32.89 | 6.94 | 9.9 | 109.0 |
| 4-6 | 0.486 | 46.49 | 5.64 | 10.4 | 120.4 |
| 6-8 | 0.719 | 39.15* | 4.95 | 11.2 | 136.9 |
| 8-10 | 0.957 | 29.51* | 4.28 | 11.0 | 124.7 |
| 10-12 | 1.181 | 20.84* | 3.63 | 10.2 | 100.0 |
| 12-14 | 1.388 | 17.28* | 3.92 | 9.8 | 54.6 |
| 16-18 | 1.770 | 8.95 | 7.37 | 8.7 | 24.8 |
| 18-20 | 1.949 | 5.58 | 7.16 | 8.5 | 18.4 |
| 20-22 | 2.129 | 3.72 | 8.52 | 8.6 | |
| 22-24 | 2.314 | 2.84 | 5.69 | 8.9 | |
| 24-26 | 2.505 | 2.32 | 5.50 | 9.4 | |
| 26-28 | 2.704 | 2.50 | 5.91 | 9.8 | |
| 28-30 | 2.909 | 2.78 | 6.23 | 9.7 | 2.7 |

Supported lead-210 activity = 2.50 dpm/g

Bob Lake Core V ( 1)

| DEPTH INTERVAL cm | CUMULATIVE MASS g/cm2 | LEAD-210 ACTIVITY dpm/g | COUNTING ERROR % | % DRY MASS |
|---|---|---|---|---|
| 0-1 | 0.042 | 38.60 | 4.50 | 10.0 |
| 1-2 | 0.133 | 39.59 | 4.95 | 12.4 |
| 2-3 | 0.225 | 40.69 | 4.75 | 12.1 |
| 3-4 | 0.324 | 31.18 | 5.61 | 13.0 |
| 4-5 | 0.434 | 33.15 | 5.99 | 13.2 |
| 5-6 | 0.545 | 22.02 | 4.45 | 13.8 |
| 6-8 | 0.715 | 23.00* | 4.55 | 13.7 |
| 8-10 | 0.939 | 9.31* | 6.10 | 13.6 |
| 10-12 | 1.156 | 5.05 | 7.76 | 13.0 |
| 12-14 | 1.380 | 3.75 | 10.13 | 14.0 |
| 14-16 | 1.619 | 3.70 | 6.46 | 14.4 |

Supported lead-210 activity = 3.70 dpm/g

## APPENDIX II:

### B. RED CHALK LAKE

RED CHALK LAKE CORE 1

| DEPTH INTERVAL cm | CUMULATIVE MASS g/cm2 | LEAD-210 ACTIVITY dpm/g | COUNTING ERROR % | % DRY MASS |
|---|---|---|---|---|
| 0-1 | 0.588 | 6.718* | 8.10 | 68.6 |
| 1-2 | 1.749 | | | 73.1 |
| 2-3 | 2.853 | 3.761* | 8.98 | 66.2 |
| 3-4 | 3.742 | 2.288* | 11.54 | 54.9 |
| 4-5 | 4.454 | 1.740* | 12.50 | 51.0 |
| 5-6 | 5.147 | 1.684 | 12.60 | 47.5 |
| 6-7 | 5.740 | 1.802 | 8.30 | 43.7 |
| 7-8 | 6.255 | 1.540 | 9.27 | 45.1 |
| 8-9 | 6.866 | 1.470 | 8.92 | 53.3 |
| 9-10 | 7.596 | 1.212 | 9.06 | 55.4 |
| 10-11 | 8.456 | 1.361 | 9.21 | 65.8 |
| 11-12 | 9.476 | | | 70.0 |
| 12-13 | 10.569 | | | 67.7 |
| 13-14 | 11.661 | | | 66.4 |
| 14-15 | 12.732 | 0.912 | 9.40 | 65.4 |
| 15-16 | 13.801 | | | 66.6 |
| 16-17 | 14.825 | | | 62.2 |
| 17-18 | 15.742 | | | 58.1 |
| 18-19 | 16.625 | | | 57.1 |
| 19-20 | 17.653 | 1.127 | 8.88 | 66.0 |

Supported lead-210 activity = 0.91 dpm/g

## RED CHALK LAKE CORE 6

| DEPTH INTERVAL cm | CUMULATIVE MASS g/cm2 | LEAD-210 ACTIVITY dpm/g | COUNTING ERROR % | % DRY MASS |
|---|---|---|---|---|
| 0-1 | 0.038 | 19.84 | 5.04 | 11.5 |
| 1-2 | 0.157 | 20.81 | 4.98 | 18.7 |
| 2-3 | 0.355 | 18.39 | 5.90 | 22.8 |
| 3-4 | 0.602 | 17.47 | 5.23 | 23.2 |
| 4-5 | 0.854 | 16.50 | 5.11 | 22.4 |
| 5-6 | 1.111 | 11.76* | 8.87 | 23.5 |
| 6-7 | 1.372 | 7.26* | 7.89 | 23.1 |
| 7-8 | 1.613 | 5.90* | 9.83 | 20.9 |
| 8-9 | 1.829 | 3.19* | 13.58 | 18.2 |
| 9-10 | 2.021 | 2.03* | 9.87 | 17.4 |
| 10-12 | 2.286 | 1.69 | 7.39 | 16.1 |
| 12-14 | 2.618 | 1.26 | 9.60 | 14.5 |
| 14-16 | 2.914 | 0.73 | 12.61 | 13.3 |
| 16-18 | 3.174 |  |  | 11.6 |
| 18-20 | 3.416 | 0.39 | 14.66 | 11.1 |

Supported lead-210 activity = 0.39 dpm/g

## RED CHALK CORE 8

| DEPTH INTERVAL cm | CUMULATIVE MASS g/cm2 | LEAD-210 ACTIVITY dpm/g | COUNTING ERROR % | % DRY MASS | TOTAL LEAD ug/g |
|---|---|---|---|---|---|
| 0-1 | 0.468 | 5.024 | 8.52 | 61.6 | 9.1 |
| 1-2 | 1.564 | 5.011 | 4.86 | 71.2 | 9.0 |
| 2-3 | 2.863 | 3.542* | 4.58 | 75.1 | 7.9 |
| 3-4 | 4.279 | 1.510* | 17.02 | 75.6 | 3.3 |
| 4-5 | 5.819 | 0.816* | 18.21 | 77.3 | 1.2 |
| 5-6 | 7.307 | 0.404* | 20.33 | 76.8 | 2.2 |
| 6-7 | 8.720 |  |  | 72.7 | 1.3 |
| 7-8 | 10.073 |  |  | 72.7 | 1.3 |
| 8-9 | 11.347 | 0.300 | 25.26 | 71.7 | 0.8 |
| 9-10 | 12.669 | 0.444 | 18.24 | 72.7 | 1.3 |
| 10-12 | 14.728 |  |  | 72.7 |  |
| 12-14 | 17.390 | 0.252 | 18.75 | 72.0 |  |

Supported lead-210 activity = 0.25 dpm/g

## RED CHALK LAKE CORE 9

| DEPTH INTERVAL cm | CUMULATIVE MASS g/cm2 | LEAD-210 ACTIVITY dpm/g | COUNTING ERROR % | % DRY MASS |
|---|---|---|---|---|
| 0-1 | 0.021 | 29.497 | 3.80 | 4.7 |
| 1-2 | 0.067 | 35.686 | 5.03 | 6.0 |
| 2-3 | 0.123 | 34.048 | 3.80 | 6.6 |
| 3-4 | 0.184 | 31.407 | 4.59 | 6.7 |
| 4-5 | 0.250 | 32.133 | 4.04 | 6.8 |
| 5-6 | 0.317 | 39.302 | 4.26 | 7.7 |
| 6-7 | 0.390 | 44.230 | 4.31 | 7.3 |
| 7-8 | 0.464 | 48.888 | 2.94 | 7.5 |
| 8-9 | 0.536 | 47.162 | 3.17 | 7.4 |
| 9-10 | 0.614 | 51.374 | 2.69 | 7.4 |
| 10-12 | 0.728 | 39.378 | 2.50 | 7.4 |
| 12-14 | 0.879 | 50.655 | 2.59 | 7.6 |
| 14-16 | 1.031 | 27.972 | 2.68 | 7.6 |
| 16-18 | 1.185 | 29.355 | 3.04 | 7.6 |
| 18-20 | 1.331 | 14.176 | 4.51 | 7.1 |

## RED CHALK CORE 10

| DEPTH INTERVAL cm | CUMULATIVE MASS g/cm2 | LEAD-210 ACTIVITY dpm/g | COUNTING ERROR % | % DRY MASS |
|---|---|---|---|---|
| 0-1 | 0.011 | 47.268 | 5.19 | 3.7 |
| 1-2 | 0.042 | 50.431* | 5.02 | 5.1 |
| 2-3 | 0.089 | 44.041* | 4.97 | 5.4 |
| 3-4 | 0.139 | 25.410* | 5.96 | 5.3 |
| 4-5 | 0.182 | 21.901* | 5.28 | 5.1 |
| 5-6 | 0.229 | 17.481* | 5.43 | 5.5 |
| 6-7 | 0.278 | 11.027* | 6.74 | 5.6 |
| 7-8 | 0.326 | 5.669* | 8.11 | 5.9 |
| 8-9 | 0.376 | 3.276* | 5.76 | 5.8 |
| 9-10 | 0.426 | 3.710 | 10.41 | 6.1 |
| 10-12 | 0.501 | 2.566 | 11.64 | 6.6 |
| 12-14 | 0.605 | 2.261 | 8.76 | 6.6 |
| 14-16 | 0.715 | 2.227 | 9.17 | 7.0 |
| 16-18 | 0.826 | 1.398 | 10.14 | 6.9 |
| 18-20 | 0.941 | 1.489 | 10.40 | 6.9 |
| 20-22 | 1.059 | 1.282 | 12.18 | 7.3 |
| 22-24 | 1.179 | 1.436 | 10.06 | 7.4 |
| 24-26 | 1.300 | 1.361 | 11.76 | 7.4 |
| 26-28 | 1.420 | 1.319 | 10.54 | 7.3 |
| 28-30 | 1.541 | 1.081 | 11.07 | 7.4 |

Supported lead-210 activity = 1.0 dpm/g

RED CHALK CORE 11

| DEPTH INTERVAL cm | CUMULATIVE MASS g/cm2 | LEAD-210 ACTIVITY dpm/g | COUNTING ERROR % | % DRY MASS |
|---|---|---|---|---|
| 0-1 | 0.012 | 38.564 | 3.38 | 3.9 |
| 1-2 | 0.040 | 34.966 | 5.30 | 5.4 |
| 2-3 | 0.071 | 37.574 | 5.84 | 5.8 |
| 3-4 | 0.101 | 37.147 | 5.39 | 5.7 |
| 4-5 | 0.128 | 35.317 | 6.19 | 6.0 |
| 5-6 | 0.158 | 33.038 | 5.60 | .1 |
| 6-7 | 0.190 | 27.651 | 7.94 | 6.2 |
| 7-8 | 0.223 | 31.148 | 18.60 | 6.7 |
| 8-9 | 0.258 | 6.509 | 6.90 | 6.4 |
| 9-10 | 0.293 | 5.192 | 7.46 | 6.7 |
| 10-12 | 0.347 | 3.570 | 7.62 | 6.8 |
| 12-14 | 0.420 | 3.981 | 7.38 | 6.7 |
| 14-16 | 0.494 | 2.957 | 8.64 | 6.8 |
| 16-18 | 0.566 | 3.314 | 8.32 | 7 |
| 18-20 | 0.638 | 3.546 | 8.10 | 6.7 |

RED CHALK LAKE CORE 12

| DEPTH INTERVAL cm | CUMULATIVE MASS g/cm2 | LEAD-210 ACTIVITY dpm/g | COUNTING ERROR % | % DRY MASS |
|---|---|---|---|---|
| 0-1 | 0.013 | 26.319 | 4.06 | 4.1 |
| 1-2 | 0.060 | 23.560 | 7.74 | 6.2 |
| 2-3 | 0.129 | 29.649 | 3.45 | 7.2 |
| 3-4 | 0.202 | 30.912 | 3.21 | 7.6 |
| 4-5 | 0.279 | 27.352 | 3.19 | 7.6 |
| 5-6 | 0.359 | 25.820 | 3.34 | 7.6 |
| 6-7 | 0.440 | 24.201 | 3.58 | 8.0 |
| 7-8 | 0.520 | 27.471 | 2.47 | 8.1 |
| 8-9 | 0.605 | 28.931 | 2.17 | 8.1 |
| 9-10 | 0.690 | 57.999 | 2.38 | 8.2 |
| 10-12 | 0.816 | 50.493 | 2.60 | 8.5 |
| 12-14 | 0.990 | 47.322 | 2.87 | 8.5 |
| 14-16 | 1.169 | 28.289 | 2.47 | 8.8 |
| 16-18 | 1.344 | 24.370 | 2.79 | 8.4 |

## RED CHALK LAKE CORE 13

| DEPTH INTERVAL cm | CUMULATIVE MASS g/cm2 | LEAD-210 ACTIVITY dpm/g | COUNTING ERROR % | % DRY MASS | TOTAL LEAD ug/g |
|---|---|---|---|---|---|
| 0-1 | 0.019 | 39.87 | 3.98 | 5.0 | 119.5 |
| 1-2 | 0.073 | 41.75 | 6.03 | 7.4 | 106.6 |
| 2-3 | 0.150 | 43.15 | 5.64 | 8.3 | 96.0 |
| 3-4 | 0.236 | 43.01 | 4.09 | 9.2 | 108.0 |
| 4-5 | 0.322 | 39.69 | 4.60 | 8.6 | 104.0 |
| 5-6 | 0.407 | 32.52 | 4.75 | 8.7 | 84.8 |
| 6-7 | 0.500 | 23.72* | 5.29 | 9.1 | 68.6 |
| 7-8 | 0.597 | 14.71* | 5.99 | 9.3 | 46.5 |
| 8-9 | 0.689 | 9.32* | 6.45 | 9.3 | 28.7 |
| 9-10 | 0.784 | 4.49* | 5.19 | 9.4 | 22.4 |
| 10-12 | 0.933 | 3.10* | 14.99 | 10.2 | 8.3 |
| 12-14 | 1.139 | 1.76 | 7.85 | 10.2 | 5.2 |
| 14-16 | 1.353 | 1.50 | 8.31 | 10.3 | 9.1 |
| 16-18 | 1.573 | 1.13 | 11.28 | 11.2 | 6.1 |
| 18-20 | 1.796 | 1.02 | 12.16 | 10.8 | 6.2 |

Supported lead-210 activity = 0.95 dpm/g

## RED CHALK LAKE CORE 14

| DEPTH INTERVAL cm | CUMULATIVE MASS g/cm2 | LEAD-210 ACTIVITY dpm/g | COUNTING ERROR % | % DRY MASS | TOTAL LEAD ug/g |
|---|---|---|---|---|---|
| 0-1 | 0.023 | 45.10 | 8.46 | 5.4 | 126.1 |
| 1-2 | 0.073 | 44.27 | 7.45 | 6.9 | 112.5 |
| 2-3 | 0.136 | 25.49 | 7.02 | 7.5 | 117.0 |
| 3-4 | 0.203 | 16.36 | 9.57 | 7.6 | 120.8 |
| 4-5 | 0.276 | 34.82 | 4.15 | 7.7 | 108.4 |
| 5-6 | 0.354 | 52.02 | 5.48 | 7.8 | 116.3 |
| 6-7 | 0.431 | 51.53 | 5.63 | 8.1 | 111.5 |
| 7-8 | 0.510 | 39.44 | 2.52 | 8.1 | 108.6 |
| 8-9 | 0.591 | 37.10* | 2.82 | 7.8 | 92.4 |
| 9-10 | 0.669 | 20.30* | 3.20 | 7.6 | 55.5 |
| 10-12 | 0.782 | 9.68* | 5.10 | 7.4 | 22.3 |
| 12-14 | 0.931 | 3.24 | 4.73 | 7.3 | 14.3 |
| 14-16 | 1.082 | 2.94 | 7.11 | 7.4 | 10.6 |
| 16-18 | 1.240 | 2.36 | 6.00 | 7.7 | 6.6 |

Supported lead-210 activity = 0.95 dpm/g

RED CHALK LAKE CORE 15

| DEPTH INTERVAL cm | CUMULATIVE MASS g/cm2 | LEAD-210 ACTIVITY dpm/g | COUNTING ERROR % | % DRY MASS | TOTAL LEAD ug/g |
|---|---|---|---|---|---|
| 0-1 | 0.022 | 58.586 | 4.47 | 4.9 | 109.3 |
| 1-2 | 0.076 | 54.867 | 4.76 | 6.1 | 110.1 |
| 2-3 | 0.141 | 56.293 | 4.21 | 6.9 | 109.0 |
| 3-4 | 0.213 | 55.339 | 3.91 | 7.5 | 103.7 |
| 4-5 | 0.289 | 54.199 | 2.94 | 7.7 | 101.9 |
| 5-6 | 0.369 | 51.932 | 3.96 | 8.0 | 91.0 |
| 6-7 | 0.450 | 55.728 | 4.25 | 8.1 | 100.9 |
| 7-8 | 0.528 | 48.120* | 4.43 | 8.1 | 91.5 |
| 8-9 | 0.608 | 35.872* | 3.33 | 8.2 | 70.2 |
| 9-10 | 0.689 | 26.008* | 3.32 | 8.3 | 51.3 |
| 10-12 | 0.816 | 6.900* | 5.59 | 8.5 | 13.3 |
| 12-14 | 0.992 | 2.199* | 10.44 | 8.6 | 13.0 |
| 14-16 | 1.174 | 2.130* | 9.47 | 8.9 | 9.1 |
| 16-18 | 1.360 | 1.480 | 10.63 | 9.2 | 2.2 |
| 18-20 | 1.551 | 1.347 | 11.16 | 9.4 | 3.5 |

Supported lead-210 activity = 0.95 dpm/g

RED CHALK LAKE CORE 16

| DEPTH INTERVAL cm | CUMULATIVE MASS g/cm2 | LEAD-210 ACTIVITY dpm/g | COUNTING ERROR % | % DRY MASS | TOTAL LEAD ug/g |
|---|---|---|---|---|---|
| 0-1 | 0.013 | 89.283 | 5.38 | 3.2 | 180.2 |
| 1-2 | 0.048 | | | 5.2 | 180.4 |
| 2-3 | 0.099 | 73.645 | 4.53 | 5.6 | 138.3 |
| 3-4 | 0.156 | 141.408 | 1.93 | 5.9 | 177.7 |
| 4-5 | 0.216 | 82.073 | 2.54 | 6.1 | 178.3 |
| 5-6 | 0.278 | 74.455 | 2.73 | 6.1 | 180.9 |
| 6-7 | 0.341 | 75.151 | 2.62 | 6.4 | 189.2 |
| 7-8 | 0.407 | 83.650 | 2.30 | 6.6 | 200.1 |
| 8-9 | 0.477 | 64.440 | 4.42 | 7.1 | 178.5 |
| 9-10 | 0.547 | 61.667 | 4.24 | 7.0 | 179.0 |
| 10-12 | 0.655 | 65.310 | 4.89 | 6.9 | 160.9 |
| 12-14 | 0.801 | 39.030* | 3.60 | 6.9 | 66.1 |
| 14-16 | 0.942 | 22.994* | 4.19 | 6.7 | 64.7 |
| 16-18 | 1.078 | 27.357 | 3.26 | 6.3 | 28.2 |
| 18-20 | 1.211 | 5.873* | 7.29 | 6.3 | 16.6 |
| 20-22 | 1.345 | 3.521* | 7.08 | 6.5 | 9.6 |
| 22-24 | 1.484 | 2.250* | 9.20 | 6.8 | 6.1 |

Supported lead-210 activity = 0.95 dpm/g

## RED CHALK LAKE CORE 17

| DEPTH INTERVAL cm | CUMULATIVE MASS g/cm2 | LEAD-210 ACTIVITY dpm/g | COUNTING ERROR % | % DRY MASS | TOTAL ug/g |
|---|---|---|---|---|---|
| 0-1 | 0.004 | 122.409 | 8.25 | 0.8 | 239.2 |
| 1-2 | 0.016 | 158.855 | 4.99 | 1.7 | 226.9 |
| 2-3 | 0.040 | 158.329 | 4.33 | 2.9 | 264.2 |
| 3-4 | 0.072 | 154.584 | 3.48 | 3.0 | 346.9 |
| 4-5 | 0.111 | 176.298 | 3.88 | 3.9 | 429.6 |
| 5-6 | 0.154 | 159.708 | 3.98 | 4.1 | 363.3 |
| 6-7 | 0.200 | 186.111 | 3.71 | 4.6 | 428.6 |
| 7-8 | 0.249 | 165.462* | 3.70 | 4.4 | 444.2 |
| 8-9 | 0.300 | 147.366* | 5.40 | 4.9 | 342.8 |
| 9-10 | 0.356 | 110.282* | 1.95 | 5.6 | 243.6 |
| 10-12 | 0.440 | 79.156* | 2.50 | 5.4 | 192.5 |
| 12-14 | 0.554 | 59.868* | 2.52 | 5.7 | 169.5 |
| 14-16 | 0.661 | 41.520* | 3.24 | 4.9 | 112.2 |
| 16-18 | 0.756 | 23.966* | 3.70 | 4.5 | 50.3 |
| 18-20 | 0.852 | 19.291* | 3.86 | 5.1 | 30.2 |
| 20-22 | 0.952 | 11.366 | 4.80 | 5.2 | 21.9 |
| 22-24 | 1.055 | 7.663 | 5.28 | 5.1 | |
| 24-26 | 1.157 | 4.190 | 6.95 | 5.1 | |
| 26-28 | 1.256 | 3.117 | 8.25 | 5.0 | |
| 28-30 | 1.367 | 4.214 | 9.57 | 6.0 | |

Supported lead-210 activity = 0.95 dpm/g

## RED CHALK LAKE CORE 18

| DEPTH INTERVAL cm | CUMULATIVE MASS g/cm2 | LEAD-210 ACTIVITY dpm/g | COUNTING ERROR % | % DRY MASS | TOTAL LEAD ug/g |
|---|---|---|---|---|---|
| 0-1 | 0.007 | 24.920 | 9.92 | 3.7 | 74.9 |
| 1-2 | 0.025 | 20.540 | 8.87 | 4.4 | 62.8 |
| 2-3 | 0.049 | | | 4.6 | 50.0 |
| 3-4 | 0.074 | 19.140 | 8.03 | 4.9 | 53.7 |
| 4-5 | 0.099 | 12.120 | 20.75 | 4.9 | 53.4 |
| 5-6 | 0.125 | 22.690 | 5.07 | 5.4 | 70.9 |
| 6-7 | 0.153 | 21.720 | 9.50 | 5.5 | 68.7 |
| 7-8 | 0.182 | 26.030 | 7.11 | 5.7 | 69.9 |
| 8-9 | 0.213 | 22.329 | 5.80 | 6.0 | 75.6 |
| 9-10 | 0.245 | 18.535 | 5.56 | 5.9 | 51.2 |
| 10-12 | 0.292 | 4.708 | 7.61 | 5.9 | 14.8 |
| 12-14 | 0.357 | 3.065 | 8.99 | 6.1 | 15.6 |
| 14-16 | 0.422 | 3.522 | 7.52 | 6.1 | 22.7 |
| 16-18 | 0.486 | 3.172 | 8.44 | 5.8 | 25.3 |
| 18-20 | 0.551 | 2.985 | 8.84 | 6.3 | 27.0 |
| 20-21 | 0.601 | 2.917 | 8.19 | 6.4 | |

RED CHALK LAKE CORE 19

| DEPTH INTERVAL cm | CUMULATIVE MASS g/cm2 | LEAD-210 ACTIVITY dpm/g | COUNTING ERROR % | % DRY MASS | TOTAL LEAD ug/g |
|---|---|---|---|---|---|
| 0-1 | 0.014 | 25.93 | 10.30 | 2.8 | 31.5 |
| 1-2 | 0.049 | 22.9d | 9.10 | 4.0 | 39.3 |
| 2-3 | 0.092 | 20.95 | 6.87 | 4.3 | 51.9 |
| 3-4 | 0.138 | 23.62 | 5.95 | 4.6 | 45.0 |
| 4-5 | 0.187 | 25.60 | 7.85 | 5.0 | 47.1 |
| 5-6 | 0.237 | 23.06 | 6.47 | 5.0 | 57.5 |
| 6-7 | 0.287 | 23.38 | 7.33 | 4.9 | 87.1 |
| 7-8 | 0.338 | 19.67 | 3.48 | 5.3 | 50.3 |
| 8-9 | 0.394 | 22.22 | 4.54 | 5.5 | 55.7 |
| 9-10 | 0.450 | 21.40 | 3.58 | 5.6 | 46.5 |
| 10-12 | 0.537 | 21.17 | 4.45 | 5.6 | 50.8 |
| 12-14 | 0.658 | 9.45 | 6.53 | 6.0 | 55.4 |
| 14-16 | 0.768 | 16.85* | 12.69 | 6.3 | 37.3 |
| 16-18 | 0.917 | 5.48* | 10.91 | 6.2 | 10.9 |
| 18-20 | 1.045 | 2.93* | 16.95 |  | 3.8 |

Supported lead-210 activity = 0.95 dpm/g

RED CHALK LAKE CORE 30

| DEPTH INTERVAL cm | CUMULATIVE MASS g/cm2 | LEAD-210 ACTIVITY dpm/g | COUNTING ERROR % | % DRY MASS | TOTAL LEAD ug/g |
|---|---|---|---|---|---|
| 0-1 | 0.009 | 109.421 | 3.77 | 2.0 | 237.1 |
| 1-2 | 0.033 | 99.360 | 3.22 | 2.7 | 259.3 |
| 2-3 | 0.064 | 93.094 | 3.52 | 3.2 | 330.2 |
| 3-4 | 0.100 | 115.104 | 2.23 | 4.3 | 429.3 |
| 4-5 | 0.143 | 85.083 | 2.22 | 4.7 | 424.4 |
| 5-6 | 0.190 | | | 4.7 | 393.9 |
| 6-7 | 0.239 | 131.400 | 3.05 | 4.9 | 483.5 |
| 7-8 | 0.289 | 73.594 | 3.55 | 4.9 | 407.1 |
| 8-9 | 0.343 | 69.242 | 3.84 | 5.6 | 260.1 |
| 9-10 | 0.397 | 59.807* | 4.08 | 5.3 | 199.5 |
| 10-11 | 0.448 | | | 5.1 | 188.4 |
| 11-12 | 0.501 | 41.941* | 4.56 | 5.6 | |
| 12-13 | 0.574 | | | 8.9 | 108.0 |
| 13-14 | 0.647 | 27.581* | 2.91 | 5.3 | |
| 14-15 | 0.699 | | | 5.0 | 97.2 |
| 15-16 | 0.746 | 20.966* | 5.19 | 4.5 | |
| 16-17 | 0.792 | | | 4.7 | 67.0 |
| 17-18 | 0.837 | 15.334* | 6.18 | 4.1 | |
| 18-19 | 0.881 | | | 4.8 | 36.2 |
| 19-20 | 0.928 | 15.765 | 4.54 | 4.9 | |
| 20-21 | 0.977 | | | 5.2 | 36.1 |
| 21-22 | 1.031 | | | 5.3 | |
| 22-23 | 1.065 | | | 1.3 | |
| 23-24 | 1.097 | | | 5.2 | |
| 24-25 | 1.149 | 4.952 | 5.19 | 5.2 | 14.4 |
| 30-31 | ----- | 2.555 | 11.33 | 4.7 | 14.8 |
| 35-36 | ----- | 2.827 | 7.61 | 6.6 | |
| 40-41 | ----- | 2.370 | 8.34 | 6.2 | 11.5 |
| 45-46 | ----- | 2.602 | 8.69 | | |

Supported lead-210 activity = 2.4 dpm/g

RED CHALK LAKE CORE 31

| DEPTH INTERVAL cm | CUMULATIVE MASS g/cm2 | LEAD-210 ACTIVITY dpm/g | COUNTING ERROR % | % DRY MASS | TOTAL LEAD ug/g |
|---|---|---|---|---|---|
| 0-1 | 0.013 | 79.724 | 4.64 | 3.3 | 190.8 |
| 1-2 | 0.048 | 73.737 | 4.35 | 5.2 | 183.2 |
| 2-3 | 0.093 | 79.898 | 4.37 | 5.9 | 182.3 |
| 3-4 | 0.144 | 74.904 | 4.60 | 6.2 | 179.4 |
| 4-5 | 0.200 | 75.875 | 3.48 | 6.3 | 184.3 |
| 5-6 | 0.258 | 74.375 | 3.44 | 6.4 | 177.1 |
| 6-7 | 0.317 | 76.187 | 4.18 | 6.5 | 180.9 |
| 7-8 | 0.378 | 78.002 | 4.11 | 6.8 | 188.4 |
| 8-9 | 0.443 | 78.125 | 4.33 | 6.9 | 182.1 |
| 9-10 | 0.509 | 79.725 | 3.92 | 6.9 | 178.7 |
| 10-11 | 0.573 | 77.224 | 2.27 | 7.0 | 181.5 |
| 1-12 | 0.640 | | | 7.1 | |
| 12-13 | 0.710 | 75.060 | 4.42 | 7.2 | 170.9 |
| 13-14 | 0.780 | | | | |
| 14-15 | 0.850 | 67.241 | 4.73 | 6.9 | 132.5 |
| 15-16 | 0.919 | | | 6.9 | |
| 16-17 | 0.989 | 67.433 | 4.51 | 7.1 | 157.9 |
| 17-18 | 1.061 | | | 7.0 | |
| 18-19 | 1.134 | 68.808 | 4.59 | 7.1 | 151.6 |
| 19-20 | 1.207 | 54.754* | 4.33 | 7.2 | 110.8 |
| 20-21 | 1.279 | 48.501* | 4.60 | 7.4 | |
| 21-22 | 1.352 | 43.157* | 5.44 | 7.3 | |
| 22-23 | 1.425 | 33.864* | 6.00 | 7.1 | |
| 23-24 | 1.498 | 34.573 | 3.18 | 7.1 | |
| 24-25 | 1.570 | 31.541* | 4.03 | 7.1 | |
| 30-31 | 2.024 | 10.677* | 5.00 | 7.1 | |
| 35-36 | 2.309 | 3.824* | 6.13 | 7.3 | |
| 40-41 | 2.826 | 2.087* | 9.28 | 8.7 | |

Supported lead-210 activity = 0.95 dpm/g

RED CHALK LAKE CORE 32

| DEPTH INTERVAL cm | CUMULATIVE MASS g/cm2 | LEAD-210 ACTIVITY dpm/g | COUNTING ERROR % | % DRY MASS | TOTAL LEAD ug/g |
|---|---|---|---|---|---|
| 0-1 | 0.016 | 63.386 | 5.30 | 4.2 | 150.9 |
| 1-2 | 0.057 | 72.114 | 2.32 | 5.3 | 158.6 |
| 2-3 | 0.110 | 73.528 | 4.24 | 5.7 | 174.4 |
| 3-4 | 0.171 | 69.069 | 5.25 | 6.2 | 163.6 |
| 4-5 | 0.232 | 62.682 | 4.75 | 6.4 | 150.1 |
| 5-6 | 0.293 | 58.207 | 2.85 | 6.3 | 134.4 |
| 6-7 | 0.352 | 22.023* | 4.26 | 5.9 | 51.5 |
| 7-8 | 0.409 | 12.505* | 7.40 | 6.0 | 26.6 |
| 8-9 | 0.467 | 9.596* | 4.93 | 6.1 | 21.8 |
| 9-10 | 0.525 | 6.753* | 6.25 | 6.1 | 22.3 |
| 10-11 | 0.585 | 5.788* | 10.24 | 6.2 | 11.8 |
| 11-12 | 0.648 |  |  | 6.4 |  |
| 12-13 | 0.712 | 4.261 | 6.17 | 6.4 | 13.5 |
| 13-14 | 0.775 |  |  | 6.4 |  |
| 14-15 | 0.837 | 3.231 | 9.38 | 6.3 | 13.1 |
| 15-16 | 0.901 |  |  | 6.3 |  |
| 16-17 | 0.965 | 3.334 | 7.14 | 6.4 | 8.0 |
| 17-18 | 1.029 |  |  | 6.3 |  |
| 18-19 | 1.095 | 2.780 | 7.23 | 6.5 | 8.4 |
| 19-20 | 1.163 | 2.473 | 7.79 | 6.3 | 8.4 |
| 25-26 | ----- | 1.476 | 11.04 | 6.9 | 1.3 |

Supported lead-210 activity = 0.95 dpm/g

RED CHALK LAKE CORE 33

| DEPTH INTERVAL cm | CUMULATIVE MASS g/cm2 | LEAD-210 ACTIVITY dpm/g | COUNTING ERROR % | % DRY MASS | TOTAL LEAD ug/g |
|---|---|---|---|---|---|
| 0-1 | 0.017 | 97.473 | 5.52 | 3.7 | 285.8 |
| 1-2 | 0.063 |  |  | 5.6 | 215.8 |
| 2-3 | 0.122 | 89.173 | 3.67 | 6.0 | 212.9 |
| 3-4 | 0.184 | 86.225 | 3.60 | 6.3 | 198.2 |
| 4-5 | 0.248 | 84.755 | 4.18 | 6.5 | 206.0 |
| 5-6 | 0.314 | 83.117 | 4.30 | 6.8 | 188.5 |
| 6-7 | 0.383 | 79.321 | 4.66 | 7.0 | 192.4 |
| 7-8 | 0.454 | 75.027 | 4.69 | 7.2 | 176.6 |
| 8-9 | 0.526 | 68.749 | 4.41 | 7.2 | 153.7 |
| 9-10 | 0.600 | 49.017* | 3.34 | 7.2 | 118.1 |
| 10-11 | 0.674 | 42.387* | 3.25 | 7.2 | 91.0 |
| 11-12 | 0.747 |  |  | 7.3 |  |
| 12-13 | 0.819 | 26.063* | 3.86 | 7.0 | 65.5 |
| 13-14 | 0.889 |  |  | 6.8 |  |
| 14-15 | 0.958 | 15.245* | 4.46 | 6.8 | 36.3 |
| 15-16 | 1.027 |  |  | 6.8 |  |
| 16-17 | 1.098 | 8.205* | 5.98 | 6.8 | 17.3 |
| 17-18 | 1.168 |  |  | 6.9 |  |
| 18-19 | 1.238 | 4.572* | 6.52 | 6.8 | 17.4 |
| 19-20 | 1.308 | 3.677* | 8.61 | 6.9 | 12.2 |
| 30-31 | ----- | 1.064 | 12.05 | 7.3 | 3.1 |

Supported lead-210 activity = 0.95 dpm/g

RED CHALK LAKE CORE 35

| DEPTH INTERVAL cm | CUMULATIVE MASS g/cm2 | LEAD-210 ACTIVITY dpm/g | COUNTING ERROR % | TOTAL LEAD ug/g |
|---|---|---|---|---|
| 0-1 | 0.015 | | | 60.6 |
| 1-2 | 0.052 | 37.974 | 6.62 | 58.5 |
| 2-3 | 0.098 | 32.067 | 6.30 | 61.5 |
| 3-4 | 0.139 | 37.977 | 6.08 | 68.3 |
| 4-5 | 0.184 | 39.366 | 6.22 | 67.8 |
| 5-6 | 0.243 | 39.775 | 6.09 | 65.6 |
| 6-7 | 0.302 | 30.125 | 5.63 | 64.2 |
| 7-8 | 0.364 | 51.923* | 4.44 | 71.2 |
| 8-9 | 0.426 | 35.525* | 5.22 | 72.1 |
| 9-10 | 0.487 | 20.226* | 6.65 | 35.2 |
| 10-11 | 0.548 | 4.817* | 10.45 | |
| 11-12 | 0.609 | | | 6.0 |
| 12-13 | 0.668 | 3.217* | 6.95 | |
| 13-14 | 0.727 | | | 6.5 |
| 14-15 | 0.789 | 2.335* | 7.77 | |
| 15-16 | 0.856 | | | 2.9 |
| 16-17 | 0.923 | 1.534* | 12.97 | |
| 17-18 | 0.991 | | | 2.1 |

Supported lead-210 activity = 0.95 dpm/g

RED CHALK LAKE CORE 37

| DEPTH INTERVAL cm | CUMULATIVE MASS g/cm2 | LEAD-210 ACTIVITY dpm/g | COUNTING ERROR % | TOTAL LEAD ug/g |
|---|---|---|---|---|
| 0-1 | 0.011 | | | 249.9 |
| 1-2 | 0.041 | 127.835 | 4.09 | 212.6 |
| 2-3 | 0.085 | 100.190 | 4.08 | 186.4 |
| 3-4 | 0.138 | | | 176.7 |
| 4-5 | 0.194 | 68.717 | 9.69 | 170.3 |
| 5-6 | 0.259 | 90.706 | 4.39 | 170.5 |
| 6-7 | 0.327 | 83.929 | 5.95 | 173.1 |
| 7-8 | 0.389 | 98.432 | 4.38 | 184.0 |
| 8-9 | 0.454 | 99.216 | 3.78 | 187.9 |
| 9-10 | 0.525 | 69.593 | 3.22 | 171.5 |
| 10-11 | 0.601 | 74.851* | 3.34 | |
| 11-12 | 0.673 | | | 133.6 |
| 12-13 | 0.742 | 53.335* | 5.50 | |
| 13-14 | 0.813 | | | 85.8 |
| 14-15 | 0.885 | 31.973* | 3.66 | |
| 15-16 | 0.955 | | | 50.7 |
| 16-17 | 1.021 | 20.596* | 5.25 | |
| 17-18 | 1.087 | | | 27.9 |
| 18-19 | 1.155 | 12.859* | 5.39 | |
| 19-20 | 1.220 | | | 19.9 |
| 20-21 | 1.284 | 9.903* | 4.84 | |
| 21-22 | 1.347 | | | 16.6 |
| 22-23 | 1.410 | 7.984* | 10.24 | |
| 23-24 | 1.476 | | | 7.8 |
| 24-25 | 1.545 | 4.214* | 6.11 | |
| 30-31 | ----- | 1.442 | 12.34 | 4.6 |
| 35-36 | ----- | 0.950 | 13.49 | 2.8 |

Supported lead-210 activity = 0.95 dpm/g

# RED CHALK LAKE CORE 39

| DEPTH INTERVAL cm | CUMULATIVE MASS g/cm2 | LEAD-210 ACTIVITY dpm/g | COUNTING ERROR % | TOTAL LEAD ug/g |
|---|---|---|---|---|
| 0-1 | 0.017 | 50.743 | 5.43 | 99.5 |
| 1-2 | 0.057 | 51.203 | 4.63 | 95.8 |
| 2-3 | 0.105 | 51.419 | 4.91 | 97.3 |
| 3-4 | 0.154 | 52.395 | 4.51 | 98.5 |
| 4-5 | 0.206 | 53.255 | 4.79 | 97.1 |
| 5-6 | 0.262 | 52.292 | 4.87 | 95.3 |
| 6-7 | 0.319 | 44.332* | 5.27 | 82.0 |
| 7-8 | 0.376 | 25.167* | 5.94 | 40.7 |
| 8-9 | 0.435 | 15.504* | 6.72 | 24.3 |
| 9-10 | 0.495 | 9.669* | 7.03 | 13.0 |
| 10-11 | 0.556 | 6.147* | 6.47 | |
| 11-12 | 0.614 | | | 18.3 |
| 12-13 | 0.673 | 15.135 | 6.59 | |
| 13-14 | 0.737 | | | 20.5 |
| 14-15 | 0.804 | 5.579 | 7.68 | |
| 15-16 | 0.869 | | | 5.0 |
| 16-17 | 0.932 | 1.857 | 10.02 | |
| 17-18 | 0.999 | | | 1.3 |
| 18-19 | 1.067 | 2.104 | 12.59 | |
| 19-20 | 1.137 | | | 3.3 |
| 20-21 | 1.209 | 2.326 | 9.35 | |
| 21-22 | 1.276 | | | 1.2 |
| 22-23 | 1.345 | 2.006 | 11.67 | |
| 23-24 | 1.415 | 1.807 | 11.34 | 1.1 |
| 24-25 | 1.484 | 1.887 | 11.35 | 1.2 |

Supported lead-210 activity = 2.0 dpm/g

RED CHALK LAKE CORE 40

| DEPTH INTERVAL cm | CUMULATIVE MASS g/cm2 | LEAD-210 ACTIVITY dpm/g | COUNTING ERROR % | TOTAL LEAD ug/g |
|---|---|---|---|---|
| 0-1 | 0.018 | 99.470 | 4.35 | 185.8 |
| 1-2 | 0.060 | | | 172.9 |
| 2-3 | 0.115 | 96.986 | 5.35 | 188.3 |
| 3-4 | 0.179 | | | 173.6 |
| 4-5 | 0.247 | 76.280 | 4.68 | 160.4 |
| 5-6 | 0.315 | 74.465 | 3.95 | 172.0 |
| 6-7 | 0.386 | 103.464 | 3.43 | 157.1 |
| 7-8 | 0.461 | 63.795 | 4.00 | 130.8 |
| 8-9 | 0.536 | 55.962* | 4.83 | 117.7 |
| 9-10 | 0.609 | 43.889* | 2.97 | 92.9 |
| 10-11 | 0.685 | 29.489* | 2.97 | |
| 11-12 | 0.757 | | | 38.1 |
| 12-13 | 0.827 | 11.991* | 7.68 | |
| 13-14 | 0.899 | | | 17.9 |
| 14-15 | 0.970 | 6.154* | 5.49 | |
| 15-16 | 1.040 | 5.960 | 7.35 | 9.9 |
| 16-17 | 1.108 | 6.689 | 8.69 | |
| 17-18 | 1.183 | 3.237* | 8.55 | 4.7 |
| 18-19 | 1.260 | | 3.41 | |
| 19-20 | 1.343 | 2.243* | 10.78 | 2.3 |

Supported lead-210 activity = 0.95 dpm/g

RED CHALK LAKE CORE 41

| DEPTH INTERVAL cm | CUMULATIVE MASS g/cm2 | LEAD-210 ACTIVITY dpm/g | COUNTING ERROR % | TOTAL LEAD ug/g |
|---|---|---|---|---|
| 0-1 | 0.018 | 74.976 | 4.69 | 185.3 |
| 1-2 | 0.062 | | | 174.0 |
| 2-3 | 0.118 | 90.414 | 4.30 | 176.5 |
| 3-4 | 0.183 | | | 173.1 |
| 4-5 | 0.254 | 84.351 | 3.77 | 172.1 |
| 5-6 | 0.329 | | | 167.9 |
| 6-7 | 0.401 | 92.533 | 8.44 | 164.9 |
| 7-8 | 0.473 | | | 151.3 |
| 8-9 | 0.549 | 69.305* | 4.08 | 132.4 |
| 9-10 | 0.627 | | | 105.6 |
| 10-11 | 0.704 | 36.037* | 7.50 | |
| 11-12 | 0.778 | | | 55.0 |
| 12-13 | 0.849 | 17.387* | 4.09 | |
| 13-14 | 0.921 | | | 22.1 |
| 14-15 | 0.993 | 8.562* | 6.05 | |
| 15-16 | 1.062 | | | 11.9 |
| 16-17 | 1.132 | 4.590* | 7.38 | |
| 17-18 | 1.202 | | | 8.0 |
| 18-19 | 1.254 | 3.050* | 9.32 | |
| 19-20 | 1.342 | | | 9.1 |
| 20-21 | 1.413 | 2.999 | 8.02 | |
| 21-22 | 1.481 | | | 5.8 |
| 22-23 | 1.548 | 8.129 | 6.77 | |
| 23-24 | 1.615 | | | 2.8 |
| 24-25 | 1.684 | 2.030 | 11.71 | |
| 45-46 | ----- | 1.021 | 13.01 | 0.8 |

Supported lead-210 activity = 0.95 dpm/g

## RED CHALK LAKE CORE 45

| DEPTH INTERVAL cm | CUMULATIVE MASS g/cm2 | LEAD-210 ACTIVITY dpm/g | COUNTING ERROR % | TOTAL LEAD ug/g |
|---|---|---|---|---|
| 0-1 | 0.011 | 127.073 | 4.90 | 206.8 |
| 1-2 | 0.044 | 120.454 | 4.44 | 196.0 |
| 2-3 | 0.090 | 99.064 | 4.42 | 186.1 |
| 3-4 | 0.143 | 96.558 | 4.25 | 186.6 |
| 4-5 | 0.200 | 93.049 | 4.47 | 185.2 |
| 5-6 | 0.261 | 89.654* | 3.77 | 173.3 |
| 6-7 | 0.325 | 68.058* | 4.23 | 130.0 |
| 7-8 | 0.393 | 46.451* | 4.74 | 92.6 |
| 8-9 | 0.459 | 55.432 | 3.75 | 68.6 |
| 9-10 | 0.521 | 29.998* | 3.93 | 66.4 |
| 10-11 | 0.585 | 19.346* | 3.86 | |
| 11-12 | 0.651 | | | 30.2 |
| 12-13 | 0.715 | 9.873* | 5.70 | |
| 13-14 | 0.780 | | | 11.8 |
| 14-15 | 0.847 | 4.989* | 6.62 | |
| 15-16 | 0.914 | | | 9.0 |
| 16-17 | 0.982 | 3.287* | 8.01 | |
| 17-18 | 1.051 | | | 6.5 |
| 18-19 | 1.119 | 3.489 | 7.39 | |
| 19-20 | 1.186 | 3.760 | 8.98 | 7.0 |
| 20-21 | 1.255 | 3.219 | 8.41 | |

Supported lead-210 activity = 0.95 dpm/g

## APPENDIX II:

### C. COSTELLO LAKE

COSTELLO LAKE CORE 2

| DEPTH INTERVAL cm | CUMULATIVE MASS g/cm2 | LEAD-210 ACTIVITY dpm/g | COUNTING ERROR % | % DRY MASS |
|---|---|---|---|---|
| 0-1 | 0.439 | 3.063* | 9.90 | 61.9 |
| 1-2 | 1.426 | 2.528* | 10.98 | 67.7 |
| 2-3 | 2.514 | 2.418* | 11.79 | 70.1 |
| 3-4 | 3.712 | 1.389* | 13.13 | 73.0 |
| 4-5 | 5.105 | 0.837 | 17.70 | 73.3 |
| 5-6 | 6.495 | 0.405 | 22.79 | 72.6 |
| 6-7 | 7.805 | 0.460 | 13.93 | 71.1 |
| 7-8 | 9.091 | 1.020 | 11.11 | 70.9 |
| 8-9 | 10.306 | 0.751 | 12.71 | 69.7 |
| 9-10 | 11.447 | | | 70.3 |
| 10-11 | 12.617 | 0.446 | 15.70 | |
| 11-12 | 13.840 | | | 70.9 |
| 12-13 | 15.060 | | | 69.4 |
| 13-14 | 16.228 | | | 68.1 |
| 14-15 | 17.443 | | | 68.2 |
| 15-16 | 18.670 | 0.361 | 14.95 | 71.6 |

Supported lead-210 activity = 0.61 dpm/g

*Composite total lead concentration = 1.36 ug/g

Costello Lake Core 4

| DEPTH INTERVAL cm | CUMULATIVE MASS g/cm2 | LEAD-210 ACTIVITY dpm/g | COUNTING ERROR % | % DRY MASS |
|---|---|---|---|---|
| 0-1 | 0.030 | 24.478 | 6.33 | 7.3 |
| 1-2 | 0.125 | 24.432* | 6.86 | 14.5 |
| 2-3 | 0.312 | 14.897* | 7.85 | 22.8 |
| 3-4 | 0.611 | 8.394* | 8.23 | 33.2 |
| 4-5 | 1.017 | 5.417* | 9.37 | 43.5 |
| 5-6 | 1.349 | 4.617 | 9.77 | 50.0 |

Supported lead-210 activity = 0.67 dpm/g

Costello Lake Core 5

| DEPTH INTERVAL cm | CUMULATIVE MASS g/cm2 | LEAD-210 ACTIVITY dpm/g | COUNTING ERROR % | % DRY MASS |
|---|---|---|---|---|
| 0-1 | 0.103 | 13.129 | 8.27 | 21.6 |
| 1-2 | 0.336 | 13.978* | 7.15 | 24.9 |
| 2-3 | 0.632 | 9.365* | 9.38 | 28.7 |
| 3-4 | 0.983 | 7.761* | 8.66 | 30.1 |
| 4-5 | 1.335 | 5.828* | 9.55 | 29.5 |
| 5-6 | 1.682 | 4.855* | 11.00 | 28.7 |
| 6-7 | 1.998 | 3.933* | 11.27 | 26.0 |
| 7-8 | 2.273 | 1.631 | 10.21 | 23.0 |
| 8-9 | 2.536 | 0.950 | 13.38 | 21.9 |
| 9-10 | 2.769 | 0.702 | 16.25 | 21.1 |
| 10-11 | 2.990 | 0.624 | 15.03 | 20.4 |
| 11-12 | 3.207 | | | 19.0 |
| 12-13 | 3.414 | 0.921 | 12.87 | 18.3 |
| 13-14 | 3.612 | | | 18.2 |
| 14-15 | 3.808 | 0.797 | 14.01 | 17.6 |
| 15-16 | 4.001 | | | 17.3 |
| 16-17 | 4.192 | 0.767 | 13.14 | 17.9 |

Supported lead-210 activity = 0.67 dpm/g

Composite total lead concentration = 7.90 ug/g

Costello Lake Core 10

| DEPTH INTERVAL cm | CUMULATIVE MASS g/cm2 | LEAD-210 ACTIVITY dpm/g | COUNTING ERROR % | % DRY MASS |
|---|---|---|---|---|
| 0-1 | 0.262 | 7.396* | 9.43 | 42.0 |
| 1-2 | 1.014 | 3.887* | 10.24 | 61.5 |
| 2-3 | 2.078 | 2.572* | 12.60 | 65.2 |
| 3-4 | 3.201 | 1.963* | 12.93 | 64.5 |
| 4-5 | 4.234 | 1.023 | 17.04 | 60.8 |
| 5-6 | 5.156 | 1.279 | 16.39 | 57.7 |
| 6-7 | 6.096 | 1.554 | 16.00 | 62.7 |
| 7-8 | 7.071 | 0.884 | 12.42 | 60.4 |
| 8-9 | 7.965 | 0.999 | 11.81 | 55.3 |
| -10 | 8.868 | 1.666 | 10.54 | 61.9 |
| 10-11 | 9.894 | 1.221 | 11.18 | 67.5 |
| 11-12 | 10.838 | | | 50.6 |
| 12-13 | 11.501 | 1.245 | 10.97 | 40.9 |

Supported lead-210 activity = 1.23 dpm/g

Costello Lake Core 11

| DEPTH INTERVAL cm | CUMULATIVE MASS g/cm2 | LEAD-210 ACTIVITY dpm/g | COUNTING ERROR % | % DRY MASS |
|---|---|---|---|---|
| 0-1 | 0.065 | 26.047 | 2.83 | 12.8 |
| 1-2 | 0.241 | 26.950 | 4.91 | 20.0 |
| 2-3 | 0.470 | 26.658 | 4.89 | 21.1 |
| 3-4 | 0.694 | 24.667 | 5.21 | 19.1 |
| 4-5 | 0.913 | 20.832 | 5.64 | 19.3 |
| 5-6 | 1.119 | 21.560 | 6.67 | 18.1 |
| 6-7 | 1.314 | 17.569 | 6.32 | 18.0 |
| 7-8 | 1.513 | 20.127 | 4.56 | 17.6 |
| 8-9 | 1.711 | 14.253 | 4.18 | 18.7 |
| 9-10 | 1.925 | 12.443 | 4.59 | 18.3 |
| 10-11 | 2.150 | 10.083* | 4.80 | 19.7 |
| 11-12 | 2.363 | 5.451* | 7.94 | 17.9 |
| 12-13 | 2.541 | 1.659* | 9.44 | 14.9 |

Supported lead-210 activity = 0.67 dpm/g

Composite total lead concentration = 23.9 ug/g

Costello Lake Core 12

| DEPTH INTERVAL cm | CUMULATIVE MASS g/cm2 | LEAD-210 ACTIVITY dpm/g | COUNTING ERROR % | % DRY MASS |
|---|---|---|---|---|
| 0-1 | 0.035 | 36.235 | 5.83 | 7.5 |
| 1-2 | 0.116 | 38.407 | 4.52 | 9.4 |
| 2-3 | 0.217 | 40.583 | 6.03 | 10.5 |
| 3-4 | 0.329 | 39.245 | 4.85 | 11.2 |
| 4-5 | 0.443 | 34.747 | 4.81 | 11.0 |
| 5-6 | 0.555 | 35.648 | 5.59 | 11.1 |
| 6-7 | 0.668 | 28.066 | 2.77 | 11.4 |
| 7-8 | 0.783 | 27.420 | 5.06 | 11.1 |
| 8-9 | 0.904 | 23.829* | 3.89 | 11.6 |
| 9-10 | 1.026 | 18.025* | 4.15 | 11.3 |
| 10-11 | 1.144 | | | 10.8 |
| 11-12 | 1.253 | 9.894* | 4.71 | 10.1 |
| 12-13 | 1.355 | | | 9.6 |
| 13-14 | 1.461 | 4.042* | 7.56 | 9.8 |
| 14-15 | 1.568 | 2.167* | 8.67 | 9.9 |

Supported lead-210 activity = 0.67 dpm/g

Composite total lead concentration = 44.4 ug/g

Costello Lake Core 13

| DEPTH INTERVAL cm | CUMULATIVE MASS g/cm2 | LEAD-210 ACTIVITY dpm/g | COUNTING ERROR % | % DRY MASS |
|---|---|---|---|---|
| 0-1 | 0.127 | 10.319 | 8.01 | 29.6 |
| 1-2 | 0.464 | 5.494 | 9.25 | 37.3 |
| 2-3 | 0.883 | 6.948 | 8.18 | 34.1 |
| 3-4 | 1.233 | 5.358* | 9.06 | 26.4 |
| 4-5 | 1.502 | 3.029* | 11.93 | 22.3 |
| 5-6 | 1.753 | 1.860* | 15.49 | 21.6 |
| 6-7 | 1.975 | 1.051* | 17.92 | 18.6 |
| 7-8 | 2.178 | 0.796 | 21.07 | 18.8 |
| 8-9 | 2.387 | 0.865 | 13.64 | 18.6 |
| 9-10 | 2.578 | 0.990 | 11.31 | 16.8 |
| 10-11 | 2.741 | 0.684 | 13.70 | 14.4 |
| 11-12 | 2.891 | | | 13.8 |
| 12-13 | 3.035 | 1.059 | 12.23 | 13.5 |
| 13-14 | 3.175 | | | 13.1 |
| 14-15 | 3.314 | 0.923 | 12.25 | 12.8 |
| 15-16 | 3.453 | | | 12.9 |
| 16-17 | 3.590 | 1.216 | 11.57 | 13.0 |
| 17-18 | 3.731 | | | 13.8 |
| 18-19 | 3.894 | 0.885 | 13.84 | 15.1 |
| 19-20 | 4.078 | 2.908 | 8.19 | 16.6 |

Supported lead-210 activity = 0.93 dpm/g

omposite total lead concentration = 4.1 ug/g

Costello Lake Core 14

| DEPTH INTERVAL cm | CUMULATIVE MASS g/cm2 | LEAD-210 ACTIVITY dpm/g | COUNTING ERROR % | % DRY MASS |
|---|---|---|---|---|
| 0-1 | 0.441 | 2.177 | 10.93 | 66.6 |
| 1-2 | 1.466 | 1.374 | 12.86 | 71.3 |
| 2-3 | 2.657 | 1.631 | 11.15 | 71.8 |
| 3-4 | 3.878 | 1.320 | 14.73 | 73.3 |
| 4-5 | 5.148 | 1.456 | 8.51 | 73.6 |
| 5-6 | 6.459 | 1.251 | 9.10 | 74.2 |
| 14-15 | 16.993 | 0.563 | 17.35 | 36.9 |
| 16-17 | 17.895 | 0.240 | 18.83 | 44.1 |

Costello Lake Core 16

| DEPTH INTERVAL cm | CUMULATIVE MASS g/cm2 | LEAD-210 ACTIVITY dpm/g | COUNTING ERROR % | % DRY MASS | TOTAL LEAD ug/g |
|---|---|---|---|---|---|
| 0-1 | 0.022 | 42.723 | 3.41 | 5.4 | 79.5 |
| 1-2 | 0.087 | 38.837 | 2.91 | 8.2 | 70.1 |
| 2-3 | 0.179 | 36.356 | 6.62 | 9.5 | 65.9 |
| 3-4 | 0.281 | 38.026 | 6.74 | 10.1 | 63.9 |
| 4-5 | 0.393 | 36.200 | 5.23 | 10.4 | 66.6 |
| 5-6 | 0.507 | 31.105 | 4.75 | 10.9 | 61.9 |
| 6-7 | 0.622 | 28.407 | 4.11 | 10.9 | 60.7 |
| 7-8 | 0.737 | 32.055* | 5.39 | 10.8 | 59.2 |
| 8-9 | 0.849 | 25.633* | 5.05 | 10.6 | 46.2 |
| 9-10 | 0.960 | 24.046* | 3.46 | 10.4 | 46.7 |
| 10-11 | 1.071 | 19.328* | 3.69 | 10.5 | |
| 11-12 | 1.183 | | | 10.5 | 25.4 |
| 12-13 | 1.293 | 11.117* | 4.89 | 10.3 | |
| 13-14 | 1.401 | | | 10.1 | 15.3 |
| 14-15 | 1.510 | 7.919* | 5.34 | 10.1 | |
| 15-16 | 1.617 | | | 10.3 | 9.4 |
| 16-17 | 1.725 | 4.236* | 6.05 | 10.4 | |
| 17-18 | 1.837 | | | | 6.2 |
| 18-19 | 1.952 | 2.759* | 8.35 | 10.8 | |
| 19-20 | 2.070 | | | 11.0 | 4.8 |
| 20-21 | 2.188 | 1.694* | 9.22 | 11.3 | |
| 21-22 | 2.306 | 1.465 | 9.54 | 11.5 | 2.5 |
| 22-23 | 2.422 | 1.397 | 10.49 | 11.6 | |

Supported lead-210 activity = 0.67 dpm/g

Costello Lake Core 20

| DEPTH INTERVAL cm | CUMULATIVE MASS g/cm2 | LEAD-210 ACTIVITY dpm/g | COUNTING ERROR % | % DRY MASS | TOTAL LEAD ug/g |
|---|---|---|---|---|---|
| 0-1 | 0.040 | 34.793 | 5.09 | 8.0 | 61.4 |
| 1-2 | 0.131 | 33.874 | 4.41 | 10.6 | 66.2 |
| 2-3 | 0.236 | 34.806 | 4.81 | 10.6 | 68.6 |
| 3-4 | 0.344 | 35.412 | 4.79 | 10.7 | 72.7 |
| 4-5 | 0.457 | 31.921* | 5.20 | 12.3 | 63.6 |
| 5-6 | 0.582 | 24.924* | 4.91 | 12.6 | 54.8 |
| 6-7 | 0.712 | 18.446* | 6.12 | 12.7 | 40.0 |
| -8 | 0.836 | 10.231* | 8.22 | 11.8 | 24.3 |
| 8-9 | 0.955 | 7.191* | 5.72 | 11.1 | 15.6 |
| 9-10 | 1.068 | 5.725* | 5.31 | 10.6 | 11.9 |
| 10-11 | 1.177 | | | 10.7 | |
| 11-12 | 1.287 | 2.722* | 14.50 | 10.7 | 8.3 |
| 12-13 | 1.399 | | | 10.8 | |
| 13-14 | 1.509 | 1.599* | 9.08 | 10.6 | 2.3 |
| 14-15 | 1.617 | | | 10.4 | |
| 15-16 | 1.725 | 1.107* | 10.54 | 10.3 | 0.0 |
| 16-17 | 1.836 | 0.860* | 11.72 | 11.0 | |

Supported lead-210 activity = 0.67 dpm/g

Costello Lake Core 23

| DEPTH INTERVAL cm | CUMULATIVE MASS g/cm2 | LEAD-210 ACTIVITY dpm/g | COUNTING ERROR % | % DRY MASS | TOTAL LEAD ug/g |
|---|---|---|---|---|---|
| 0-1 | 0.024 | 55.600 | 4.67 | 4.7 | 136.2 |
| 1-2 | 0.079 | 54.221 | 4.59 | 5.9 | 137.4 |
| 2-3 | 0.149 | 52.125 | 7.55 | 7.4 | 124.6 |
| 3-4 | 0.232 | 48.186 | 5.20 | 8.8 | 114.1 |
| 4-5 | 0.329 | 61.197 | 7.70 | 9.9 | 110.9 |
| 5-6 | 0.432 | 47.196 | 5.33 | 10.0 | 108.9 |
| 6-7 | 0.536 | 43.493 | 5.50 | 9.7 | 107.1 |
| 7-8 | 0.638 | 41.241* | 5.38 | 9.6 | 93.0 |
| 8-9 | 0.736 | 33.044* | 6.50 | 9.6 | 66.4 |
| 9-10 | 0.835 | 23.563* | 4.61 | 9.7 | 52.4 |
| 10-11 | 0.938 | 22.929* | 4.67 | 10.1 | |
| 11-12 | 1.038 | | | 10.0 | 46.5 |
| 12-13 | 1.138 | 17.581* | 4.50 | 9.6 | |
| 13-14 | 1.239 | | | 9.6 | 23.6 |
| 14-15 | 1.328 | 15.365* | 5.07 | 8.6 | |
| 15-16 | 1.417 | | | 8.3 | 24.6 |
| 16-17 | 1.500 | 10.819* | 5.19 | 7.8 | |
| 17-18 | 1.577 | | | 7.6 | 20.4 |
| 18-19 | 1.653 | 6.751* | 6.11 | 7.6 | |
| 19-20 | 1.731 | | | 7.7 | 7.8 |
| 20-21 | 1.810 | 4.348* | 7.81 | 7.5 | |
| 21-22 | 1.887 | | | 7.6 | 8.0 |
| 22-23 | 1.965 | 2.962* | 8.85 | 7.9 | |

*Supported lead-210 activity = 0.67 dpm/g

COSTELLO LAKE CORE 24

| DEPTH INTERVAL cm | CUMULATIVE MASS g/cm2 | LEAD-210 ACTIVITY dpm/g | COUNTING ERROR % | % DRY MASS | TOTAL LEAD ug/g |
|---|---|---|---|---|---|
| 0-1 | 0.020 | 47.396 | 4.91 | 6.4 | 76.2 |
| 1-2 | 0.084 | 40.870 | 4.60 | 9.7 | 65.6 |
| 2-3 | 0.197 | 37.593 | 4.60 | 11.2 | 60.8 |
| 3-4 | 0.325 | 39.189 | 5.22 | 11.3 | 61.6 |
| 4-5 | 0.440 | 35.621 | 3.94 | 11.8 | 53.5 |
| 5-6 | 0.557 | 30.195* | 5.53 | 11.9 | 48.9 |
| 6-7 | 0.671 | 22.591* | 5.79 | 12.0 | 41.7 |
| 7-8 | 0.783 | 16.473* | 4.42 | 11.7 | 27.6 |
| 8-9 | 0.895 | 12.063* | 4.63 | 11.2 | 18.4 |
| 9-10 | 1.002 | 9.058* | 6.33 | 11.0 | 14.8 |
| 10-11 | 1.107 | 6.824* | 7.12 | 11.3 | 12.5 |
| 11-12 | 1.216 | | | 11.2 | |
| 12-13 | 1.324 | 4.506* | 6.42 | 10.6 | 7.6 |
| 13-14 | 1.435 | | | 10.9 | |
| 14-15 | 1.546 | 2.212* | 9.38 | 11.0 | 2.1 |
| 15-16 | 1.655 | | | 11.1 | |
| 16-17 | 1.767 | 1.366 | 11.58 | 11.4 | 2.2 |
| 17-18 | 1.885 | | | 11.1 | |
| 18-19 | 2.003 | 1.221 | 13.74 | 11.0 | 0.6 |
| 19-20 | 2.115 | 1.005 | 12.31 | 11.3 | 0.5 |

Supported lead-210 activity = 0.67 dpm/g

Costello Lake Core 27

| DEPTH INTERVAL cm | CUMULATIVE MASS g/cm2 | LEAD-210 ACTIVITY dpm/g | COUNTING ERROR % | % DRY MASS |
|---|---|---|---|---|
| 0-1 | 0.029 | 42.382* | 4.30 | 6.2 |
| 1-2 | 0.101 | 39.145* | 4.36 | 8.6 |
| 2-3 | 0.192 | 35.818* | 6.24 | 9.5 |
| 3-4 | 0.293 | 37.131 | 4.68 | 10.4 |
| 4-5 | 0.399 | 34.155 | 4.54 | 10.5 |
| 5-6 | 0.508 | 28.712 | 2.88 | 10.6 |
| 6-7 | 0.617 | 24.776 | 5.46 | 10.6 |
| 7-8 | 0.727 | 20.518 | 5.62 | 10.8 |
| 8-9 | 0.841 | 14.727 | 5.15 | 10.7 |
| 9-10 | 0.950 | 14.300 | 4.23 | 10.4 |
| 10-11 | 1.056 | 12.448 | 3.82 | 10.3 |
| 11-12 | 1.163 | | | 10.5 |
| 12-13 | 1.276 | 11.283 | 4.73 | 11.0 |
| 13-14 | 1.392 | | | 10.9 |
| 14-15 | 1.504 | 10.975 | 4.77 | 10.8 |
| 15-16 | 1.615 | | | 10.9 |
| 16-17 | 1.730 | 8.093 | 5.65 | 10.8 |
| 17-18 | 1.844 | | | 10.8 |
| 18-19 | 1.956 | 7.505 | 4.85 | 10.9 |
| 19-20 | 2.071 | | | 11.3 |
| 20-21 | 2.190 | 1.588 | 9.18 | 11.3 |
| 21-22 | 2.305 | | | 10.8 |
| 22-23 | 2.415 | 0.973 | 13.97 | 10.4 |
| 23-24 | 2.522 | | | 10.3 |
| 24-25 | 2.633 | | | 10.9 |
| 25-26 | 2.747 | | | 10.8 |
| 26-27 | 2.862 | | | 11.2 |
| 27-28 | 2.982 | 0.890 | 13.77 | 11.5 |

Supported lead-210 activity = 0.67 dpm/g

Composite total lead concentration = 26.8 ug/g

Costello Lake Core 28

| DEPTH NTERVAL cm | CUMULATIVE MASS g/cm2 | LEAD-210 ACTIVITY dpm/g | COUNTING ERROR % | % DRY MASS | TOTAL LEAD ug/g |
|---|---|---|---|---|---|
| 0-1 | 0.015 | 88.965 | 4.31 | 3.9 | 143.2 |
| 1-2 | 0.058 | 80.480 | 3.67 | 5.8 | 137.5 |
| 2-3 | 0.120 | 75.476 | 2.34 | 6.6 | 131.2 |
| 3-4 | 0.193 | 69.463 | 3.92 | 7.8 | 135.7 |
| 4-5 | 0.276 | 64.917 | 3.86 | 8.4 | 125.2 |
| -6 | 0.364 | 62.330 | 3.94 | 9.1 | 129.0 |
|  |  |  | 06 | 9.6 | 123.1 |
| 7-8 | 0.559 |  |  | 10.1 | 112.6 |
| 9 | 0.663 | 58.527* | 3.85 | 10.1 | 109.9 |
| 9-10 | 0.766 | 50.933* | 2.88 | 10.0 | 92.4 |
| 10-11 | 0.862 | 30.260* | 3.34 | 9.9 | 57.5 |
| 11-12 | 0.961 | 19.319* | 4.02 | 10.0 |  |
| 12-13 | 1.070 | 17.293* | 3.94 | 9.8 | 33.3 |
| 13-14 | 1.163 | 15.037* | 4.23 | 8.8 | 30.5 |

Supported lead-210 activity = 0.67 dpm/g

Costello Lake Core 29

| DEPTH INTERVAL cm | CUMULATIVE MASS g/cm2 | LEAD-210 ACTIVITY dpm/g | COUNTING ERROR % | % DRY MASS | TOTAL LEAD ug/g |
|---|---|---|---|---|---|
| 0-1 | 0.028 | 57.652 | 5.27 | 6.0 | 91.2 |
| 1-2 | 0.098 | 55.829 | 4.36 | 8.3 | 87.7 |
| 2-3 | 0.188 | 49.178 | 4.56 | 9.2 | 80.0 |
| 3-4 | 0.286 | 49.750 | 5.07 | 9.6 | 78.8 |
| 4-5 | 0.389 | 50.140 | 4.59 | 10.1 | 88.8 |
| 5-6 | 0.496 | 44.350 | 3.10 | 10.2 | 84.3 |
| 6-7 | 0.604 | 42.308 | 3.19 | 10.3 | 84.3 |
| 7-8 | 0.714 | 40.502 | 4.70 | 10.7 | 73.3 |
| 8-9 | 0.827 | 38.804* | 3.39 | 10.4 | 68.7 |
| 9-10 | 0.937 | 28.860* | 6.04 | 10.0 | 54.5 |
| 10-11 | 1.042 | 20.828* | 4.13 | 10.0 | 41.8 |
| 11-12 | 1.144 | 17.750* | 4.10 | 9.9 | |
| 12-13 | 1.246 | 14.902* | 4.56 | 9.4 | 32.1 |
| 13-14 | 1.345 | 13.470* | 5.06 | 9.1 | |
| 14-15 | 1.443 | 9.137* | 5.92 | 9.0 | 22.5 |
| 15-16 | 1.543 | 6.137* | 6.55 | 9.0 | 12.4 |

Supported lead-210 activity = 0.67 dpm/g

Costello Lake Core 30

| DEPTH NTERVAL cm | CUMULATIVE MASS g/cm2 | LEAD-210 ACTIVITY dpm/g | COUNTING ERROR % | % DRY MASS | TOTAL LEAD ug/g |
|---|---|---|---|---|---|
| 0-1 | 0.035 | 29.139 | 5.37 | 7.3 | 61.2 |
| 1-2 | 0.116 | 30.819 | 4.88 | 8.9 | 56.9 |
| 2-3 | 0.217 | 27.163 | 5.28 | 10.3 | 51.6 |
| 3-4 | 0.330 | 28.847 | 2.75 | 11.0 | 64.8 |
| 4-5 | 0.446 | 30.802 | 10.49 | 12.0 | 54.1 |
| 5-6 | 0.566 | 27.670* | 4.84 | 11.8 | 51.3 |
| 6-7 | 0.684 | 17.645* | 5.98 | 10.8 | 34.8 |
| 7-8 | 0.790 | 10.047* | 7.42 | 9.6 | 14.6 |
| 8-9 | 0.892 | 8.185* | 7.32 | 9.9 | 17.0 |
| 9-10 | 0.992 | 7.480* | 5.36 | 9.7 | 14.7 |
| 10-11 | 1.092 | 5.862* | 6.05 | 9.6 | 12.3 |
| 11-12 | 1.190 | | | 9.3 | |
| 12-13 | 1.287 | 3.449* | 7.12 | 9.4 | 7.2 |
| 13-14 | 1.385 | | | 9.5 | |
| 14-15 | 1.484 | 2.895 | 8.71 | 9.6 | 2.0 |
| 15-16 | 1.587 | | | 9.9 | |
| 16-17 | 1.691 | 2.259 | 8.91 | 9.9 | 2.1 |
| 17-18 | 1.797 | | | 10.1 | |
| 18-19 | 1.904 | 1.895 | 9.08 | 10.0 | 2.1 |
| 19-20 | 2.007 | | | 9.9 | |
| 20-21 | 2.119 | 1.127 | 11.02 | 11.5 | 2.1 |
| 21-22 | 2.235 | 1.315 | 10.76 | 10.2 | |

Supported lead-210 activity = 0.67 dpm/g

Costello Lake Core 31

| DEPTH INTERVAL cm | CUMULATIVE MASS g/cm2 | LEAD-210 ACTIVITY dpm/g | COUNTING ERROR % | % DRY MASS |
|---|---|---|---|---|
| 0-1 | 0.029 | 41.131 | 2.99 | 5.7 |
| 1-2 | 0.100 | 33.518 | 5.24 | 8.5 |
| 2-3 | 0.189 | 35.732 | 7.05 | 9.5 |
| 3-4 | 0.286 | 34.353 | 5.19 | 10.0 |
| 4-5 | 0.386 | 33.150 | 3.48 | 10.4 |
| 5-6 | 0.493 | 27.558* | 2.92 | 10.3 |
| 6-7 | 0.599 | 15.960* | 14.16 | 9.9 |
| 7-8 | 0.693 | 13.765* | 8.55 | 9.8 |
| 8-9 | 0.787 | 12.149* | 6.56 | 9.7 |
| 9-10 | 0.887 | 5.103* | 6.91 | 9.9 |
| 10-11 | 0.995 | 7.166 | 5.42 | 9.5 |
| 11-12 | 1.126 | | | 4 |
| 12-13 | 1.196 | 8.217 | 6.01 | 9.2 |
| 13-14 | 1.292 | | | 9.3 |
| 14-15 | 1.391 | 8.551 | 5.71 | 9.3 |
| 15-16 | 1.490 | | | 9.5 |
| 16-17 | 1.591 | 1.843 | 10.12 | 9.8 |
| 17-18 | 1.694 | | | 10.0 |
| 18-19 | 1.799 | 0.853 | 13.68 | 10.1 |
| 19-20 | 1.908 | 0.972 | 12.40 | 10.3 |

Supported lead-210 activity = 0.67 dpm/g

*Composite total lead concentration = 15.5 ug/g

Costello Lake Core 32

| DEPTH INTERVAL cm | CUMULATIVE MASS g/cm2 | LEAD-210 ACTIVITY dpm/g | COUNTING ERROR % | % DRY MASS | TOTAL LEAD ug/g |
|---|---|---|---|---|---|
| 0-1 | 0.030 | 40.168 | 4.41 | 6.3 | 77.9 |
| 1-2 | 0.107 | 33.089 | 4.42 | 9.4 | 74.1 |
| 2-3 | 0.206 | 37.855 | 4.59 | 10.1 | |
| 3-4 | 0.315 | 37.343 | 4.38 | 11.0 | 77.3 |
| 4-5 | 0.431 | 36.850 | 4.38 | 11.5 | 70.8 |
| 5-6 | 0.558 | 34.272 | 4.76 | 12.5 | 75.0 |
| 6-7 | 0.693 | 33.405 | 4.57 | 12.8 | 75.9 |
| 7-8 | 0.828 | 34.042 | 3.04 | 12.6 | 71.5 |
| 8-9 | 0.956 | 31.764 | 3.16 | 12.0 | 66.1 |
| 9-10 | 1.081 | 28.615* | 3.46 | 11.8 | 58.8 |
| 10-11 | 1.202 | 25.475* | 3.50 | 11.5 | 51.4 |
| 11-12 | 1.319 | | | 11.0 | |
| 12-13 | 1.431 | 14.665* | 4.35 | 10.4 | 37.6 |
| 13-14 | 1.533 | | | 9.7 | |
| 14-15 | 1.632 | 10.094* | 4.62 | 9.9 | 23.0 |
| 15-16 | 1.731 | | | 9.3 | |
| 16-17 | 1.826 | 6.507* | 5.30 | 9.3 | 14.7 |
| 17-18 | 1.921 | | | 9.6 | |
| 18-19 | 2.020 | 3.496* | 6.45 | 9.9 | 7.1 |

Supported lead-210 activity = 0.67 dpm/g

Costello Lake Core 35

| DEPTH INTERVAL cm | CUMULATIVE MASS g/cm2 | LEAD-210 ACTIVITY dpm/g | COUNTING ERROR % | % DRY MASS | TOTAL LEAD ug/g |
|---|---|---|---|---|---|
| 0-1 | 0.040 | 34.724 | 4.85 | 7.8 | 55.0 |
| 1-2 | 0.130 | 34.978 | 6.86 | 10.8 | 55.8 |
| 2-3 | 0.248 | 33.460 | 4.72 | 12.6 | 55.3 |
| 3-4 | 0.387 | 29.572 | 4.98 | 14.7 | 52.7 |
|  |  |  |  |  | 49.3 |
| 5-6 | 0.711 | 25.549 | 5.13 | 16.2 | 47.5 |
| 6-7 | 0.885 | 20.072 | 7.12 | 16.4 | 40.8 |
|  | 1.058 | 18.808* | 6.06 | 14.8 | 37.4 |
| 8-9 | 1.200 | 11.982* | 8.04 | 12.6 | 17.6 |
| 9-10 | 1.324 | 9.650* | 5.36 | 11.8 | 19.8 |
| 10-11 | 1.445 | 8.349* | 4.99 | 11.2 | 16.0 |
| 11-12 | 1.558 |  |  | 10.9 |  |
| -13 | 1.666 | 4.464* | 6.78 | 10.6 | 10.2 |
| 13-14 | 1.777 |  |  |  |  |
| 14-15 | 1.890 | 2.022* | 10.46 | 15.8 | 7.5 |
| 15-16 | 2.003 |  |  | 10.8 |  |
| 16-17 | 2.113 |  |  | 10.9 | 3.2 |
| 17-18 | 2.228 |  |  |  |  |
| 18-19 | 2.346 | 0.956* | 12.90 | 11.1 | 2.7 |
| 19-20 | 2.460 | 0.667 | 14.77 | 11.3 |  |
| 21 | 2.578 | 0.696 | 14.25 | 11.6 | 2.4 |

Supported lead-210 = 0.67 dpm/g