# Environmental change and atmospheric contamination on Svalbard: sediment chronology*

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## Abstract

Sediment cores collected from eight lakes along the western coast of Svalbard as part of a project investigating atmospheric pollution and environmental change in Arctic regions were dated radiometrically using natural ($^{210}$Pb) and artificial ($^{137}$Cs and $^{241}$Am) fallout radionuclides. At four sites the sedimentation rates were relatively uniform, and in consequence the $^{210}$Pb dates were relatively unambiguous. At the remaining sites there were irregularities in the $^{210}$Pb activity versus depth profiles, indicating significant variations in the net sediment accumulation rate during the past 120 years. At these sites there were significant differences between $^{210}$Pb dates calculated using the two standard simple dating models (CRS and CIC). In most cases, stratigraphic dates based on the $^{137}$Cs and $^{241}$Am records supported use of the CRS model, though at one site (Ossian Sarsfjellet) the CIC model appeared more appropriate. The irregularities in the $^{210}$Pb records were mainly caused by episodes of accelerated sedimentation due, for example, to inwash or slump events, though at some sites there appears to have been a systematic increase in sediment accumulation rates in recent decades. Sediment accumulation rates were generally lower at the northern sites, and higher at the more southerly locations. Mean sediment accumulation rates varied by an order of magnitude, ranging from 0.002 - 0.050 g cm$^{-2}$ y$^{-1}$ (0.02 – 0.10 cm y$^{-1}$). $^{210}$Pb fluxes measured from the core inventories were mostly in the range 34 - 80 Bq m$^{-2}$ y$^{-1}$ typical of Arctic sites. Much higher values, recorded at two sites (Birgervatnet and Daltjørna), may be due to significant inputs from in the catchments during spring thaw.

## Introduction

In an investigation of the impact of recent environmental change in Arctic regions, detailed palaeolimnological studies were carried out on sediment sequences from several lakes along the western coast of Svalbard (Birks et al. 2004), at sites ranging from 77º33′ N to 79º44′ N. Such sequences have been shown to contain high quality records of a range of environmental parameters, and may be used to make reconstructions of the history and impact of changes in the recent past. Essential to this approach, is a reliable means for dating the sediment records. The most widespread technique on time-scales spanning the past 100 - 150 years uses the natural fallout radionuclide $^{210}$Pb. The method is unequivocal where environmental conditions have remained constant and the unsupported $^{210}$Pb concentration versus depth profile follows a simple exponential relation. Deviations from such a relation are, however, to be expected at sites where environmental conditions have varied during the last 100 - 150 years. Different models have been developed to account for such deviations (Appleby and Oldfield 1978; Robbins 1978) and the accuracy of $^{210}$Pb dates at these sites will depend on the validity of the model used. There are two standard simple models for calculating $^{210}$Pb dates, the CRS (constant rate of supply) and CIC (constant initial concentration) models. Where they yield different results, the problem of model validation is usually resolved by using independently determined dates from stratigraphic records of the artificial fallout radionuclides $^{137}$Cs (Pennington et al. 1973) and $^{241}$Am (Appleby et al. 1991) from the atmospheric testing of nuclear weapons. At sites where neither of the simple models is consistent with the $^{137}$Cs and $^{241}$Am record, it may be necessary to use more complicated models involving a number of different processes. The objective of this paper is to give an account of the records of fallout radionuclides in the eight Svalbard cores examined and to present reliable sediment chronologies based on an assessment of these records that can be used to date biostratigraphic and geochemical records of the lake ecosystems, and to estimate fluxes of atmospheric pollutants.

## Methods

The cores were collected using a Glew (1989) gravity corer. Five were collected in 1995 (Birks et al. 2004), and three were collected earlier in 1993 as part of the EU funded AL:PE2 project (Wathne et al. 1997). Details of the cores and their locations are given in Table 1 and Figure 1. The cores were sectioned at intervals ranging from 0.25 - 1.0 cm, and sub-samples of dried sediment from each section were sent to the Liverpool University Environmental Radioactivity Research Centre (ERRC) for radiometric analysis by direct gamma assay using Ortec HPGe GWL series well-type coaxial low background intrinsic germanium detectors (Appleby et al. 1986). $^{210}$Pb was determined via its gamma emissions at 46.5keV, and $^{226}$Ra by the 295keV and 352keV γ-rays emitted by its daughter isotope $^{214}$Pb following three weeks storage in sealed containers to allow radioactive equilibration. $^{137}$Cs and $^{241}$Am were measured by their emissions at 662keV and 59.5keV respectively. The absolute efficiencies of the detectors were determined using calibrated sources and sediment samples of known activity. Corrections were made for the effect of self-absorption of low energy γ-rays within the sample (Appleby et al. 1992). Unsupported (atmospherically delivered) $^{210}$Pb was calculated by subtracting $^{226}$Ra (supported $^{210}$Pb) activity from total $^{210}$Pb. Radiometric dates were calculated from the $^{210}$Pb and $^{137}$Cs records using the procedures described in Appleby and Oldfield (1983) and Appleby (1998).

## Results and discussion

The results of the radiometric analyses are shown in Figure 2. Because of the large variations in dry bulk density within each core and from site to site, to facilitate a better comparison between cores, radionuclide concentrations have been plotted against depth measured as cumulative dry mass (g cm$^{-2}$). Table 2 summarises a number of radiometric parameters determined for each core, including the maximum unsupported $^{210}$Pb concentration, the unsupported $^{210}$Pb and $^{137}$Cs inventories, and the constant $^{210}$Pb flux required to sustain the measured $^{210}$Pb inventory.

*Table 1*. Sites details of the $^{210}$Pb dated cores from Svalbard

| Lake | Location | Catchment Area (km$^2$) | Lake Area (km$^2$) | Max Depth (m) | Mean Depth (m) | Core | Coring date |
|---|---|---|---|---|---|---|---|
| Ossian Sarsfjellet (C) | 78° 57' N 12° 28' E | 1.8 | 0.13 | 26 | 11 | SBAC1 | 1995 |
| Ytertjørna (Q) | 78° 13' N 12° 56' E | ~1.5 | 0.14 | 2.6 | 1.2 | SBAQ2 | 1995 |
| Vassauga (S) | 77° 45' N 13° 57' E | ~1.8 | 0.037 | 1.3 | 0.8 | SBAS3 | 1995 |
| Daltjørna (T) | 77° 33' N 14° 13' E | 4.9 | 0.054 | 10.5 | 7.4 | SBAT4 | 1995 |
| Tenndammen (U) | 78° 06' N 15° 02' E | 2.1 | 0.15 | 2.5 | 1.5 | SBAU4 | 1995 |
| Arresjøen | 79° 40' N 10° 51' E | ~3.1 | 0.34 | 29 | 18 | ARSJ93/4 | 1993 |
| Birgervatnet | 79° 48' N 11° 37' E | ~2.0 | 0.15 | 15 | 8 | BIRJ93/1 | 1993 |
| 'Scurvy Pond' | 79° 44' N 12° 18' E | ~1.5 | 0.10 | 1 | 0.8 | SCUR93/1 | 1993 |

*Figure 1*. Map of Svalbard showing the locations of the study sites.

*Lead-210 activity*

The $^{210}Pb$ activity versus depth profiles (Figure 2i) suggest a north-south trend in which cores from the more southerly lakes have higher sedimentation rates and more frequent irregularities in the process of sediment accumulation. At the three northern sites (Arresjøen (Arsj), Birgervatnet (Bir), 'Scurvy Pond' (Scur)) $^{210}Pb/^{226}Ra$ equilibrium (corresponding to ca. 150 years accumulation) is achieved at depths of between 3 - 5 cm (0.3 - 1.5 g $cm^{-2}$; Figure 2i(a)). This compares with depths of between 8 - 11 cm (4 - 8 g $cm^{-2}$) at the three most southern sites (Vassauga (S), Daltjørna (T), Tenndammen (U); Figure 2i(c)). At Vassauga and Tenndammen, the $^{210}Pb$ activity versus depth profiles both have significant non-monotonic features associated with layers of dense inorganic sediment that presumably record episodes of rapid accumulation, possibly associated with slump events. The significantly lower surficial $^{210}Pb$ activities at these sites (Table 2) suggest that they also have higher intrinsic sedimentation rates.

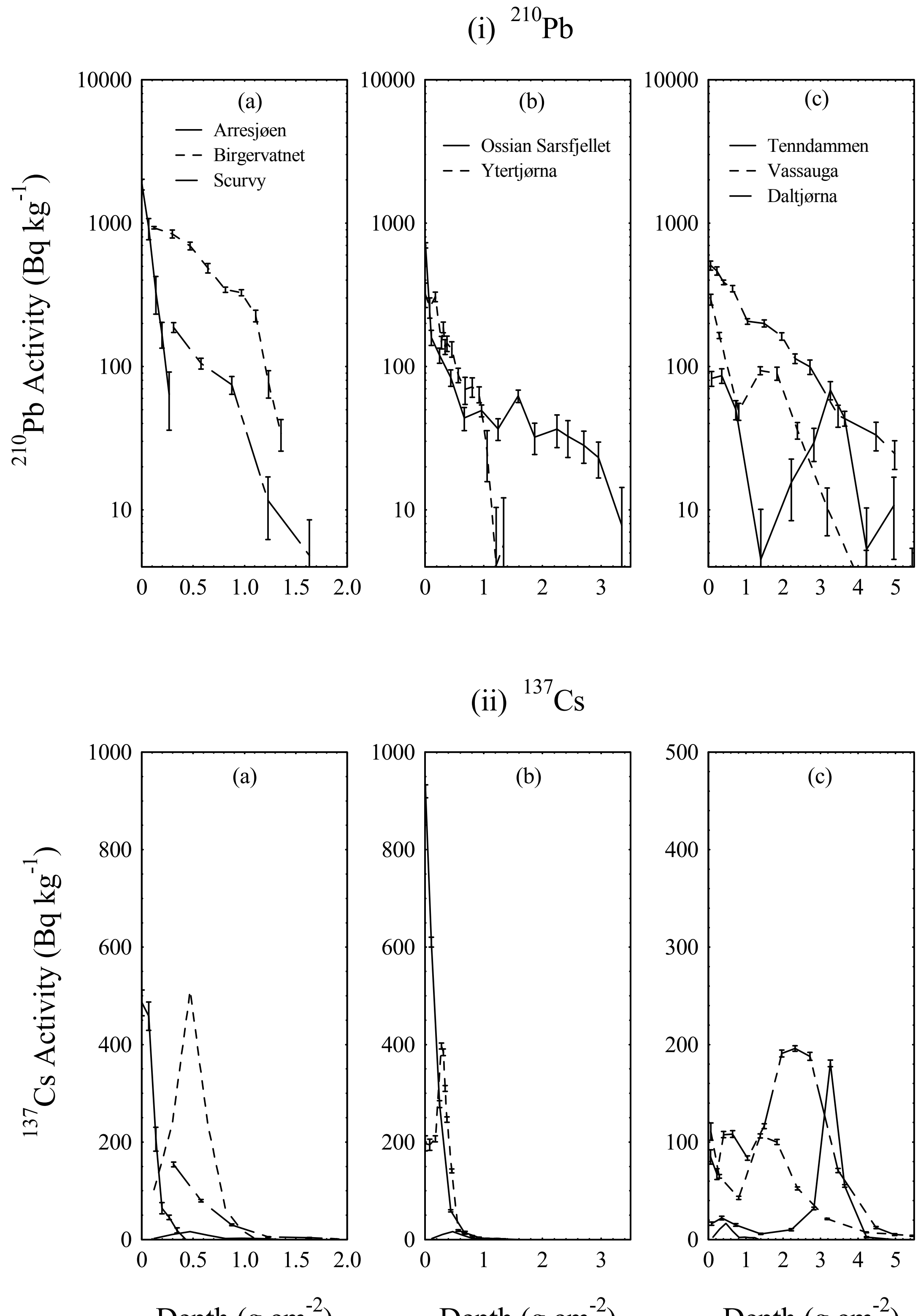


*Figure 2*. Fallout radionuclides in Svalbard cores showing (i) unsupported $^{210}$Pb and (ii) $^{137}$Cs concentrations versus depth (measured as cumulative dry mass). Figures (a) show the results for Arresjøen, Birgervatnet, and 'Scurvy Pond', (b) the results for Ossian Sarsfjellet and Ytertjørna, and (c) the results for Vassauga, Daltjørna, and Tenndammen.

*Table 2*. Radionuclide inventories of Svalbard lake sediment cores. Also shown are the maximum $^{210}$Pb concentrations and the mean fluxes required to sustain the $^{210}$Pb inventories.

| | Unsupported $^{210}$Pb | | | | | | Weapons $^{137}$Cs | |
|---|---|---|---|---|---|---|---|---|
| | Maximum Activity | | Inventory | | Flux | | Inventory | |
| | Bq kg$^{-1}$ | ± | Bq m$^{-2}$ | ± | Bq m$^{-2}$y$^{-1}$ | ± | Bq kg$^{-1}$ | ± |
| Ossian Sarsfjellet | 701 | 29 | 1914 | 89 | 60 | 3 | 1898 | 55 |
| Ytertjørna | 320 | 61 | 1455 | 68 | 45 | 2 | 1274 | 28 |
| Vassauga | 293 | 25 | 2582 | 114 | 80 | 4 | 2371 | 53 |
| Daltjørna | 507 | 37 | 7904 | 216 | 246 | 8 | 5032 | 99 |
| Tenndammen | 83 | 10 | 1497 | 125 | 47 | 4 | 1499 | 41 |
| Arresjøen | 1861 | 156 | 1560 | 171 | 50 | 5 | 715 | 35 |
| Birgervatnet | 928 | 17 | 6968 | 203 | 217 | 6 | 2044 | 63 |
| 'Scurvy Pond' | 421* | 34 | 1750 | 90 | 54 | 3 | 1558 | 56 |
| Mean values | | | 3204 | | 100 | | 2049 | |
| | | | | | 56† | | 1553† | |

* Extrapolated value – the value for the surficial section (0-1 cm) was not determined.
† Mean values excluding the anomalously high values at Birgervatnet and Daltjørna

## *Artificial fallout radionuclide activities*

At five of the eight sites, the $^{137}$Cs activity versus depth profile (Figure 2ii) had a relatively well-resolved subsurface peak recording the 1963 fallout maximum from the atmospheric testing of nuclear weapons. In most cases this identification was corroborated by the presence at approximately the same depth of a similar but smaller peak in $^{241}$Am activity (Appleby et al. 1991). At two sites (Ossian Sarsfjellet (C), Arresjøen) the maximum $^{137}$Cs concentration occurred in the uppermost sediment layer, most probably because of the very slow contemporary sedimentation rate. At the remaining site ('Scurvy Pond'), the uppermost sample was not available for radiometric analysis.

## *Core chronologies*

At four sites (Vassauga (S), Daltjørna (T) Arresjøen (Arsj), 'Scurvy Pond' (Scur)) there was little significant discrepancy between dates calculated using the CRS and CIC dating models. Both models indicated no major secular change in sedimentation during the past 120 years. At those sites where there were significant discrepancies (Ossian Sarsfjellet (C), Ytertjørna (Q), Tenndammen (U), Birgervatnet (Bir)), the $^{137}$Cs records were used to assess which model, or combination of models, was most appropriate. Best chronologies (dates and accumulation rates) for each core are given in Tables 3 - 10. These Tables also give extrapolated dates for core depths below the base of the $^{210}$Pb record calculated using the best estimate of the mean sediment accumulation rate appropriate to the core.

### *Ossian Sarsfjellet core SBAC1*

This core has a somewhat unusual $^{210}$Pb profile. The relatively high $^{210}$Pb activity in the surficial sediments (Table 2) and steep decline in the top 2 cm (0.5 g cm$^{-2}$; Figure 2i(b)) suggest that present-day sedimentation rates are intrinsically low, as implied by the $^{137}$Cs record (Figure 2ii(b)). High $^{137}Cs$ concentrations occur only in the top 1.5 cm of the core, and are coupled with significant $^{241}Am$ concentrations. Between 2 and 6 cm (0.5 - 3 g cm$^{-2}$), $^{210}Pb$ activity declines much more slowly, suggesting an earlier period of more rapid accumulation. A further steep fall in $^{210}Pb$ activity between 6 and 7 cm (3 - 3.5 g cm$^{-2}$), suggests a reversion to low accumulation rates in the older sections of the core, comparable in value to those in the top 2 cm.

There is a major difference between the CRS and CIC model chronologies for this core. The CIC model dates place 1963 at a depth of ca. 1.25 cm, and are in better agreement with the $^{137}Cs$ and $^{241}Am$ records than the CRS model. The latter places 1963 at ca. 3 cm, well below the depths recording high $^{137}Cs$ and $^{241}Am$ concentrations. The results of the CIC model calculations, presented in Table 6, suggest that the middle section of the $^{210}Pb$ record records a major slump dating from the period 1890 - 1910. The lithostratigraphy shows that these sediments were relatively dense and inorganic. The validity of the CIC model suggests that they were composed largely of surficial sediments from that period. Although this might be expected to cause a substantial increase in the unsupported $^{210}Pb$ inventory, the relatively slight impact on the present-day value (Table 2) can be attributed to radioactive decay during the intervening 90 years. The (normal) sedimentation rate following the slump is estimated to be 0.0088 ± 0.0025 g cm$^{-2}$ y$^{-1}$. Dates prior to the slump have been calculated using this value.

*Table 3.* $^{210}Pb$ chronology of Arresjøen core ARSJ93/4

| Depth | | Chronology | | | Sedimentation Rate | | |
|---|---|---|---|---|---|---|---|
| | | Date | Age | | | | |
| cm | g cm$^{-2}$ | AD | y | ± | g cm$^{-2}$ y$^{-1}$ | cm y$^{-1}$ | ± (%) |
| 0.00 | 0.00 | 1993 | 0 | | | | |
| 0.25 | 0.01 | 1987 | 6 | 2 | 0.0023 | 0.033 | 13% |
| 0.50 | 0.03 | 1978 | 15 | 3 | 0.0023 | 0.027 | 13% |
| 0.75 | 0.06 | 1969 | 24 | 4 | 0.0023 | 0.023 | 13% |
| 1.00 | 0.08 | 1956 | 37 | 6 | 0.0023 | 0.018 | 13% |
| 1.25 | 0.12 | 1941 | 52 | 8 | 0.0023 | 0.017 | 13% |
| 1.50 | 0.15 | 1927 | 66 | 10 | 0.0023 | 0.018 | 13% |
| 1.75 | 0.18 | 1914 | 79 | 11 | 0.0023 | 0.019 | 13% |
| 2.00 | 0.21 | 1900 | 93 | 13 | 0.0023 | 0.017 | 13% |
| *2.50* | *0.28* | *1869* | *124* | *17* | *0.0023* | *0.015* | |
| *3.00* | *0.36* | *1836* | *157* | *21* | *0.0023* | *0.014* | |
| *3.50* | *0.45* | *1798* | *195* | *26* | *0.0023* | *0.013* | |
| *4.00* | *0.55* | *1756* | *237* | *32* | *0.0023* | *0.011* | |
| *4.50* | *0.67* | *1703* | *290* | *39* | *0.0023* | *0.010* | |
| *5.00* | *0.78* | *1653* | *340* | *45* | *0.0023* | *0.011* | |
| *5.50* | *0.88* | *1609* | *384* | *51* | *0.0023* | *0.012* | |
| *6.00* | *0.98* | *1568* | *425* | *56* | *0.0023* | *0.012* | |
| *6.50* | *1.07* | *1528* | *465* | *61* | *0.0023* | *0.012* | |
| *7.00* | *1.16* | *1488* | *505* | *67* | *0.0023* | *0.012* | |
| *7.50* | *1.26* | *1446* | *547* | *72* | *0.0023* | *0.012* | |
| *8.00* | *1.36* | *1404* | *589* | *78* | *0.0023* | *0.012* | |
| *8.50* | *1.45* | *1364* | *629* | *83* | *0.0023* | *0.012* | |
| *9.00* | *1.55* | *1321* | *672* | *88* | *0.0023* | *0.012* | |
| *9.50* | *1.64* | *1278* | *715* | *94* | *0.0023* | *0.011* | |
| *10.00* | *1.76* | *1227* | *766* | *101* | *0.0023* | *0.010* | |

*NB: Extrapolated values below the base of the $^{210}Pb$ record, shown in italics, have been calculated using the mean post-1900 sedimentation rate of 0.0023 g cm$^{-2}$ y$^{-1}$ (see text).*

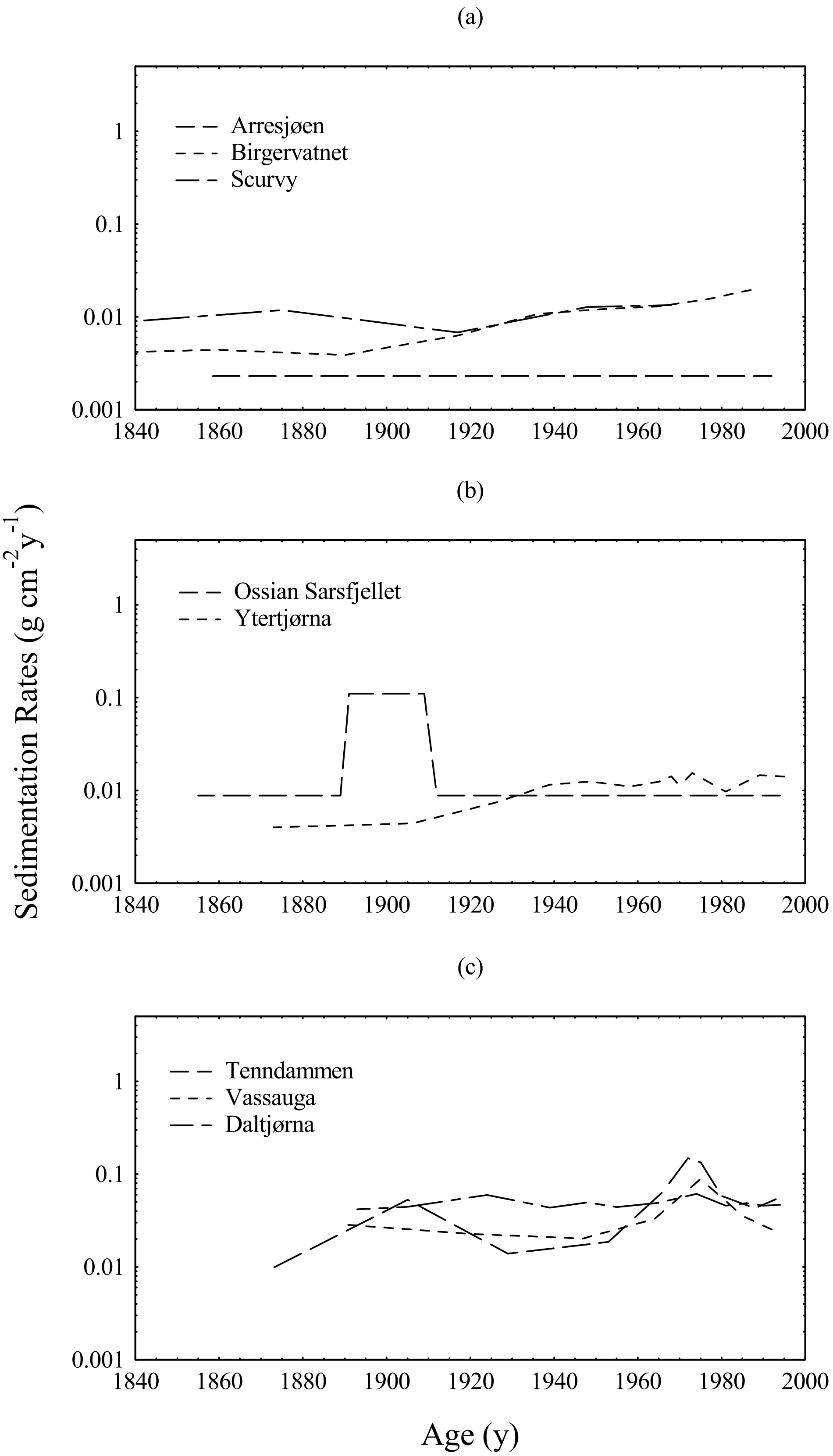


*Figure 3*. Sedimentation rates (g cm$^{-2}$ y$^{-1}$) versus time in Svalbard lake sediment cores. Figure (a) shows the results for Arresjøen, Birgervatnet, and 'Scurvy Pond', (b) the results for Ossian Sarsfjellet and Ytertjørna, and (c) the results for Vassauga, Daltjørna, and Tenndammen. Note that the sedimentation rates are plotted on a logarithmic scale.

*Table 4.* $^{210}$Pb chronology of Birgervatnet core BIRJ93/1

| Depth | | Chronology | | | Sedimentation Rate | | |
|---|---|---|---|---|---|---|---|
| cm | g cm$^{-2}$ | Date AD | Age y | ± | g cm$^{-2}$ y$^{-1}$ | cm y$^{-1}$ | ± (%) |
| 0.00 | 0.00 | 1993 | 0 | | | | |
| 0.50 | 0.08 | 1990 | 3 | 1 | 0.0200 | 0.091 | 3.4 |
| 1.00 | 0.21 | 1982 | 11 | 2 | 0.0175 | 0.053 | 5.5 |
| 1.50 | 0.38 | 1971 | 22 | 2 | 0.0143 | 0.042 | 7.3 |
| 2.00 | 0.56 | 1958 | 35 | 2 | 0.0125 | 0.036 | 8.1 |
| 2.50 | 0.73 | 1943 | 50 | 2 | 0.0114 | 0.032 | 7.8 |
| 3.00 | 0.89 | 1927 | 66 | 3 | 0.0085 | 0.025 | 8.0 |
| 3.50 | 1.04 | 1903 | 90 | 4 | 0.0051 | 0.019 | 13.1 |
| 4.00 | 1.17 | 1875 | 118 | 8 | 0.0042 | 0.017 | 26.9 |
| 4.50 | 1.29 | 1845 | 148 | 16 | 0.0041 | 0.016 | 40.9 |
| *5.00* | *1.42* | *1814* | *179* | *19* | *0.0041* | *0.016* | |
| *5.50* | *1.55* | *1781* | *212* | *23* | *0.0041* | *0.015* | |
| *6.00* | *1.69* | *1747* | *246* | *27* | *0.0041* | *0.015* | |
| *6.50* | *1.83* | *1714* | *279* | *30* | *0.0041* | *0.015* | |
| *7.00* | *1.96* | *1681* | *312* | *34* | *0.0041* | *0.015* | |
| *7.50* | *2.10* | *1649* | *344* | *37* | *0.0041* | *0.015* | |
| *8.00* | *2.23* | *1616* | *377* | *41* | *0.0041* | *0.016* | |
| *8.50* | *2.36* | *1584* | *409* | *44* | *0.0041* | *0.015* | |
| *9.00* | *2.49* | *1551* | *442* | *48* | *0.0041* | *0.015* | |
| *9.50* | *2.63* | *1518* | *475* | *51* | *0.0041* | *0.015* | |
| *10.00* | *2.77* | *1484* | *509* | *55* | *0.0041* | *0.015* | |
| *10.50* | *2.91* | *1450* | *543* | *59* | *0.0041* | *0.015* | |
| *11.00* | *3.04* | *1419* | *574* | *62* | *0.0041* | *0.016* | |
| *11.50* | *3.16* | *1388* | *605* | *65* | *0.0041* | *0.018* | |
| *12.00* | *3.27* | *1363* | *630* | *68* | *0.0041* | *0.020* | |
| *12.50* | *3.37* | *1338* | *655* | *71* | *0.0041* | *0.020* | |
| *13.00* | *3.47* | *1313* | *680* | *74* | *0.0041* | *0.020* | |
| *13.50* | *3.57* | *1288* | *705* | *76* | *0.0041* | *0.019* | |
| *14.00* | *3.69* | *1261* | *732* | *79* | *0.0041* | *0.018* | |
| *14.50* | *3.80* | *1233* | *760* | *82* | *0.0041* | *0.018* | |
| *15.00* | *3.91* | *1206* | *787* | *85* | *0.0041* | *0.018* | |

*NB: Extrapolated values below the base of the $^{210}$Pb record, shown in italics, have been calculated using the estimated pre-1900 sedimentation rate of 0.0041 g cm$^{-2}$ y$^{-1}$ (see text).*

### *Yterjørna core SBAQ2*

In the top section of this core, down to 6 cm (0.7 g cm$^{-2}$), unsupported $^{210}$Pb activity declines more or less exponentially with depth (Figure 2i(b)). For this section, dating from ca. 1940, the CRS and CIC models suggest similar accumulation rates, with a mean value of 0.013 ± 0.002 g cm$^{-2}$ y$^{-1}$. This is in relatively good agreement with the $^{137}$Cs and $^{241}$Am records. The $^{137}$Cs profile (Figure 2ii(b)) has a well-resolved subsurface peak at 2.5 cm (0.3 g cm$^{-2}$) and a distinct $^{241}$Am peak at the same depth. Dating these features to 1963 gives a mean post-1963 sedimentation rate of 0.010 ± 0.001 g cm$^{-2}$ y$^{-1}$. Below ca. 8 cm $^{210}$Pb activity declines much more steeply and $^{210}$Pb/$^{226}$Ra equilibrium is reached at a depth of ca. 10 cm (1.25 g cm$^{-2}$). In consequence, CRS model dates in the deeper sections are significantly older than those given by the CIC model. During the period 1900 - 1940 the CRS model suggests a steady increase in accumulation rates from a 19th century value of ca. 0.0042 g cm$^{-2}$ y$^{-1}$. The CIC model suggests a later and more dramatic increase, during the 1930s. Since the results given in Table 2 show no evidence of an elevated $^{210}$Pb flux, as would be demanded by the CIC model, the CRS model is thought to be more appropriate at this site. The sediment dates and accumulation rates chronology determined by this method are given in Table 7.

*Table 5.* $^{210}$Pb Chronology of 'Scurvy Pond' core SCUR93/1

| Depth | | Chronology | | | Sedimentation Rate | | |
|---|---|---|---|---|---|---|---|
| | | Date | Age | | | | |
| cm | g cm$^{-2}$ | AD | y | ± | g cm$^{-2}$ y$^{-1}$ | cm y$^{-1}$ | ± (%) |
| 0.00 | 0.00 | 1993 | 0 | | | | |
| 0.50 | 0.10 | 1989 | 8 | 1 | 0.0130 | 0.060 | 10.5 |
| 1.00 | 0.21 | 1979 | 17 | 1 | 0.0130 | 0.059 | 10.5 |
| 1.50 | 0.31 | 1968 | 25 | 2 | 0.0130 | 0.058 | 10.5 |
| 2.00 | 0.44 | 1958 | 35 | 3 | 0.0130 | 0.052 | 12.2 |
| 2.50 | 0.58 | 1948 | 45 | 3 | 0.0130 | 0.045 | 13.8 |
| 3.00 | 0.73 | 1932 | 61 | 5 | 0.0100 | 0.033 | 18.5 |
| 3.50 | 0.88 | 1917 | 76 | 6 | 0.0068 | 0.021 | 23.2 |
| 4.00 | 1.05 | 1896 | 97 | 9 | 0.0093 | 0.026 | 40.8 |
| 4.50 | 1.23 | 1875 | 118 | 13 | 0.0120 | 0.031 | 58.4 |
| 5.00 | 1.43 | 1855 | 138 | 20 | 0.0100 | 0.026 | 68.8 |
| 5.50 | 1.63 | 1836 | 157 | 27 | 0.0087 | 0.021 | 79.1 |
| *6.00* | *1.85* | *1811* | *182* | *31* | *0.0087* | *0.020* | |
| *6.50* | *2.06* | *1786* | *207* | *36* | *0.0087* | *0.020* | |
| *7.00* | *2.28* | *1761* | *232* | *40* | *0.0087* | *0.020* | |
| *7.50* | *2.50* | *1737* | *256* | *44* | *0.0087* | *0.020* | |
| *8.00* | *2.72* | *1710* | *283* | *49* | *0.0087* | *0.019* | |
| *8.50* | *2.95* | *1684* | *309* | *53* | *0.0087* | *0.019* | |
| *9.00* | *3.19* | *1657* | *336* | *58* | *0.0087* | *0.018* | |
| *9.50* | *3.43* | *1629* | *364* | *63* | *0.0087* | *0.018* | |
| *10.00* | *3.67* | *1601* | *392* | *67* | *0.0087* | *0.018* | |
| *10.50* | *3.92* | *1573* | *420* | *72* | *0.0087* | *0.017* | |
| *11.00* | *4.18* | *1543* | *450* | *77* | *0.0087* | *0.017* | |
| *11.50* | *4.43* | *1514* | *479* | *82* | *0.0087* | *0.017* | |
| *12.00* | *4.70* | *1483* | *510* | *88* | *0.0087* | *0.018* | |
| *12.50* | *4.97* | *1452* | *541* | *93* | *0.0087* | *0.016* | |
| *13.00* | *5.25* | *1420* | *573* | *98* | *0.0087* | *0.016* | |
| *13.50* | *5.52* | *1389* | *604* | *104* | *0.0087* | *0.016* | |
| *14.00* | *5.80* | *1357* | *636* | *109* | *0.0087* | *0.016* | |
| *14.50* | *6.07* | *1326* | *667* | *115* | *0.0087* | *0.016* | |
| *15.00* | *6.35* | *1293* | *700* | *120* | *0.0087* | *0.016* | |
| *15.50* | *6.63* | *1261* | *732* | *126* | *0.0087* | *0.015* | |
| *16.00* | *6.92* | *1228* | *765* | *132* | *0.0087* | *0.015* | |

*NB: Extrapolated values below the base of the $^{210}$Pb record, shown in italics, have been calculated using the estimated 19$^{th}$ century sedimentation rate of 0.0087 g cm$^{-2}$ y$^{-1}$ (see text).*

*Table 6.* $^{210}$Pb chronology of Ossian Sarsfjellet core SBAC1

| Depth | | Chronology | | | Sedimentation Rate | | |
|---|---|---|---|---|---|---|---|
| | | Date | Age | | | | |
| cm | g cm$^{-2}$ | AD | y | ± | g cm$^{-2}$ y$^{-1}$ | cm y$^{-1}$ | ± (%) |
| 0.00 | 0.00 | 1995 | 0 | | | | |
| 0.50 | 0.08 | 1986 | 9 | 4 | 0.0088 | 0.027 | |
| 1.00 | 0.21 | 1971 | 24 | 5 | 0.0088 | 0.027 | |
| 1.50 | 0.39 | 1951 | 44 | 5 | 0.0088 | 0.027 | 28% |
| 2.00 | 0.61 | 1926 | 69 | 6 | 0.0088 | 0.027 | |
| 2.50 | 0.87 | 1909 | 86 | 6 | | | |
| 3.00 | 1.17 | 1907 | 88 | 6 | 0.11 | 0.21 | |
| 4.00 | 1.79 | 1901 | 94 | 7 | 0.11 | 0.21 | |
| 5.00 | 2.31 | 1897 | 98 | 9 | 0.11 | 0.21 | 37% |
| 6.00 | 2.83 | 1892 | 103 | 10 | 0.11 | 0.21 | |
| 6.50 | 3.05 | 1889 | 106 | 14 | | | |
| 7.00 | 3.25 | 1867 | 128 | 23 | 0.0088 | 0.022 | |
| *8.00* | *3.67* | *1831* | *164* | *32* | *0.0088* | *0.020* | |
| *9.00* | *4.15* | *1776* | *219* | *42* | *0.0088* | *0.017* | |
| *10.00* | *4.61* | *1724* | *271* | *52* | *0.0088* | *0.025* | |
| *11.00* | *4.92* | *1689* | *306* | *59* | *0.0088* | *0.028* | |
| *12.00* | *5.23* | *1653* | *342* | *66* | *0.0088* | *0.028* | |
| *13.00* | *5.54* | *1618* | *377* | *73* | *0.0088* | *0.030* | |
| *14.00* | *5.82* | *1586* | *409* | *79* | *0.0088* | *0.037* | |
| *15.00* | *6.00* | *1566* | *429* | *83* | *0.0088* | *0.059* | |
| *16.00* | *6.15* | *1549* | *446* | *86* | *0.0088* | *0.054* | |
| *17.00* | *6.33* | *1529* | *466* | *90* | *0.0088* | *0.049* | |
| *18.00* | *6.49* | *1510* | *485* | *94* | *0.0088* | *0.055* | |
| *19.00* | *6.69* | *1488* | *507* | *98* | *0.0088* | *0.033* | |
| *20.00* | *7.02* | *1450* | *545* | *105* | *0.0088* | *0.025* | |
| *21.00* | *7.35* | *1413* | *582* | *112* | *0.0088* | *0.032* | |
| *22.00* | *7.59* | *1386* | *609* | *117* | *0.0088* | *0.035* | |
| *23.00* | *7.88* | *1352* | *643* | *124* | *0.0088* | *0.027* | |
| *24.00* | *8.22* | *1313* | *682* | *131* | *0.0088* | *0.026* | |
| *25.00* | *8.51* | *1281* | *714* | *138* | *0.0088* | *0.040* | |
| *26.00* | *8.71* | *1258* | *737* | *142* | *0.0088* | *0.042* | |

*NB: Extrapolated values below the base of the $^{210}$Pb record, shown in italics, have been calculated using the estimated normal sedimentation rate (excluding slump events) of 0.0088 g cm$^{-2}$ y$^{-1}$ (see text).*

*Vassauga core SBAS3*

The $^{210}$Pb profile for this core (Figure 2i(c)) also includes a significant non-monotonic feature, at 2.5 cm depth, that again coincides with a layer of dense inorganic sediment. Although this precluded use of the CIC model to calculate $^{210}$Pb dates, use of the CRS model was validated by the $^{137}$Cs results. The CRS model dates place 1963 at a depth of 3.5 cm, in reasonable agreement with the $^{137}$Cs record, which has a relatively well resolved peak between 3.5 - 4.5 cm (1.4 - 1.8 g cm$^{-2}$; (Figure 2ii(c)). The $^{210}$Pb results, given in detail in Table 8, indicate an episode of rapid sedimentation during the mid 1970s. Excluding this episode, sedimentation rates appear to have been relatively uniform during the past century, with a mean value of 0.023 ± 0.002 g cm$^{-2}$ y$^{-1}$.

*Table 7.* $^{210}$Pb chronology of Yterjørna core SBAQ2

| Depth | | Chronology | | | Sedimentation Rate | | |
|---|---|---|---|---|---|---|---|
| | | Date | Age | | | | |
| cm | g $cm^{-2}$ | AD | y | ± | g $cm^{-2}$ $y^{-1}$ | cm $y^{-1}$ | ± (%) |
| 0.0 | 0.00 | 1995 | 0 | | | | |
| 0.5 | 0.03 | 1993 | 2 | 2 | 0.014 | 0.18 | 18 |
| 1.0 | 0.07 | 1990 | 5 | 2 | 0.015 | 0.15 | 16 |
| 1.5 | 0.13 | 1985 | 10 | 2 | 0.012 | 0.11 | 12 |
| 2.0 | 0.20 | 1979 | 16 | 2 | 0.011 | 0.07 | 9 |
| 2.5 | 0.29 | 1972 | 23 | 2 | 0.013 | 0.09 | 11 |
| 3.0 | 0.36 | 1967 | 28 | 2 | 0.013 | 0.11 | 14 |
| 3.5 | 0.42 | 1962 | 33 | 2 | 0.012 | 0.11 | 14 |
| 4.0 | 0.47 | 1957 | 38 | 3 | 0.011 | 0.10 | 14 |
| 4.5 | 0.52 | 1953 | 42 | 3 | 0.012 | 0.10 | 14 |
| 5.0 | 0.58 | 1948 | 47 | 3 | 0.012 | 0.10 | 16 |
| 5.5 | 0.65 | 1942 | 53 | 3 | 0.012 | 0.094 | 21 |
| 6.0 | 0.71 | 1936 | 59 | 4 | 0.011 | 0.083 | 23 |
| 6.5 | 0.77 | 1929 | 66 | 4 | 0.0084 | 0.068 | 21 |
| 7.0 | 0.83 | 1921 | 74 | 5 | 0.0066 | 0.054 | 21 |
| 7.5 | 0.89 | 1911 | 84 | 6 | 0.0051 | 0.041 | 23 |
| 8.0 | 0.96 | 1898 | 97 | 9 | 0.0043 | 0.033 | 25 |
| 8.5 | 1.03 | 1882 | 113 | 12 | 0.0042 | 0.031 | 27 |
| *9.0* | *1.10* | *1866* | *129* | *14* | *0.0042* | *0.029* | |
| *10.0* | *1.25* | *1830* | *165* | *17* | *0.0042* | *0.031* | |
| *11.0* | *1.37* | *1800* | *195* | *21* | *0.0042* | *0.033* | |
| *12.0* | *1.51* | *1767* | *228* | *24* | *0.0042* | *0.027* | |
| *13.0* | *1.69* | *1726* | *269* | *29* | *0.0042* | *0.023* | |
| *14.0* | *1.85* | *1687* | *308* | *33* | *0.0042* | *0.032* | |
| *15.0* | *1.97* | *1659* | *336* | *36* | *0.0042* | *0.032* | |
| *16.0* | *2.13* | *1621* | *374* | *40* | *0.0042* | *0.023* | |
| *17.0* | *2.30* | *1579* | *416* | *44* | *0.0042* | *0.027* | |
| *18.0* | *2.44* | *1545* | *450* | *48* | *0.0042* | *0.030* | |
| *19.0* | *2.58* | *1514* | *481* | *51* | *0.0042* | *0.033* | |
| *20.0* | *2.70* | *1483* | *512* | *54* | *0.0042* | *0.032* | |
| *21.0* | *2.84* | *1452* | *544* | *58* | *0.0042* | *0.032* | |
| *22.0* | *2.96* | *1422* | *573* | *61* | *0.0042* | *0.033* | |
| *23.0* | *3.10* | *1389* | *606* | *64* | *0.0042* | *0.028* | |
| *24.0* | *3.25* | *1354* | *641* | *68* | *0.0042* | *0.031* | |
| *25.0* | *3.37* | *1324* | *671* | *71* | *0.0042* | *0.034* | |
| *26.0* | *3.50* | *1293* | *702* | *75* | *0.0042* | *0.028* | |

*NB: Extrapolated values below the base of the $^{210}$Pb record, shown in italics, have been calculated using the mean 19th century sedimentation rate of 0.0042 g $cm^{-2}$ $y^{-1}$ (see text).*

### *Daltjørna Core SBAT4*

Sedimentation rates at this site appear to have been relatively uniform throughout the past 100 years or more. $^{210}$Pb activity declines more or less exponentially with depth and there is little significant difference between the CRS and CIC model dates. There is a small discrepancy between the $^{210}$Pb and $^{137}$Cs/$^{241}$Am results that is slightly higher than might have been expected in view of the uniform accumulation. The $^{210}$Pb chronology (Table 9) places 1963 at a depth of 3.25 cm whereas the peak $^{137}$Cs activity occurs between 3.75 and 5 cm (1.8 - 2.8 g $cm^{-2}$; Figure 2ii(c)). The difference could be due to a small amount of mixing (the $^{137}$Cs peak is less well resolved than in other cores) or to a small loss of sediment from the top of the core before or during coring. The mean sedimentation rate during the past 100 years is calculated to be 0.050 ± 0.002 g $cm^{-2}$ $y^{-1}$.

*Table 8.* $^{210}Pb$ chronology of Vassauga core SBAS3

| Depth | | Chronology | | | Sedimentation Rate | | |
|---|---|---|---|---|---|---|---|
| | | Date | Age | | | | |
| cm | g $cm^{-2}$ | AD | y | ± | g $cm^{-2}$ $y^{-1}$ | cm $y^{-1}$ | ± (%) |
| 0.0 | 0.00 | | 0 | | | | |
| 0.5 | 0.07 | 1992 | 3 | 2 | 0.025 | 0.13 | 8.5 |
| 1.0 | 0.18 | 1989 | 6 | 2 | 0.030 | 0.11 | 6.6 |
| 1.5 | 0.29 | 1985 | 10 | 2 | 0.036 | 0.10 | 4.7 |
| 2.0 | 0.55 | 1980 | 15 | 2 | 0.062 | 0.13 | 9.8 |
| 2.5 | 0.81 | 1975 | 20 | 2 | 0.089 | 0.16 | 14.9 |
| 3.0 | 1.10 | 1970 | 25 | 2 | 0.061 | 0.11 | 12.7 |
| 3.5 | 1.39 | 1964 | 31 | 2 | 0.033 | 0.06 | 10.4 |
| 4.0 | 1.61 | 1956 | 39 | 3 | 0.027 | 0.05 | 12.9 |
| 4.5 | 1.83 | 1947 | 48 | 4 | 0.023 | 0.04 | 15.4 |
| 5.0 | 2.11 | 1935 | 60 | 5 | 0.023 | 0.04 | 20.2 |
| 5.5 | 2.38 | 1923 | 72 | 7 | 0.023 | 0.03 | 24.9 |
| 6.0 | 2.78 | 1905 | 90 | 11 | 0.023 | 0.032 | 27.6 |
| 6.5 | 3.17 | 1888 | 107 | 14 | 0.023 | 0.031 | 30.2 |
| *7.0* | *3.70* | *1864* | *131* | *17* | *0.023* | *0.021* | |
| *7.5* | *4.22* | *1841* | *154* | *20* | *0.023* | *0.020* | |
| *8.0* | *4.84* | *1814* | *181* | *24* | *0.023* | *0.018* | |
| *8.5* | *5.45* | *1787* | *208* | *27* | *0.023* | *0.019* | |
| *9.0* | *6.00* | *1762* | *233* | *30* | *0.023* | *0.020* | |
| *9.5* | *6.56* | *1738* | *257* | *34* | *0.023* | *0.023* | |
| *10.0* | *6.98* | *1719* | *276* | *36* | *0.023* | *0.027* | |
| *10.5* | *7.41* | *1700* | *295* | *38* | *0.023* | *0.028* | |
| *11.0* | *7.78* | *1684* | *311* | *41* | *0.023* | *0.031* | |
| *11.5* | *8.15* | *1668* | *327* | *43* | *0.023* | *0.031* | |
| *12.0* | *8.50* | *1652* | *343* | *45* | *0.023* | *0.032* | |
| *12.5* | *8.85* | *1636* | *359* | *47* | *0.023* | *0.032* | |
| *13.0* | *9.20* | *1621* | *374* | *49* | *0.023* | *0.032* | |
| *13.5* | *9.55* | *1605* | *390* | *51* | *0.023* | *0.033* | |
| *14.0* | *9.89* | *1590* | *405* | *53* | *0.023* | *0.033* | |
| *14.5* | *10.23* | *1575* | *420* | *55* | *0.023* | *0.034* | |
| *15.0* | *10.56* | *1561* | *434* | *57* | *0.023* | *0.035* | |
| *15.5* | *10.88* | *1546* | *449* | *59* | *0.023* | *0.030* | |
| *16.0* | *11.30* | *1528* | *467* | *61* | *0.023* | *0.027* | |
| *16.5* | *11.72* | *1510* | *485* | *63* | *0.023* | *0.023* | |
| *17.0* | *12.27* | *1485* | *510* | *67* | *0.023* | *0.020* | |
| *17.5* | *12.82* | *1461* | *534* | *70* | *0.023* | *0.020* | |

*NB: Extrapolated values below the base of the $^{210}Pb$ record, shown in italics, have been calculated using the estimated normal sedimentation rate (excluding slump events) of 0.023 g $cm^{-2}$ $y^{-1}$ (see text).*

*Tenndammen core SBAU4*

The $^{210}Pb$ results for this core (Figure 2i(c)) are dominated by a major non-monotonic feature at 3.5 cm (1 g $cm^{-2}$) depth. The presence of this feature, which coincides with a layer of dense inorganic sediment, precluded use of the CIC dating model and dates for this core have been calculated using the CRS model alone. The results, given in Table 10, indicate that the dense layer records a brief episode of very rapid sedimentation in the early 1970s, presumably due to a slump of catchment derived material or old marginal sediments, possibly as a result of human activity in the catchment associated with the use of the lake as a water supply for Colesbukta prior to the closure of the mine there in 1967. There are indications of a similar though smaller episode (at 8.5 cm depth) at the beginning of this century. Excluding these events, it is estimated that sedimentation rates are normally ca. 0.015 g $cm^{-2}$ $y^{-1}$.

The $^{137}Cs$ results for this core (Figure 2ii(c)) record a well resolved peak in the 6 - 7 cm (3.0 - 3.4 g $cm^{-2}$) section. Traces of $^{241}Am$ between 5 and 8 cm confirm that this feature records the weapons fallout maximum in the early 1960s. The $^{210}Pb$ dates place 1963 at a depth of 5.75 cm, in relatively good agreement with the $^{137}Cs$ and $^{241}Am$ records. Since rapid changes in bulk density between 3 and 6 cm may have caused some distortion of the fallout record, the $^{137}Cs$ peak has not been used to adjust the $^{210}Pb$ chronology.

*Table 9.* $^{210}Pb$ chronology of Daltjørna core SBAT4

| Depth | | Chronology | | | Sedimentation Rate | | |
|---|---|---|---|---|---|---|---|
| | | Date | Age | | | | |
| cm | g $cm^{-2}$ | AD | y | ± | g $cm^{-2}$ $y^{-1}$ | cm $y^{-1}$ | ± (%) |
| 0.00 | 0.00 | 1995 | 0 | | | | |
| 0.50 | 0.18 | 1991 | 4 | 2 | 0.046 | 0.13 | 7.7 |
| 1.00 | 0.36 | 1987 | 8 | 2 | 0.048 | 0.12 | 6.0 |
| 1.50 | 0.59 | 1982 | 13 | 2 | 0.047 | 0.10 | 6.6 |
| 2.00 | 0.85 | 1977 | 18 | 2 | 0.053 | 0.10 | 7.1 |
| 2.50 | 1.12 | 1972 | 23 | 2 | 0.059 | 0.10 | 7.4 |
| 3.00 | 1.41 | 1967 | 28 | 2 | 0.051 | 0.085 | 8.5 |
| 3.50 | 1.72 | 1960 | 35 | 2 | 0.047 | 0.074 | 9.8 |
| 4.00 | 2.05 | 1954 | 41 | 3 | 0.045 | 0.067 | 11.5 |
| 4.50 | 2.41 | 1946 | 49 | 4 | 0.048 | 0.063 | 14.7 |
| 5.00 | 2.82 | 1937 | 58 | 5 | 0.046 | 0.054 | 19.3 |
| 5.50 | 3.25 | 1929 | 66 | 6 | 0.055 | 0.060 | 24.4 |
| 6.00 | 3.72 | 1919 | 76 | 8 | 0.056 | 0.058 | 30.6 |
| 6.50 | 4.23 | 1910 | 85 | 10 | 0.048 | 0.049 | 37.9 |
| 7.00 | 4.73 | 1899 | 96 | 14 | 0.043 | 0.043 | 44.7 |
| 7.25 | 4.98 | 1893 | 102 | 16 | 0.042 | 0.043 | 48.0 |

### *Arresjøen core ARSJ93/4*

Both the very high surficial $^{210}Pb$ activity (Table 2) and the steep gradient of the unsupported $^{210}Pb$ activity versus depth profile (Figure 2i(a)), indicate that sedimentation rates in this lake are extremely low. $^{210}Pb/^{226}Ra$ equilibrium, corresponding to c.130 year's accumulation, is reached at a depth of about 2.75 cm (0.32 g $cm^{-2}$). The unsupported $^{210}Pb$ activity versus depth profile is more or less exponential and there is little significant difference between $^{210}Pb$ chronologies calculated using the CRS and CIC $^{210}Pb$ dating models. Both models indicate a more or less constant sedimentation rate of 0.0023 ± 0.003 g $cm^{-2}$ $y^{-1}$. $^{210}Pb$ dates calculated using this value are given in Table 3.

The $^{137}Cs$ profile (Figure 2ii(a)) does not have a sub-surface peak recording the 1963 weapons fallout maximum, but this is not surprising in view of the very low accumulation rate. The $^{210}Pb$ chronology puts the 1963 level at a depth of only 0.75-1.0 cm. A mid 1960s date for this level is broadly supported by the distribution of the $^{137}Cs$, the bulk of which is contained in the top 1cm of the core.

*Table 10.* $^{210}$Pb chronology of Tenndammen core SBAU4

| Depth | | Chronology | | | Sedimentation Rate | | |
|---|---|---|---|---|---|---|---|
| | | Date | Age | | | | |
| cm | g cm$^{-2}$ | AD | y | ± | g cm$^{-2}$ y$^{-1}$ | cm y$^{-1}$ | ± (%) |
| 0.0 | 0.00 | 1995 | 0 | | | | |
| 0.5 | 0.09 | 1993 | 2 | 2 | 0.054 | 0.20 | 15 |
| 1.0 | 0.22 | 1990 | 5 | 2 | 0.048 | 0.20 | 16 |
| 1.5 | 0.36 | 1988 | 7 | 2 | 0.043 | 0.17 | 16 |
| 2.0 | 0.54 | 1984 | 11 | 2 | 0.051 | 0.13 | 18 |
| 2.5 | 0.73 | 1980 | 15 | 2 | 0.059 | 0.17 | 20 |
| 3.0 | 1.07 | 1978 | 17 | 3 | 0.096 | 0.20 | 23 |
| 3.5 | 1.40 | 1975 | 20 | 3 | 0.134 | 0.25 | 25 |
| 4.0 | 1.81 | 1974 | 21 | 3 | 0.142 | 0.33 | 36 |
| 4.5 | 2.22 | 1972 | 23 | 3 | 0.149 | 0.20 | 48 |
| 5.0 | 2.52 | 1969 | 26 | 4 | 0.107 | 0.17 | 39 |
| 5.5 | 2.82 | 1966 | 29 | 4 | 0.065 | 0.11 | 30 |
| 6.0 | 3.04 | 1960 | 35 | 5 | 0.042 | 0.077 | 28 |
| 6.5 | 3.26 | 1953 | 42 | 6 | 0.019 | 0.053 | 26 |
| 7.0 | 3.45 | 1941 | 54 | 9 | 0.016 | 0.042 | 35 |
| 7.5 | 3.65 | 1929 | 66 | 13 | 0.014 | 0.042 | 44 |
| 8.0 | 3.94 | 1917 | 78 | 20 | 0.033 | 0.042 | 85 |
| 8.5 | 4.23 | 1905 | 90 | 26 | 0.053 | 0.036 | 126 |
| 9.0 | 4.59 | 1889 | 106 | 32 | 0.031 | 0.031 | 151 |
| 9.5 | 4.96 | 1873 | 122 | 38 | 0.015 | 0.020 | 176 |
| *10.0* | *5.37* | *1839* | *156* | *49* | *0.012* | *0.015* | |
| *10.5* | *5.78* | *1805* | *190* | *59* | *0.012* | *0.014* | |
| *11.0* | *6.24* | *1766* | *229* | *71* | *0.012* | *0.013* | |
| *11.5* | *6.70* | *1728* | *267* | *83* | *0.012* | *0.013* | |
| *12.0* | *7.17* | *1689* | *306* | *95* | *0.012* | *0.013* | |
| *12.5* | *7.64* | *1649* | *346* | *108* | *0.012* | *0.012* | |
| *13.0* | *8.15* | *1607* | *388* | *121* | *0.012* | *0.012* | |
| *13.5* | *8.66* | *1564* | *431* | *134* | *0.012* | *0.012* | |
| *14.0* | *9.18* | *1521* | *474* | *148* | *0.012* | *0.012* | |
| *14.5* | *9.70* | *1478* | *517* | *161* | *0.012* | *0.012* | |
| *15.0* | *10.18* | *1438* | *557* | *174* | *0.012* | *0.012* | |
| *15.5* | *10.66* | *1398* | *597* | *186* | *0.012* | *0.012* | |
| *16.0* | *11.19* | *1354* | *641* | *200* | *0.012* | *0.011* | |
| *16.5* | *11.72* | *1310* | *685* | *213* | *0.012* | *0.011* | |
| *17.0* | *12.27* | *1264* | *731* | *228* | *0.012* | *0.011* | |
| *17.5* | *12.82* | *1218* | *777* | *242* | *0.012* | *0.011* | |

*NB: Extrapolated values below the base of the $^{210}$Pb record, shown in italics, have been calculated using the estimated mid-19$^{th}$ century sedimentation rate of 0.012 g cm$^{-2}$ y$^{-1}$.*

*Birgervatnet core BIRJ93/1*

Total $^{210}$Pb activity reached equilibrium with the supporting $^{226}$Ra at a depth of ca. 5.5 cm (1.55 g cm$^{-2}$). The unsupported $^{210}$Pb activity versus depth profile (Figure 2i(a)) can be divided into two distinct parts. Below 3.5 cm (1.04 g cm$^{-2}$) the concentration varies exponentially with depth, indicating uniform accumulation. Above this depth the profile has a progressively shallower gradient, suggesting steadily increasing sedimentation rates.

The $^{137}$Cs activity versus depth profile (Figure 2ii(a)) has a well-resolved peak at 1.75 cm (0.47 g cm$^{-2}$). The detection of a small but significant peak in $^{241}$Am activity at the same depth confirms that this feature records the 1963 fallout maximum from the atmospheric testing of nuclear weapons.

$^{210}$Pb chronologies calculated using the CRS and CIC dating models both suggest uniform sediment accumulation rates prior to the transition at 3.5 cm, followed by a prolonged period of accelerating sedimentation rates, though there is a significant difference in timing. The CIC model dates the increase to the late 1940s, whereas the CRS model suggests an earlier increase at around 1900. The CRS model chronology places 1963 at a depth of 1.75 cm, in good agreement with the $^{137}$Cs record, in contrast to the CIC model which places 1963 at a depth of nearly 2.5 cm. The CRS model has accordingly been used to calculate the chronology shown in Table 4. The mean sedimentation rate prior to 1900 is estimated to be 0.0041 ± 0.004 g cm$^{-2}$ y$^{-1}$. Since then it has increased five-fold to reach a current value of ca. 0.020 g cm$^{-2}$ y$^{-1}$.

*'Scurvy Pond' core SCUR93/1*

The unsupported $^{210}$Pb activity versus depth profile again divides into two distinct parts (Figure 2i(a)). In this core, however, the change in gradient is partly attributable to a progressive decline in dry bulk sediment density towards the surface of the core, from more than 0.4 g cm$^{-3}$ at 5.5 cm to less than 0.2 g cm$^{-3}$ in the surficial sediments.

The $^{137}$Cs activity versus depth profile (Figure 2ii(b)) has its maximum value in the uppermost sample analysed, at 1 - 2 cm (0.2 - 0.4 g cm$^{-2}$). Since traces of $^{241}$Am were also detected in this sample, sediments from this depth can be presumed to date from the mid 1960s.

In this core there is little significant difference between $^{210}$Pb chronologies calculated using the CRS and CIC dating models, and both are in good agreement with the 1963 level suggested by the artificial radionuclides. The $^{210}$Pb results place 1963 at a depth of between 1.5 and 1.75 cm. Using both models, the mean sedimentation rate since the mid 19$^{th}$ century is calculated to be 0.010 ± 0.02 g cm$^{-2}$ y$^{-1}$. The detailed results, given in Table 5, have been determined using the CRS model. These suggest that there may have been a small increase in sedimentation rates during the $^{210}$Pb period, from a mean value of ca. 0.0087 g cm$^{-2}$ y$^{-1}$ in the 19$^{th}$ century to a contemporary value of ca. 0.013 g cm$^{-2}$ y$^{-1}$.

*Atmospheric fluxes of fallout radionuclides*

There are very few data of atmospheric fluxes of fallout radionuclides at high latitudes. Data from a number of lake sediment and peat-bog cores in the ERRC data-base suggest values for the $^{210}$Pb flux in the range 30 - 70 Bq m$^{-2}$ y$^{-1}$, though the actual amount at any given site will depend on the mean annual rainfall. Excluding the two anomalous sites (Daltjørna (T) and Birgervatnet), the $^{210}$Pb fluxes recorded in the Svalbard cores are consistent with those from other Arctic sites. Since there is quite a weak correlation between the $^{210}$Pb flux and mean sedimentation rate, it appears that sediment focussing is not a major factor at these sites. The mean $^{210}$Pb flux of 56 Bq m$^{-2}$ y$^{-1}$ recorded in the sediments (excluding the two anomalous sites) can thus be regarded as a reasonable measure of the atmospheric flux. The mean $^{137}$Cs inventory at these sites is 1553 Bq m$^{-2}$, though since $^{137}$Cs is less strongly associated with particulates than $^{210}$Pb this figure will be less reliable as an estimator of the atmospheric flux. Since the mean sediment accumulation rates at Birgervatnet and Daltjorna are not significantly different from those at the sites with normal $^{210}$Pb fluxes, it appears likely that the abnormally high $^{210}$Pb fluxes at these two sites (Table 2) are due to significant inputs of fallout radionuclides (and presumably other pollutants) from the catchment during the annual spring thaw (Appleby et al. 1995).

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