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Lead-210 chronology of the Scandinavian SWAP sites

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In the Surface Water Acidification Project (SWAP) sediment profiles from five Scandinavian sites were analysed for ^{210}Pb by using refined isotope dilution alpha spectrometry. The ^{210}Pb parameters of these lakes were very similar to those obtained for protected forest lakes with no land-use activities. These data demonstrated almost exclusive atmospheric inputs and an internal deposition regulated by the organic fractionation and the grain-size distribution in the sediments. Preliminary speciation experiments showed minor losses of ^{210}Pb ($\leqslant 5\%$) through enhanced dissolution of fulvic compounds at acid conditions (pH $\geqslant 4$). The sediment accumulation rates (constant rate of unsupported ^{210}Pb supply (CRS) model) of the lakes gradually increased, by at least a factor of three, over the past century although ^{210}Pb parameters did not show any strong signs of enhanced land-use activities. This is perhaps caused by more efficient preservation of the sediments through humic precipitation under more acid conditions.

Introduction

The most suitable dating method for recent freshwater sediments of the past 150 years or so is to use ^{210}Pb (cf. El-Daoushy 1988). Low accumulation rates typical of acid lakes may make the construction of sediment chronologies difficult (cf. Davis *et al.* 1984; El-Daoushy 1988). Moreover, the poor understanding of the influence of acidification on the accumulation of ^{210}Pb (cf. Gambrell *et al.* 1980; Hanson *et al.* 1982; Nriagu 1984; Simola & Liehu 1984) in such lakes has caused further limitations in evaluating and modelling chronological anomalies. The observed correlation between ^{210}Pb minima and diatom-inferred pH minima (Simola & Liehu 1984) may indicate either major losses of unsupported ^{210}Pb through dissolution of fulvic fractions (lower ^{210}Pb fluxes) or increased sedimentation (lower ^{210}Pb concentrations) by effective precipitation and accumulation of humic compounds. Speciation studies have shown, however, that acidification alone cannot explain the observed variations of the ^{210}Pb fluxes in acidified freshwater lakes (El-Daoushy & Garcia-Tenorio 1988).

Materials and methods

The Scandinavian SWAP sites and lake characteristics are described elsewhere (Battarbee & Renberg, this symposium). The organic content of sediments ranged from 30 % to 70 % and the average total dry mass in samples analysed was about 0.5 g. Surface sediment layers amounted to $\leqslant 0.1$ g whereas deeper samples contained as much as 1 g dry matter. Calculated dry-matter densities of the sediments by using organic and water contents agreed well with measured values for Lilla Öresjön, Verevatn and Röyrtjörna, thus suggesting that the assumed organic and inorganic dry densities of 1.4 and 2.5 g cm^{-3} were quite reasonable and that the composition of the sediments could be described as simple organo-clay deposits along with diatom minerals. Such comparisons were not possible for Gulspettvann and Holmevatn as the data required were missing. Several sediment layers from Gulspettvann and Holmevatn contained appreciable amounts of other minerals, such as graphite (Gulspettvann) and fine sand (Holmevatn), despite the high organic content in these layers (50 %).

Because of the high organic content of the sediments examined, a chemical extraction was used that provided high-quality alpha sources free from organic and inorganic remnants. Absolute ^{210}Pb measurements of the small samples required further refinements of laboratory routines through careful examination of memory effects arising from adsorption on glassware and long-term background records of the detectors.

Results and discussion

With the exception of Holmevatn, values for the supported ^{210}Pb (0.4–1.0 pCi g^{-1}) could be determined for each core by using the deeper sediments (figure 1*a*). Preliminary speciation experiments demonstrated that ^{210}Pb fractionation in these sediments was similar to that occurring in inland lakes in Sweden (El-Daoushy 1988). Speciation studies in these lakes

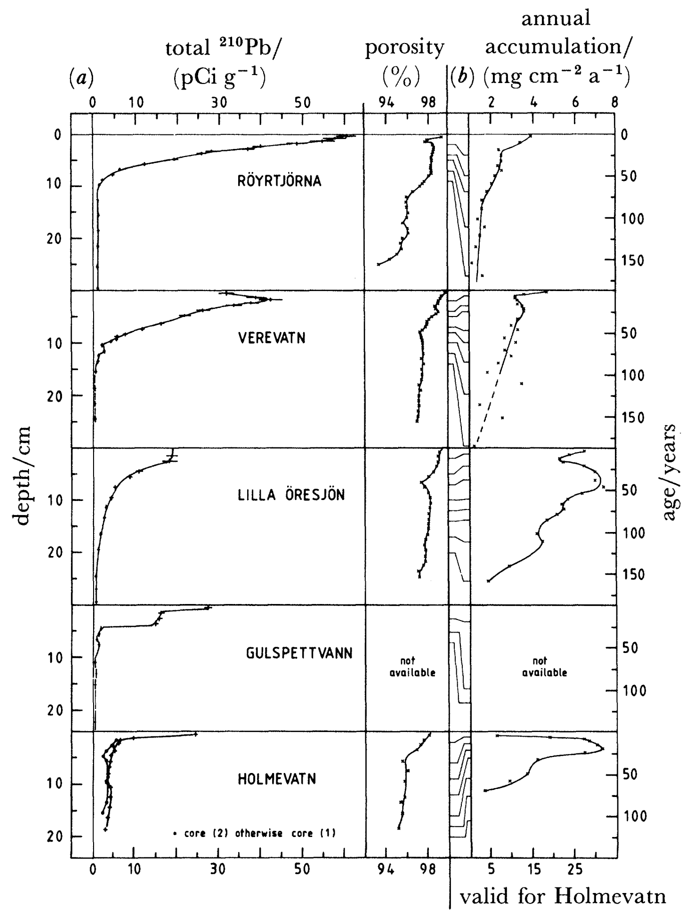

FIGURE 1. Total ^{210}Pb activity and porosity against actual depth (*a*); activities are given with one standard deviation. Annual accumulation against ^{210}Pb ages (*b*). Cores from Holmevatn are probably not long enough to provide supported ^{210}Pb; (*a*) and (*b*) are correlated to show chronological changes in various profiles. Holmevatn has much higher annual accumulation than other lakes and a special scale is used for it. The scatter of sediment accumulation in the deeper part of Verevatn may be due to age uncertainties rather than to real changes.

showed that the unsupported ^{210}Pb was controlled by organic fulvic and humic compounds whereas the supported ^{210}Pb was limited to organo-clay complexes. According to these experiments the estimated levels of the supported ^{210}Pb (figure 1*a*) are close to expectations. The general features of the ^{210}Pb against depth profiles are similar to profiles obtained for Swedish inland lakes, which demonstrated secular equilibrium between ^{226}Ra and ^{210}Pb (El-Daoushy 1988) and constant levels of supported ^{210}Pb in most cases. Speciation results gave an indication that the two cores from Holmevatn were probably not long enough to allow for a complete decay of the unsupported ^{210}Pb. In these cores the supported ^{210}Pb found in the organo-clay complexes of the deeper sediments was much lower than the values shown in figure 1*a* and supported ^{210}Pb was assumed for this lake. Apart from Holmevatn, the stable and low levels of ^{210}Pb in the deeper sediments (figure 1*a*) suggest minor chronological variations in the origin and composition of the lake sediments. Calculated dry matter densities of Lilla Öresjön, Verevatn and Röyrtjörna showed that these lakes have a sediment composition similar to Swedish inland lakes. The course of sediment accumulation in these inland lakes was mainly governed by grain-size distribution. However, chemical speciation is also important (El-Daoushy & Garcia-Tenorio 1988) and at the neutral pH values of inland lakes, these processes

TABLE 1. AGES OF SEDIMENT LAYERS DATED ACCORDING TO THE CONSTANT RATE OF UNSUPPORTED ^{210}Pb SUPPLY (CRS) MODEL

(Ages of sediment layers at Gulspettvann are dated by using the constant initial ^{210}Pb concentration (CIC) model.)

actual depth/cm	ages/(^{210}Pb years) Gulspettvann	Holmevatn	Lilla Öresjön	Verevatn	Röyrtjörna
0.5	—	—	—	—	3±1
1.0	—	4.5±2	3±1	2±1	10±1
1.5	17.5±1	—	—	4±1	19.5±1
2.0	—	7±2	7±1	6.5±1	25.5±1
2.5	18±1	—	—	9.5±1	31.5±1
3.0	—	8.5±2	12±1	12.5±1	38±1
3.5	20±1	—	—	15.5±1	44±1
4.0	—	10.5±2	16.5±1.5	18±1	50±1
4.5	92±7	—	—	21±1	59±1
5.0	—	12.5±2	22±1.5	24.5±1	69±1.5
5.5	105±7	—	—	—	78±2
6.0	—	15.5±2	29±1.5	34.5±1	89±2
6.5	128±12	—	—	41.5±1	101±2.5
7.0	—	—	38.5±1.5	48±1	111±3
7.5	103±12	—	—	56±1	121±5
8.0	—	20±2.5	46.5±2	62±1.5	135±8
8.5	—	—	—	71±1.5	154±10
9.0	—	22.5±2.5	54±2	78±1.5	170±20
9.5	—	—	—	86±2	185±25
10.0	—	25±2.5	61±2	98±2	—
11.0	—	29±2.5	67±2	111±3	—
12.0	—	33±3	73±3	136±4	—
13.0	—	37.5±3.5	79±3	153±5	—
14.0	—	43.5±4	86±4	186±15	—
15.0	—	51±4	—	—	—
16.0	—	59±5	103±4	—	—
17.0	—	70±7	112±6	—	—
18.0	—	83±9	—	—	—
19.0	—	105±11	141±8	—	—
20.0	—	—	159±10	—	—

may have caused losses of fine particulates because of inefficient flocculation. The ^{210}Pb fluxes in the lakes studied under SWAP were independent of the sediment accumulation rates and similar to those obtained for the inland lakes. The flux values were about 0.16 pCi cm^{-2} a^{-1} for Holmevatn and Verevatn, 0.12 and 0.24 pCi cm^{-2} a^{-1} for Lilla Öresjön and Röyrtjörna, respectively. As for inland lakes, the initial ^{210}Pb concentrations were lower at sites with higher accumulation rates because of dilution (figure 1*b*). This suggests that the progressive decceleration of ^{210}Pb concentrations towards the surface (figure 1*a*) is due to an accelerating sediment accumulation (figure 1*b*) during the past century (table 1), possibly because of the enhanced preservation of the humic sediments as a consequence of a continuous lowering of pH in the lakes. However, the influence of land-use activities may have contributed to the increase of sediment accumulation in Röyrtjörna as its ^{210}Pb flux was slightly higher than the atmospheric flux (El-Daoushy 1988). The porosity characteristics (figure 1*a*) show that accumulation of the sediments (figure 1*b*) occurs through chemical precipitation and flocculation followed by physical sedimentation and compaction. The chemical deposition in these lakes is more important than the physical sedimentation in freshwater lakes with low organic content.

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