CM 1996/R:9

ICES 1996 Annual Science Conference
27 Sep-4 Okt 1996 Reykjavik Iceland

Contribution to
"Results of Baseline Study of Contaminants in Baltic Sediments"
Convenor: M. Pertillä   Theme session R.

Determination of accumulation rate, mixing and sensitivity for sediment monitoring using Pb210 Profiles on the Baltic Baseline Sediment Stations.

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Abstract:
The purpose of the Baltic Sediment Baseline study is to identify reference sediment monitoring stations in the Baltic basins. Pb210 profiles in the upper 25 cm was measured on each of the station. The content of unsupported Pb210 (that is Pb210 not produced in the sediment) decreases regularly downwards in undisturbed and steadily deposited sediment owing to radioactive decay; departures from this predictable profile permits an assessment of the mixing and/or intermittent erosion as well as the rate of deposition. This has been used for an estimate of the expected response on the concentrations in the surface 1 cm sample on a given change in the flux of the contaminant on the station.
Of the 25 geological carefully selected stations 4 was so disturbed, that no dating and thus estimate of accumulation rate was possible. Core stations with high accumulation rates (4.5-15 mm/yr) and/or low mixing, which is excellent for dating of the pollution history and for monitoring purposes, were identified in the Gdansk Basin, near the Lithuanian Coast, in the Gulf of Riga, 2 stations in the Gulf of Finland and 3 in the Bothnian Sea. The sediment stations in the Gotland Basin are disturbed, the reason for that is unclear. Most of the other station have accumulation rates at 1.5- 2.5 mm/yr or 250-500 g/m2/yr and with mixing of the upper 2-4 cm. Assuming a sampling of the upper most 1cm every 5 years, steady state in relation to accumulation rate and mixing rate, and a 10% relative standard deviation for the chemical analysis, the sensitivity analysis indicates that we expect to be able to detect changes in flux of a contaminant in the order of 10-15% (in the 5 years) in the excellent stations, while a 60-200% increase is needed to cause a significant change in concentration in the other stations.

The text is a report by Arne Jensen, VQI 904740/41 : 210Pb-Dating of Sediment Cores from the Baltic Sediment Baseline Study.
The technical appendicies 1-25 has been left out.

1. INTRODUCTION

^{210}Pb (isotope of lead) in a sediment core originates partly from atmospheric deposition (unsupported ^{210}Pb) and partly from the decay of radon in the sediment core (supported ^{210}Pb). The background content of ^{210}Pb is calculated from the concentration of supported ^{210}Pb that is independent of the sedimentation, and estimated by measurement of supported ^{210}Pb in the deeper parts of the sediment, where the concentration is constant since all unsupported ^{210}Pb has decayed.

The ^{210}Pb isotope with a half life of 22.3 years is produced in the atmosphere through the decay of radon-222, which is spread by diffusion from the surface of the earth. These isotopes are part of the natural radioactive decay of uranium-238. ^{210}Pb enters the aquatic environment mostly via atmospheric deposition and descends, adsorbed to particles, to the sediments. The age of the sediments, and the average sedimentation rate can be determined by measurements of the ^{210}Pb concentration in different sediment layers.

In about ten slices (1 cm thickness) of the sediment core distributed down through the core the ^{210}Pb concentration is measured indirectly by analyzing the concentration of ^{210}Po (Polonium) with α-spectrometry (Madsen and Sørensen, 1979). The dried sediment samples (about 0.5 g) are decomposed in a mixture of hydrochloric and nitric acid and ^{210}Po is deposited on a silver plate at 65°C. The activity of ^{210}Po is measured by α-spectrometry. Samples are spiked with ^{208}Po for determination of chemical yield and a ^{210}Pb standard treated as the sediment samples is used for calibration. ^{210}Pb activity is assumed to be equal to the measured ^{210}Po activity.

2. CRS AND CIC DATING

From the unsupported ^{210}Pb activity profile in the core the age of different horizons in the profile can be calculated based on the assumption that ^{210}Pb is immobile in the core. The calculation can be carried out in two ways based on two different assumptions. The CIC-method (Constant Initial Concentration) assumes that the concentration of unsupported ^{210}Pb in the depositing material is constant in time for the same locality.

Normally, the cores are dated by the CRS-method (Constant Rate of Supply of ^{210}Pb) which assumes that the flux of unsupported ^{210}Pb to the sediment is constant in time for the locality. The principle for dating of the sediment core by the CRS-method are described in detail by by Madsen and Sørensen, 1979. All datings were performed on the basis of the dry matter content in the different core slices with correction for salt content.

3. CALCULATION OF ACCUMULATION RATE OF THE SEDIMENT

The accumulation rate of the sediment (g m^{-2} yr^{-1}) is calculated on the basis of the concentration of ^{210}Pb in the dried sediment slices down through the core by application of the models mentioned below (Christensen, 1982, and Christensen and Bhunia, 1986).

3.1 Model

The distribution of unsupported ^{210}Pb in a sediment core can be modelled by the advection-diffusion equation:

(1)
$$\frac{dA}{dt} = D\frac{d^2A}{dz^2} - \omega\frac{dA}{dz} - \lambda A$$

where

A = concentration of ^{210}Pb (dpm g^{-1})

D = mixing coefficient (cm^{-2} yr^{-1})

z = depth below the sediment-water interface (cm)

ω = linear accumulation rate (cm yr^{-1})

λ = decay constant for ^{210}Pb (yr^{-1})

t = time (year)

Using the steady state solution for (1) with the condition of constant rate of sediment accumulation (dA/dt = 0), the parameters ω, D and the flux of ^{210}Pb to the sediment surface can be calculated. The mixing intensity D is assumed to follow a half Gaussian distribution, (Christensen, 1982, and Christensen and Bhunia, 1986):

(2) $$D = D_0 e^{-\frac{z^2}{2\sigma^2}}$$

where D_0 is the mixing coefficient at the sediment surface, and σ is the effective mixing depth (cm). The mixing parameters are calculated by optimizing equation (1) in relation to the measured ^{210}Pb profile.

3.2 Results

Figure 4 shows for each locality the total concentration of ^{210}Pb as a function of the depth of the sediment slices and the concentrations of ^{137}Cs are included where it has been measured.

The age of the sediment in relation to the depth below the sediment surface is calculated by the CRS-method as well as the CIC-method. The results from the CRS-method for all sediment cores (except four) are shown in Figure 1 in Appendices 2A-23A (excluding Appendices 10A, 14A and 18A). It was impossible to perform datings at the cores from station no. 156 (Kattegat), 180 (LL-19), 184 (GF-5) and 189 (Åland Sea) due to intense mixing.

Figure 2 (in the Appendices) shows the measured concentrations of unsupported ^{210}Pb (logarithmic scale) and the optimized solution of equation (1) for the cores as a function of the dry mass depth (g cm^{-2}). The solution of equation (1) is based on the number of slices, as indicated in Table 1. Frequently, the upper part of the sediment core is mixed by e.g. bioturbation, trawling and sometimes the mixing is caused by the sampling equipment. To obtain the most optimal model solution for estimation of the sediment accumulation rate, some slices might be excluded from the upper part of the core, as indicated in Table 1. This implies that the sediment accumulation rate has been calculated from the subsequent sediment slices by estimating the linear decrease below the mixing zone. The mixing coefficient, D_0, and the effective mixing depth is estimated by an iterative process over the whole sediment profile.

Appendixes 1B-23B contain all the data used for performing the dating of the sediment cores.

Table 1. Number of sediment slices included in the model calculations for sediments from the Baltic Baseline Study.

Station name and no.	Appendix no.	Supported ^{210}Pb - depth [1] dpm g^{-1}	Number of slices included in model	Number of slices excluded in model optimization	Remarks
Kattegat, 156	1				Dating impossible
Kiel Bight, 157	2	1.02-25	20	10 (0-10 cm)	
Lübeck Bay, 160	3	1.01-21	19	5 (0-3, 10-11, 12-13 cm)	
Arkona Basin, 166	4	1.03-24	22	13 (0-13 cm)	
Bornholm Basin, 167	5	1.02 (157)	10	3 (0-3 cm)	
Gdansk Bay, 169	6	1.02 (157)	21	0	
Lithuan Coast, 170	7	0.99-19	12	1 (0-1 cm)	
Gotland Deep, 171	8.1	6.26-29	13	3 (0-3 cm)	Dating 0-13 cm.
	8.2	1.00	30	11 (0-11 cm)	Dating 12-30 cm
Gulf of Riga, 175	9	1.93	45	1 (0-1 cm)	
Western Gotland Deep, 178	10.1	4.01-30	10	5 (0-5 cm)	Dating 0-10 cm
	10.2	1.02	31	14 (0-14 cm)	Dating 15-31 cm
LL-19, 180	11	30.5-24			Dating impossible
GF-1, 181	12	1.60-24	13	7 (0-7 cm)	
GF-2, 182	13	0.70	25	5 (0-5 cm)	Core not deep enough, only 25 cm deep
GF-4, 183	14	2.20-21	20	12 (0-12 cm)	Dating 12-20 cm.
GF-5, 184	15	12.6-14			Dating impossible
GF-6, 185	16	1.00	16	1 (0-1 cm)	Core not deep enough, only 25 cm deep
GF-3, 186	17	1.00	25	15 (0-15 cm)	
XV-1, 187	18	14.15-34	31	5 (0-5 cm)	
Aaland Sea, 189	19	High ^{210}Pb			Dating impossible
EB-1, 190	20	2.50	25	0	Core not deep enough, only 25 cm deep
Harnosand, 192	21	2.50	25	9 (0-9 cm)	Core not deep enough, only 25 cm deep
BO-3, 193	22	2.50	13	5 (0-5 cm)	
F2, 195	23	2.50	13	3 (0-3 cm)	

[1] The activity of supported ^{210}Pb (SPB) is given as dpm g^{-1} and at which depth it has been measured (cm). If the core has not been long enough the SPB from a nearby core has been used (indicated by the core number). In several cases another value of SPB have been chosen which gives the best fit in the model.

3.3 Comments

3.3.1 General comments

Figure 1 (in the Appendices) for the different cores indicates normally a linear accumulation rate in the upper part of the sediment core (0-5 cm or more), with a very little standard deviation for the estimated ages (the horizontal bars indicate the 68% prediction interval). The inclination changes below this depth, and the standard deviation increases significantly.

With a constant sedimentation rate, the relation between the logarithm of unsupported ^{210}Pb concentrations as a function of the mass depth will theoretically be linear (Figure 2 in the Appendices). If this is the actual situation, the results of the dating can be evaluated with good accuracy which normally implies a fine correlation between the depth and age of the sediment (Fig. 1). The age relation in the individual slices can be complicated due to mixing.

The optimal solution to the steady state model (Figure 2 in Appendices) correlates mostly with the measured concentration of unsupported ^{210}Pb. Because of this, the calculated accumulation rate describes the sedimentation during this period. Deviations from the linear trend in the upper part of the profile (Figure 2 in Appendices) are an indication of disturbances by bioturbation etc. Generally, a linear decrease of ^{210}Pb is observed below the disturbed zone.

Table 2 gives a summary of the estimated parameters and with an indication of the quality of the dating. The calculated effective mixing depth (σ cm) is equivalent to a real mixing depth of 2-3 times σ, since the effective mixing depth is calculated as a half Gaussian distribution.

Figure 3 shows different types of ^{210}Pb profiles which are also represented by some of the present datings. It should be noted that the individual slices of the sediment represent a defined time span when the profile is undisturbed or nearly so. However, when the sediment is mixed, sediments from different time periods are mixed in the individual slices.

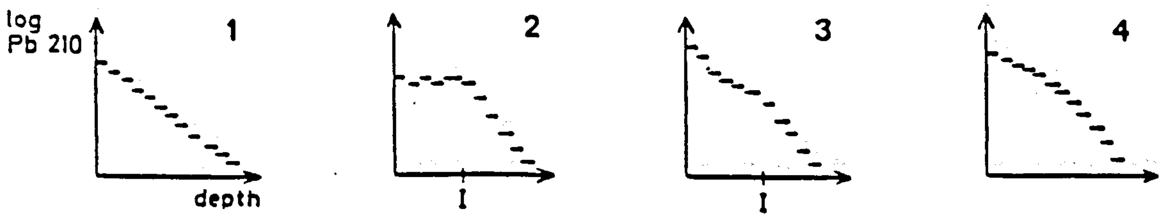

Figure 3. ^{210}Pb profiles with depth of sediment core. 1. Undisturbed, steady accumulation of dry matter. 2. Totally mixed to depth I. 3. Moderately mixed to depth I. 4. Gradually increasing accumulation of dry matter.

Some of the cores have had a sufficient length that the concentration of ^{210}Pb in the deepest part is constant (Table 1 - supported ^{210}Pb (SPB)). However, for several cores it has been necessary to use a value from a nearby sediment core as the core has not been long enough. For others cores which were not deep enough and which have a high concentration of ^{210}Pb down to 20-25 cm a SPB has been chosen giving the best fit to the model. This information is included in Table 1.

Figure 4 shows for the different cores the total concentration of ^{210}Pb as a function of the sediment depth with ^{137}Cs concentrations included where it has been measured. Normally, the deepest part indicates the concentration of supported ^{210}Pb.

3.3.1 Specific comments to each dating

St. no. 156 (Kattegat)

High and constant concentrations of ^{210}Pb have been measured down to 25 cm depth (Figure 4). This indicates a fairly recent deposition of a well mixed layer. It is impossible to perform a dating on this core.

St. no. 157, Kiel Bight

Table 2 shows that the real mixing depth is 6-9 cm indicating an extensive mixing (Figure 2 in Appendix 2A). The determination of the accumulation rate was excellent (CV = 3%) despite the mixing in the top.

St. no. 160, Lübeck Bay

The ^{210}Pb profile (Figure 2 in Appendix 3A) is almost linear from 3 to about 18 cm indicating some disturbance in the upper 3 cm with extensive mixing; but with an excellent determination of the sediment accumulation rate (CV = 4%). Two slices (10-11 cm and 12-13 cm depth) have been excluded in the model due to a higher ^{210}Pb concentration which did not fit in the model. Modelling is needed to clarify the age relations in the individual sediment slices.

St. no. 166, Arkona Basin

The ^{210}Pb profile (Figure 2 in Appendix 4A) shows an intensive mixing with real mixing down to 8-12 cm which indicates that this core is not useful for studying pollutant records. The sediment accumulation rate is very low.

This area (station B2 - 54° 56 N, 13°48.2 E at 50 m depth) has also been dated in 1983 as shown in Appendix 24; but with a very bad result with nearly complete mixing in the whole core. The position is not exactly the same as the present one.

St. no. 167, Bornholm Basin

The ^{210}Pb profile (Figure 2 in Appendix 5A) shows an intensive mixing with real mixing down to 2.2-3.3 cm. Figure 4 shows a nearly constant concentration of ^{210}Pb below 9 cm depth. The estimation of the sediment accumulation rate is reasonable (CV = 9%). Modelling is needed to clarify the age relations in the individual sediment slices.

This area (station B16 - 55° 14 N, 16° 01 E at 88 m depth) has also been dated in 1983 as shown in figure 2 in Appendix 25; but with a similar result. The position is not exactly the same as the present one.

St. no. 169, Gdansk Bight

The ^{210}Pb is almost linear from top to about 21 cm indicating a low degree of disturbances (Figure 2 in Appendix 6A). Table 2 shows that the reel mixing depth is only 0.2-0.3 cm; but with an extensive mixing. The determination of the accumulation rate was reasonable (CV

= 10%). The low mixing suggests that the slices are representative for the estimated time periods.

St. no. 170, Lithuan Coast

The ^{210}Pb profile is almost linear from top to about 12 cm (Figure 2 in Appendix 7A); but with intensive mixing and a reel mixing depth of 0.8-1.2 cm. The determination of the accumulation rate was not very good (CV = 22%); but the rate is high. Modelling is needed to clarify the age relations in the individual sediment slices.

St. no. 171, Gotland Deep

The ^{210}Pb concentrations in the upper part of the core is extremely high (Figure 4) and with a very low percentage of dry matter (below 5%) in the upper 5 cm (Appendix 8.1B). This core has been dated in two sections, 0-13 cm and 12-30 cm. The ^{210}Pb profile for the upper part (Figure 2 in Appendix 8.1A) is almost linear from 5-13 cm indicating disturbances in the upper 5 cm - with the very low percentage of dry matter - with intensive mixing. The estimation of the very low accumulation rate is reasonable (7%).

The deeper part of this core, the section from 12-30 cm, has been dated separately (Figure 2 in Appendix 8.2A). The sediment accumulation rate is very high and estimated with a bad accuracy (CV = 17%). High and nearly constant ^{210}Pb concentrations have been measured in the deeper part of the core (30-50 cm, Figure 4). Generally, this core is not very suitable for measurements of pollution records. The sediment accumulation rate is much higher in the deepest part than in the upper part indicating a shift in the accumulation rate in the beginning of this century.

St. No. 175, Gulf of Riga

Table 2 shows that the reel mixing depth is 2.4-3.6 cm with an intensive mixing (Figure 2 in Appendix 9A). The core is dated to a depth of 45 cm. The determination of the accumulation rate was excellent (CV = 4%) despite the mixing at the top. The slices will be fairly representative of the estimated time periods.

St. no. 178, Western Gotland Deep

The ^{210}Pb concentrations in the upper part of the core is also extremely high (Figure 4) and with a low concentration of dry matter in the upper part (Appendix 10.1B). This core has been dated in two parts. An upper part from 0-10 cm and a lower part from 12-30 cm. The ^{210}Pb profile (Figure 2 in Appendix 10.1A) shows an intensive mixing with real mixing down to 3.6-5.4 cm. The estimation of the sediment accumulation rate is reasonable (CV = 7%); but with a very low accumulation rate. This core is not very useful for studying pollutant records.

The ^{210}Pb profile for the deeper part (Figure 2 in Appendix 10.2A) is almost linear from 15-31 cm and with an excellent determination of the sediment accumulation rate (CV = 5%). The sediment accumulation rate is much higher in the deepest part than in the upper part indicating a shift in the accumulation rate in the beginning of this century.

St. no. 180, LL-19

The ^{210}Pb profile in Figure 4 shows an increase of the ^{210}Pb concentrations down to 13 cm and an decrease in the deeper part of the core. It is impossible to perform a dating on this core.

St. no. 181, GF-1

The ^{210}Pb profile (Figure 2 in Appendix 12A) shows an intensive mixing with real mixing down to 4.4-6.6 cm which indicates that this core is not useful for studying pollutant records. The sediment accumulation rate is estimated with a low accuracy (CV = 20%). The ^{210}Pb profile in Figure 4 shows a high concentration down to 10 cm and a constant concentration below 15 cm indicating old sediments in the deeper part.

St. no. 182, GF-2

The ^{210}Pb profile (Figure 2 in Appendix 13A) shows an intensive mixing with real mixing down to 6-9 cm; but with a excellent estimation of the high sediment accumulation rate (CV = 6%). The core is not deep enough to reach a constant ^{210}Pb concentration as the ^{210}Pb concentration in 25 cm depth is very high (Figure 4). Modelling is needed to clarify the age relations in the individual sediment slices.

St. no. 183, GF-4

The ^{210}Pb profile (Figure 4) shows a constant ^{210}Pb concentration from 0-8 cm which makes the dating impossible of this part of the core. The dating is performed on 12-20 cm depth and shows a linear ^{210}Pb profile (Figure 2 in Appendix 14A) and with a excellent estimation of the sediment accumulation rate (CV = 3%). This dating gives an estimation of the sediment accumulation rate. If the rate is the same in the whole core an age-depth relation ship can also be calculated.

St. no. 184, GF-5

High and constant concentrations of ^{210}Pb have been measured in the whole core down to 15 cm depth (Figure 4). This indicates a fairly recent deposition of a totally mixed layer. It is impossible to perform a dating on this core.

St. no. 185, GF-6

The ^{210}Pb is linear from top to about 16 cm indicating a low degree of disturbances (Figure 2 in Appendix 16A). Table 2 shows that the reel mixing depth is only 0.2-0.3 cm; but with an extensive mixing. The determination of the high accumulation rate was good (CV = 7%). The low mixing suggests that the slices are representative for the estimated time periods. The core is not deep enough to reach a constant ^{210}Pb concentration as the ^{210}Pb concentration in 25 cm depth is very high (Figure 4).

St. no. 186, GF-3

The ^{210}Pb profile (Figure 2 in Appendix 17A) shows an intensive mixing with real mixing down to 7.4-11.1 cm. The estimation of the sediment accumulation rate (CV = 13%) is reasonable. The core is not deep enough to reach a constant ^{210}Pb concentration as the ^{210}Pb concentration in 25 cm depth is high (Figure 4).

St. no. 187, XV-1

The ^{210}Pb profile (Figure 2 in Appendix 18A) is almost linear from top to about 31 cm and with extensive mixing; but with a low real mixing depth down to 0.6-0.9 cm. The determination of the sediment accumulation rate was uncertain (CV = 17%) due to the irregularity down through the core.

St. no. 189, Åland Sea

High and constant concentrations of ^{210}Pb have been measured down to 25 cm depth (Figure 4). This indicates a fairly recent deposition of a well mixed layer. It is impossible to perform a dating on this core.

St. no. 190, EB-1

The ^{210}Pb is linear from top to about 25 cm indicating a low degree of disturbances (Figure 2 in Appendix 20A). Table 2 shows that the reel mixing depth is 1.0-1.5 cm; but with an extensive mixing. The determination of the high accumulation rate was excellent (CV = 6%) despite the mixing in the top. Modelling is needed to clarify the age relations in the individual sediment slices. The core is not deep enough to reach a constant ^{210}Pb concentration as the ^{210}Pb concentration in 25 cm depth is high (Figure 4).

St. no. 192, Harnosand

The ^{210}Pb is linear from 9 cm to about 25 cm and with extensive mixing in the upper part (Figure 2 in Appendix 21A). Table 2 shows that the reel mixing depth is 5.2-7.8 cm. The determination of the high accumulation rate was excellent (CV = 6%) despite the mixing in the top. Modelling is needed to clarify the age relations in the individual sediment slices. The core is not deep enough to reach a constant ^{210}Pb concentration as the ^{210}Pb concentration in 25 cm depth is high (Figure 4). Generally, the ^{210}Pb concentrations are high in the whole core.

St. no. 193, BO-3

The ^{210}Pb profile (Figure 2 in Appendix 22A) shows an intensive mixing with real mixing down to 2.8-4.2 cm. Figure 4 shows a nearly constant concentration of ^{210}Pb below 18 cm depth. The estimation of the sediment accumulation rate is reasonable (CV = 9%). Modelling is needed to clarify the age relations in the individual sediment slices.

St. no. 195, F2X

The ^{210}Pb profile (Figure 2 in Appendix 23A) shows an intensive mixing with real mixing down to 2.8-4.2 cm. Figure 4 shows a nearly constant concentration of ^{210}Pb below 15 cm

Table 2. Accumulation rate, mixing coefficient, and effective mixing depth for sediments from the Baltic Baseline Study.

Station name and no.		Accumulation rate		Mixing coefficient	Mixing depth cm		Quality of dating
		Mass g m⁻² yr⁻¹ ± s.d.	Linear mm yr⁻¹ (depth 0-2 cm)	cm² yr⁻¹	Effective model	Real	
Kattegat, 156							Dating impossible.
Kiel Bight, 157		313±9	1.5	150	3.0	6-9	**
Lübeck Bay, 160		509±18	2.3	1	2.1	4.2-6.3	**
Arkona Basin, 166		261±58	1.4	150	4.1	8.2-12.3	*
Bornholn Basin, 167		250±22	1.6	43	1.1	2.2-3.3	**
Gdansk Bay, 169		880±91	7.5	12	0.1	0.2-0.3	***
Lithuan Coast, 170		1,113±242	5.4	43	0.4	0.8-1.2	***
Gotland Deep, 171	0-13 cm	104±7 ?	8.7	43	1.7	3.4-5.1	*
	12-30 cm	1,669±289 ?	-	-	-	-	*
Gulf of Riga, 175		1,217±48	6.3	525	1.2	2.4-3.6	***
Western Gotland Deep, 178	0-10 cm	74±5 ?	1.9	150	1.8	3.6-5.4	*
	14-31 cm	3,959±191 ?	-	-	-	-	**
LL-19, 180							Dating impossible.
GF-1, 181		281±56	1.3	525	2.2	4.4-6.6	*
GF-2, 182		1,157±73	10.3	1840	3.0	6.0-9.0	**
GF-4, 183		391±11	-	-	-	-	**
GF-5, 184							Dating impossible.
GF-6, 185		1,850±127	15.1	43	0.1	0.2-0.3	***
GF-3, 186		701±89	5.3	525	3.7	7.4-11.1	**
XV-1, 187		1,115±185	9.9	150	0.3	0.6-0.9	***
Aaland Sea, 189							Dating impossible.
EB-1, 190		1,521±95	6.0	150	0.5	1.0-1.5	***
Harnosand, 192		1,174±74	4.6	525	2.6	5.2-7.8	***
BO-3, 193		325±29	1.8	43	1.4	2.8-4.2	***
F2, 195		352±30	1.9	12	1.4	2.8-4.2	**

s.d. = standard deviation

*** excellent dating, ** reasonable dating, *poor dating depth. The estimation of the sediment accumulation rate is reasonable (CV = 8%). Modelling is needed to clarify the age relations in the individual sediment slices.

4. SENSITIVITY FOR POLLUTION MEASUREMENTS

Another model calculation was performed on the basis of the datings. The purpose of this calculation was to evaluate the sensitivity of the sediment areas to measure changes in pollution input. The principle of this sensitivity analysis is described by Larsen and Jensen, 1989.

The following input were used in the model calculations:

- depth of sediment surface sample (10 mm used)
- the sediment accumulation rate
- the mixing described by D and σ
- the number of years between sampling: 3, 5, and 10 years
- the relative analytical standard deviations (% RSD) for the chemical analyses selected at 10%. These RSD are obtainable for the methods normally used, for example, atomic absorption spectroscopy used in heavy metal analysis. If a higher RSD is expected the per cent relative change in pollution input flux shall be multiplied by this factor (a RSD of 20% means that the flux shall be multiplied by two).

Table 3 shows the results of these model calculations and indicates that several locations are very useful in monitoring changes in pollution inputs. If sediment samples are taken and analyzed every fifth year, it will be possible to detect changes in pollution input from 10-50 % for station no. 160 (Lübeck Bay), 169 (Gdansk Bay) , 170 (Lithuan Coast), 175 (Gulf of Riga), 182 (GF-2), 185 (GF-6), 187 (XV-1), 190 (EB-1) and 195 (F2X). The differences is caused by the different accumulation rates and mixing in the upper part of the sediment cores. If sampling is only performed with a frequency of ten years the majority of localities where datings has been performed are very suitable to use in a pollution monitoring programme with changes in input flux of less than 50%. The exceptions are st. no. 157 (Kiel Bight), st. no. 166 (Arkona Basin), 178 (Western Gotland Deep) and 181 (GF-1).

Table 3. Sensitivity for pollution monitoring with a relative standard deviation of 10% for the chemical analysis.

Station name and no.	% change in input flux		
	Number of years between sampling		
	3	5	10
Kiel Bight, 157	235	155	85
Lübeck Bay, 160	40	30	20
Arkona Basin, 166	310	205	115
Bornholm Basin, 167	105	65	35
Gdansk Bay, 169	10	10	10
Lithuan Coast, 170	15	15	10
Gulf of Riga, 175	35	25	15
Western Gotland Deep, 178	200	130	70
GF-1, 181	295	180	95
GF-2, 182	85	50	30
GF-6, 185	10	10	10
GF-3, 186	135	85	50
XV-1, 187	10	10	10
EB-1, 190	20	15	10
Harnosand, 192	90	60	30
BO-3, 193	100	65	35
F2X, 195	75	50	30

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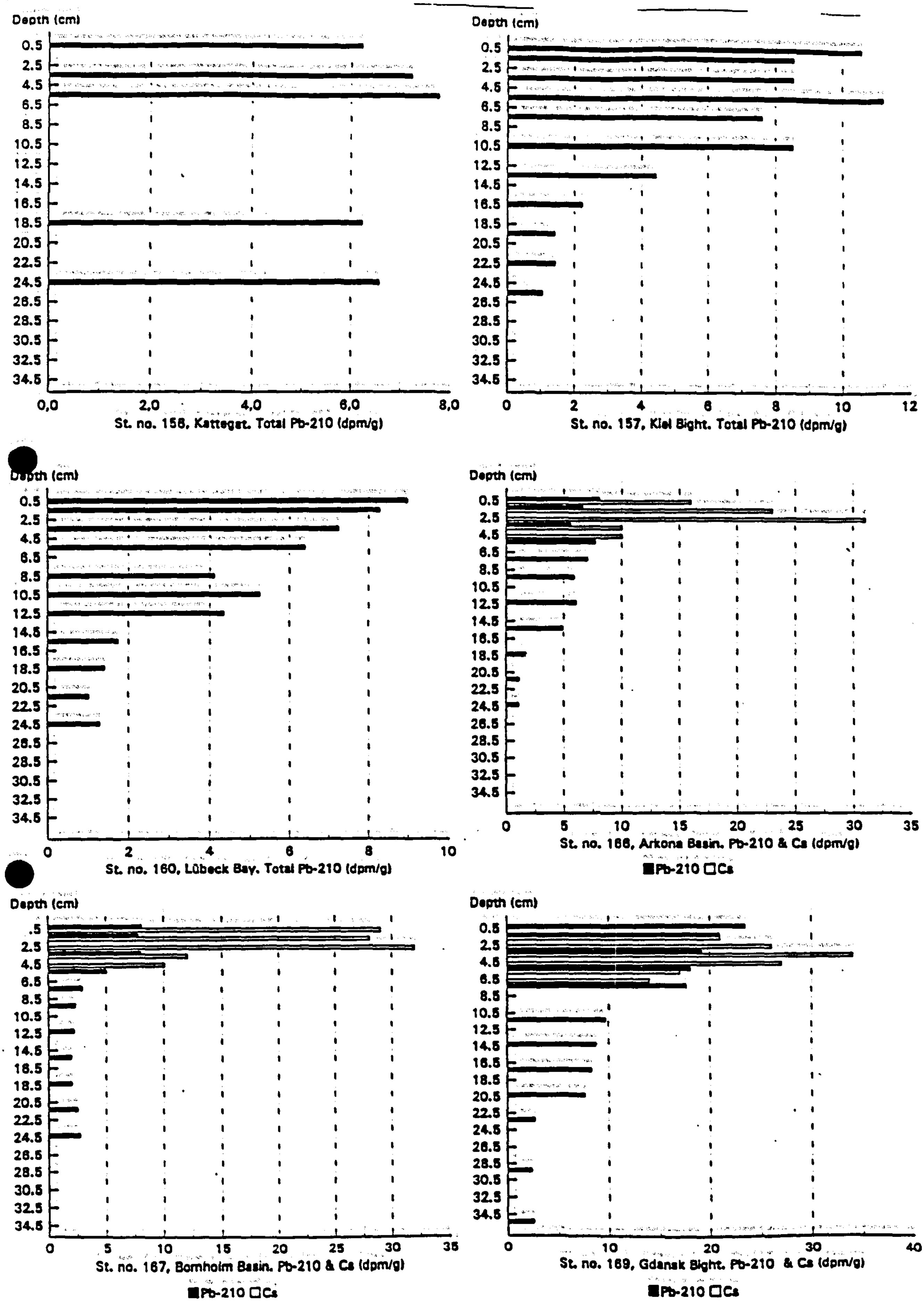
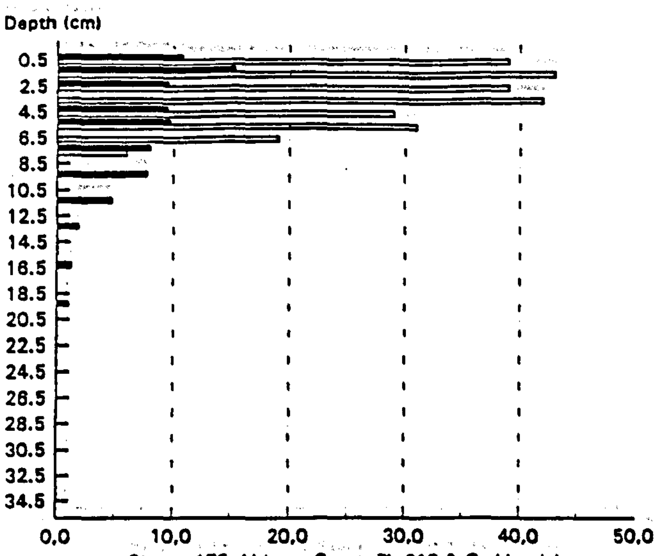
Larsen B. and Jensen A., 1989. Evaluation of the Sensitivity of Sediment Stations in Pollution Monitoring. Mar. Pollut. Bull. 20, 556-560.

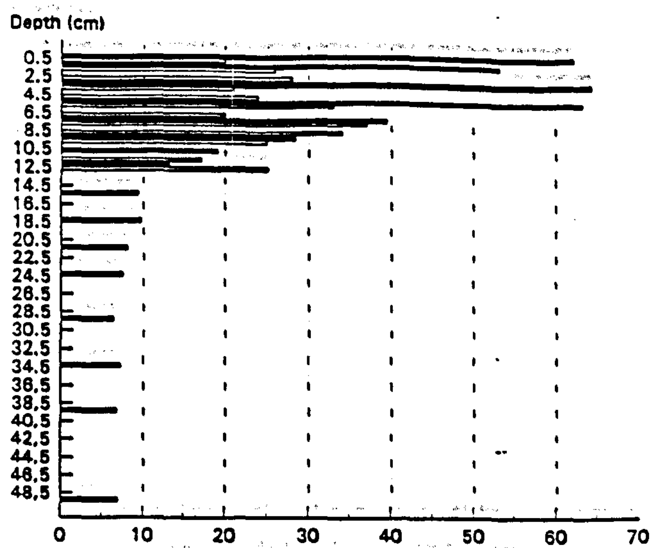
FIGURE 4
Profiles ^{210}Pb and ^{137}Cs as function of sediment depth





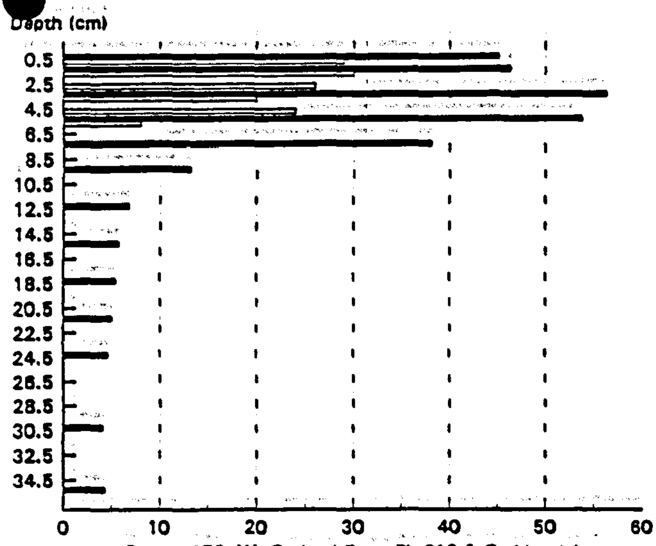
St. no. 170, Lithuan Coast. Pb-210 & Cs (dpm/g)

■Pb-210 □Cs



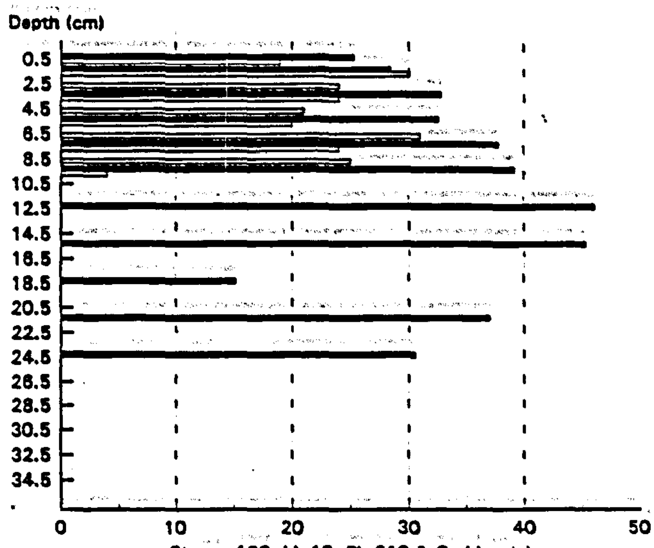
St. no. 171, Gotland Dep. Pb-210 & Cs (dpm/g)

■Pb-210 □Cs



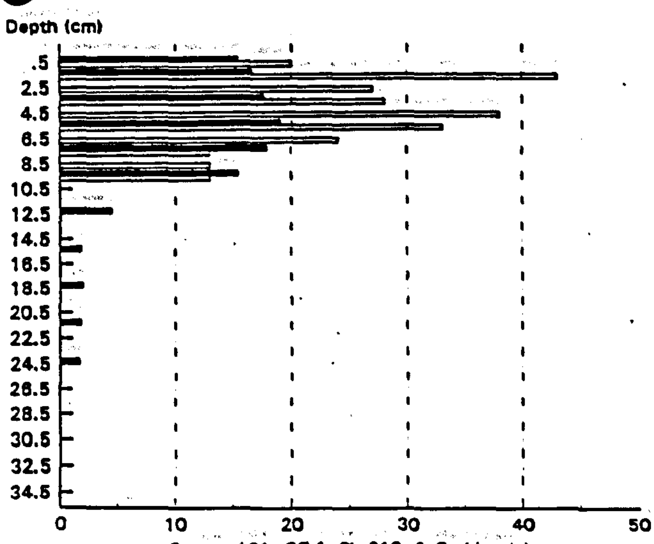
St. no. 178, W. Gotland Deep.Pb-210 & Cs (dpm/g)

■Pb-210 □Cs



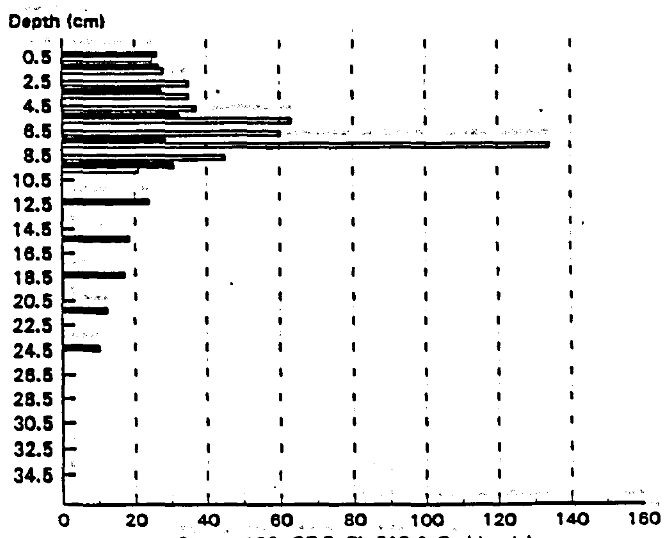
St. no. 180, LL-19. Pb-210 & Cs (dpm/g)

■Pb-210 □Cs



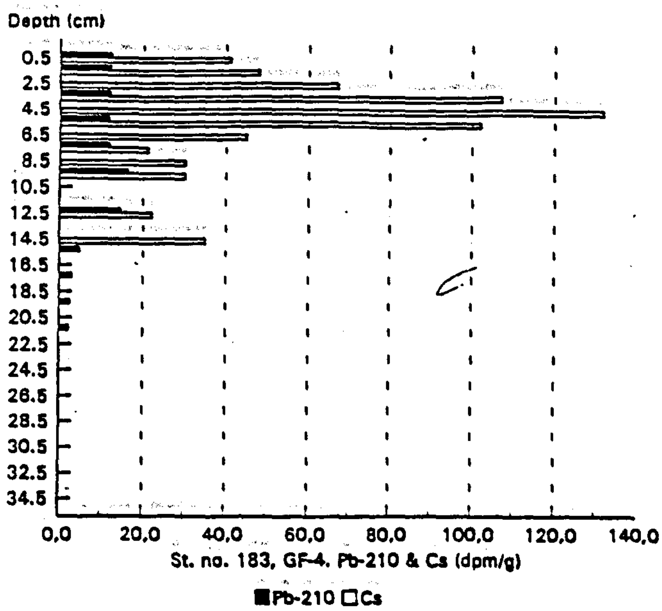
St. no. 181, GF-1. Pb-210 & Cs (dpm/g)

■Pb-210 □Cs



St. no. 182, GF-2. Pb-210 & Cs (dpm/g)

■Pb-210 □Cs



Depth (cm)
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2.5
4.5
6.5
8.5
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12.5
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16.5
18.5
20.5
22.5
24.5
26.5
28.5
30.5
32.5
34.5
0,0
20,0
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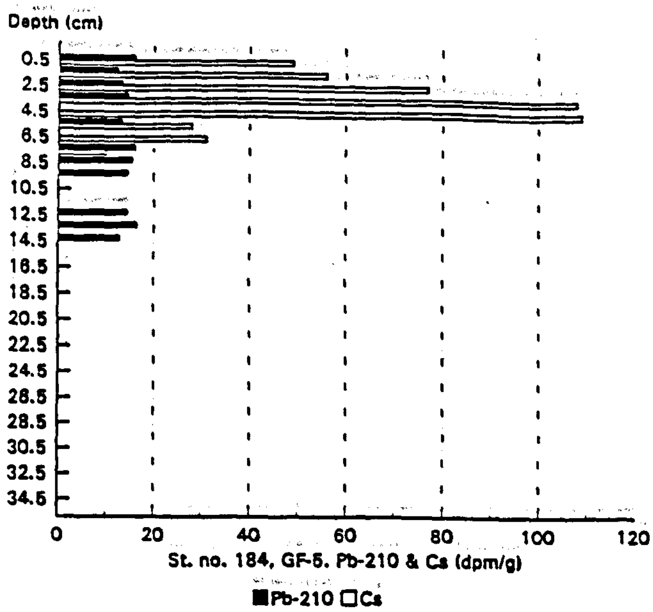
80,0
100,0
120,0
140,0
St. no. 183, GF-4. Pb-210 & Cs (dpm/g)
Pb-210 Cs



Depth (cm)
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10.5
12.5
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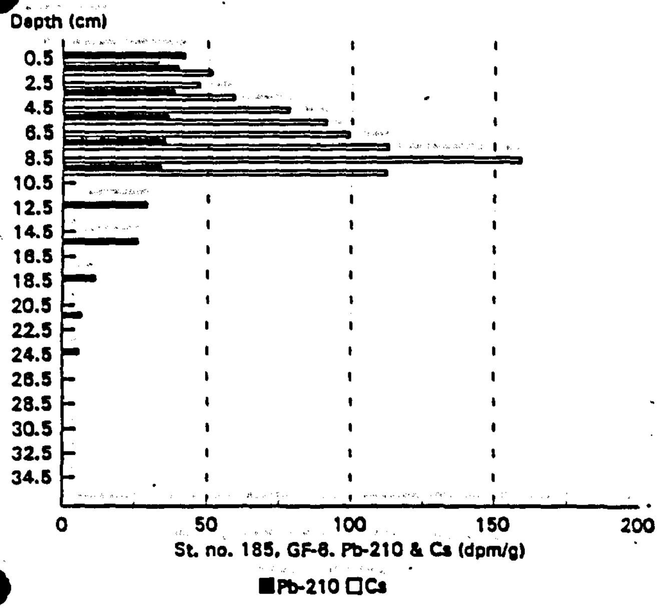
18.5
20.5
22.5
24.5
26.5
28.5
30.5
32.5
34.5
0
20
40
60
80
100
120
St. no. 184, GF-5. Pb-210 & Cs (dpm/g)
Pb-210 Cs



Depth (cm)
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12.5
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16.5
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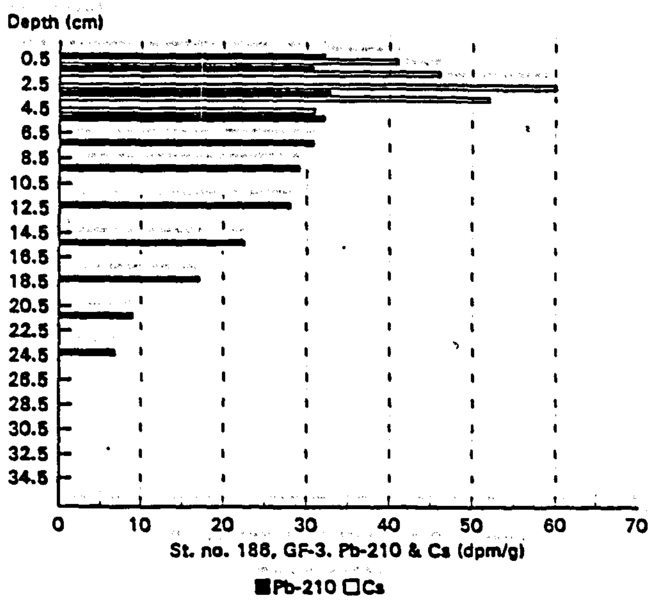
22.5
24.5
26.5
28.5
30.5
32.5
34.5
0
50
100
150
200
St. no. 185, GF-6. Pb-210 & Cs (dpm/g)
Pb-210 Cs



Depth (cm)
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10.5
12.5
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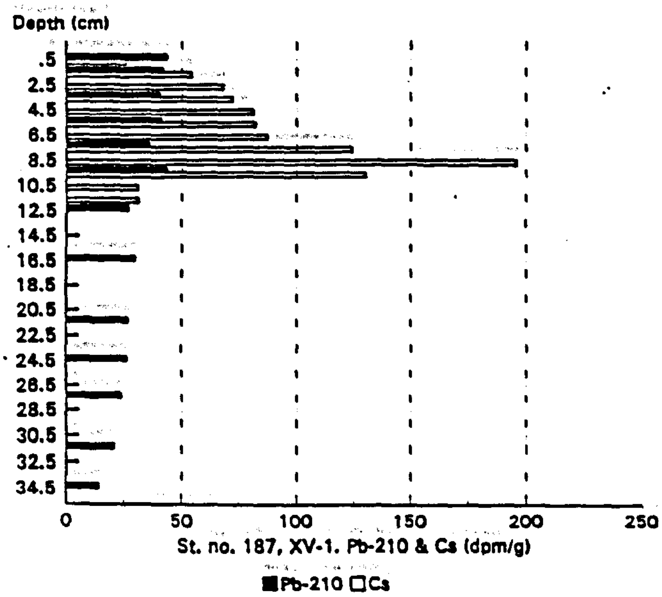
18.5
20.5
22.5
24.5
26.5
28.5
30.5
32.5
34.5
0
10
20
30
40
50
60
70
St. no. 186, GF-3. Pb-210 & Cs (dpm/g)
Pb-210 Cs



Depth (cm)
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6.5
8.5
10.5
12.5
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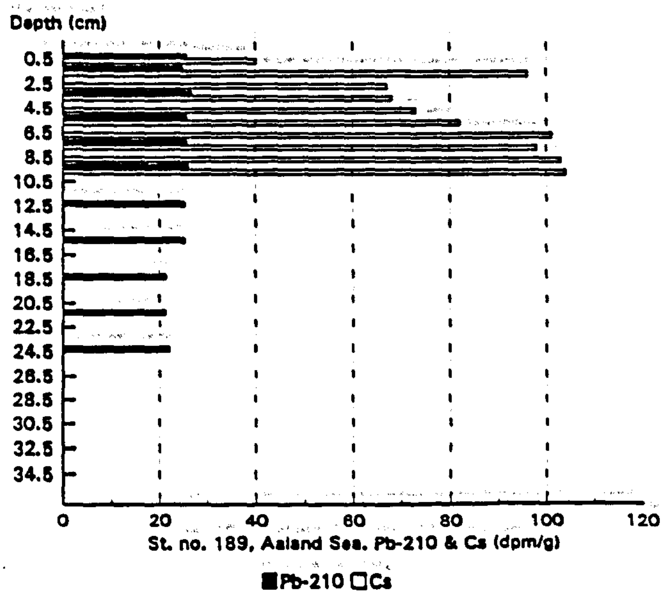
18.5
20.5
22.5
24.5
26.5
28.5
30.5
32.5
34.5
0
50
100
150
200
250
St. no. 187, XV-1. Pb-210 & Cs (dpm/g)
Pb-210 Cs



Depth (cm)
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12.5
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16.5
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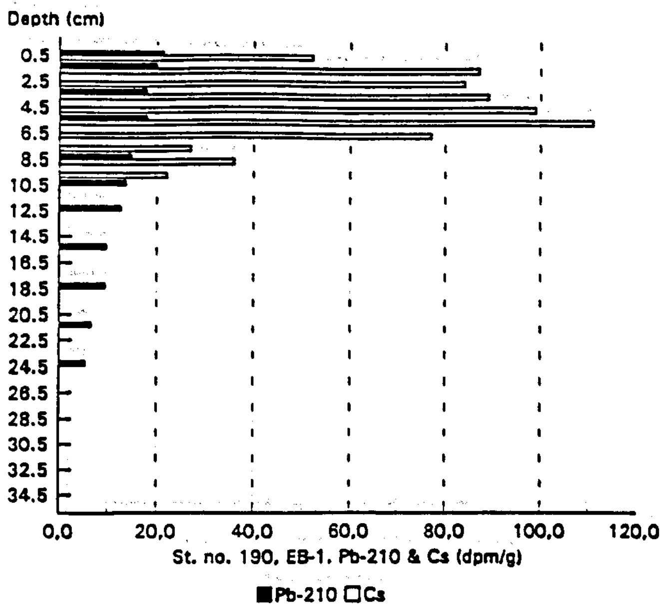
22.5
24.5
26.5
28.5
30.5
32.5
34.5
0
20
40
60
80
100
120
St. no. 189, Aaland Sea. Pb-210 & Cs (dpm/g)
Pb-210 Cs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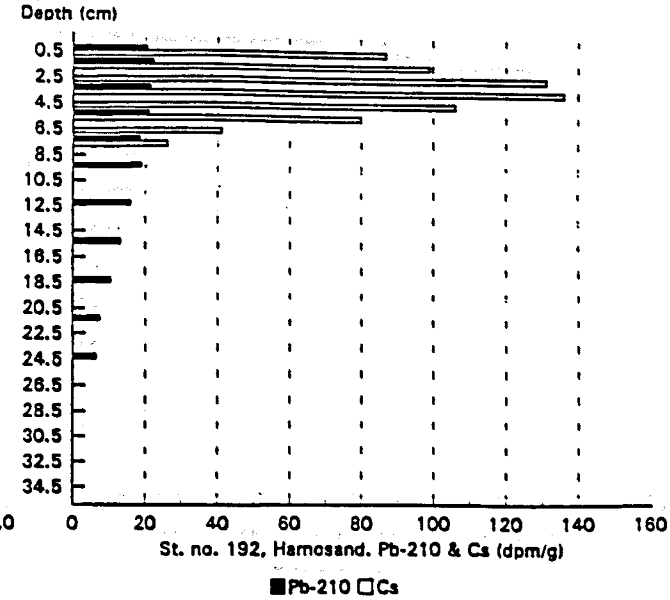
22.5
24.5
26.5
28.5
30.5
32.5
34.5
0,0
20,0
40,0
60,0
80,0
100,0
120,0
St. no. 190, EB-1. Pb-210 & Cs (dpm/g)
Pb-210 Cs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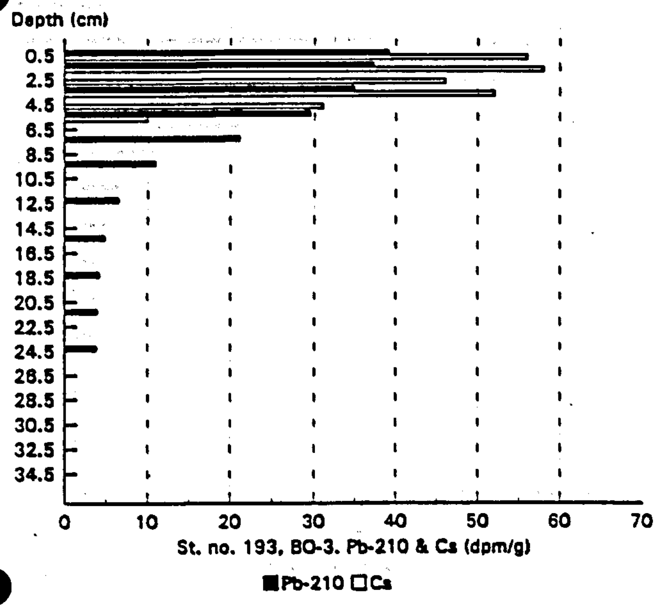
16.5
18.5
20.5
22.5
24.5
26.5
28.5
30.5
32.5
34.5
0
20
40
60
80
100
120
140
160
St. no. 192, Harnosand. Pb-210 & Cs (dpm/g)
Pb-210 Cs


Depth (cm)
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12.5
14.5
16.5
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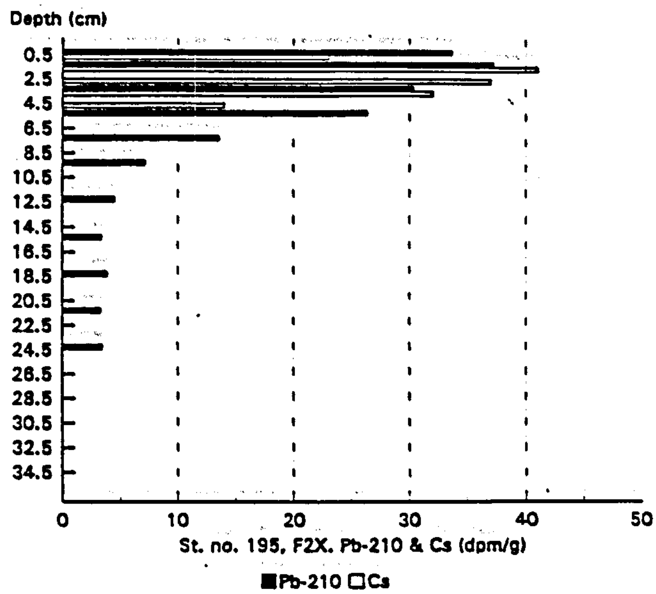
20.5
22.5
24.5
26.5
28.5
30.5
32.5
34.5
0
10
20
30
40
50
60
70
St. no. 193, BO-3. Pb-210 & Cs (dpm/g)
Pb-210 Cs


Depth (cm)
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12.5
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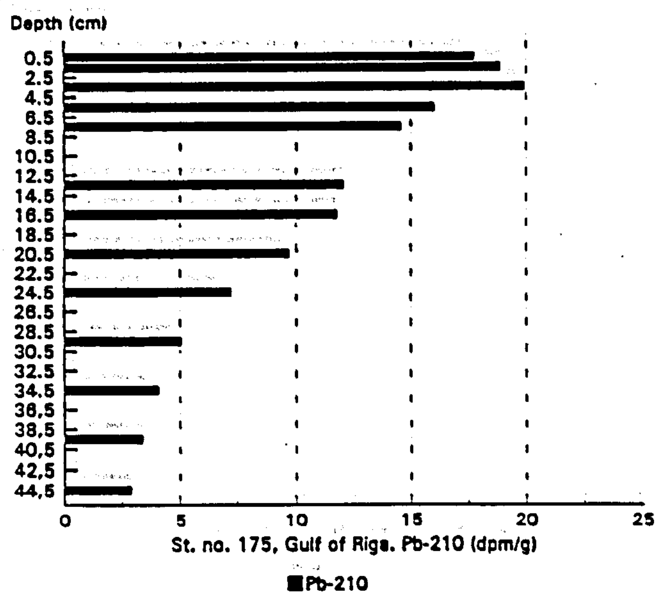
18.5
20.5
22.5
24.5
26.5
28.5
30.5
32.5
34.5
0
10
20
30
40
50
St. no. 195, F2X. Pb-210 & Cs (dpm/g)
Pb-210 Cs


Depth (cm)
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12.5
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22.5
24.5
26.5
28.5
30.5
32.5
34.5
36.5
38.5
40.5
42.5
44.5
0
5
10
15
20
25
St. no. 175, Gulf of Riga. Pb-210 (dpm/g)
Pb-210