
Estimation of rates of sedimentation in lakes / reservoirs by ^{210}Pb dating technique

1.0 Introduction

Lead-210 is a member of the U-238 decay series. Disintegration of the intermediate isotope ^{226}Ra (half-life 1622 years) yields the inert gas ^{226}Rn . This in turn decays (half-life 3.83 days) through a series of short-lived isotopes to ^{210}Pb . Radium-226 is supplied to the lake sediments as part of the particulate erosive input. (Figure 1.) The ^{210}Pb formed by the in situ decay of this radium is termed as the “supported ^{210}Pb ” and is normally assumed to be in radioactive equilibrium with the radium. In general, however, this equilibrium will be disturbed by a supply of ^{210}Pb from other sources. Lead-210 activity in excess of the supported activity is called the “excess” or “unsupported” ^{210}Pb . The principal source of unsupported ^{210}Pb is generally taken to be direct atmospheric fallout, although the importance of the other sources has not been extensively evaluated. Figure 1 outlines the main pathways by which “excess ^{210}Pb ” or “unsupported ^{210}Pb ” reaches the sediments. Three components have been identified (Oldfield and Appleby, 1984):

1. Direct atmospheric fallout: A fraction of the radon atoms formed by ^{226}Ra decay in soils escape into the interstices and then diffuse through the soil into the atmosphere. The decay of radon in the atmosphere yields ^{210}Pb , which may be removed either by dry deposition or wet fallout. Lead-210 falling directly into the lakes is absorbed onto sediment particles and deposited on the bed of the lake.
2. Indirect atmospheric fallout: Atmospheric ^{210}Pb also reaches the lake indirectly via the lake catchment. Although the distinction may be less clear-cut in practice, it is convenient to separate a sub-component of this one, which is incorporated into the drainage network and flows quickly

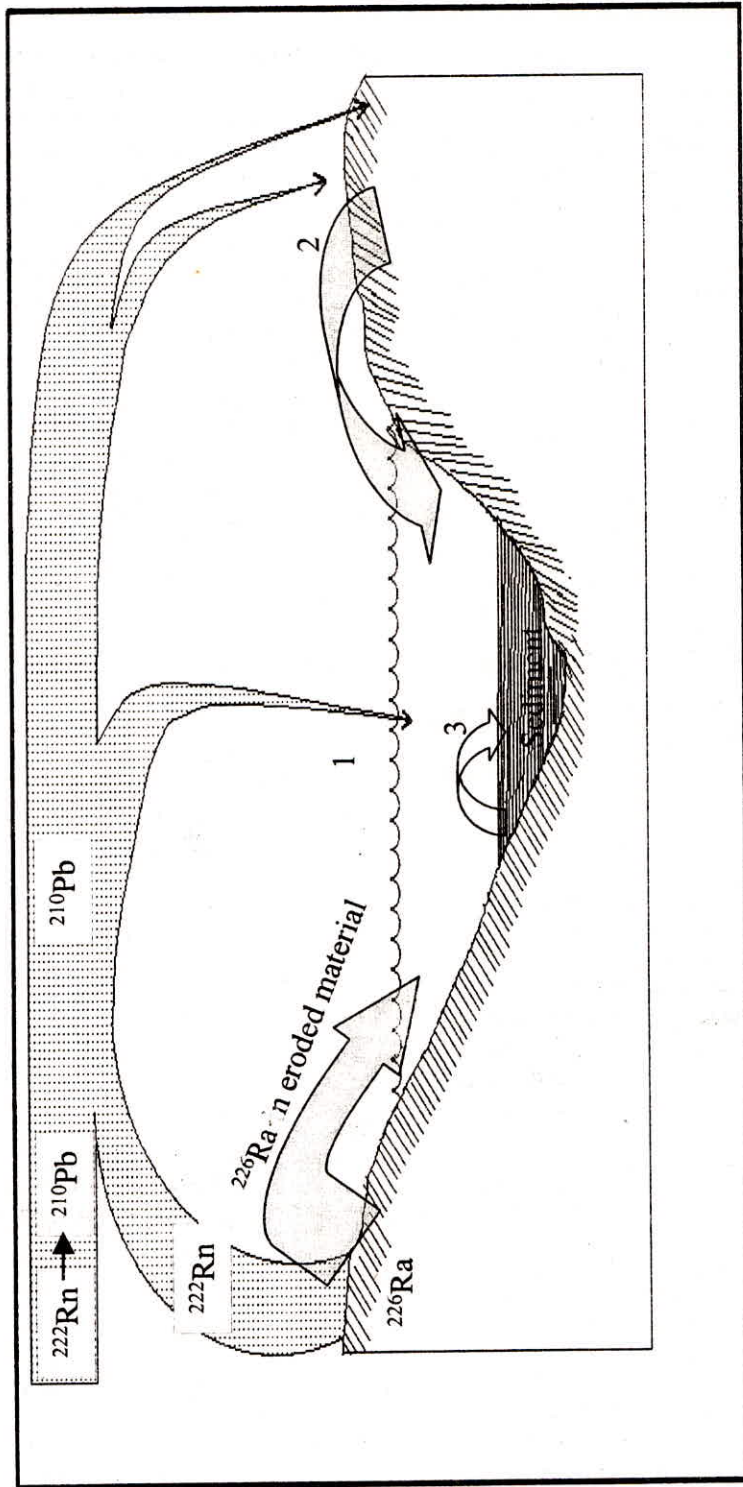


Figure 1. Pathways through which ^{210}Pb reaches lake sediments (After Oldfield and Appleby, 1984)

into the lake without being detained on solid terrestrial particles and another sub-component, which may have a long residence time in the catchment before being delivered to the lake in association with the erosive input of fine surface particulate to which it is attached.

3. Radon decay in the water column: Radon is delivered to the lake waters by diffusion from the underlying sediments, and by the decay of ^{226}Ra in the water column and inflowing streams. A part of the radon is lost by diffusion across the surface of the lake, and the remainder decays in the water column to ^{210}Pb .

Studies by Benninger et al., (1975) on the fate of ^{210}Pb in the Susquehanna river system showed that dissolved ^{210}Pb in the river waters was quickly removed from solution by suspended particles. Further, stream borne particles carried away no more than 0.8 % of the atmospheric flux of ^{210}Pb , which reached the catchment soils. Studies by Hammond et al., (1975) and Krishnaswamy and Lal (1978) of the production of ^{222}Rn and ^{210}Pb in the lake waters have indicated that this component too may be negligible, around 2 orders of magnitude lower than the atmospheric flux. On the other hand, Imboden and Stiller have estimated that both the riverine input and in situ production of ^{210}Pb in Lake Kinneret, Israel, are of the same order of magnitude as the direct atmospheric flux. Although, for climatic reasons the latter case may well be a typical, it nonetheless illustrates the need for further investigation of these components.

In dating by ^{210}Pb , only the "unsupported" component is used, since once incorporated in the sediment it decays exponentially with time in accordance with its half-life. The supported ^{210}Pb activity is estimated by assay of the ^{226}Ra . Although Radon diffusion through the sediments may result in a small disequilibrium between the ^{226}Ra and supported ^{210}Pb near the sediment - water interface, provided that the total ^{210}Pb activity is well in excess of the ^{226}Ra

activity, a correction for this will generally be negligible. Once the supported ^{210}Pb activity is known, the “unsupported ^{210}Pb ” can be determined by subtraction from the total ^{210}Pb activity. (Figure 2). Ideally total ^{210}Pb and ^{226}Ra assays should be carried out on every sample. In practice, total ^{210}Pb determination may be scattered down a profile with intervening levels unanalyzed and the supported component is often estimated from only 2 or 3 ^{226}Ra determinations, from amalgamated samples, or simply from the total ^{210}Pb activity of sediments too old to give any significant disintegration from “unsupported ^{210}Pb ”.

In determining a ^{210}Pb chronology it is assumed that the “unsupported ^{210}Pb ”, once incorporated in a sediment layer, declines with age in accordance with the ^{210}Pb radioactive decay law. The validity of the chronology will then rest on the accuracy with which the ^{210}Pb dating model represents the ^{210}Pb delivery mechanism outlined above. This assumes that the unsupported ^{210}Pb , once incorporated in the sediments, does not “migrate” or “diffuse” via the pore water of the sediment. Strong empirical evidence in support of this assumption is derived from the presence of sharply defined peaks and inflexions in some ^{210}Pb profiles, and from profiles considered here and elsewhere in which the unsupported ^{210}Pb activity at independently dated depths is as expected from the operation of in situ radioactivity decay alone. There is evidence in some cases for redistribution of ^{210}Pb in association with sediment mixing or sediment re-suspension. Where this takes place, the decay law will operate only for sediment layers beneath the zone of mixing. There are different models that are used in different conditions. The details of these models are discussed under section 6.0.

2.0 Scope

All references made about the locations and manufacturers of equipment, reagents and tools in this manual pertain to the current practices followed at the Environmental Isotope Laboratory (EIL) at National Institute of Hydrology,

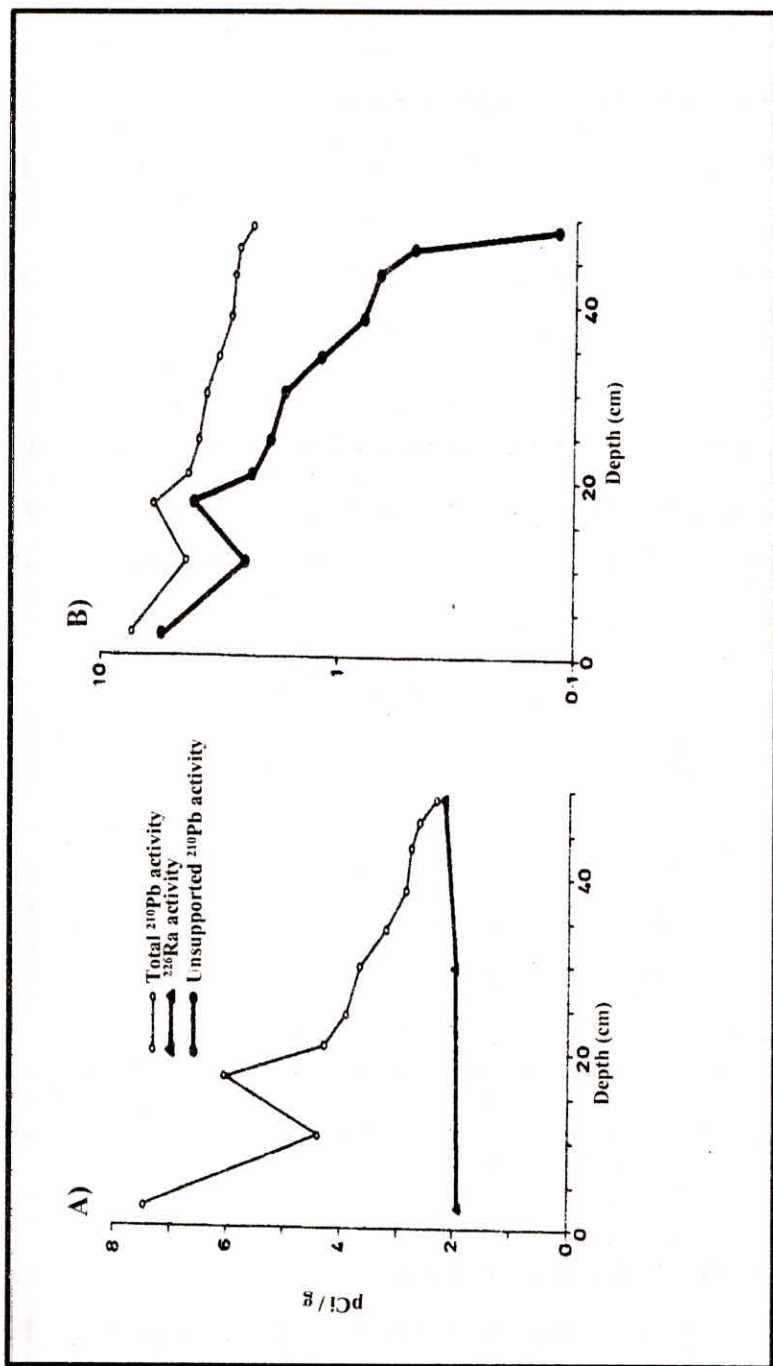


Figure 2. A) Total ^{210}Pb and ^{226}Ra activities in linear scale. B) Semi-log plot of variation of total and unsupported ^{210}Pb activities with depth. (After Oldfield and Appleby, 1984)

Roorkee. The contents shall aid the users in employing the ^{210}Pb dating technique for estimating the rates of sedimentation with the facilities available currently at the EIL.

3.0 Collection and Processing of samples

The details of the procedures to be followed for the collection of sediment cores from lakes and the preprocessing to be carried out prior to measurement of ^{210}Pb activity is similar to the ones adopted in the case of ^{137}Cs technique. These procedures are given in the ^{137}Cs part of this manual.

4.0 Measurement of ^{210}Pb concentration in sediment samples

The basic radionuclide decay data pertaining to the isotopes of interest in Uranium series that are pertinent to the ^{210}Pb dating techniques are given in the following table:

Isotope	Half-life	Decay mode	Energy (MeV)	%
^{226}Ra	1600y	α	5.684	94.5
		α	5.442	5.5
^{222}Rn	3.823d	α	5.486	
^{210}Pb	21y	β	0.061	19.0
		β	0.015	81.0
		γ	0.046	4.0
^{210}Bi	5.01d	β	1.16	99.0
^{210}Po	138.4d	α	5.035	

From the above table it is seen that ^{210}Pb may be measured directly by gamma counting using a gamma counter or through its daughter product ^{210}Bi using a liquid scintillation counter or through its granddaughter product ^{210}Po using an alpha spectrometer. The most preferred method is to measure ^{210}Pb

activity through ^{210}Po by alpha spectrometry. However, the ^{210}Bi technique is also used in certain laboratories including that at NIH. In this manual the ^{210}Bi technique is given in detail. However other methods are also presented in brief.

4.1 Lead-210 separation from sediment samples

^{210}Pb is low energy beta emitter with a low transformation yield for the gamma transition (about 4%) at energy of 46.52 KeV. ^{210}Pb decay to a high energy beta emitter Bismuth-210 (half life 5.012 d) followed by alpha emitter Po-210 (half-life 138.38 days). If Pb-210 is counted directly by gamma spectrometry, the time needed for sample preparation is short but the detection limit is too high for most environmental samples. Therefore, after radiochemical separation of the ^{210}Pb fraction, the beta radiation of Bi-210 is detected after a build-up of at least 30 days. The waiting time increases substantially if one is interested in using the more sensitive alpha spectrometry for Po-210.

Presently, the Nuclear Hydrology Laboratory at NIH uses the Quantulus Liquid scintillation system adopting the Bi-210 daughter isotope method. The detailed procedure is outlined below:

1. Ash a small quantity (usually 1g) of dried sediment at 550°C in the muffle furnace (as described above).
2. Leach the ashed sample with 0.8M HBr. This is done by taking the sediment sample in a Teflon beaker and adding 10 ml of 0.8M HBr, cover with a Teflon lid. Leave it overnight. Drydown the sample solution completely by placing it in a hotplate at 95°C . Elute the sample with 1ml of 0.8M HBr and 1 ml carrier solution of lead (10ppm).
3. The above solution is subjected to anionic exchange to separate Pb and Bi. This is a time consuming and sensitive procedure. The steps to be followed in the anionic exchange column are given below:

Description of Anion Exchange Columns:

The column is a very simple one with a sintered disc fused near the bottom (above the stop-valve) (Figure 3). The column is filled with DOWEX resin up to 10cc volume. The following steps are involved in lead separation.

a. Equilibration of column (Column preparation)

1. Pass 40ml Double distilled water through column three times.
2. Pass 40ml 1N HCl through column three times.
3. Pass 40ml Double distilled water through column.
4. Pass 40 ml 6.2N HCl through column three times.
5. Pass 40 ml Double distilled water through column.

Now the column is ready to be used for the lead separation.

b. First step of lead separation through the column

1. Pass 40 ml 0.8M HBr through column.
2. Load the sample (in 1 ml 0.8M HBr and 1 ml Pb carrier solution).
3. Pass 40 ml 0.8M HBr through column two times.
4. Pass 10 ml 6.2N HCl through column five times
5. Collect the solution in a clean Teflon beaker. Add few drops of H_3PO_4 in beaker. Dry down the sample solution completely by placing it in a hotplate at $90^\circ C$.
6. Add 2 ml of 3N HCl.

c. Re-equilibration of the column.

1. Pass 40ml double distilled water through column three times.
2. Pass 40ml 1N HCl through column three times.
3. Pass 40ml Double distilled water through column.

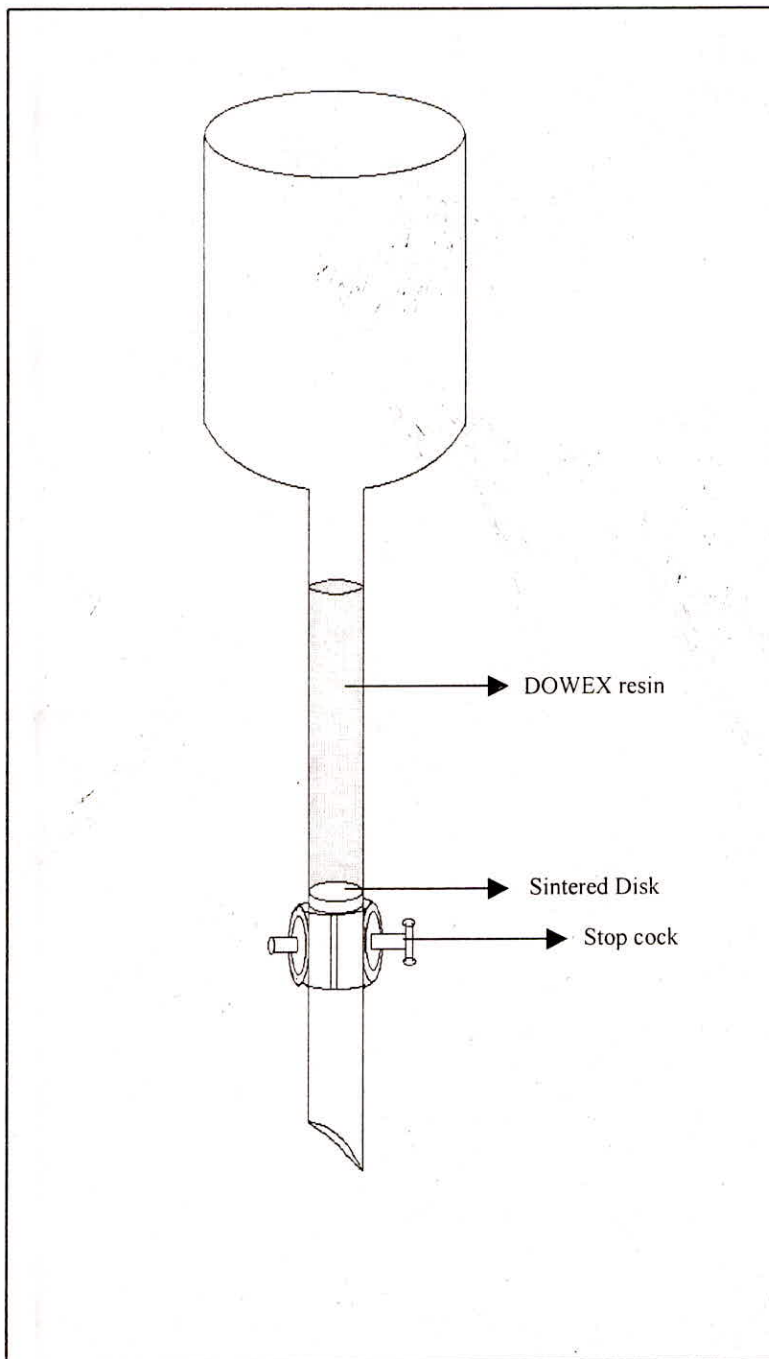


Figure 3. Sketch of the ion exchange column for extracting lead from the sediment sample

4. Pass 40 ml 6.2N HCl through column three times.
5. Pass 40 ml double distilled water through column.

d. *Second step of lead separation*

1. Pass 40 ml 3N HCl through column.
2. Load the final solution of Step I in the column.
3. Pass 10 ml 3N HCl through the column two times.
4. Pass 40 ml 6.2N HCl through the column
5. Collect the solution in a clean Teflon beaker,
6. Add few drops of H_3PO_4 .
7. Dry down the sample solution completely by placing it in a hotplate at $90^\circ C$.
8. Add 7 ml 0.5N HCl in Teflon beaker and
9. Transfer the final solution in to clean plastic vials.

4.2 Lead-210 measurement using Liquid Scintillation Counter

The final solution collected in plastic vials, as stated above, is subjected to β -counting in Ultra Low Level Liquid Scintillation Counter (Quantulus) after a waiting period of approximately 30 days. This waiting period is for establishment of secular equilibrium between ^{210}Pb and ^{210}Bi . Usually 6 half-lives are sufficient for this purpose (the half-life of ^{210}Bi is about 5 days). The sample is transferred into a scintillation grade vial of 20ml capacity. 10ml of a special cocktail called "UltimaGold AB" is added into the vial containing the sample. The UltimaGold AB cocktail is highly useful for alpha and beta decay event discrimination in the samples. The vial is then placed in the Quantulus counting chamber.

A special counting protocol is used for the purpose. The MCA settings are set to the in-built α/β counting setup. Spectra 11 records the pure beta events and spectra 12 records the pure alpha events, spectra 21 records the guard anti-

coincidence events and the spectra 22 records the guard coincident events. The Pulse Shape Analyser is set to 100%. The configuration is set in such a way that only spectra 11 and 12 are saved in the registry. The coincidence bias is set to low. (For detailed use of Q-manager program, please refer to the tritium part of this manual or refer the Q-manager software manual). A typical plot of the beta spectrum with ^{210}Pb and ^{210}Bi peaks is given in Figure 4a. The plot of alpha spectrum of ^{210}Po is give in Figure 4b.

In a single batch of counting in Quantulus, in addition to the samples at least two standards and two backgrounds are added. The standard that is used presently was purchased from IAEA, Vienna, Austria. The standard is known as IAEA-300 Baltic Sea sediment. The ^{210}Pb activity in the IAEA-300 standard is about 366mBq/g as on 01.01.1991. The standard is also subjected to the ashing and column separation procedure, therefore, the overall efficiency in lead separation and counting procedures may be evaluated from the activity measured in the counter (CPM) and the known activity as reported in the Activity Information Report of the IAEA-300. Similar to the procedures followed in the low level tritium measurement in Quantulus, the procedure to be adopted for ^{210}Pb also makes use of the higher Figure of merit technique to evaluate the appropriate windows setting.

The activity measured in CPM is then converted to mBq/g units using the overall efficiency and then corrected for density of the corresponding sediment sample. Once the ^{210}Pb activity in each sample of a sediment core is measured, the data is plotted against the depth of the sample, in a semi-logarithmic paper. The slope of the exponential fitting will give the ratio of radioactive decay constant of ^{210}Pb to the rate of sedimentation. The minimum activity measured in the lower parts of sediment core is considered as that due to supported fraction of ^{210}Pb . This value is then deducted from the total ^{210}Pb activity to evaluate the

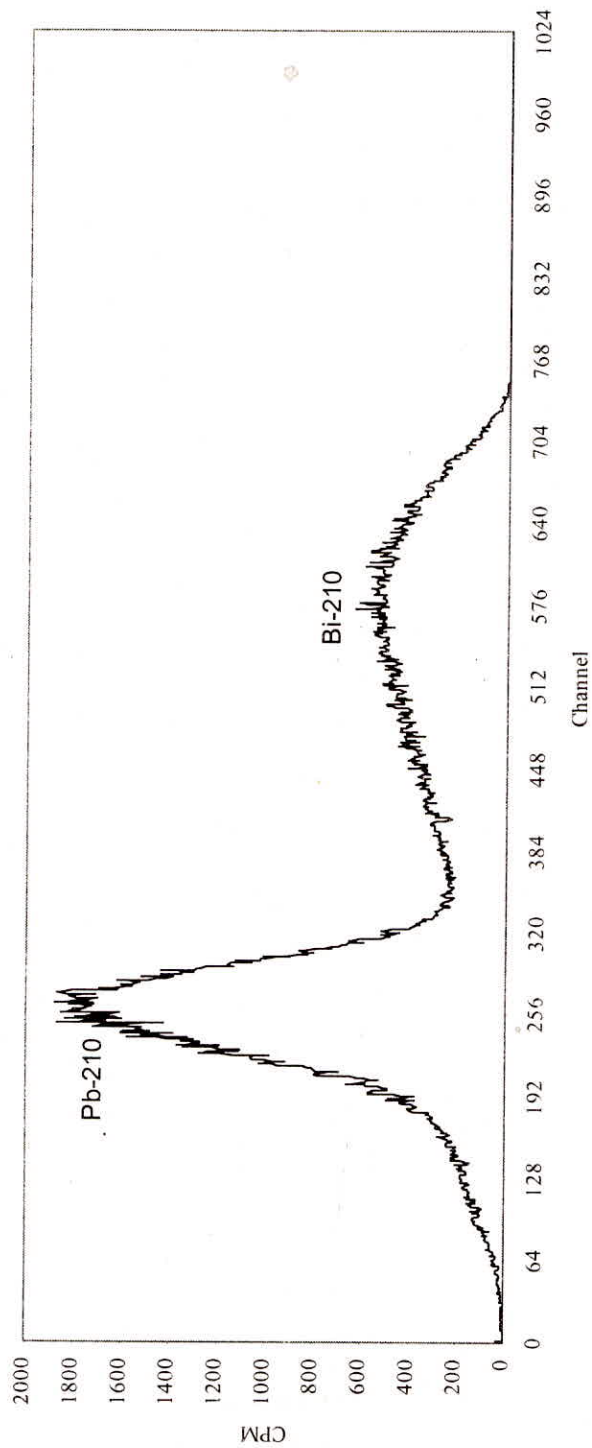


Figure 4a Spectrum plot showing Pb-210 and Bi-210 beta peaks. Spectrum (SP11) acquired using Quantulus LSC.

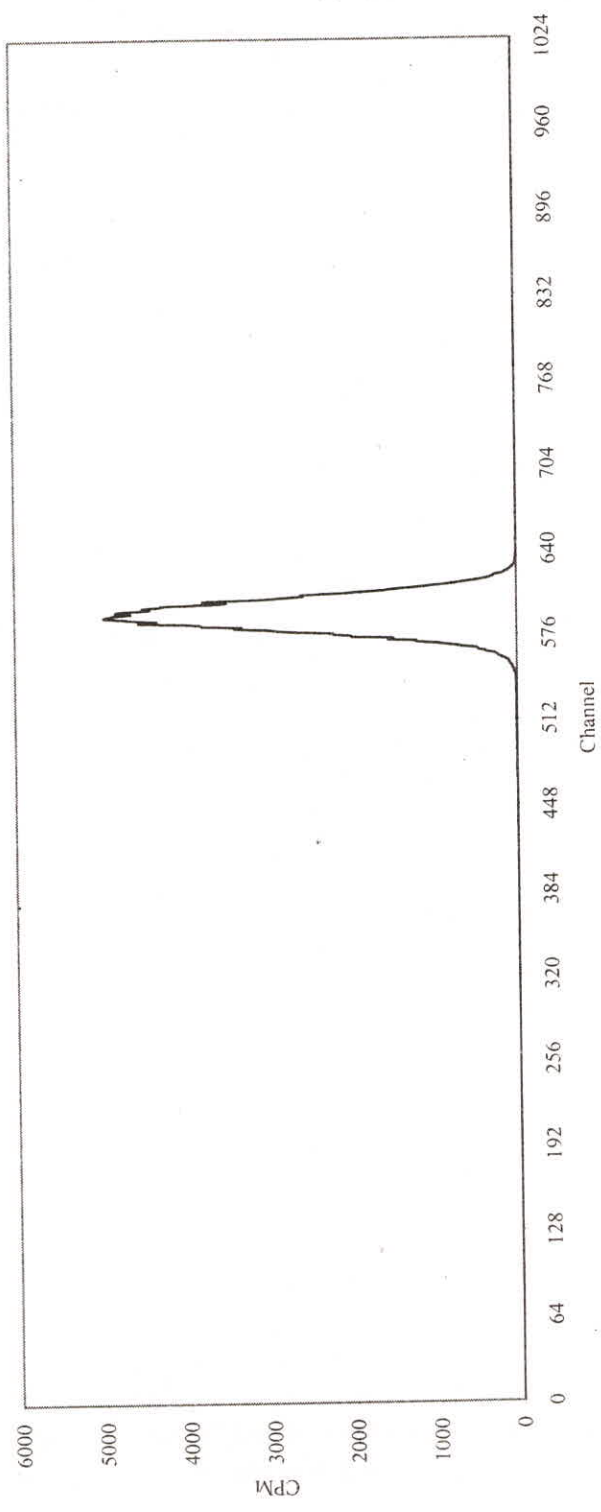


Figure 4b Spectrum plot showing Po-210 alpha peak. Spectrum (SP12) acquired using Quantulus LSC.

unsupported portion of ^{210}Pb activity. The slope of the best-fit curve for the unsupported ^{210}Pb activity versus depth gives the ratio of rate of sedimentation to the radioactive decay constant of ^{210}Pb . This is achieved by dividing the slope with the decay constant of ^{210}Pb (~ 0.031) and the result is expressed in cm/y units.

5.0 Lead-210 measurement by other methods

The measurement of ^{210}Pb may be carried out alternatively by alpha spectrometry with ^{210}Po or Gamma spectrometry with ^{210}Pb . These two methods are briefly outlined below:

5.1 Lead-210 measurement by Alpha Spectrometry

This method involves digestion of the sample, spontaneous deposition on a silver planchet / copper disc and counting in the Alpha Spectrometer (Silicon surface barrier detector coupled with Multi Channel analyzer). The method uses the granddaughter product viz. ^{210}Po and a secular equilibrium is presumed for the purpose of ^{210}Pb dating. The steps to be followed are given below:

5.1.1 Digestion

- 1 Weigh 1.0 g of dried sediment into a 250 ml Erlenmeyer flask. Record sample ID and date.
- 2 Pipette 1.0 ml of Po-209 standard into flask. Check the delivery of the pipette before use. Record the activity of the standard and the date.
- 3 Add 100 ml of 6 N Hydrochloric Acid (1:1, water: Conc. Acid, always add the acid slowly to the water with mixing) to the flask. Add 2 ml of 30% Hydrogen Peroxide and 2 drops of Octanol.
- 4 Place the flask on a hot plate and heat to 90-95°C. Heat for 30 min. and remove from the hot plate and cool slightly. Add two drops of Octanol and 2 ml of 30% hydrogen peroxide, if the samples foam vigorously add more Octanol. Return the samples to heat for 30 min. Repeat the addition of peroxide at least two more times. If the samples continue to foam add additional peroxide until foaming subsides. Continue to heat for a total of four hours.

- 5 Remove the samples from heat, cover with a watch glass, and let stand over night.
- 6 Label the back of a copper disk / silver planchet with a water proof marker, spray with urethane, use three light coats. Label should contain sample ID (Lake, Station and Depth)

5.1.2 Filtration

1. Filter the sample through a Whatman No. 42 filter paper into another Erlenmeyer flask. A Buchner funnel attached to vacuum is best for this step.
2. Rinse the digestion flask three times with small portions of Type 1 water and add to the filter.

5.1.3 Plating

Caution: This procedure uses Concentrated Hydrochloric acid and 30% Hydrogen Peroxide both of which can cause severe burns - Safety glasses, protective gloves and a lab coat must be worn while performing this procedure. The following steps are followed in plating ^{210}Pb in silver planchet / copper disk.

- 1 Place the flask on a hot plate, carefully reduce the volume to approx. 5 mL. Do not let the sample go to dryness. Cool it.
- 2 Measure the pH, adjust to between 0.5 and 1.0, use HCl or NaOH.
- 3 Add 0.1 to 0.2 gm of Ascorbic acid to each sample and dissolve. The ascorbic acid is added to form a complex with ferric iron, thereby preventing its possible interference with the Po-210 plating.
- 4 Transfer the sample to a 125 ml plastic bottle rinse the flask three times.
- 5 Polish the previously labeled disk with polishing, rub it off with a high quality tissue paper
- 6 Add the disk to the sample in the plastic bottle, make sure the polished side is up. Cap the bottle.
- 7 Place the bottle in a oven at 95°C and heat overnight.

- 8 Remove the samples from the oven. To remove the copper disk, tighten the cap on the bottle and turn it upside down, the copper disk should be in the cap. Slowly turn the bottle over, the disk should remain in the cap.
- 9 Remove the disk, rinse with Type 1 water then with ethanol, pat dry (do not rub), place in a plastic zip lock bag. The bag should be labeled with the sample ID, date digested and the date plated.

The ^{210}Po and ^{209}Po concentration on each disk is determined by alpha spectrometry using silicon surface barrier detectors and a multi-channel analyzer system. The disks are counted in vacuum chambers to enhance the resolution of the ^{210}Po and ^{209}Po alpha peaks. The outputs from the silicon detectors are amplified and transmitted through a multiplexer system into a computer based multi-channel analyzer. The ^{210}Po and ^{209}Po peaks are displayed on screen across an energy spectrum, separated by cursors and recorded. The relative concentrations are determined from the number of counts within each region of interest, the counting time is typically between 40,000 to 60,000 sec. The concentration of ^{210}Pb at the time of sediment sampling is calculated from the count rates corrected for counting background, growth and decay, counting efficiency and recovery of the ^{209}Po yield monitor.

5.2 Lead-210 measurement by Gamma Spectrometry

The activity of ^{210}Pb may be directly measured by using the weak (4%) gamma emitted by ^{210}Pb . This method is unlike the previously described methods in that this uses the direct measurement procedures rather than daughter or granddaughter products. Further, this does not require separation or deposition steps that require yield estimations. By this method, one directly places sufficient quantity of the sediment sample in the HPGe detector (described in the ^{137}Cs part of the manual) and counts the gamma activity of 46.52 keV energy. With proper calibration and longer counting time reasonably accurate measurements are possible by this method. However, due to larger background as noise is generated

in the lower energy part of the spectrum, it is often difficult to get sufficiently large net-counts. Because of this reason very few laboratories opt for this method.

6.0 Models for ^{210}Pb profiles interpretation

Three main approaches to the interpretation of ^{210}Pb sediment profiles are currently in use, the Constant Initial Concentration (CIC) Model, The Constant Rate of Supply (CRS) Model and Constant Flux & Constant Rate of Sediment (CFCS) model. These often yield similar chronologies for the more recent sediments, but there is sometimes divergence in the time scales relating to deeper deposits. There are no definitive criteria for choosing one model in preference to another. Each sediment profile should be considered in relation to all available data, to other chronologies and, wherever possible, to other sediment cores taken from the same water body.

6.1 Constant initial concentration (CIC) model

The ^{210}Pb dating technique was first applied to lake sediments by Krishnaswamy et al. (1971). These and many other workers found that a semi-logarithmic plot of the total ^{210}Pb concentration per unit weight of sediment against depth showed a roughly monotonic decline until a region of unchanging concentration was reached. The region of unchanging concentration is the supported ^{210}Pb maintained by ^{226}Ra within the sediment. Subtraction of the supported ^{210}Pb component from the profile results in the lower curve, which is a plot of the unsupported ^{210}Pb against depth. The unsupported ^{210}Pb decreases exponentially and the slope of the line represents a mean sedimentation rate. By a comparison of the concentration at any depth with that at the surface, the life of the sediment at that depth can be calculated from the equation for radioactive decay, which in this case can be expressed as:-

$$C_d = C_0 e^{-\lambda t} \quad (1)$$

where, C_d = concentration of ^{210}Pb at depth d

C_0 = concentration of ^{210}Pb at the surface

λ = decay constant for ^{210}Pb (0.03114)

t = life of sediment at depth d . [$t = d / r$]

r = Sedimentation rate

d = depth of sediment sample in a sediment core

This model assumes that, over the time scale being studied, the concentration of ^{210}Pb in sediment at the mud-water interface has been constant. Because of this, it is often referred to as the Constant Initial Concentration (CIC) model that has been validated for marine sediments by Koide et al., 1972. In some profiles, a semi-logarithmic plot of the unsupported ^{210}Pb against depth is predominately linear, but the slope decreases near the surface. This is often simply the result of reduced compaction of near-surface sediments and the non-linearity is avoided by plotting the ^{210}Pb concentration against the cumulative dry mass of sediment. This technique has been adopted by many workers and has largely superseded the earlier procedure.

Non-linearity in a ^{210}Pb profile near the surface of a core will also occur if the surface sediments are disturbed. The most common cause of sediment mixing is bioturbation, which normally affects only the top few cm of a core. The redistribution of surface sediments by deposit-feeding organisms has been investigated and found that beneath the zone of mixing, the unsupported ^{210}Pb profile in a core of constant sediment accumulation rate was linear. Bioturbation is normally less in freshwater sediments than those of marine origin, partly because of the small size of the freshwater benthos and anoxic sediments are in general suitable for ^{210}Pb dating but that toxic sediments are often too disturbed by bioturbation.

A further source of non-linearity in a ^{210}Pb profile is a change in the accumulation rate. During the last 50-100 years, the sediment accumulation rate in many water bodies has increased, often due to eutrophication. One of two assumptions is implicit in the use of the CIC model to interpret such a profile:-

- (1) There is a large excess of ^{210}Pb in solution in the overlying water and increased sedimentation merely entrains more of the excess. If the sediment has a limited capacity for ^{210}Pb this will result in its concentration remaining constant despite a change in accumulation rate.
- (2) The main source of ^{210}Pb in sediment is material uniformly labelled with ^{210}Pb on the catchment and more of this is being transferred to the lake because of environmental change.

However the use of the CIC model to interpret ^{210}Pb profiles where the sediment accumulation rate is changing does not always yield a chronology consistent with independent time scales and an alternative interpretation has been sought.

6.2 Constant rate of supply (CRS) or constant flux (CF) model

In equation (1) discussed under section 6.1, $C_0 = F/r$ where F is the flux of unsupported ^{210}Pb to the sediment/water interface and r is the sediment accumulation rate. A change in the accumulation rate implies a change in either C_0 or F (or possibly both). The CIC model assumes that C_0 is constant but an alternative approach is to consider that F , the flux of unsupported ^{210}Pb to the sediment, is constant. This is termed as the constant rate of supply or CRS model. It was first outlined by Goldberg (1963) and has since been developed by Appleby and Oldfield (1983). The constant flux assumption implies a constant residual of unsupported ^{210}Pb within the sediment column and the life t of

sediments at depth d may be calculated from the radioactive decay law expressed as

$$A_d = A_0 e^{-\lambda t} \quad (2)$$

where A_d is the unsupported ^{210}Pb in the core below depth ' d ' and A_0 is the entire unsupported ^{210}Pb below the mud/water interface. The varying sediment accumulation rate r can be calculated from

$$r = A_d / C_d \quad (3)$$

where C_d is the unsupported ^{210}Pb concentration. The general effect of applying the CRS model is to assign greater ages to sediments at lower depths in a core, whereas there is often reasonable agreement between the chronologies for near-surface sediments. It should be noted that both the CIC and CRS models would give the same chronology if a semi-logarithmic plot of unsupported ^{210}Pb against the cumulative dry mass of sediment is linear. The other model can be a combination of both, i.e., constant initial concentration and constant flux or constant flux and constant rate of sediment (CFCS).

6.3 Constant Flux Constant Sedimentation Rate (CFCS) model:

Few authors have set out fully and explicitly the assumptions they have used, though most in calculating age/depth profiles and sedimentation rates from ^{210}Pb measurement have assumed, at least implicitly, a constant flux of unsupported ^{210}Pb from the lake waters to the sediments. In the majority of cases the assumption of a constant flux is coupled also with an assumed constant dry mass sedimentation rate. Where both assumptions are satisfied the unsupported ^{210}Pb concentration, C in the sediments will vary exponentially with the cumulative dry mass of sediment, m in accordance with the formula (Robbins, 1978)

$$C = C_0 e^{-km/r}$$

Where C_0 is the unsupported ^{210}Pb concentration at the sediment – water interface, r is the dry-mass sedimentation rate and k is the decay constant of ^{210}Pb . ($k=0.03114/\text{yr}$). If the unsupported ^{210}Pb concentration C is plotted on a logarithmic scale against the cumulative dry mass m , the resulting ^{210}Pb profile will be linear, with slope $-k/r$. The sedimentation rate, r can be determined graphically from the mean slope of the profile, or alternatively by a least-square fit procedure. This dating model has been called the simple model (Robbins, 1978), or the Constant Flux Constant Sedimentation Rate model. Linear profiles characterizing an exponential variation in C , have been observed in many lakes and have provided a basis for calculating mean sedimentation rates for the past 100 – 150 years.

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