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Recipient evolution – transport and distribution of elements in the lake Sibbo-Trobbofjärden area

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ABSTRACT

The field studies in SKB-project Recipient evolution within the Lake Sibbo- and Trobbofjärden areas have given the following results.

Material balance calculations have shown that resuspension is one important parameter for calculations of the turnover of elements in sediment. The leakage of for example chloride from the Lake Trobbofjärden sediment has been determined.

The elemental distribution in sediment cores show minor variations with depth. The redox front is found less than 5 cm from the sediment surface.

The elemental distribution between solid and water phase has been found to be on the order of 1 000 to 10 000.

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1 BACKGROUND

The KBS Technical Report 84-17 (AGN84) summarized the first part of the Recipient Evolution Project. In this report it was concluded that the continued program should include both field and laboratory studies. The field investigations were concentrated to the drainage areas of Lake Sibbo- and Trobbofjärden, see Fig 1. The field studies had two main purposes, firstly to achieve knowledge of the complicated dynamic system a lake and its surroundings constitute, secondly to map the distribution of different elements and radionuclides within these lake systems.

Other reports concerning this project are "Quantitative estimates of sedimentation rates and sediment growth in two Swedish lakes" (EVA 86) and "Description of vegetation in Lake Trobbo- and Sibbofjärden during the summer 1985" (AGN 86).

2 SAMPLES AND METHODS

The two investigated field areas Lake Trobbo- and Sibbofjärden are described in the Stage 1 Report of this project (AGN84). However, some complementary data will be presented below.

Lake Sibbofjärden is nowadays an enclosed brackish bay with a canal in the south, Strömstugan, see Figures 1 and 2, that is the connection to the Baltic Sea.

Lake Trobbofjärden was also a brackish bay until 1956 when it was closed to the sea with a dam, to obtain a fresh water reservoir. Catchment statistics for the two areas and subcatchments are presented in Table 1.

Table 1

Catchment statistics

Catchment and gauging stations	Area (km^2)	Land use (%) Field	Forest	Wetland	Lake
Sibbofjärden	83.3	25	66	2	7
Hässle	13.9	4	87	6	3
Ekekulla	20.4	47	52	1	0
Brokulla	11.3	49	50	1	0
Trobbofjärden	49.0	15	69	5	11
Segersta	4.5	22	77	1	0
Tegelkällan	7.9	19	69	8	4
Nynäs	20.2	13	74	2	11

2.1 Water discharge and lake volumes

The water level has initially been measured at 8 stations, see Fig 1. Rating curves for the different stations were estimated from discharge measurements at different water stages.

The discharge from the different stations was evaluated after half a year. This evaluation and a comparison of landuse, topography etc showed that it was possible to reduce the net of discharge stations to only four. These four were Hässle and Brokulla in the catchment of Lake Sibbofjärden, Tegelkälla and Nynäs within the catchment of Lake Trobbofjärden.

The water level in the Baltic Bay Tvären has been registered since 1964. The water flow at Strömstugan is influenced by the water level in the Baltic Sea. Because of this level it has been of interest to measure the water level at Strömstugan. Besides the registration of the velocity of the in- and outgoing water, temperature and salinity have been registered at the test site. Aanderaa equipment has been used for these measurements.

The volume of Lake Trobbofjärden was estimated earlier. Sounding was carried out in Lake Sibbofjärden to determine its bottom configuration and total water volume. The contour map of Lake Sibbofjärden is shown in Figure 2 and hypsographic curves for Lake Sibbo- and Trobbofjärden are presented in Figures 3 - 5.

2.2 Suspended matter

Sampling of suspended matter has been done in the streams and the lakes at different periods covering periods with both high and low contents of suspended matter.

2.3 Dissolved material

Water samples were taken about 10 times during one year at the different stations and in the lakes, see Figure 1. The macro constitutents were analysed, i.e. Na, K, Ca, Mg, Cl, SO_4^{2-} and HCO_3^-. Besides pH, conductivity, Fe, Mn, NH_4^+, NO_2^-, SO_4^{2-} and PO_4^{3-} were determined.

2.4 Trace elements

Trace elements were analysed for water, soil, sedimenting material, sediment (porewater and solid phase). ICP (Inductively Coupled Plasma-emission spectroscopy) was used for most of the water samples, while NAA (Neutron Activation Analysis) was used for the other samples. Usually it was possible to analyse 20 to 30 elements.

2.5 Sedimentation

The amount of sedimented material was measured by sediment traps at different depths in Lake Sibbo- and Trobbofjärden, see Evans (EVA86).

2.6 Sediment

Sediment cores were taken in Lake Sibbo- and Trobbofjärden, Rundbosjön, Käxlan and Frillingen. The core diameter was 60 mm and the lengths were different, 160 cm at most. The cores were directly transported to the laboratory, where the redox potential was measured in the undisturbed core. The cores were then cut into 2 cm thick slices. Ultra-high centrifugation was used to separate the liquid and solid phase. Conductivity, pH and content of chloride of the porewater were measured. The water content and the loss of ignition were also determined.

2.7 Soil

Soil samples were taken from the surroundings of the lakes. These samples represent "old" sediments. Samples were taken from different depths, depending on the structure of the soil. The deepest profile was 160 cm.

3 WATER TRANSPORT

Rating curves were constructed from the discharges measurements at different water stages. This was done for all stations and one example of a rating curve is shown in Figure 6. Usually a power curve fit is the best one for a rating curve, i.e. a straight line is obtained in a log-log diagram, as can be seen in Figure 6.

The discharge has been coverted to runoff values for the different catchments. The runoff is expressed as l/s km^2. From Tables 1 and 2 one can see that the coefficients of variation is high within the year depending among other things on the percentage of lake and arable land area. These effects are also visualized in Fig 7 and 8. The Nynäs station shows slow and small variations, while the Brokulla station shows the opposite, due to the fact that there are no lakes within the catchment and that this area was ditched just before the study started.

Table 2

Runoff 1985 (unit: $l/s \cdot km^2$).

Station	Mean	Max	Min	C_v (%)
Hässle	11.4	125	1.5	56.7
Brokulla	14.4	185	3.5	155.5
Tegelkälla	10.4	96	2.0	142.3
Nynäs	13.3	68	5.5	93.3

The mean runoff for the hydrological region belonging to Södermanland, varies between 7 to 11 l/s km^2 (GOT75). These figures stand for catchment areas of several 1 000 sq.km. Taking into account the quite low lake percentage and the higher precipitation (+15 %) during 1985 than normal the figures observed are representative for further use in calculating the transport of material.

Another way to express the differences between the two stations is a plot of the duration curve. Such a curve shows what percentage of the time that the runoff exceeds a certain value. Figure 9 is an example of two duration curves. The Nynäs curve has for example a runoff of 22 l/s km^2 or higher during 10 percent of the time, while the Brokulla runoff is 27 l/s km^2 for the same fraction of time.

The water transport through the out/inlet of Lake Sibbofjärden, called Strömstugan, is controlled by the inflow from the surrounding areas and by the sea level. The relation between water level at Strömstugan and at a reference point in the Baltic Sea (Tvären) is presented in Figure 10. This diagram shows two curves, one representing in- flow situations and the other outflow periods. There is a significant difference of about 5 cm between the two curves, the higher level for outflow situations.

Variables such as temperature and salinity show what type of water mass goes through the canal at Strömstugan. Figure 11 is a good example of how the salinity reflects the flow pattern. The salinity of Lake Sibbofjärden just after the spring flood is around 2 % and the salinity of the Baltic is around

6 %. The period shown starts with outflow during one day, with a short period of inflow, followed by a four-day period of outflow. The next six days show a variable flow pattern with a periodicity of less than 24 hours. Finally there is a six-day period of inflow from the sea.

Table 3 is a summary of waterflow measurements at Strömstugan. Outflow occurs during 2/3 of the time from Lake Sibbofjärden. Besides these outflow periods have an average duration which is twice as long as the inflow periods, 34 hours and 17 hours respectively.

Table 3

Direction of waterflow through Strömstugan.

Period	Total time (h)	Outflow Time (%)	Outflow Mean duration (h)	Inflow Time (%)	Inflow Mean duration (h)
Oct-Nov 1984	574	94	135	6	11
Nov-Dec 1984	1 120	84	53	16	10
April-May 1985	720	100	720		
May-June 1985	445	50	18	50	18
June-August 1985	1 169	38	12	62	20
August-Sept 1985	781	47	13	53	15
Sum	4 809				
Mean		67	34*	33	17

* except spring-flood April-May

4 MATERIAL TRANSPORT

4.1 Suspended matter

The amount of suspended matter was measured at the discharge stations, see Figure 1.

The variation of the content of suspended matter for two stations are shown in Figure 12. Table 4 provides the statistics for suspended matter. The variation between the different areas is considerable, compare Nynäs and Brokulla. This depends mainly on the differences in lake percentage and arable land area. Besides, Lake Rundbosjön is situated close to the outlet of the Nynäs catchment. Thus the heaviest particles will settle within the lake before they reach the outlet at Nynäs.

Table 4

Suspended matter 1985 (unit: mg/l).

Station	Mean	Max	Min	C_v (%)
Hässle	16	25	6	54
Brokulla	44	95	29	35
Tegelkälla	29	94	11	65
Nynäs	7	18	1	63

The transport of suspended matter has been calculated using the discharge and the concentration of suspended matter in the water for the different stations according to:

$$T = \sum_{t=1}^{365} Q_t * C_t$$

where

T = total transport of suspended matter/(kg/year)

Q_t = discharge (m^3/day)

C_t = concentration of suspended matter (kg/m^3)

The average daily transport, presented in Table 5, varies as much as a by factor of 10. Usually the transport is given as ton/km^2 year and the corresponding values thus varies between 26 and 3 ton/km^2 year. The highest values are equal to a denudation of the bedrock of about 1 mm/100 years. The transport values are in accordance with transport figures from the region of Svealand, (BRA82).

Table 5

Transport of suspended matter 1985 (unit: kg/d·km^2).

Station	Mean	Max	Min	C_v (%)
Hässle	17	269	0.2	222.7
Brokulla	71	1 087	9.5	197.3
Tegelkälla	43	647	3.2	273.2
Nynäs	7	36	1.1	106.0

Relations between runoff and transport have been calculated. Results from the calculations of two areas are shown in Figures 13 and 14. The first one (Tegelkälla) indicates a very good correlation, best fit with a power function (r^2 = 0.939). The exponent is 1.46 which agrees well with what has been found even for larger river systems, where big particles dominated the transport (NIL72). Nilsson mentions the value of the exponent to be around 1.5. The curve for Nynäs where Lake Rundbosjön dominated the content of suspended matter, as mentioned earlier, shows low correlation between transport values at Nynäs, where the exponent is close to 1 the power curve fit roughly gives a linear relation instead.

The cumulative suspended transport for the four main catchments is presented in Figure 15.

Another method of calculating the transport is to use the estimated distribution functions of the runoff and concentration of suspended matter, where the nonlinearity can be considered. This has also been done and a comparison shows that this type of calculation will give an increased transport of about 10 % for Brokulla and Tegelkällan areas, where the transport is high. In the areas where the transport is low, there is on the other hand an increase of about 50 - 60 %.

This type of calculation implies that the distribution of the concentration of suspended matter and the runoff coincide in time. This is however not always probable, because the maximum outwash usually occurs before the peak in runoff is reached. This method is useful for obtaining maximum values of this transport and is especially valid if there are not so many measurements available.

The first method of transport calculation has been used for the following analysis. Correlations between transport of suspended matter and land use have been estimated. The result, see Table 6, shows that the area of arable land in relation to the total catchment area gives the highest correlation. This is also what can be expected because particles from this type of soil is more influenced by exogen processes. The linear relations obtained have been used to calculate the total transport to Lake Sibbo- and Trobbofjärden. The weighted transport calculations gave a value of 17.0 and 10.5 ton/km^2 respectively.

Table 6

Correlation between transport of suspended matter and land use.

Landuse	Correlation (r^2)
Arable land	0.92
Forest land	0.88
Lake area	0.80
Wetland	0.16

Balance calculations showed that about 1 000 ton suspended matter were accumulated within Lake Sibbofjärden during one year. The corresponding value of Lake Trobbofjäden was about 300 ton.

4.2 Dissolved material

The corresponding calculations have been done for dissolved material. The total transport of the major dissolved constitutents has been calculated for 1985. The result is presented in Table 7.

Table 7

Transport of dissolved material in 1985 (unit: $ton/km^2/y$).

Element	Hässle	Brokulla	Tegelkällan	Nynäs
Ca	5.0	19.7	10.3	6.3
Mg	5.0	19.7	10.3	6.3
Na	1.3	0.8	0.5	3.2
K	0.5	2.4	1.0	0.9
HCO_3^-	6.7	23.5	6.2	7.3
$SO_4^=$	5.2	29.4	20.0	11.6
Cl^-	1.7	10.0	6.1	3.3
NO_3^-	0.8	2.1	1.8	0.5
Total	21.2	87.9	45.9	33.1

All calculations concerning the balance of Lake Sibbo- and Trobbofjärden are summarized in Figures 17 to 18. There are differences between both lakes and constitutents. It is evident that there must exist a leakage from the bottom sediment of Lake Trobbofjärden so as to be able to explain the high negative values obtained for conservative elements as sodium, potassium and chloride. The sediment is of the same character as the recent sediment of Lake Sibbofjärden, but during the 30 years period as a fresh water lake, the conditions in the top sediment of Lake Trobbofjärden have changed. Thus this mainly depends on leakage and to a minor part of new sedimentation. A non-conservative element as nitrate exhibits an accumulation within the lakes. Sayles (DRE82) has calculated the diffusional flux across the sediment-water interface for the oceans. These calculations show a leakage of 30 - 50 % of river input for sodium, 25 - 30 % for bicarbonate and an influx of about 80 - 100 % for potassium.

The leakage from the top sediment of Lake Trobbo-sediment is very clear, see Figure 19, where the chloride content of porewater from the sediments in Lake Trobbo- and Sibbofjärden is shown. The sediment of Lake Trobbofjärden is affected as far as 70 cm below the recent sediment surface.

The sedimentation in Lake Trobbofjärden is estimated to be 10 cm during its 30 years as a freshwater lake. The other 60 cm was built up during the brackish water period.

It is possible to calculate the amount of leakage, if the processes are assumed to follow the laws of diffusion. Drever (DRE82) gives the following relations:

$$J = -D' \cdot dc/dx$$

$$D' = D \cdot \phi / \Theta_2$$

where

J = flux of chloride (mol/m^2/s)
D' = effective diffusion coefficient (m^2/s)
dc/dx = concentration gradient (mol/l/m)
D = diffusion coefficient in solution (m^2/s)
ϕ = porosity
Θ = tortuosity

The gradient is 2 000 ppm/m = 56.3 mol/m^3/m, porosity 0.7, tortuosity 1.2 and diffusion coefficient 2.0E-09 m^2/s. This gives a flux of 62 g/m^2·y, equivalent to a total leakage of 185 ton/y. This will give an additional chloride content of the lake water of 15 ppm. The inflowing water contains on average about 15 ppm, i.e. about 30 ppm together. The measured content in Lake Trobbofjärden is on average 30 ppm. The curve fitting of the concentration gradient of chloride gives the best fit with an exponential curve, with a half-distance of 12 cm. There is a small break in the curve around 50 cm with a lower gradient below this depth.

The pH gradient also shows the same pattern as the chloride profiles do, see Figure 20.

It is also possible to find a chloride gradient in the sediment of Lake Rundbosjön. This lake is situated just above Lake Trobbofjärden at an altitude of 3.5 m.a.s.l. Consequently the lake was cut off from the Baltic Sea about 1 000 years ago. During this period the growth of the sediment is on the order of one meter, i.e. equivalent to the core length. In Figure 21, the chloride content of porewater from Lake Rundbosjön, Trobbofjärden and also Käxlan, an oligotrophic lake situated 28 m.a.s.l., is presented. It is striking that the content of chloride in the Rundbosjön sediment is as high as 50 - 75 % of the chloride content in the Lake Trobbofjärden sediment. This means that there exists a continous leakage from the old sea sediment through the recent sediment.

The closing of Lake Trobbofjärden from the Baltic Sea 30 years ago, caused, of course, a decreasing chloride content in the lake water. This decrease is shown in Figure 22. The exponential decrease is shown with a half-life time of 15 months. This time can be compared with the residence time of 8 months, calculated from the theoretical time (V/Q), where V is the lake volume and Q is the water discharge to the lake during one year.

Another application of the material balance has been used to calculate the average inflow from the sea to Lake Sibbofjärden. The following simple balance equations have been used

$$Q_{in} + Q_{sea} = Q_{out}$$

$$C_{in} * Q_{in} + C_{sea} * Q_{sea} = C_{out} * Q_{out}$$

Combining these two equations will give:

$$Q_{sea} = Q_{in} * (C_{in} - C_{out})/(C_{out} - C_{sea})$$

Four different conservative elements have been used. They are sodium, potassium, calcium and chloride. The calculated Q_{sea} became 0.58, 0.57, 0.64 and 0.55 m^3/s respectively. Thus the average of these is 0.6 m^3/s which will be compared with the fresh water inflow of 1.1 m^3/s. The total volume of Lake Sibbofjärden is 3.5E7 m^3. These two inflows will thus give a mean residence time of about 8 months.

5 DISTRIBUTION OF TRACE ELEMENTS

According to Drever (DRE82) - trace elements are defined as those elements which generally occur in water at concentrations of less than 1 mg/l. However, it has been found useful to include major elements and heavy metals within the same chapter.

Samples have been taken of surface water, sedimenting material, sediment (solid and liquid phase) and soil.

The aim has been to study the distribution of the elements in the sediment in relation to the depth and the distribution between the liquid and solid phase. Besides the differences between soil (former sediment) and the recent sediment have also been of interest. The distributions found will be used in the future model work to calculate the mobility and migration of radionuclides during the lifetime of lakes.

In Figures 23 to 44 data from different element analyses are presented as examples of the above mentioned measurements.

Some of the major cations, as sodium, potassium and iron are shown in Figures 23 to 25. The sediment values show no marked gradient except for Stora Frillingen. This lake is an oligotrophic lake and its sediment mainly consists of organic matter with a low degree of decomposition. The elemental composition of sediment and soil samples is shown in Table 8 and have been taken from this study, the Viskan Valley study, Landström (LAN67) and average values in soil according to NSEPE (BEI78). There are small deviations from the "standard values" of the major elements mentioned.

On the other hand, chromium, cobalt and especially zinc have increased concentration, see Figures 26 - 28.

Cesium and rubidium profiles are presented in Figures 29 - 30. There are only minor deviations from "standard" for Cs, see Table 8. The Rb-values are higher especially for the Sibbo sediment. The surrounding bedrock (the dominating gneiss) contains on average 125 ppm (LAN86), while the Sibbo sediment value has around 200 ppm.

Table 8

Elemental composition

Element	Unit	Sediment Sibbo-fjärden	Sediment Stora Frillingen	Soil Björksund	Soil Holmtorp	Viskan Valley a) Present lake	Viskan Valley a) Sea sediment	SNV Soil
Na	%	1.3	0.3	1.4	0.9	1.2	1.0	0.6
K	"	2.7	0.8	-	-	-	-	1.4
Fe	"	5.5	2.8	4.4	5.0	6.2	5.8	3.8
Cr	"	90	60	70	75	53	47	100
Co	ppm	19	13	12	12	21	11	8
Zn	"	200	-	160	150	118	87	50
Br	"	-	37	10-90	90	6.7	131	-
Ce	"	7	4	5	5	6.8	4.7	6
Rb	"	210	75	150	130	115	90	100
La	"	55	26	50	52	56	55	30
Ce	"	150	85	105	120	243	207	50
Eu	"	1.5	0.9	1.3	1.4	2.5	2.2	-
Sm	"	10.5	6.5	7.5	9	15	15	-
Yb	"	4.0	2.5	3.5	3.5	2.5	1.9	-
Lu	"	0.8	0.4	0.6	0.8	1.0	0.6	-
Th	"	26	12	20	18	14	12	5
U	"	7	4	-	-	6	5	1

a) Landström et al (LAN67)

The amounts of thorium and uranium have also been determined, see Figures 31 - 34. The thorium values are about three times higher than the uranium content which corresponds well with the normal ratio in the bedrock. The composition of the bedrock can give big differences on the local scale. In the Käxlan sediment, see Figures 33 - 34, the ratio is only about one due to high uranium content in the surroundings.

Six rare earth elements (REE) have also been included in this study. They are Lanthanum, cerium, samarium, europium, ytterbium and luthenium. The results are presented in Figures 35 to 40. The pattern is the same as for the other elements with the highest values for the Sibbo sediment, which has an element content that is about twice as high when compared to the Frillingen sediment. The soil samples taken at Holmtorp are between the two sediment values, but have values closer to those found in the Sibbo sediment.

The elemental composition for 17 elements is presented in Table 8 and the corresponding ratios in relation to the Sibbo sediments are shown in Table 9. There are variations between the different elements but it is possible to see that there is a significant difference between the Sibbo sediment in relation to the other sites. The content in the top layer of Stora Frillingen sediment is about half of the Sibbo sediment. This reflects the difference between sediment build up during oligotrophic conditions and eutrophic conditions.

Table 9

Elemental ratios in relation to Lake Sibbofjärden sediment

Element	Stora Frillingen	Björksund	Holmtorp
Na	0.23	1.08	0.69
K	0.30	-	-
Fe	0.51	0.80	0.91
Cr	0.67	0.78	0.83
Co	0.68	0.63	0.63
Zn	-	0.80	0.75
Cs	0.57	0.71	0.71
Rb	0.36	0.71	0.62
La	0.47	0.91	0.95
Ce	0.57	0.70	0.80
Eu	0.60	0.87	0.93
Sm	0.62	0.71	0.86
Yb	0.63	0.88	0.88
Lu	0.50	0.75	1.00
Th	0.46	0.77	0.60
U	0.71	-	-
Mean	0.53	0.80	0.80
Coeff. variation (%)	27	15	15
Range	0.23-0.71	0.63-1.08	0.60-1.00

The Holmtorp values describe soil, formed before the 1400's in a lake dominated by gyttja clay with quite high organic content. The site has a level of about 6 m.a.s.l. The Björksund site is situated a few hundred meters from the recent shore line at a level of 0.5 m.a.s.l. and is characterized by a gyttja clay sediment. A detailed description and characterization of these two sites and some others sites within the Lake Sibbofjärden area is in preparation (GUM86).

These two sediments from earlier stages of the evolution of Lake Sibbofjärden do not differ from each other very much, see Table 9. Usually the differences are within 10 %. One exception is sodium whose content is about 40 % higher in the Björksund soil. This probably depends on the brackish condition with a higher salinity during the sedimenting period at the Björksund site. However, the average decrease of the element content of the two soil sites is the same and is equal to a decrease of 20 %. This indicates that a leakage of that size has occurred since the sediment was "converted" to soil, i.e. about 20 % of the different elements have on average been mobilized.

A comparison of the content of some elements is shown in Figures 41 to 44. The comparison includes the content of surface water, sedimenting material, sediment (solid and liquid phase) and soil. The values can be divided into two groups, a liquid and a solid group. The liquid values vary between 5 - 20 ppb, while the solid values have a range of 10 - 200 ppm. This means that there are concentration differences on the order of 1 000 to 10 000 between the solid and liquid phase.

It is possible to use the elemental analysis of the profiles above for much more detailed analyses of the variation of pH, redox conditions, grain size distribution etc in relation to element content. This will, however, be reported by Gummesson (GUM86) and Andersson (AND87). Karin Andersson has been responsible for the laboratory investigations for the project.

6 CONCLUSIONS

The results presented in this report mainly concern data from 1985. However, the measuring program continued during the first half of 1986. The climatological conditions were similar during the two years with cold winters and late spring seasons. The spring flood came two weeks earlier in 1986 and had a lower peak discharge. The total transport of suspended matter and dissolved material was about the same during the two spring seasons. The deviations from the "normal" year with lower air-temperature (-1.9 degrees) and higher precipitation (+15 %) for 1985 will not affect the possibility using these data as reference data for the future model calculations.

The transport of different materials from areas with different land-use has been used to calculate the material balance of Lake Sibbo- and Trobbofjärden. The balance of suspended matter, together with internal biomass production show that the resuspension is an important parameter (EVA86), which must be considered when modelling the transport and distribution of different nuclides during the ageing of a lake.

Leakage of, for example, chloride from the Trobbo-sediment has been observed.

The elemental distribution in sediment cores has only minor variations with depth, especially in the Lake Sibbofjärden sediment. The redox front is found less than 5 cm below the sediment surface, but no clear elemental variations that can be related to this transion can be found. A slight increase with depth of the pH has been measured in the cores.

The elemental distribution in sediment and soil is also useful as natural analogs for actinides (CHA84), where cerium can be mentioned as one example.

The elemental distribution between solid and water phase has been found to be on the order of 1 000 to 10 000, with higher concentration in the solid phase.

The different lakes included in this study represent lakes in different stages of evolution. Lake Sibbofjärden is a semi-enclosed brackish bay and thus it is going to become a fresh water lake within a few hundred years. The land area around the lake is gradually becoming agricultural land.

Lake Trobbofjärden became a fresh water lake 30 years ago, before that it was in the same stage of evolution as Lake Sibbofjärden. It is obvious from the sediment studies that during the period of 30 years there was a substantial leakage of elements as sodium, potassium, chloride and carbonate. This type of condition has also been found in Lake Rundbosjön, that became a lake about 1 000 years ago. Chloride gradients in the interstial water in sediment, show that there is a continuous leakage from the old sea sediment through the recent sediment into the lake water.

The elemental composition of Lake Sibbofjärden sediment and surrounding agricultural areas differ about 20 - 30 %. This difference is expected to be a measure of the leakage of the agricultural land during the time of cultivation.

Within this project a long-term in situ experiment with "spiked" sediment cores was started in 1985. Nine different nuclides have been added to cores so as to study the migration of the nuclides within the cores.

All the data that have so far been collected within this project concerning the transport of suspended matter and dissolved material, leakage from sediment, chemistry of solid and water phase of sediment, elemental distribution between solid in sediment and soil in relation to liquid phase, nuclide migration in cores, biomass distribution along the shores (AGN86) will be used in stage 3, the modelling of the mobility of radionuclides during the recipient evolution.

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The author is grateful to Rune Axelsson, Svante Lampe and Carina Gummesson for field assistance. Thorough laboratory work and data evaluation have been done by Yvonne Stiglund. Many thanks to Sverker Evans, Karin Andersson and Ulla Bergström for all the planning and discussion concerning this project.
Tönis Papp, SKB, has to a high degree inspired this work.

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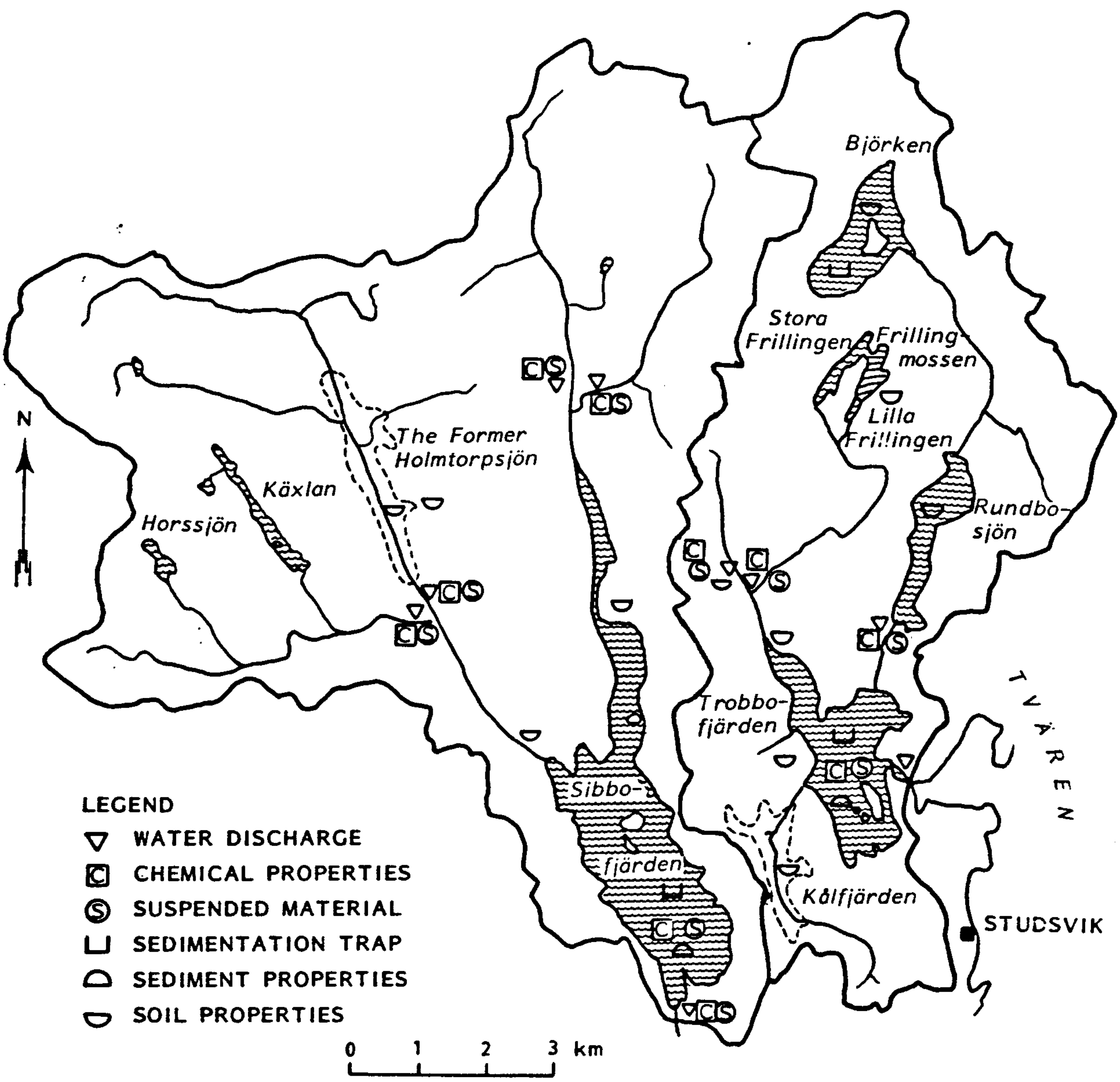


FIGURE 1
THE SIBBO- AND TROBBOFJÄRDEN AREA

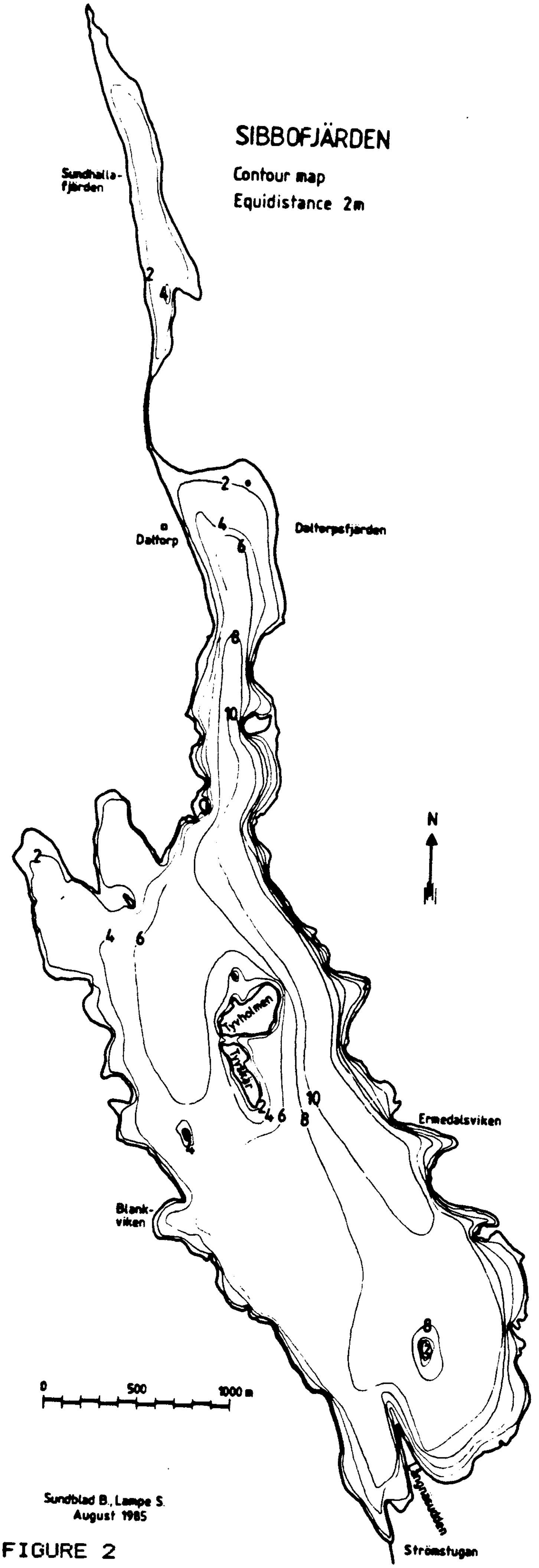

SIBBOFJÄRDEN
Contour map
Equidistance 2m
Sundhalla-
fjärden
Daltorp
Daltorpsfjärden
N
Tyholmen
Ermedalsviken
Blank-
viken
0
500
1000 m
Sundblad B., Lampe S.
August 1985
Strömstugan

FIGURE 2

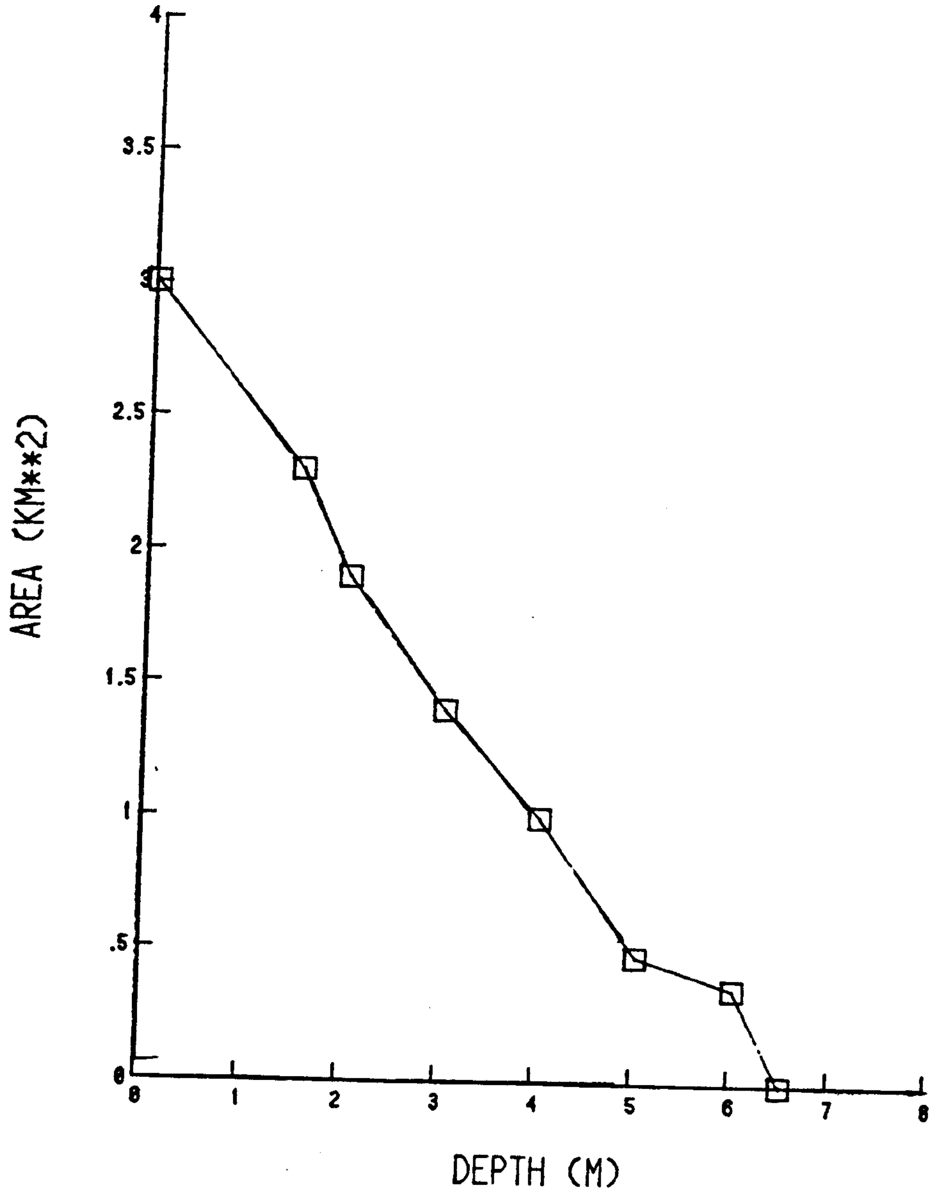


FIGURE 3
HYPSOGRAPHIC CURVE TROBBOFJÄRDEN

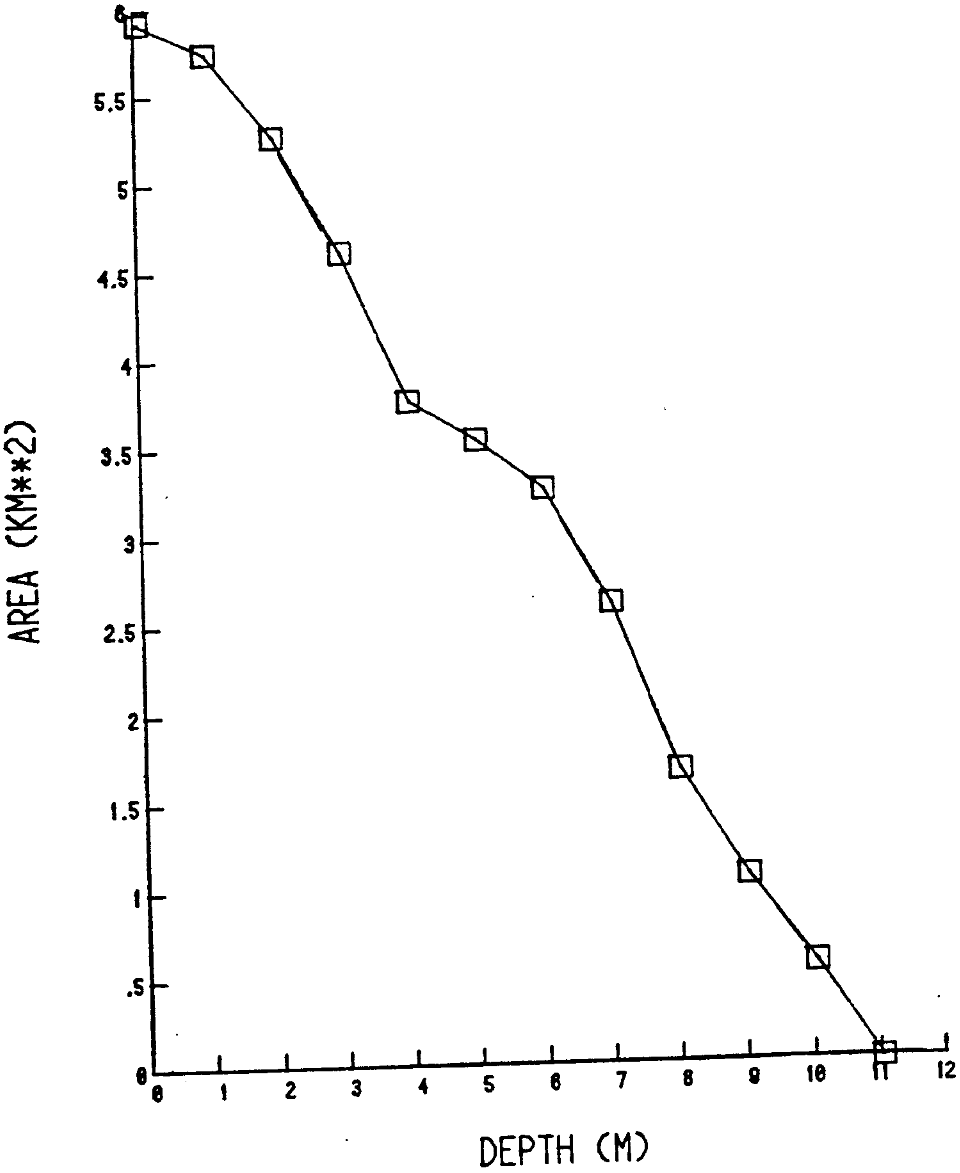


FIGURE 4
HYPSOGRAPHIC CURVE SIBBOFJÄRDEN

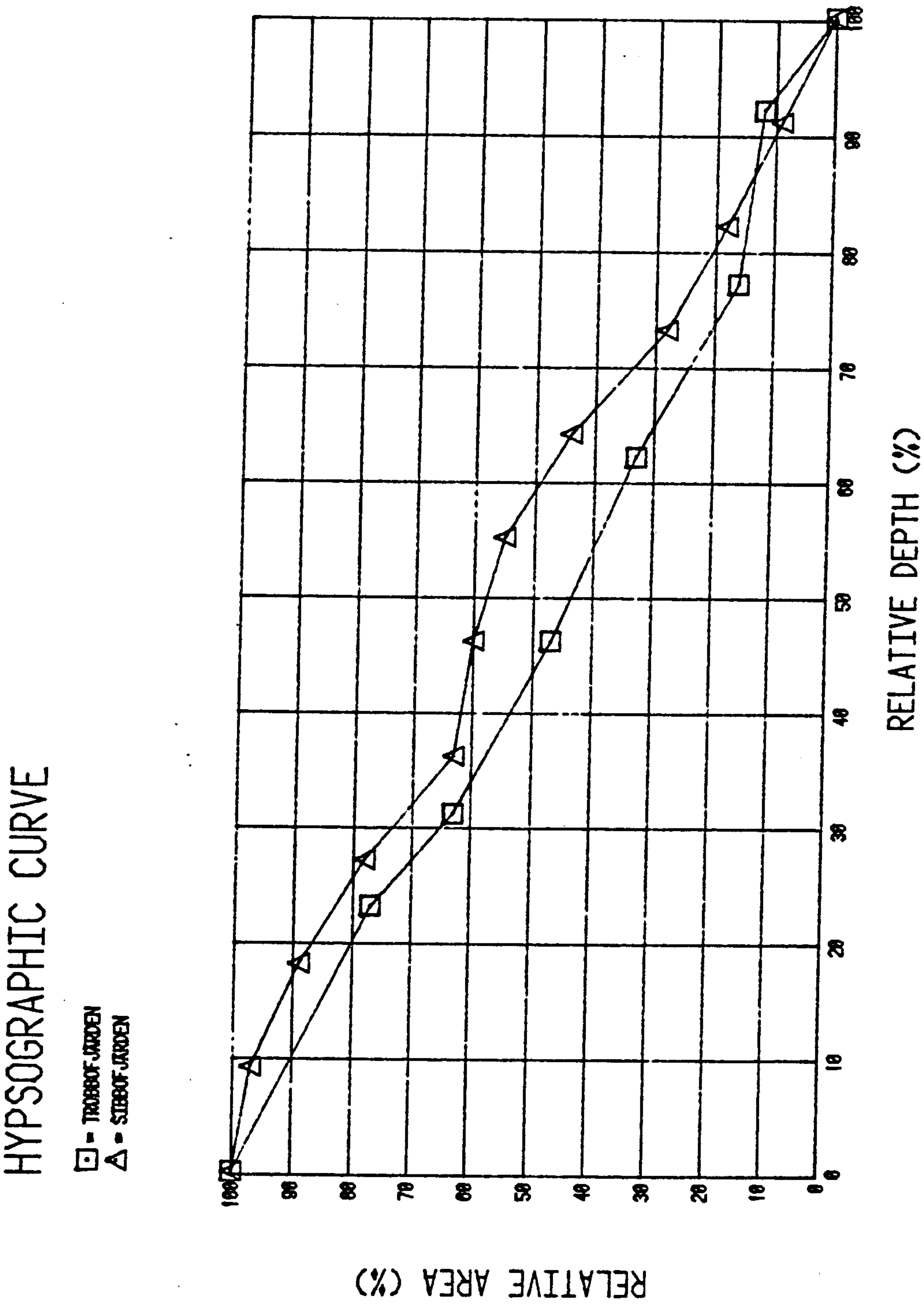


FIGURE 5
RELATIVE HYPSOGRAPHIC CURVES

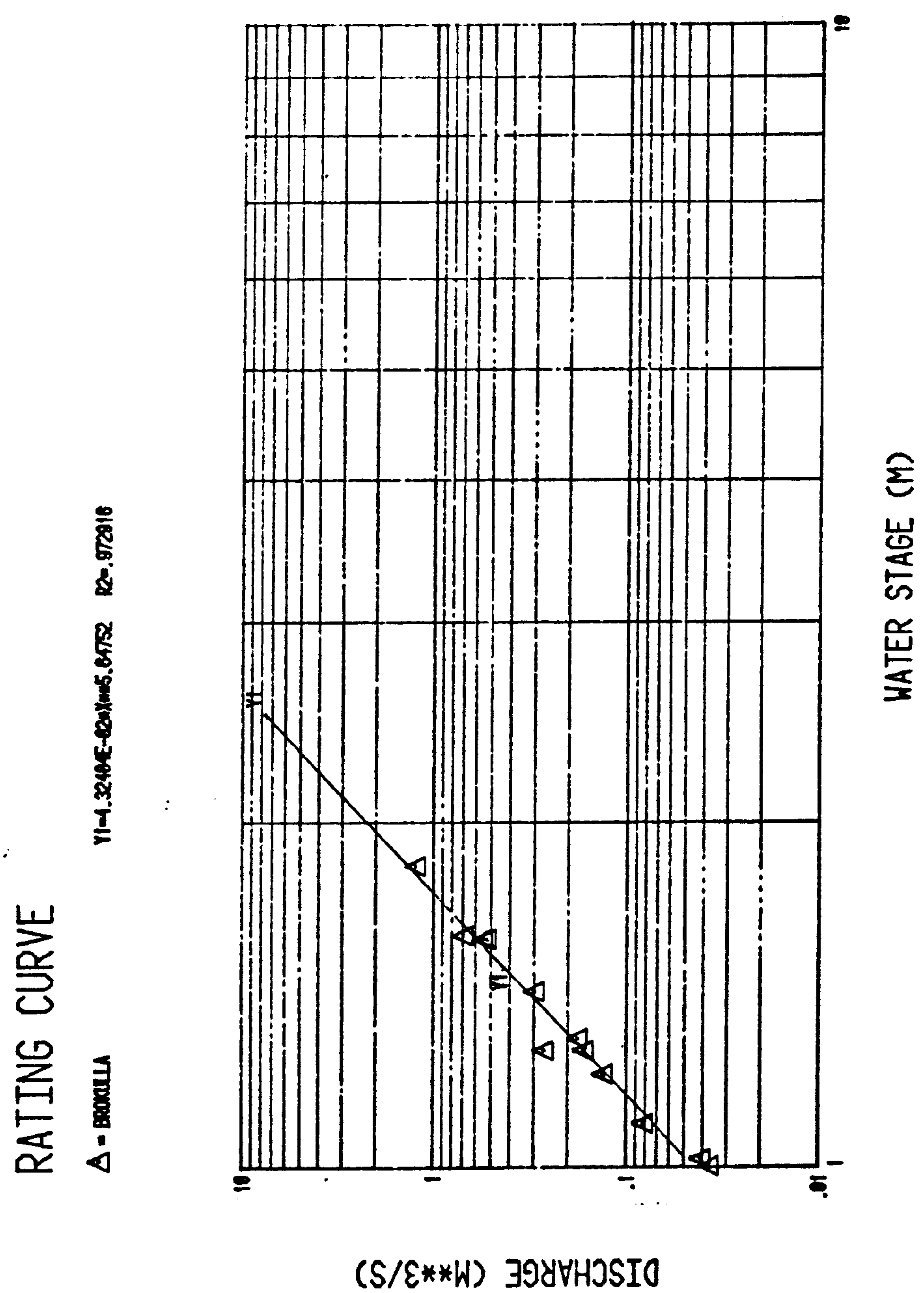


FIGURE 6
RATING CURVE BROKULLA

RUNOFF NYNÄS 1985

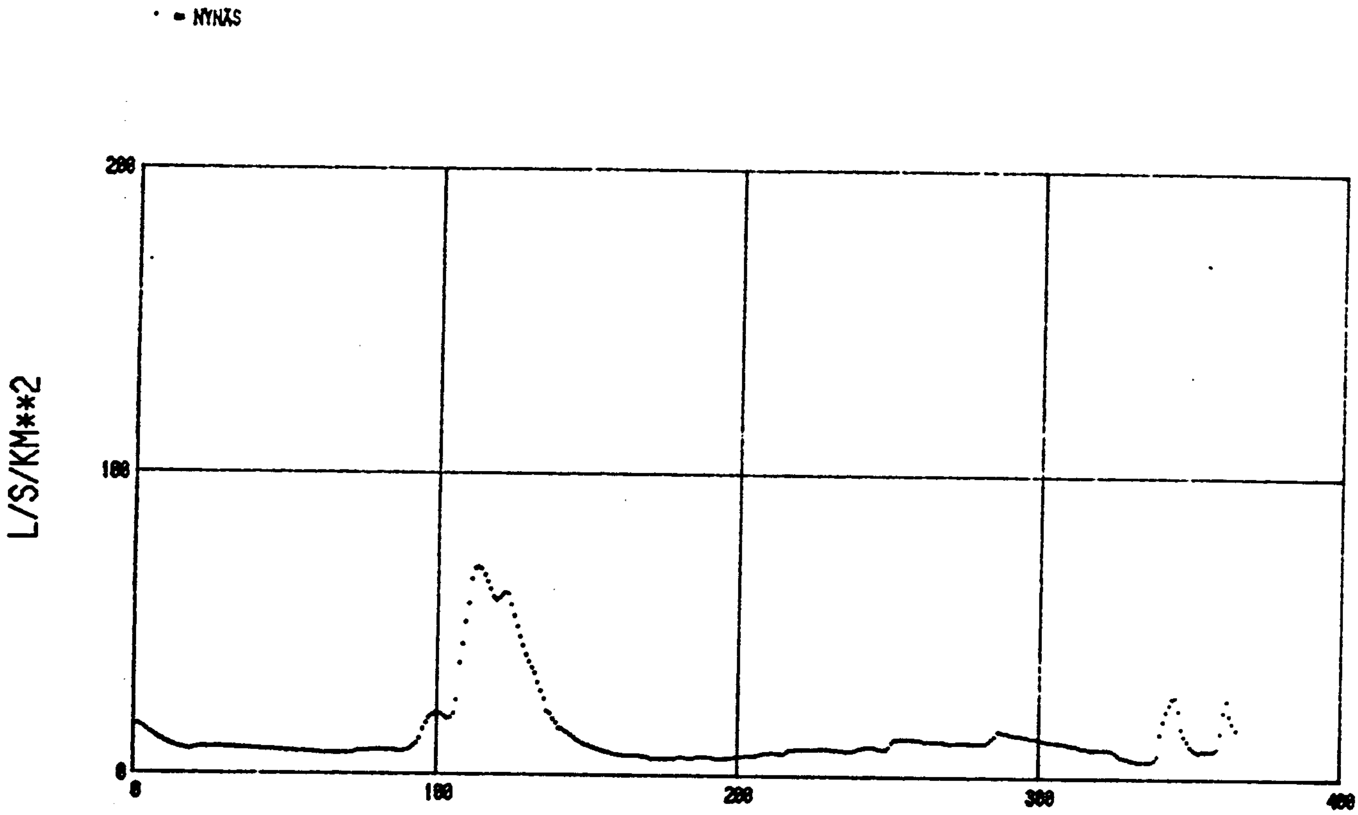


FIGURE 7

RUNOFF BROKULLA 1985

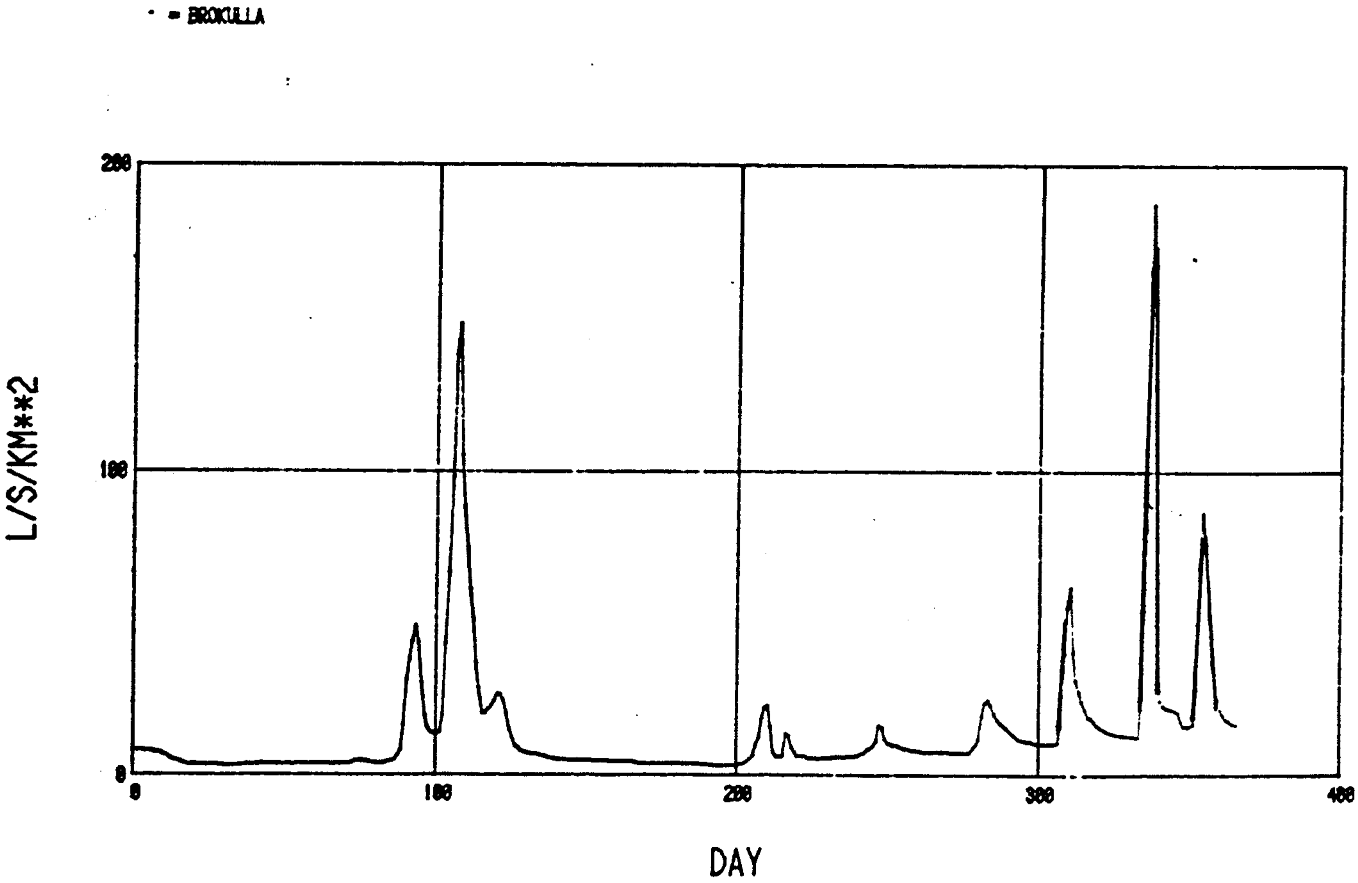


FIGURE 8

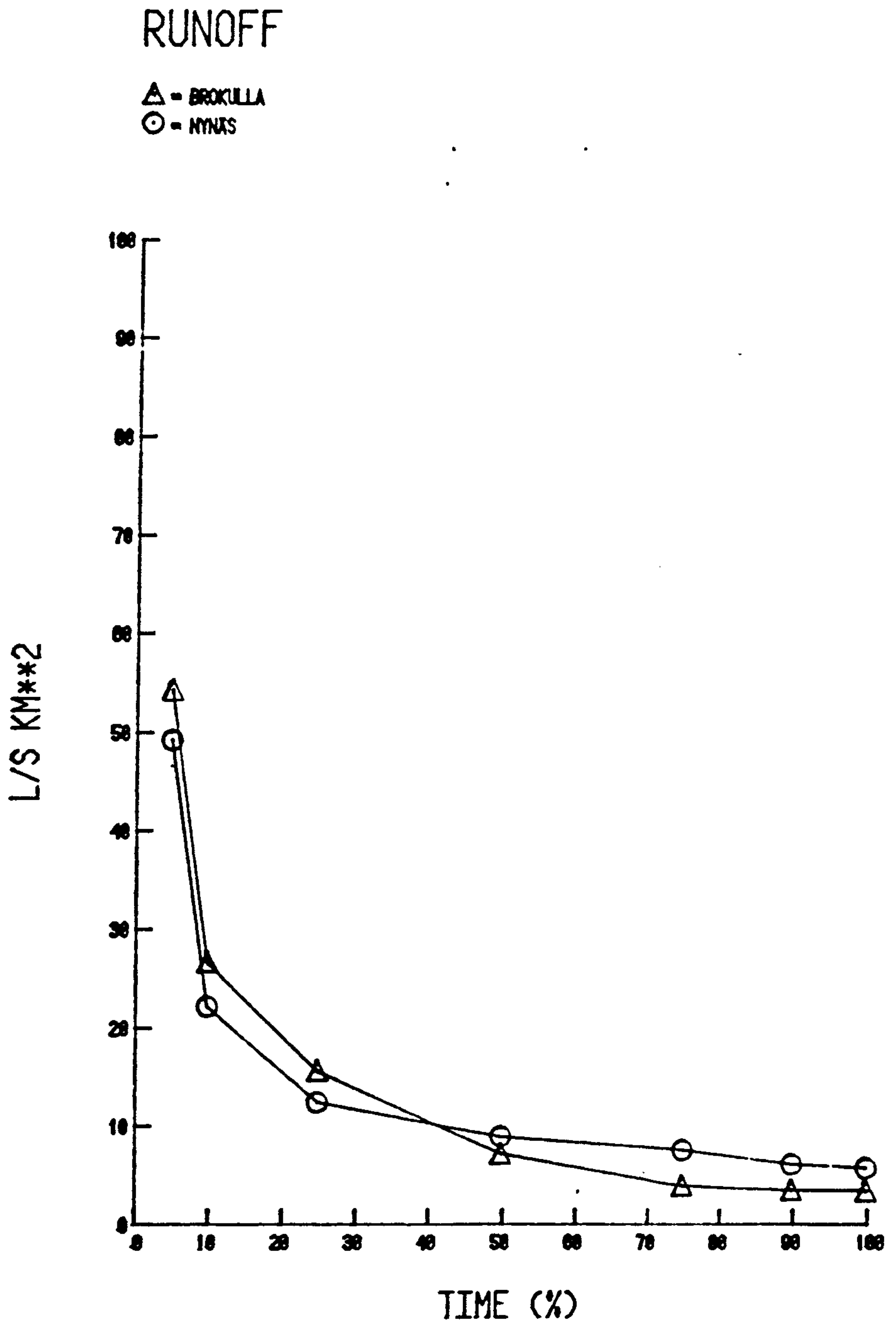


FIGURE 9
DURATION CURVES

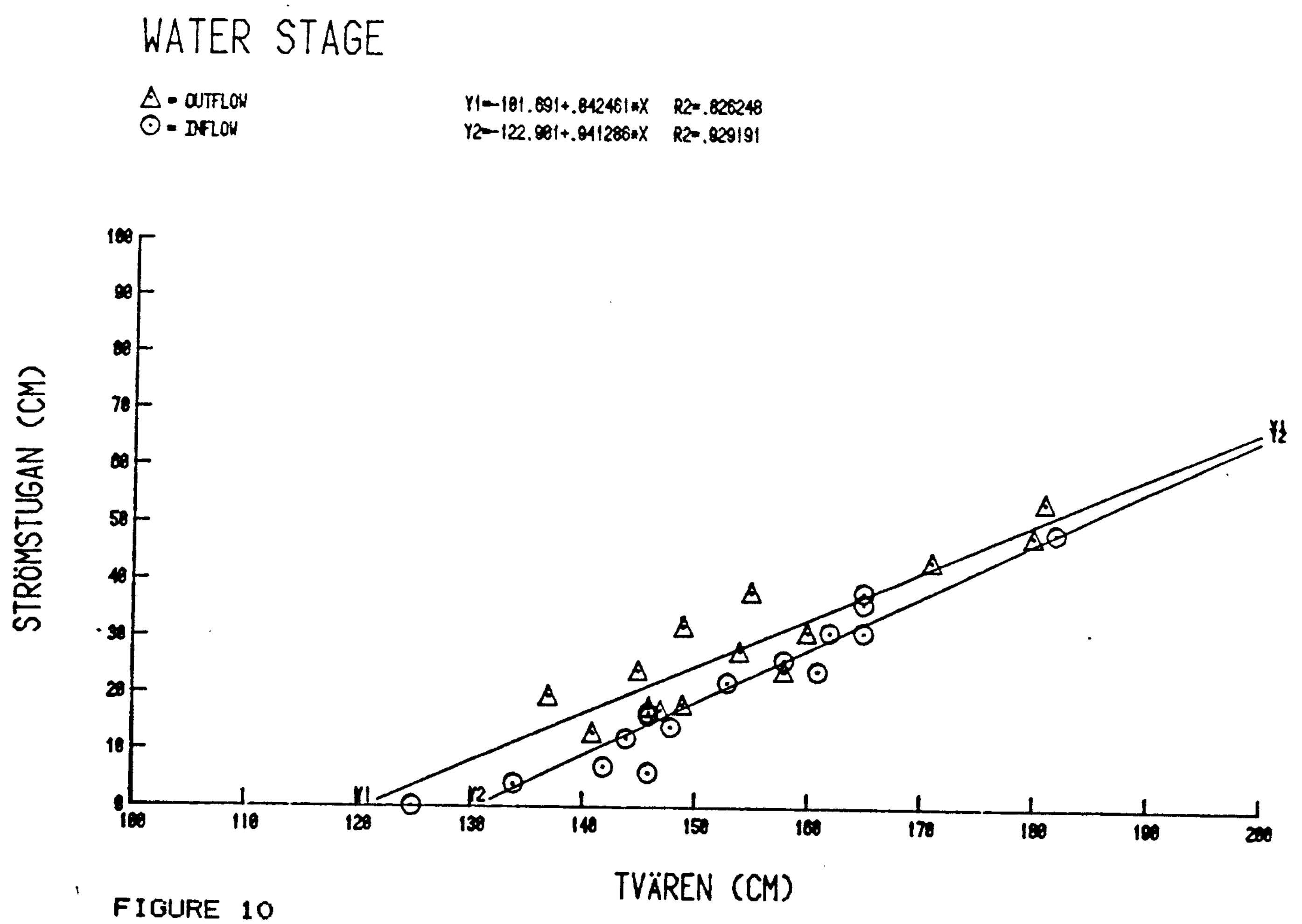


FIGURE 10
RELATION BETWEEN WATER STAGE IN THE BALTIC AND AT STRÖMSTUGAN

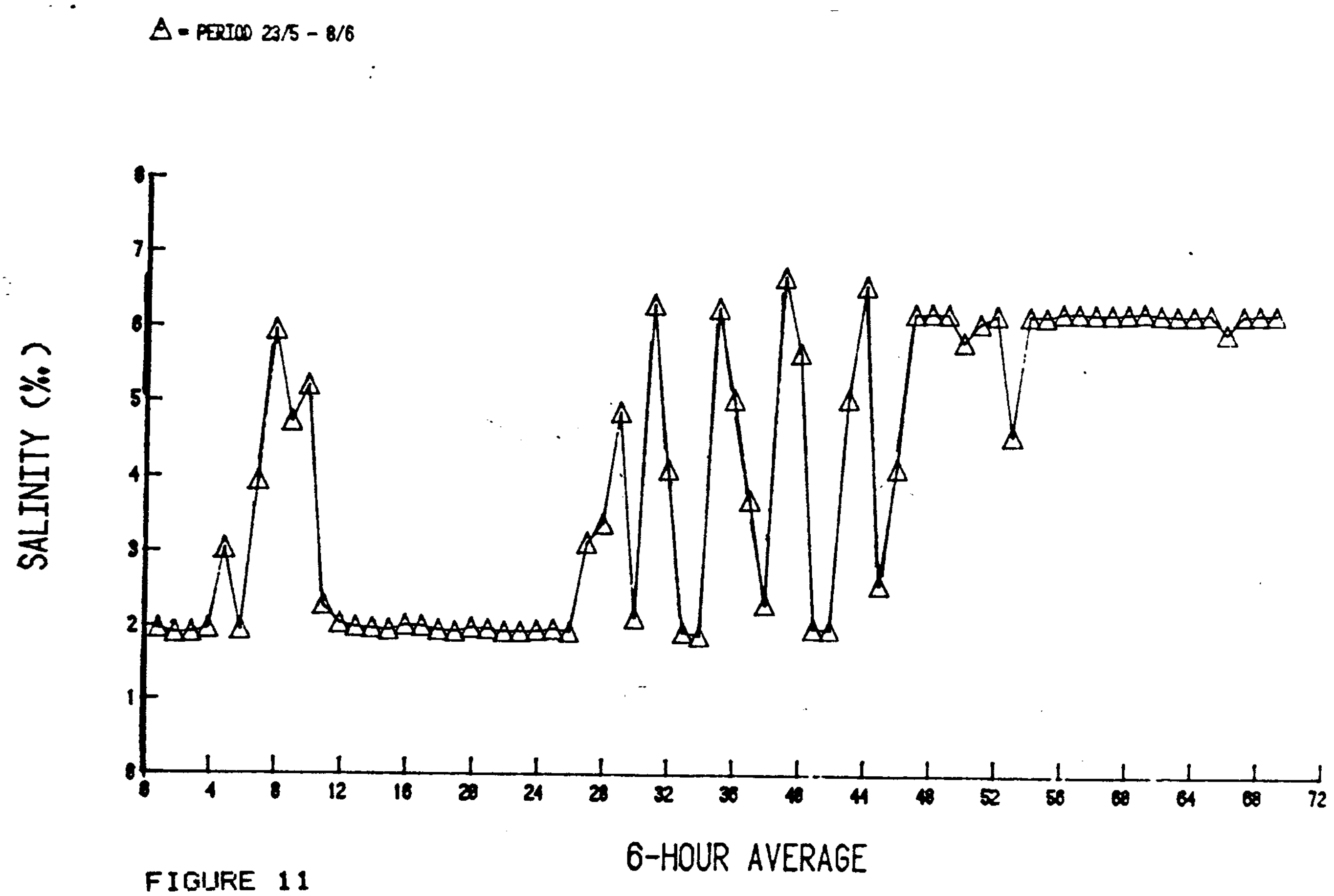


FIGURE 11
SALINITY AT THE OUTLET OF SIBBOFJÄRDEN

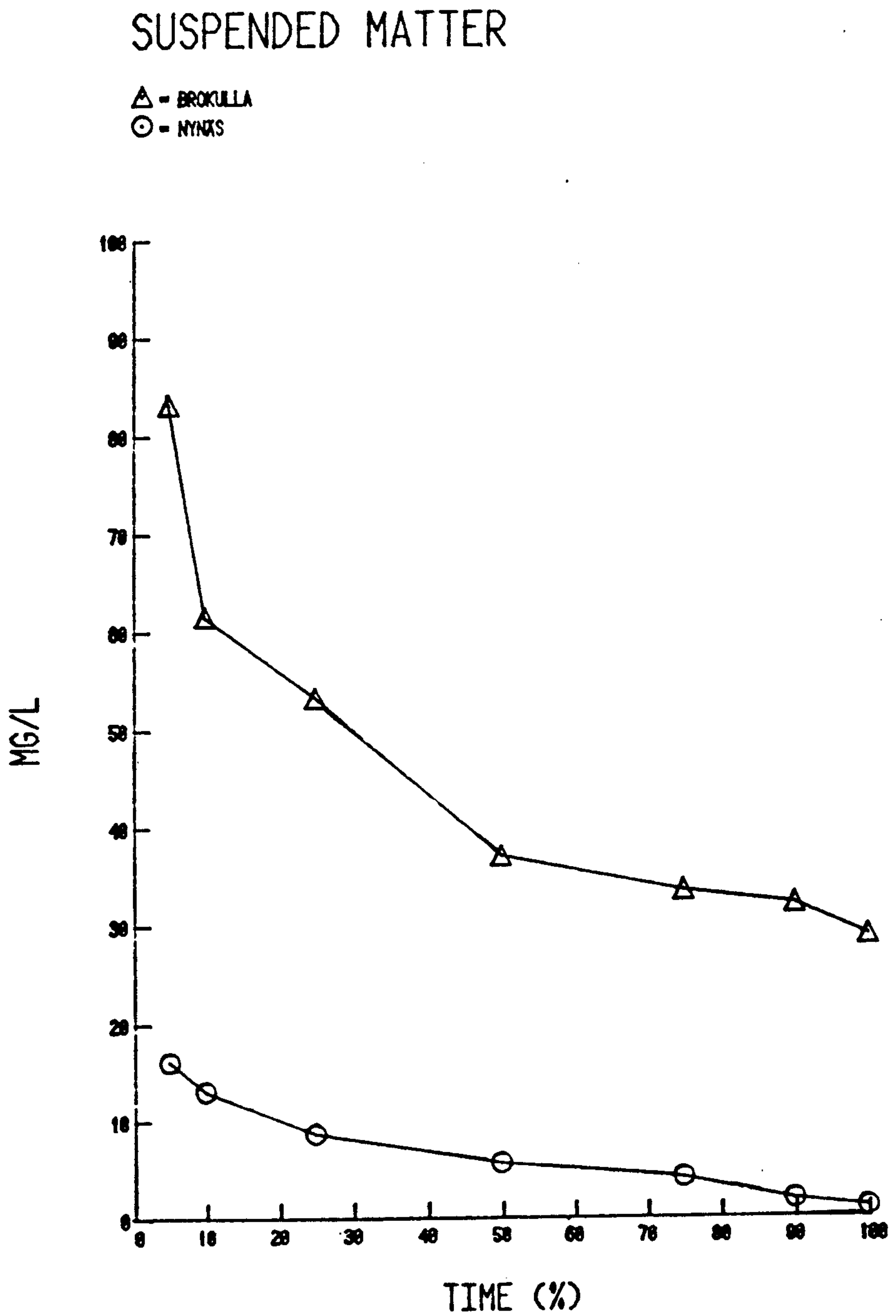

SUSPENDED MATTER
△ = BROKULLA
⊙ = NYNÄS
MG/L
100
90
80
70
60
50
40
30
20
10
0
0
10
20
30
40
50
60
70
80
90
100
TIME (%)

FIGURE 12

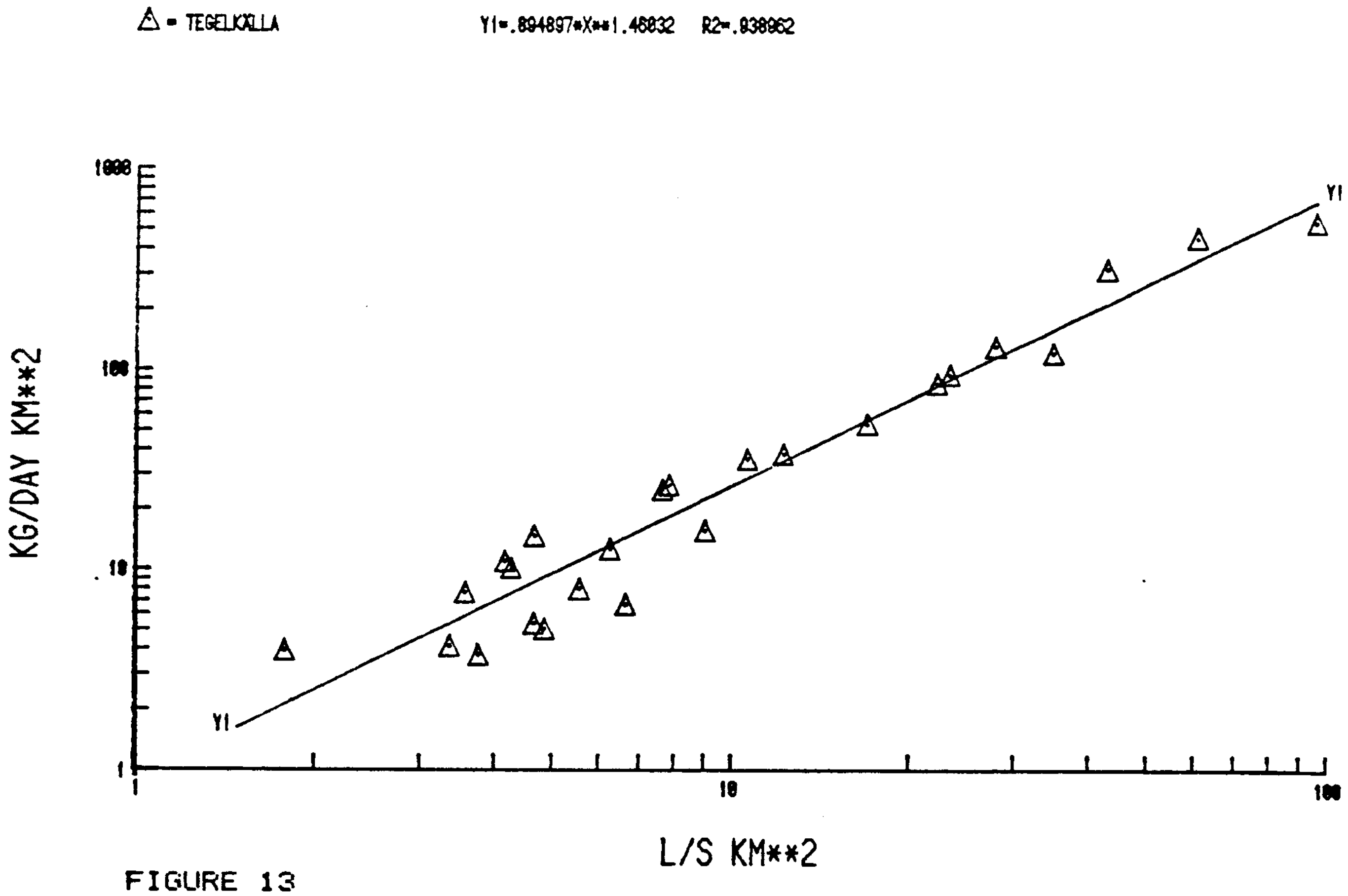


FIGURE 13
TRANSPORT OF SUSPENDED MATTER AS A FUNCTION OF RUNOFF AT TEGELKÄLLAN

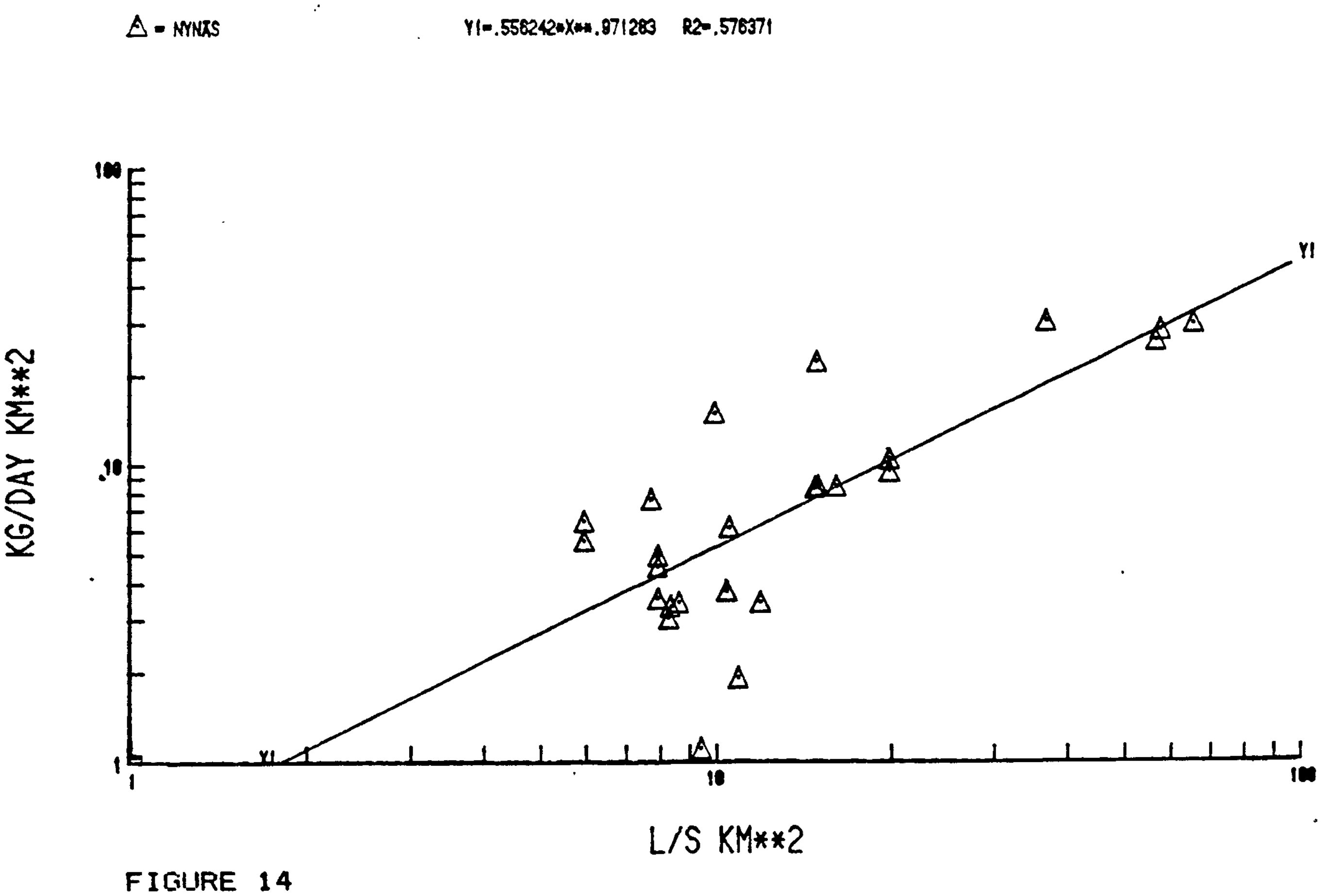


FIGURE 14
TRANSPORT OF SUSPENDED MATTER AS A FUNCTION OF RUNOFF AT NYNÄS

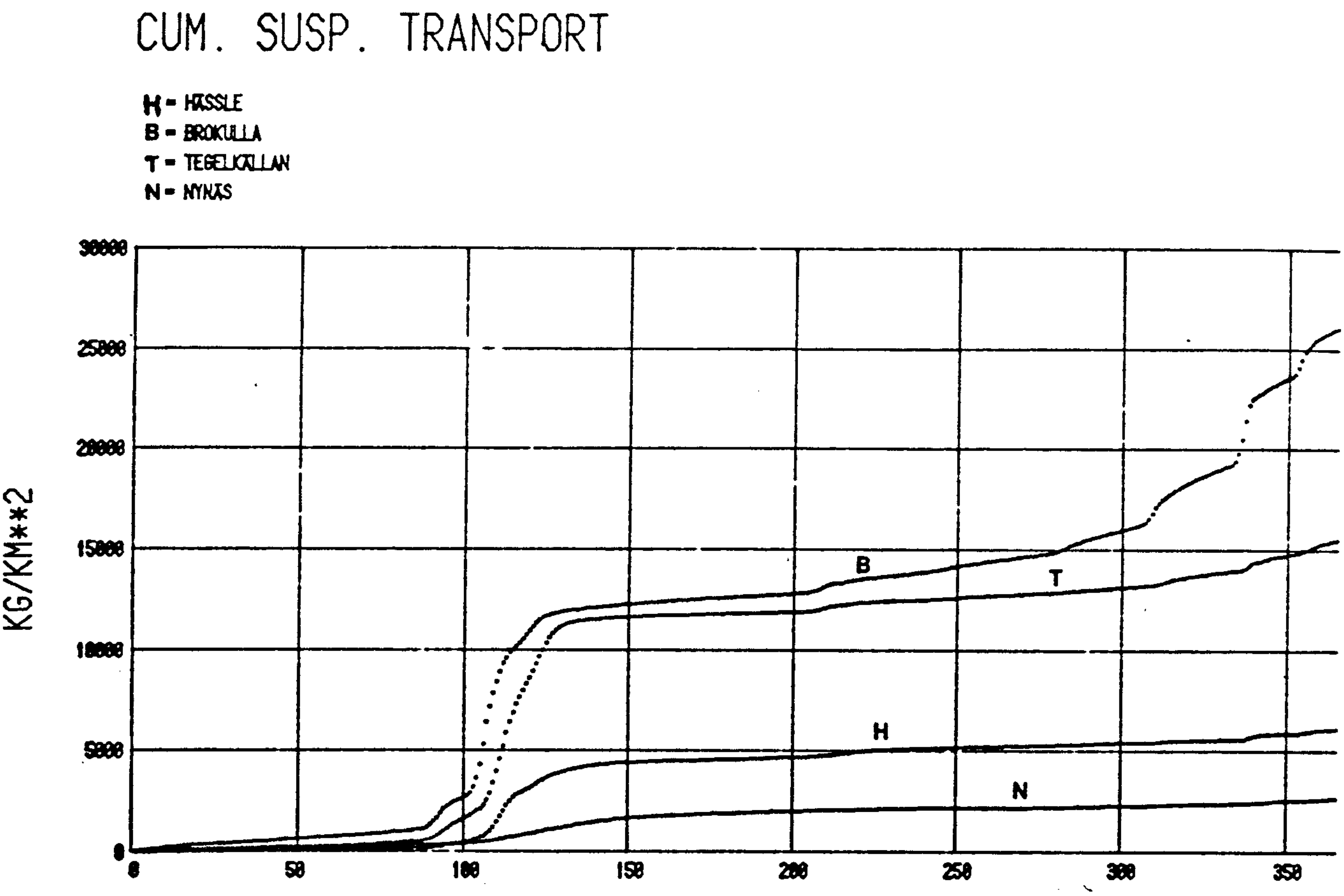


FIGURE 15
CUMULATIVE SUSPENDED MATTER IN 1985

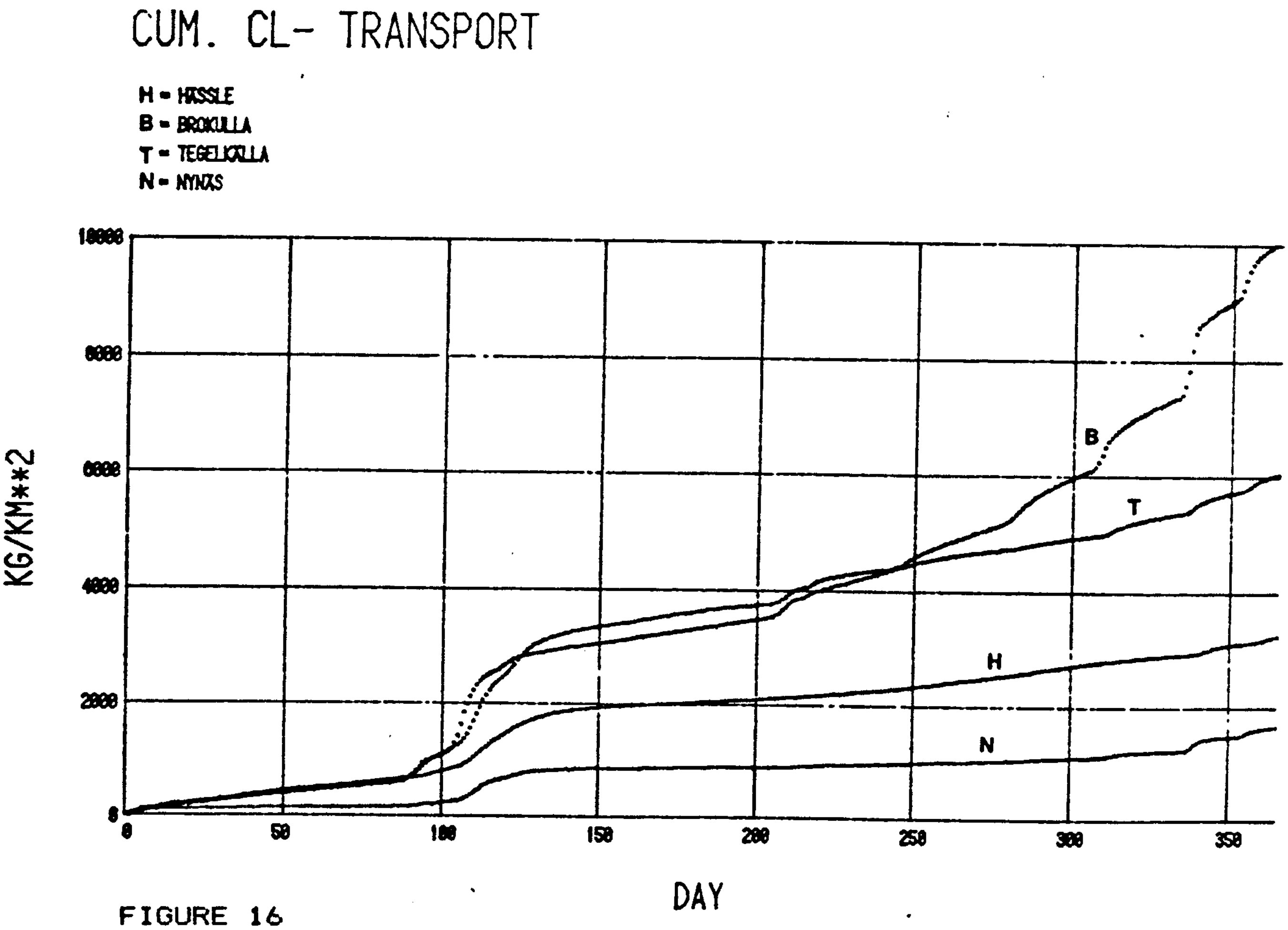


FIGURE 16
CUMULATIVE CLORIDE TRANSPORT IN 1985

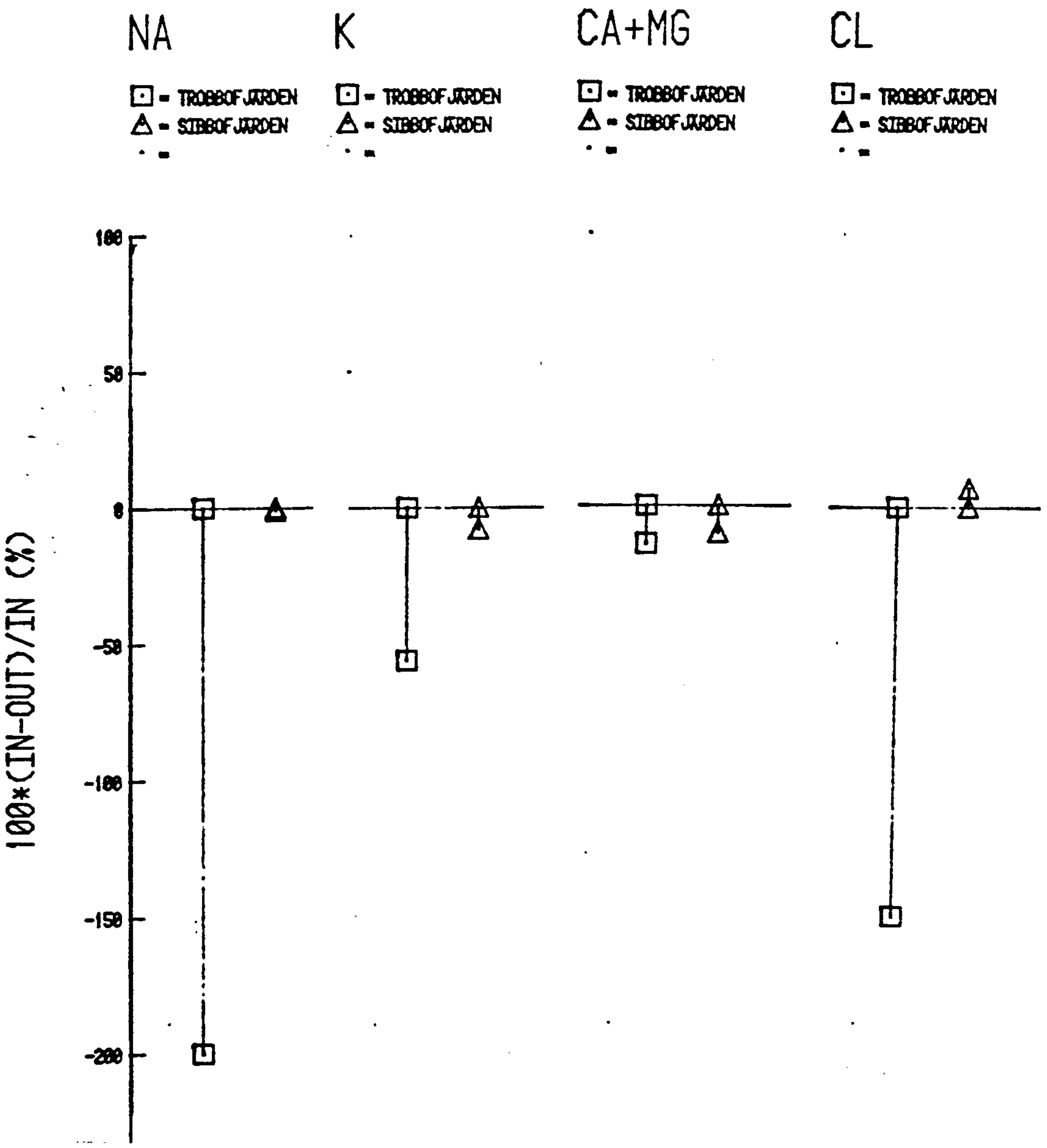


FIGURE 17
MATERIAL BALANCE FOR SIBBO-AND TROBBOFJÄRDEN IN 1985

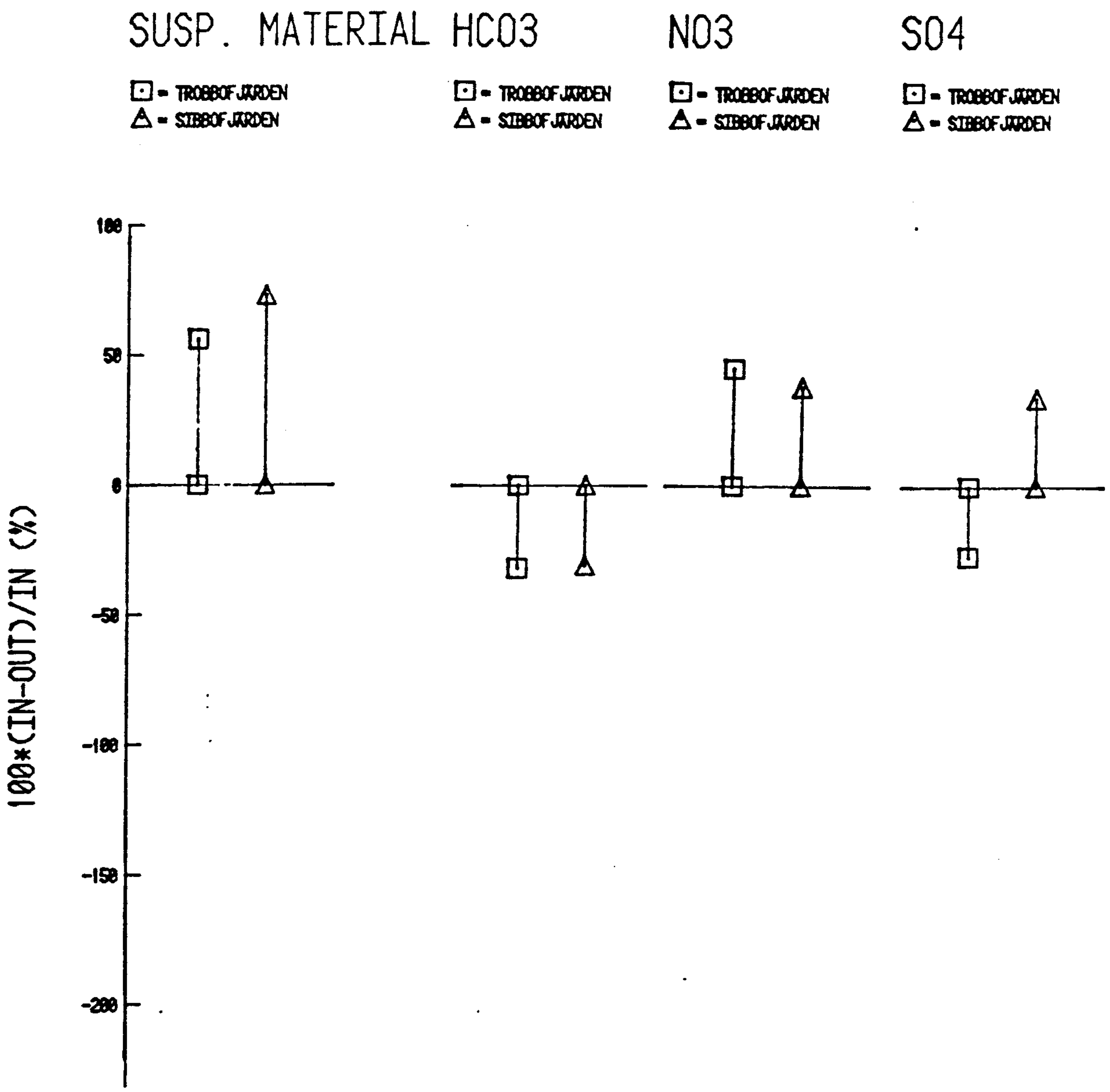


FIGURE 18
MATERIAL BALANCE FOR SIBBO- AND TROBBOFJÄRDEN 1985

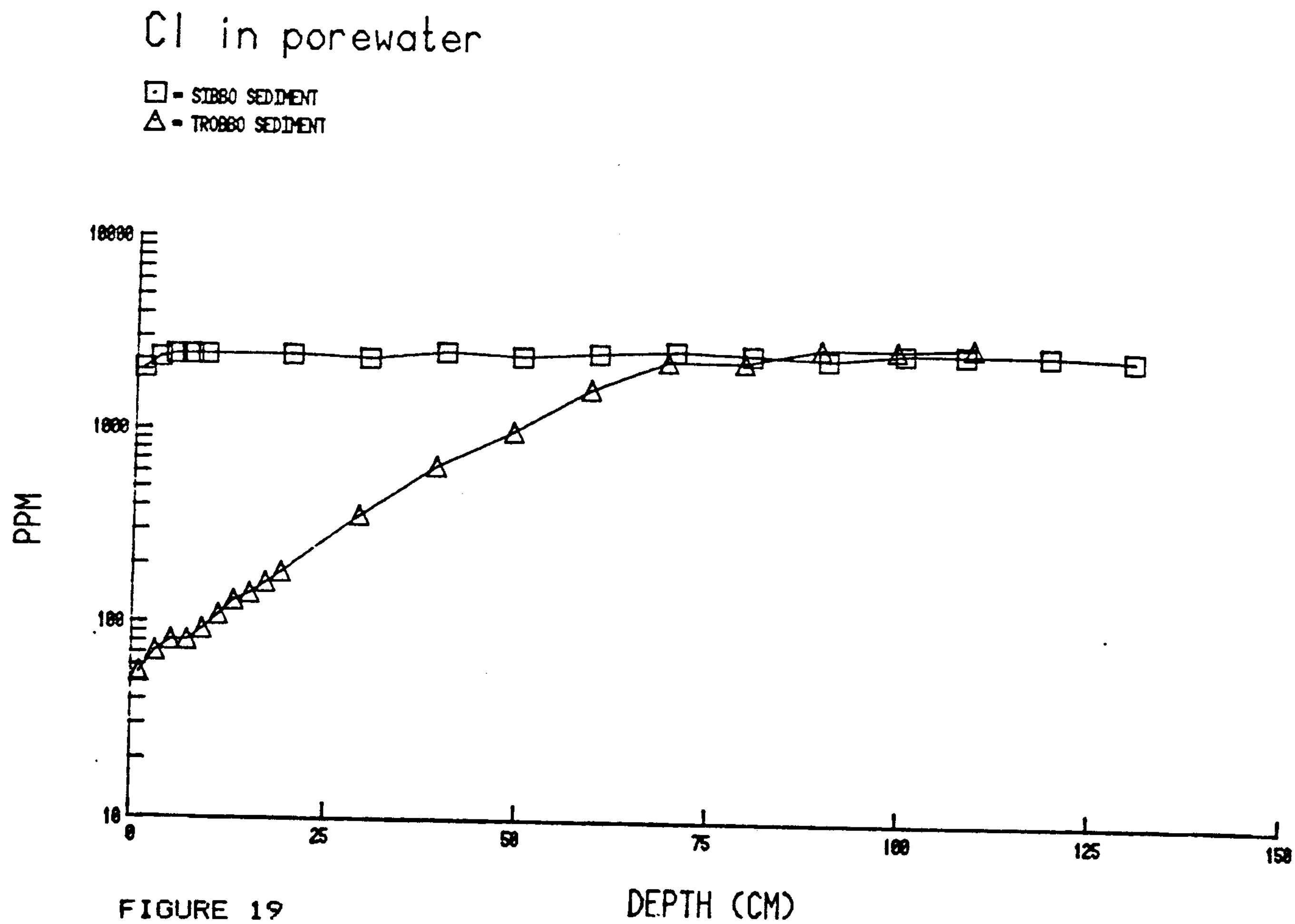


FIGURE 19
CLORIDE CONTENT IN SEDIMENT

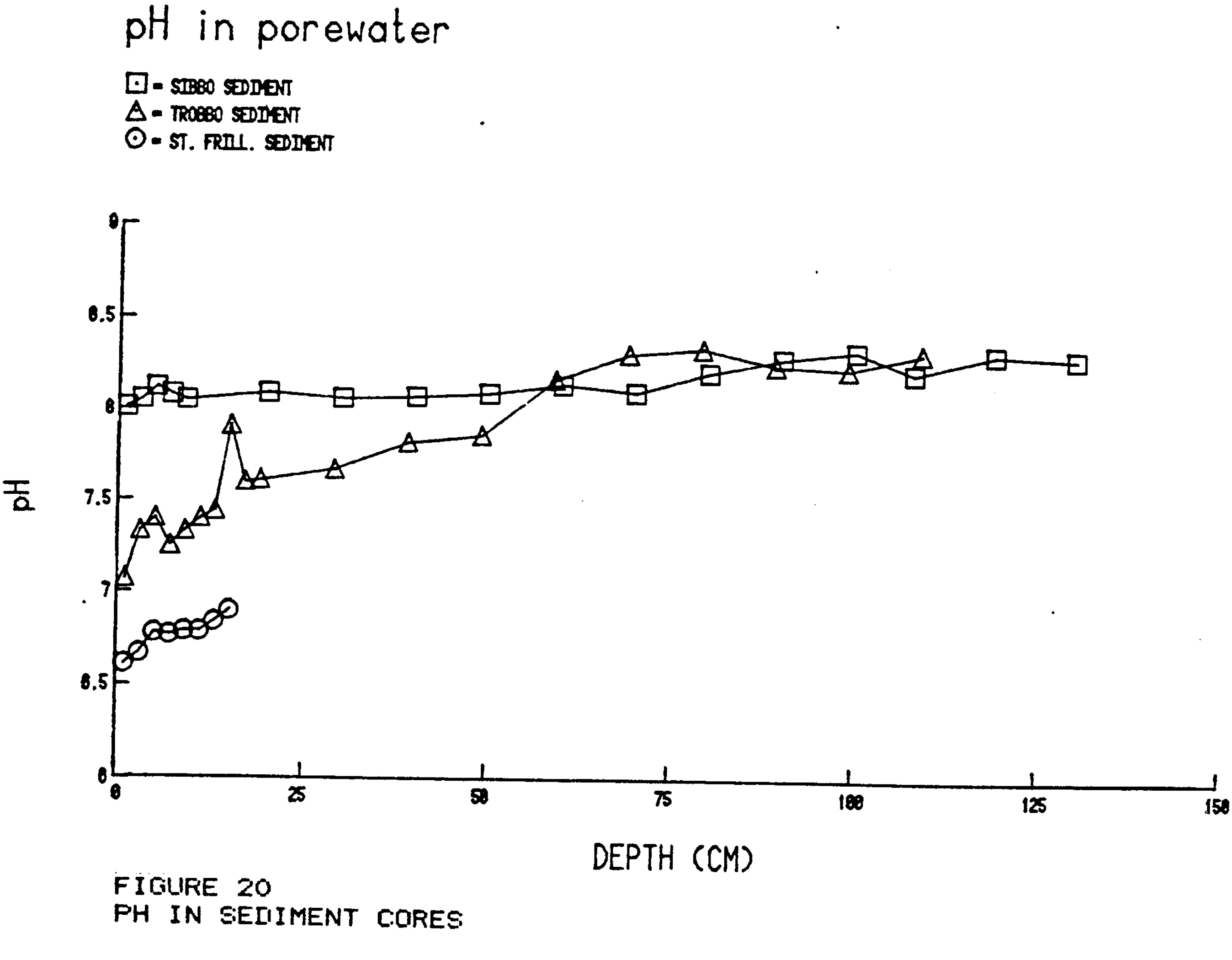


FIGURE 20
PH IN SEDIMENT CORES

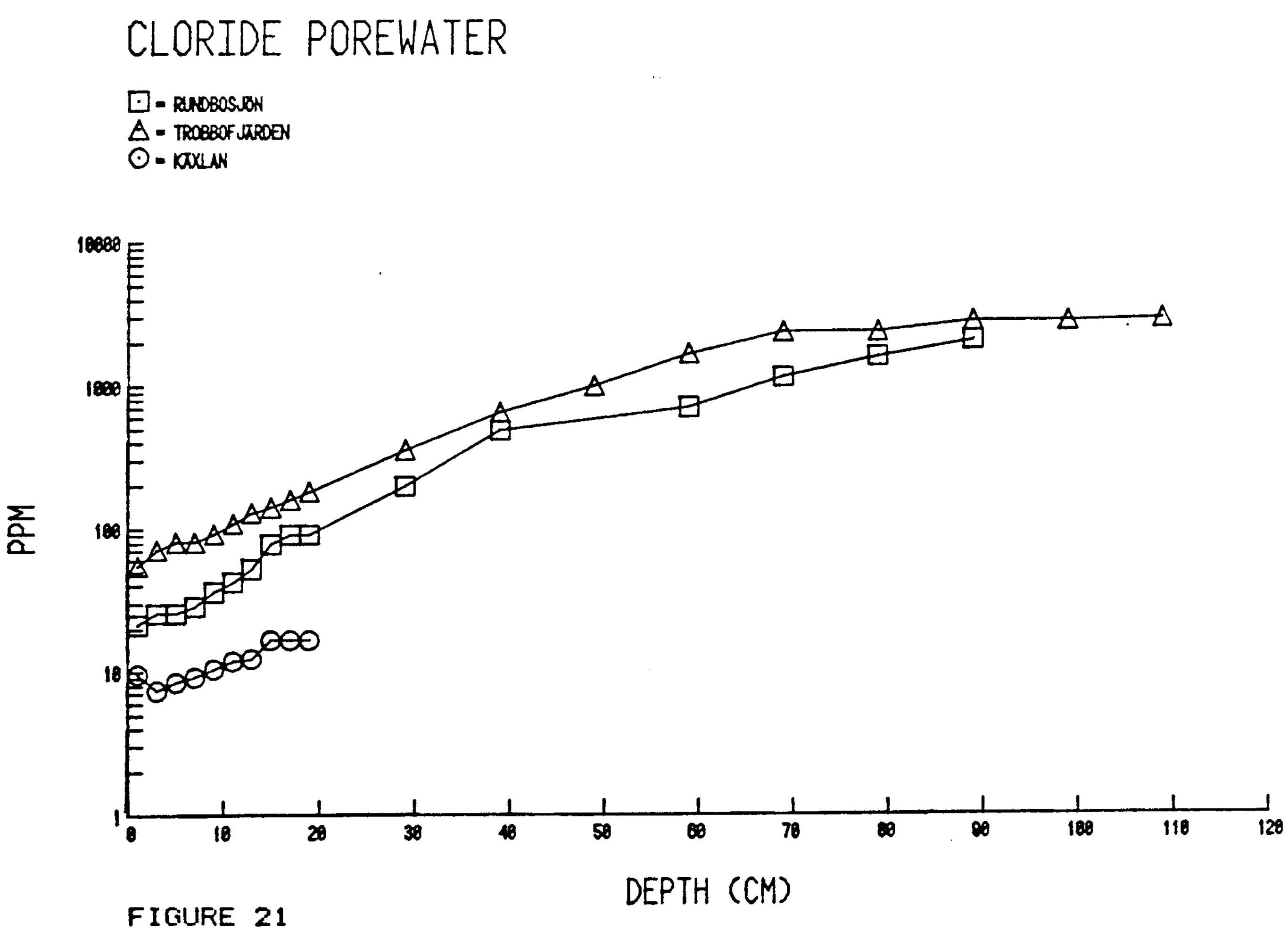


FIGURE 21
CLORIDE CONTENT IN SEDIMENT POREWATER

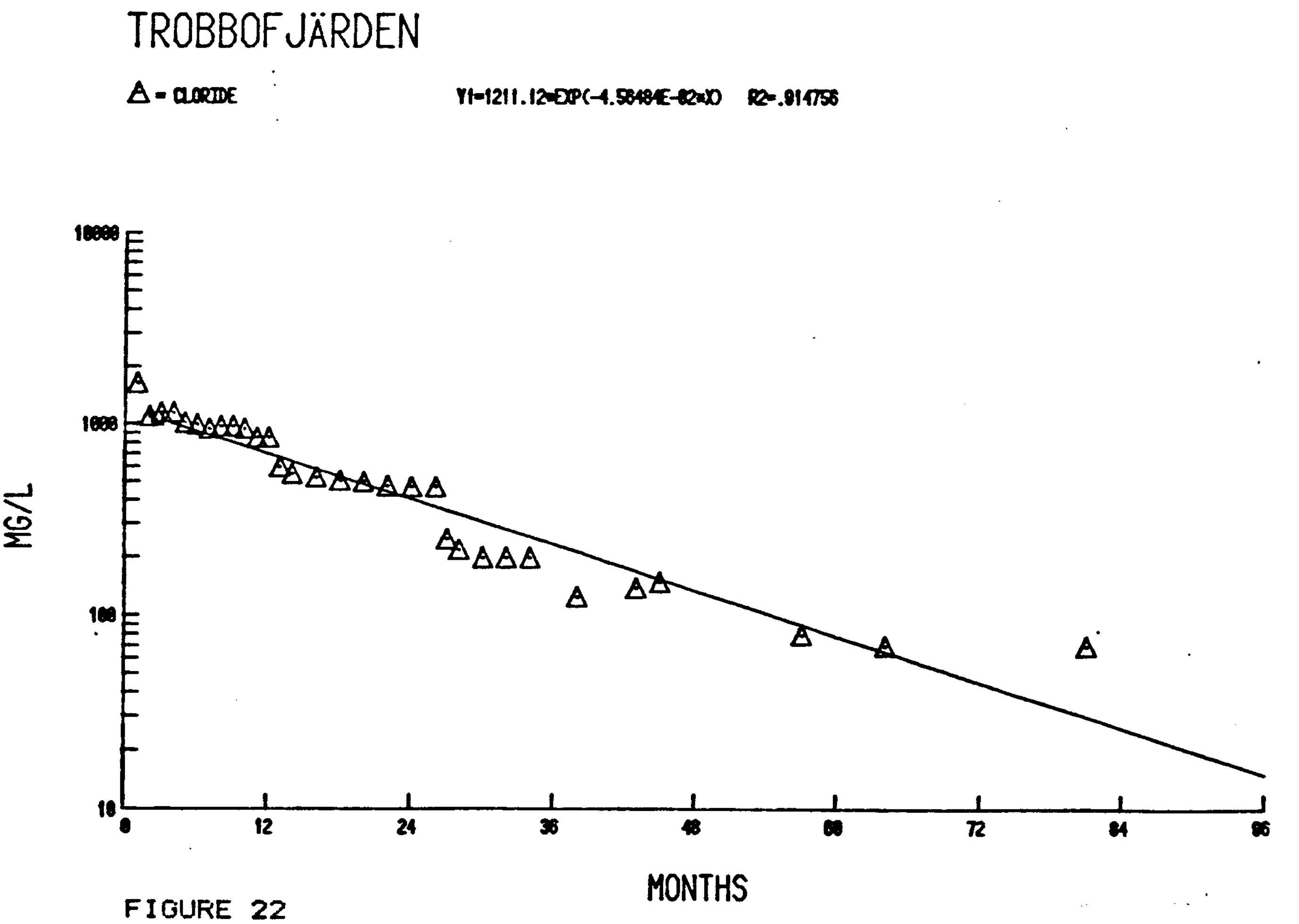
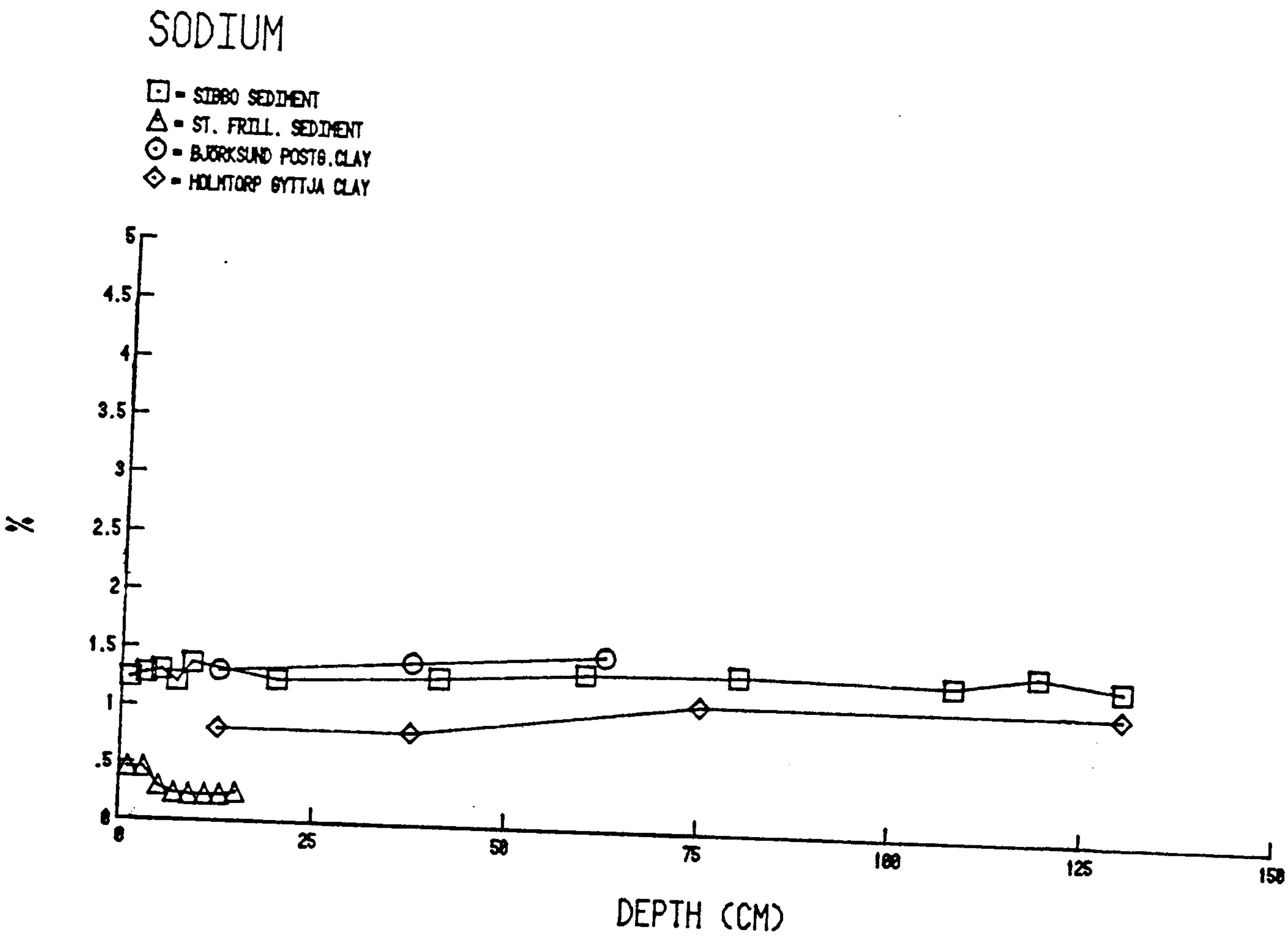


FIGURE 22
CLORIDE CONTENT OF TROBBFJÄRDEN 1956 -63



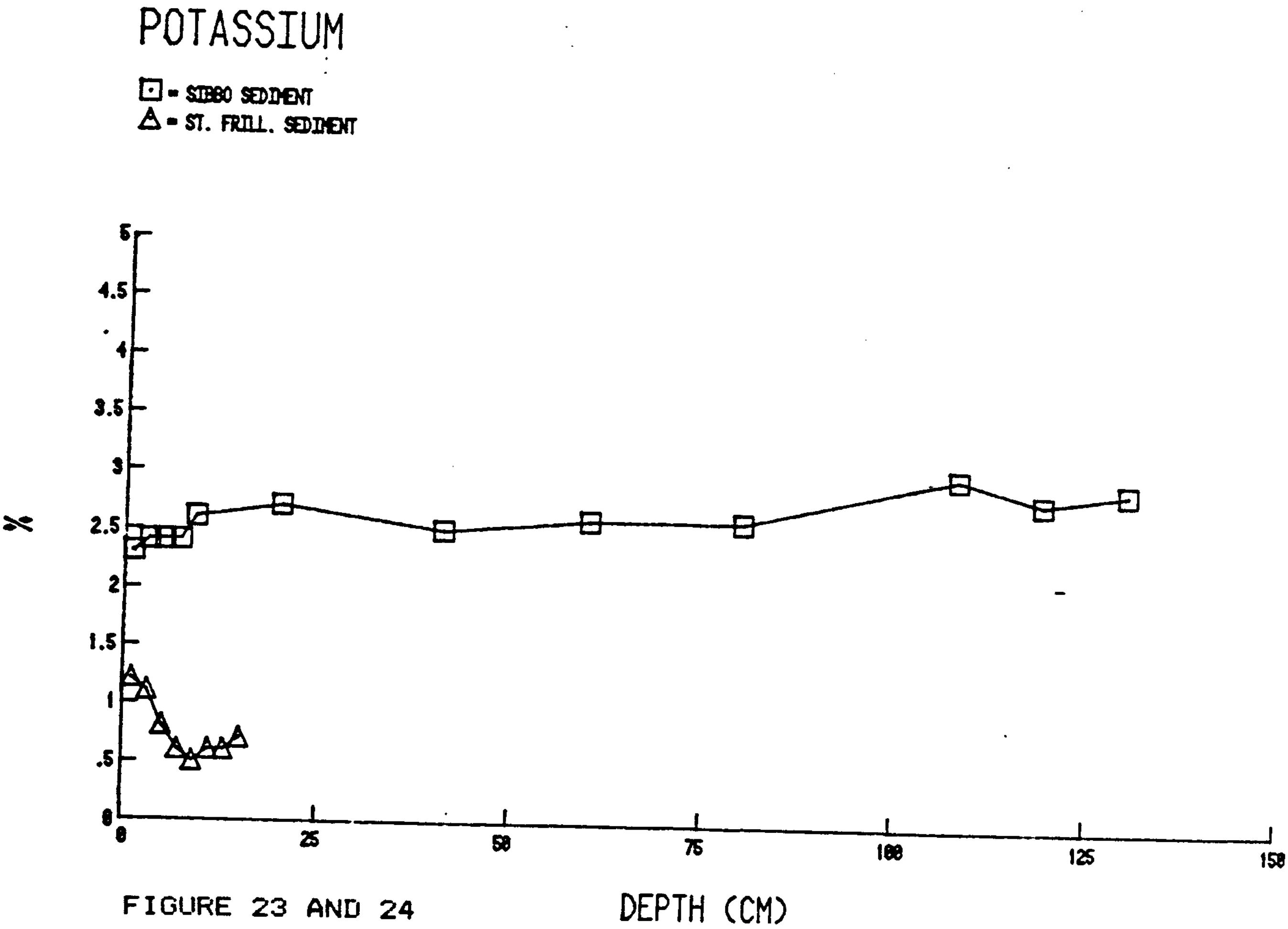
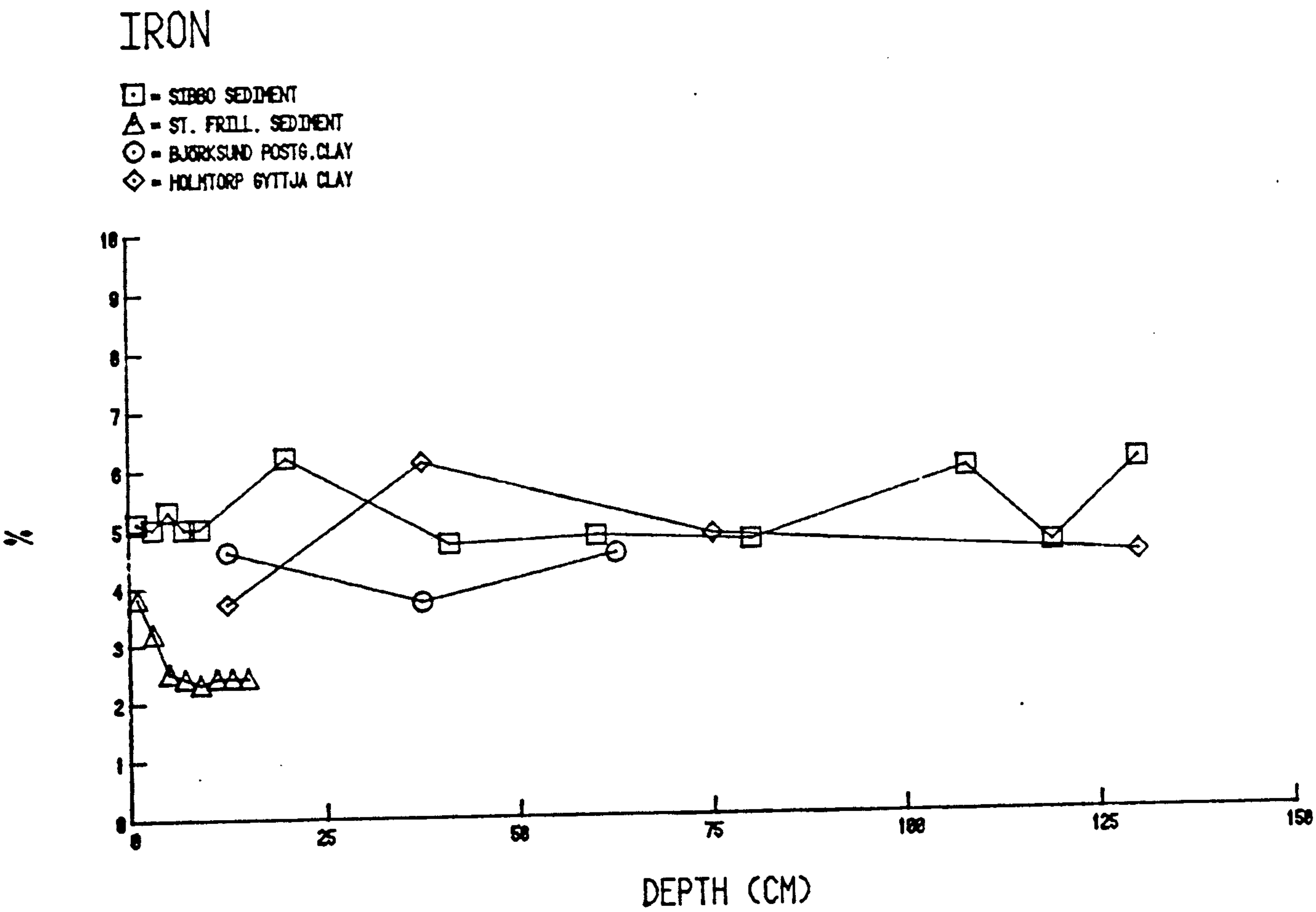


FIGURE 23 AND 24



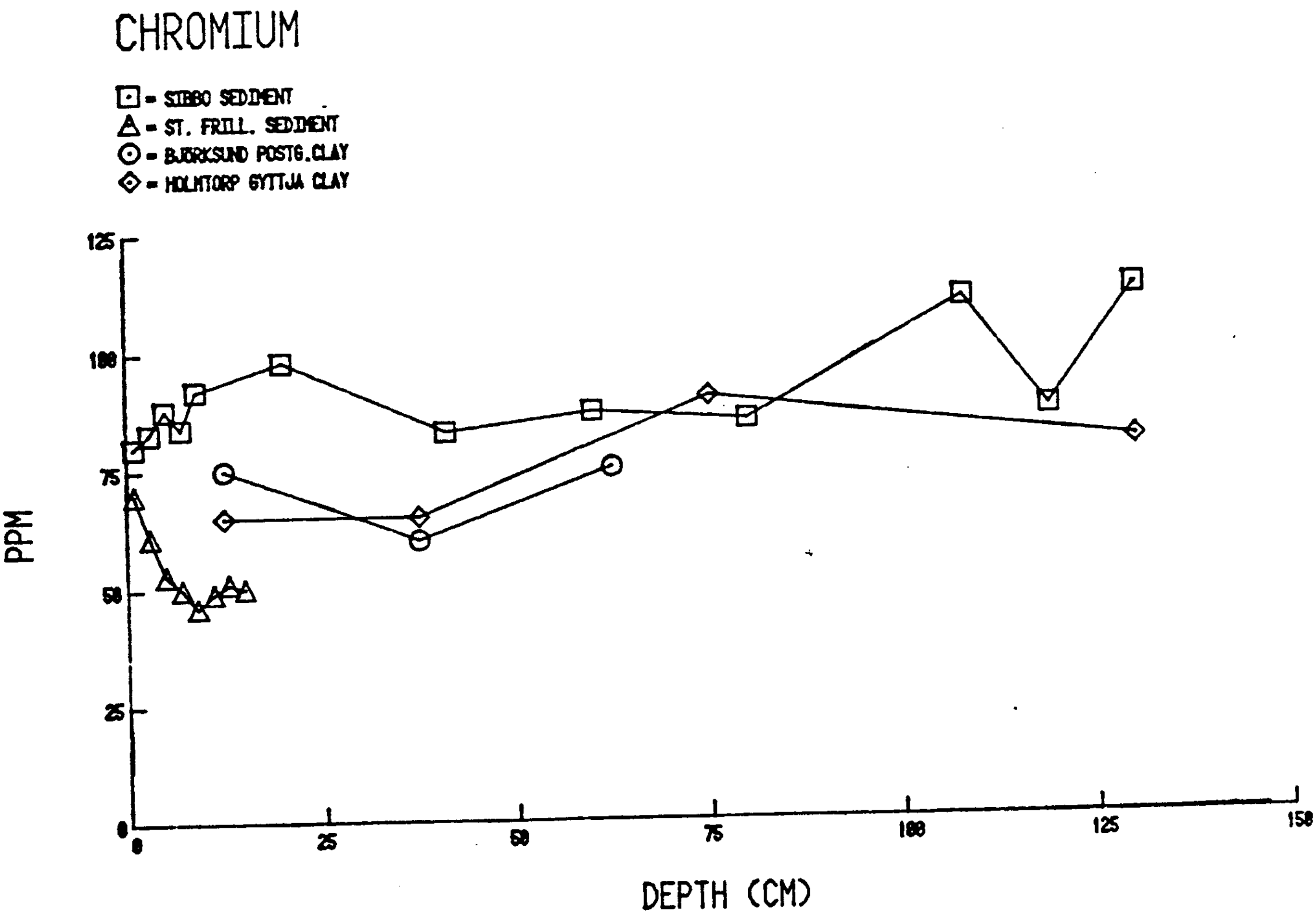
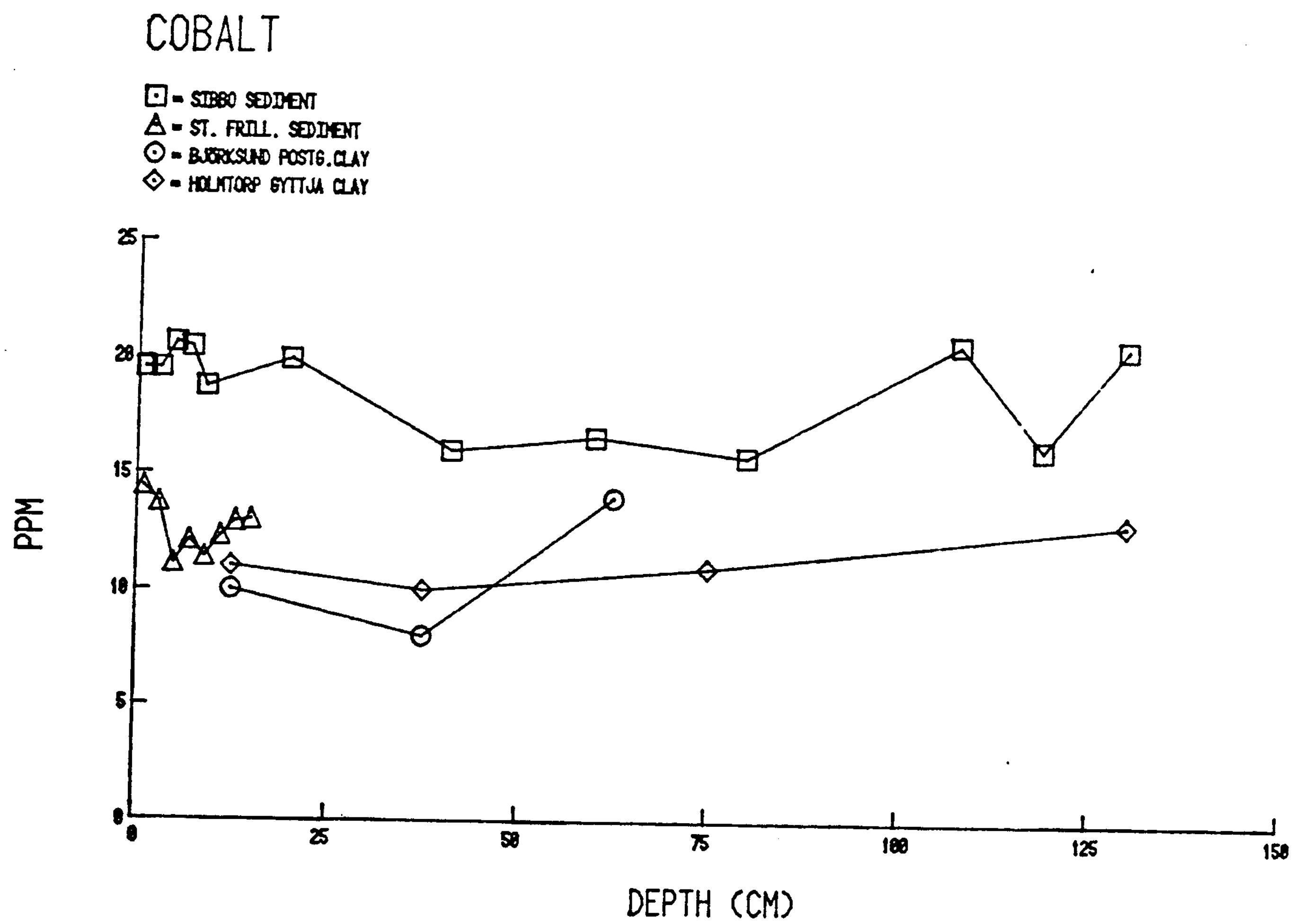


FIGURE .25 AND 26



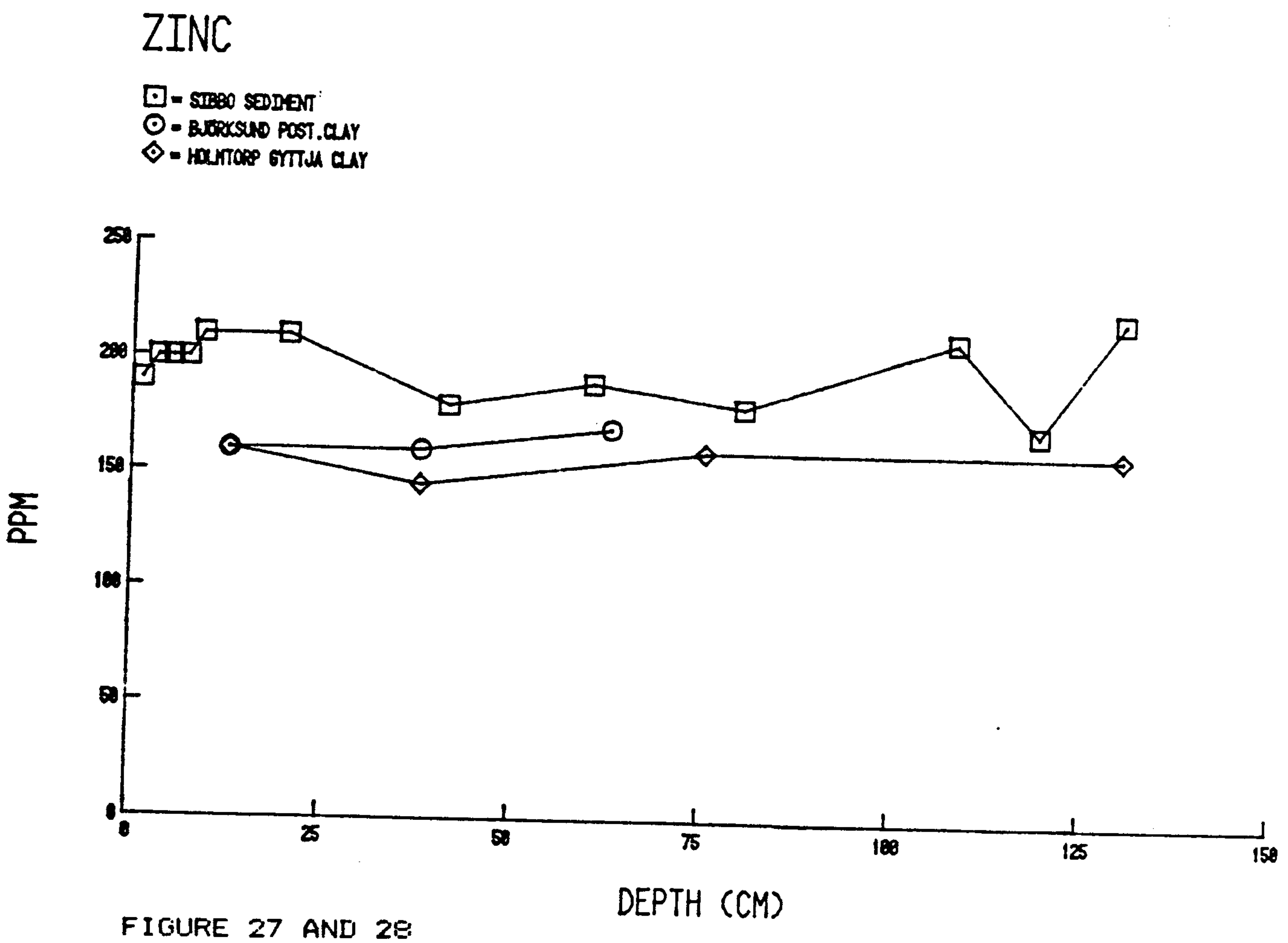
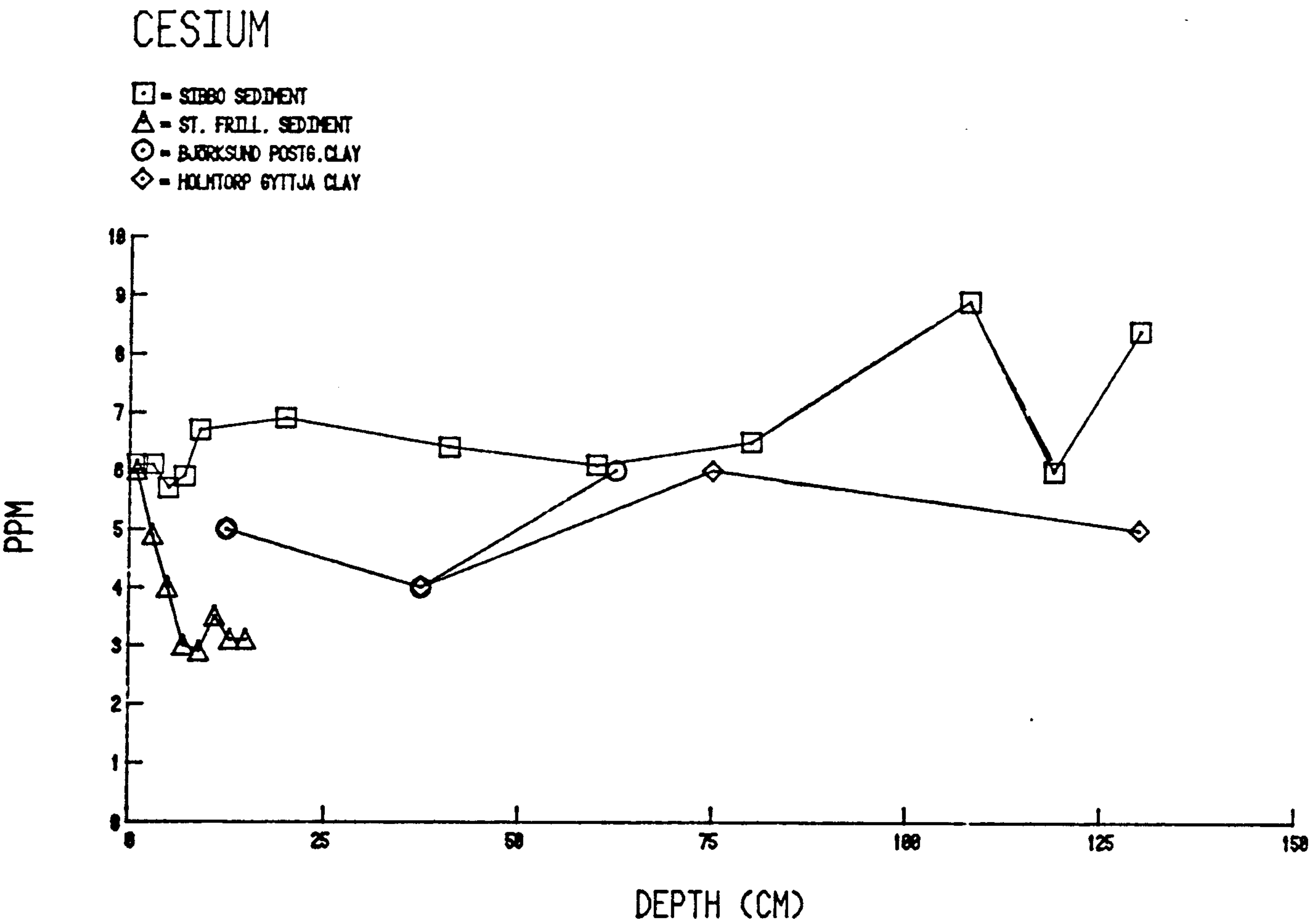


FIGURE 27 AND 28



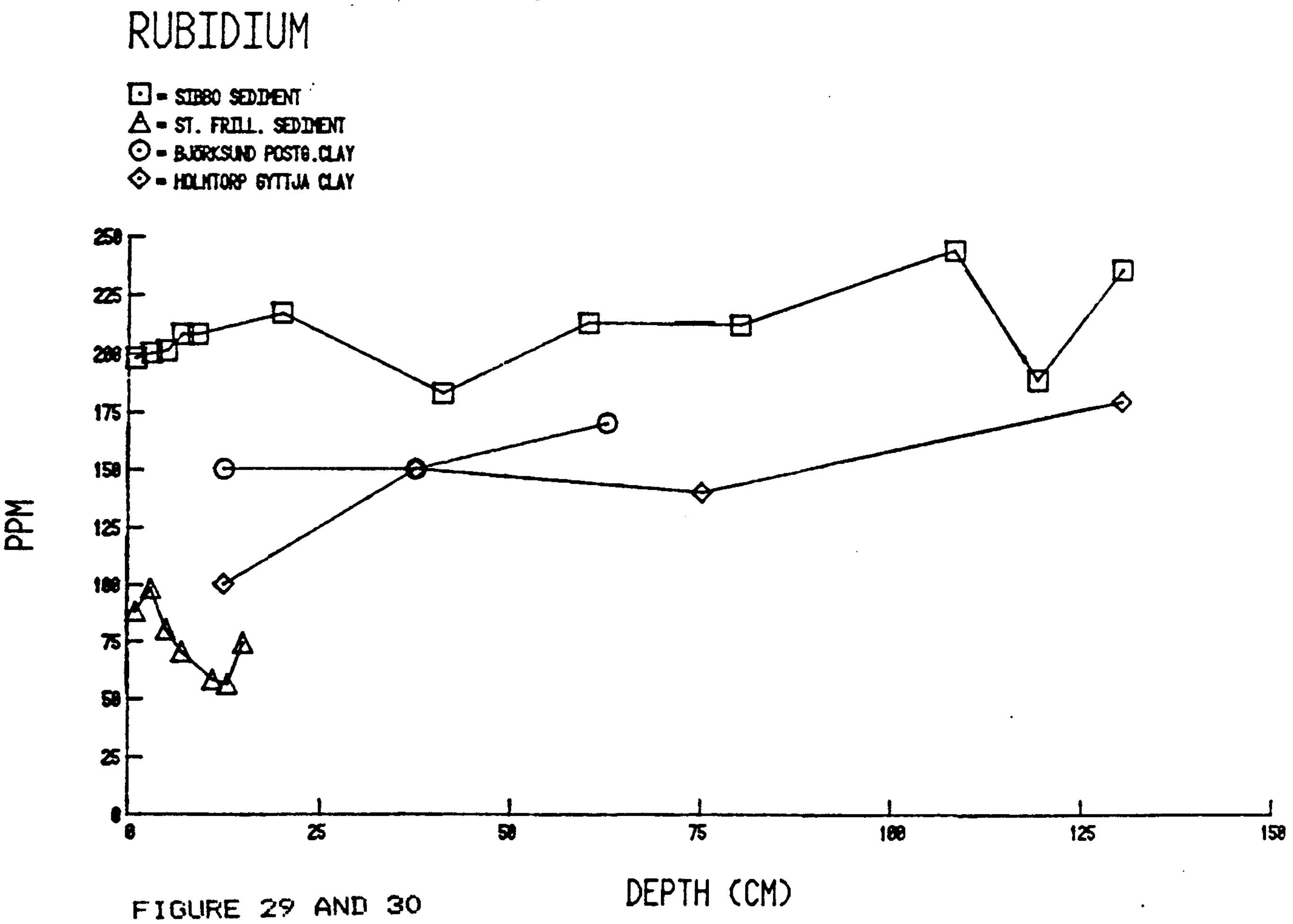
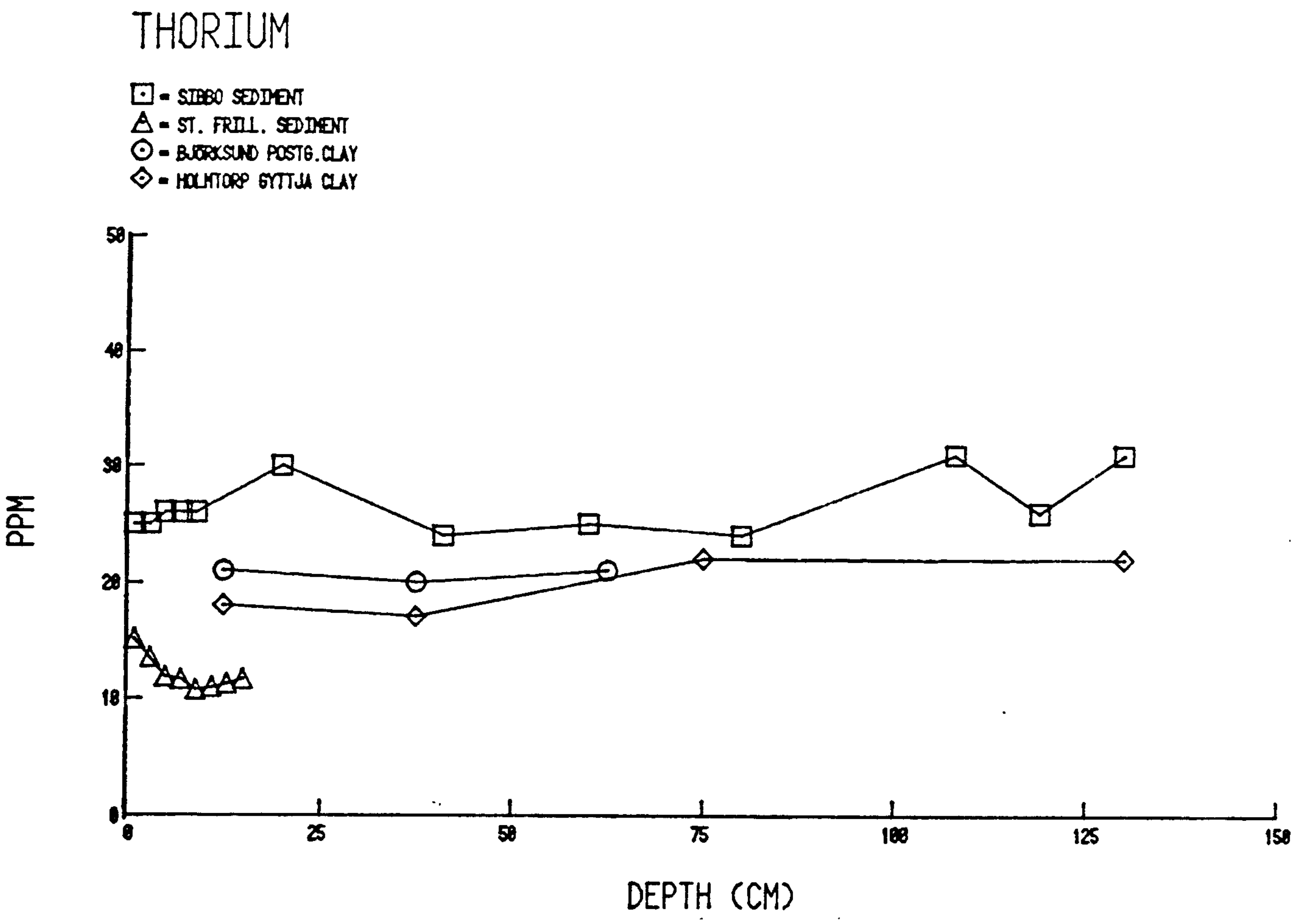


FIGURE 29 AND 30



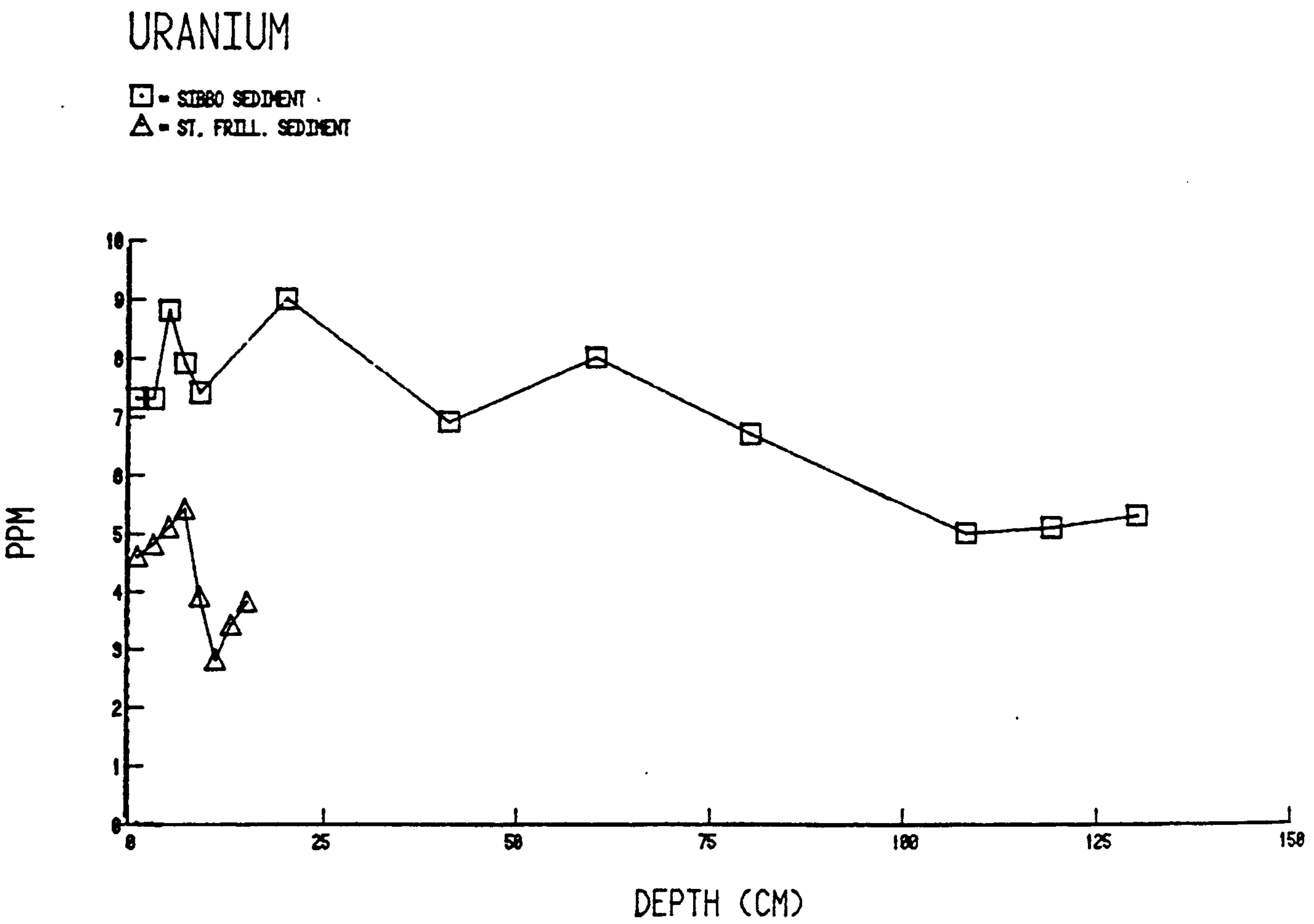
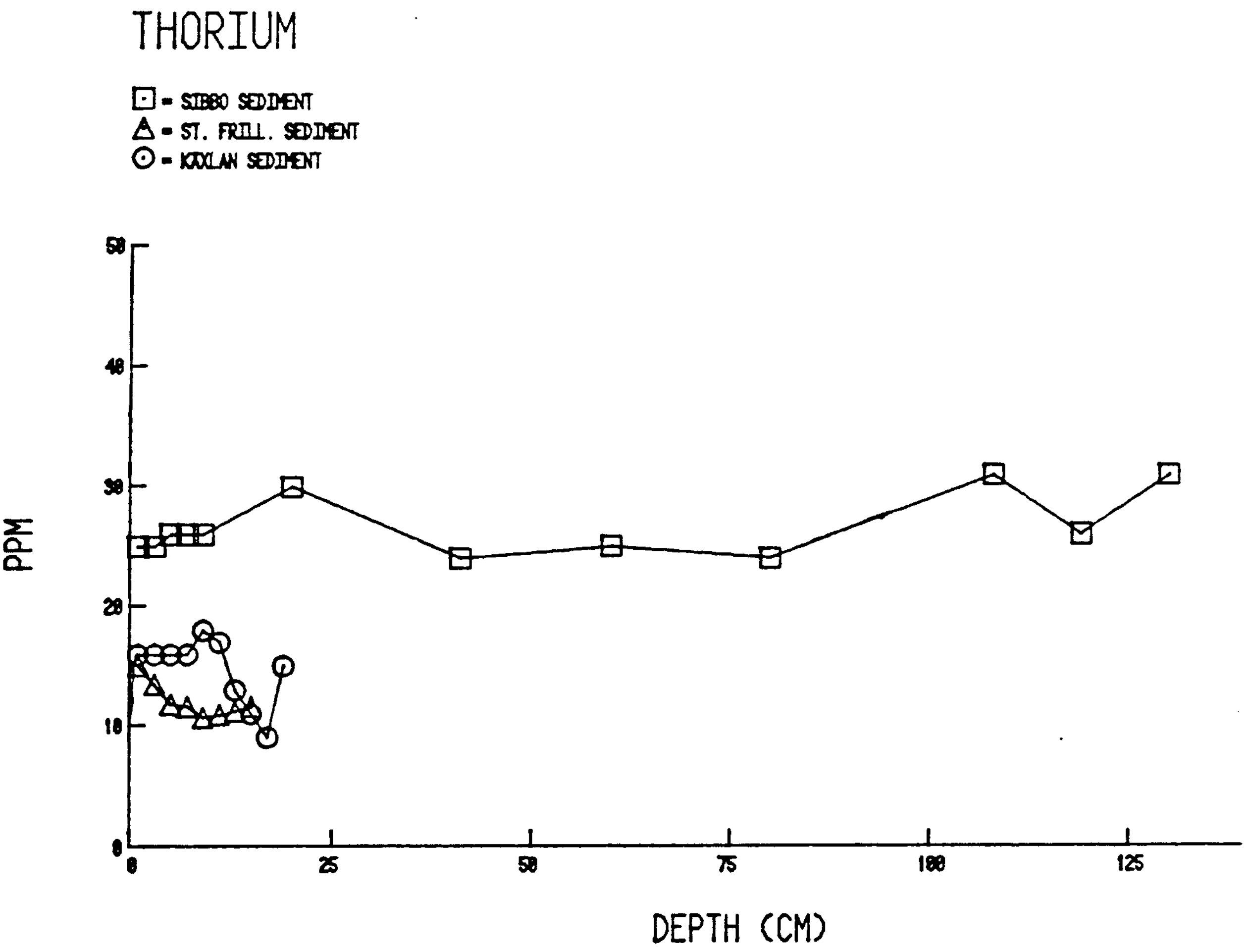


FIGURE 31 AND 32



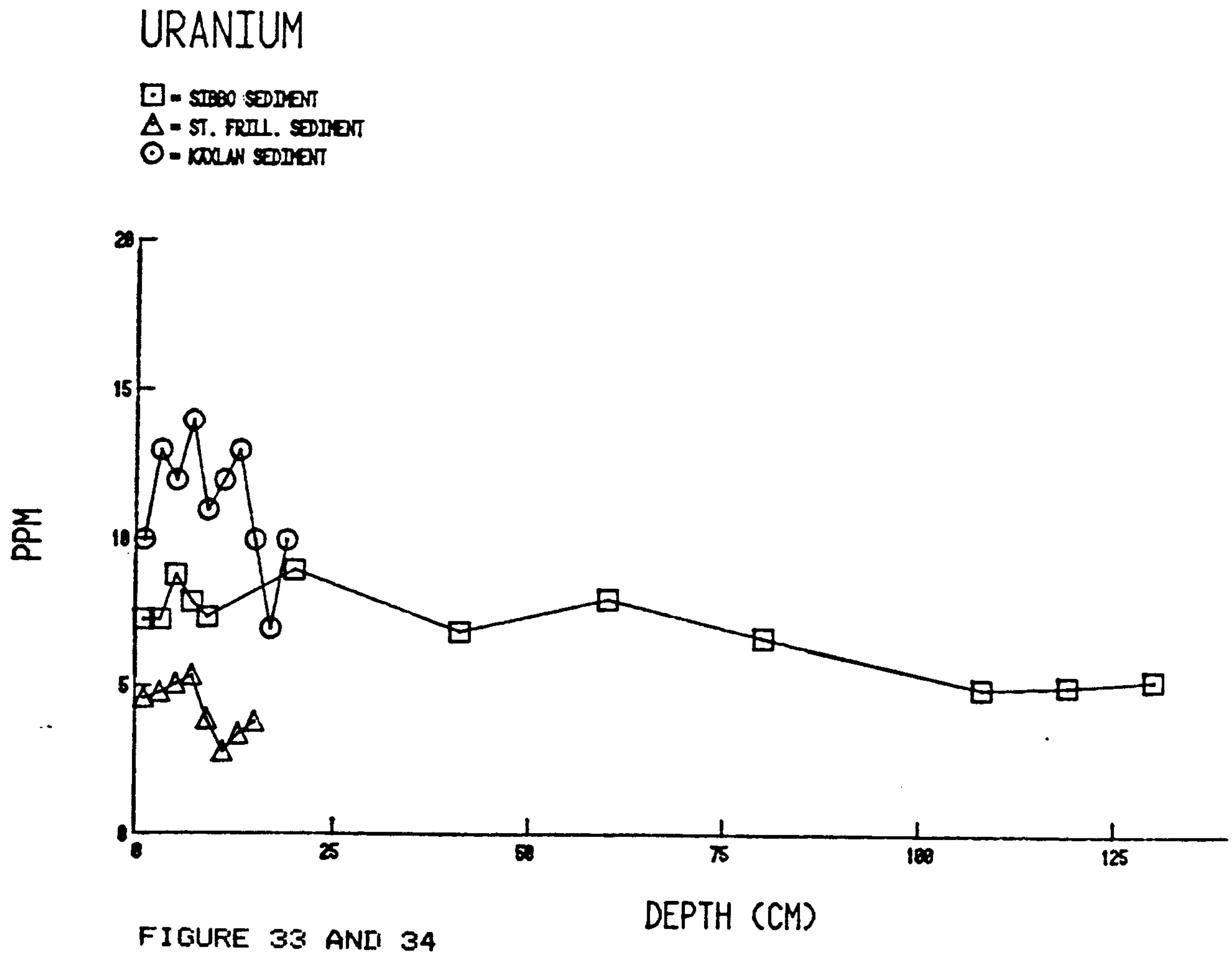
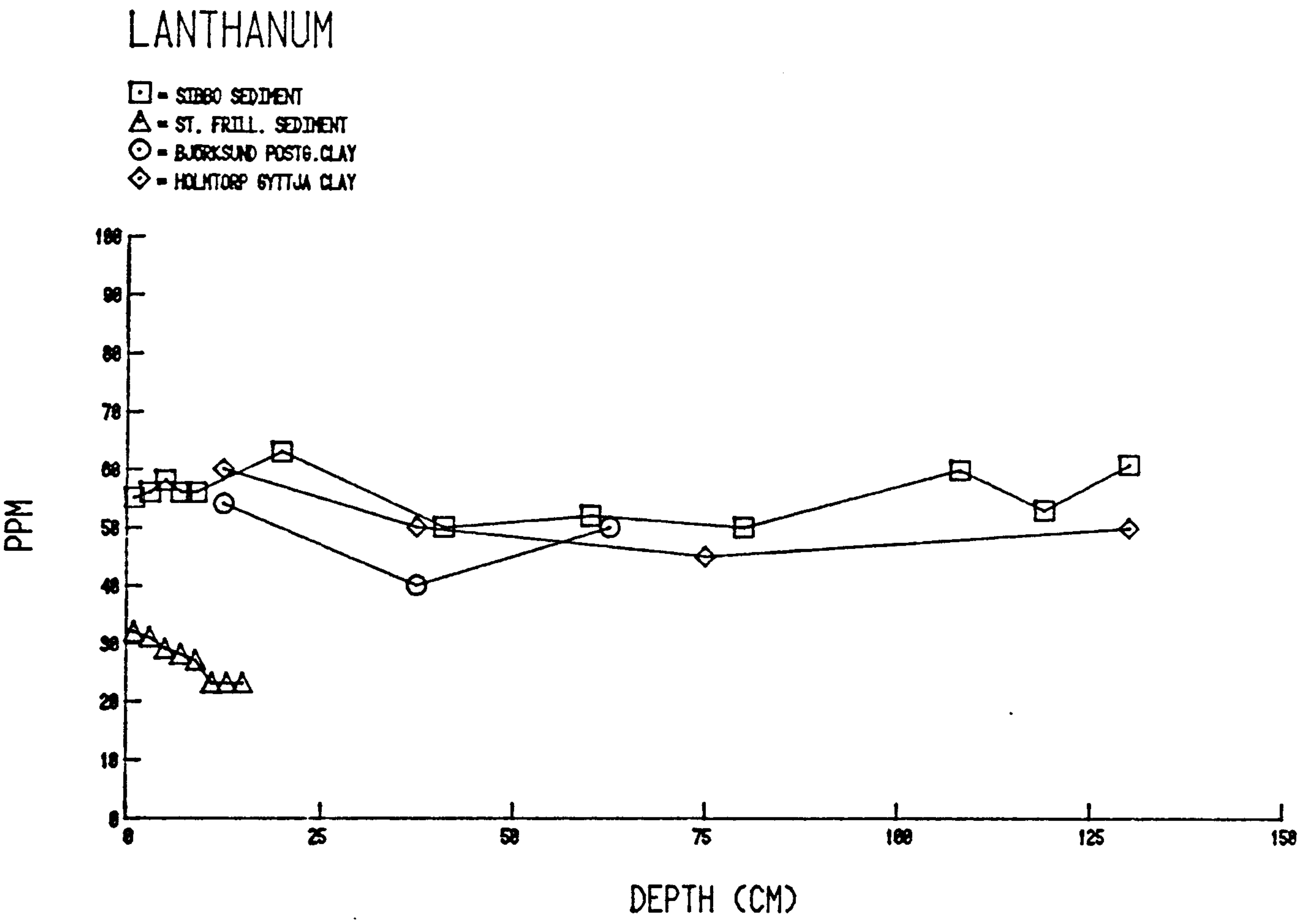


FIGURE 33 AND 34



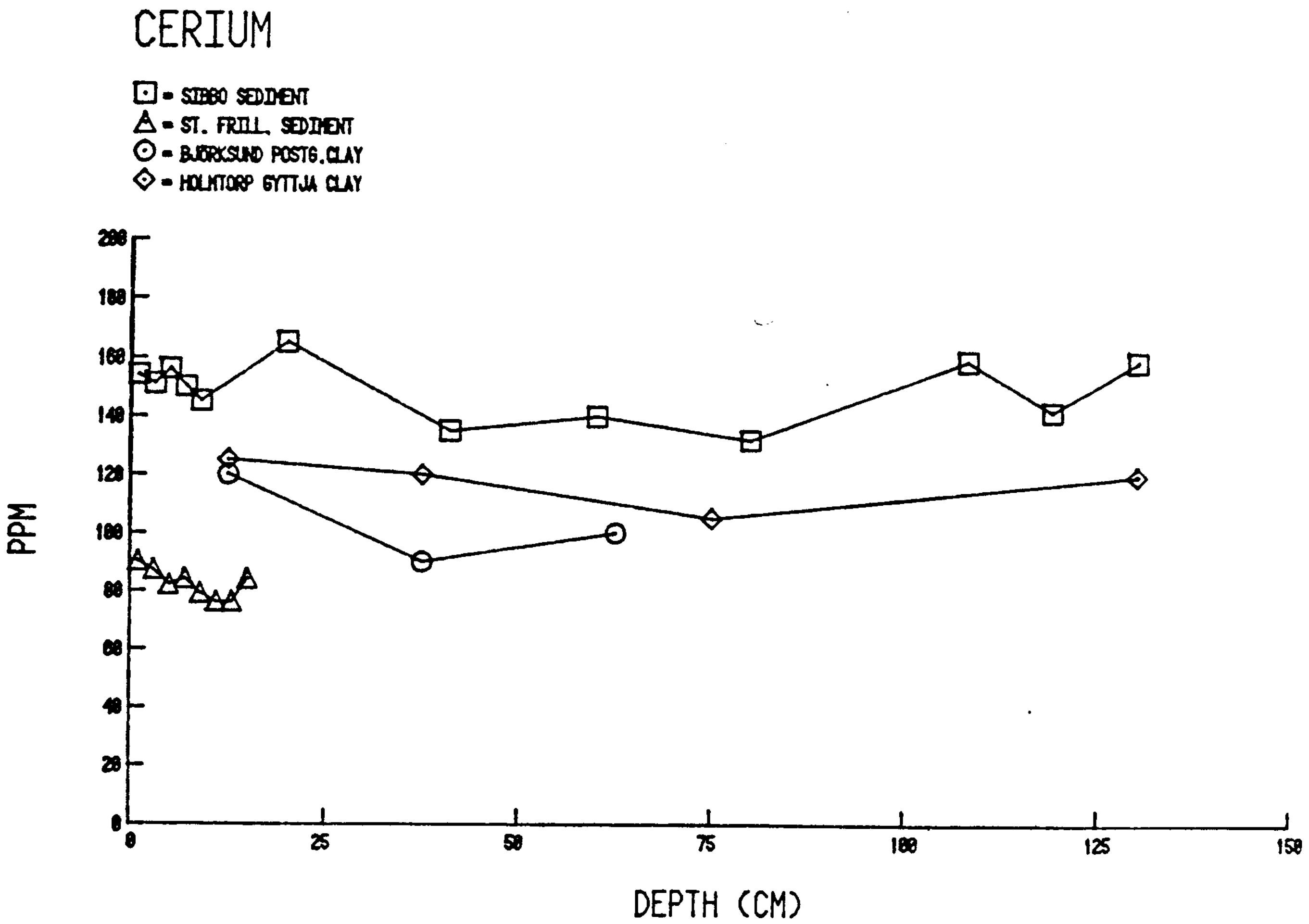
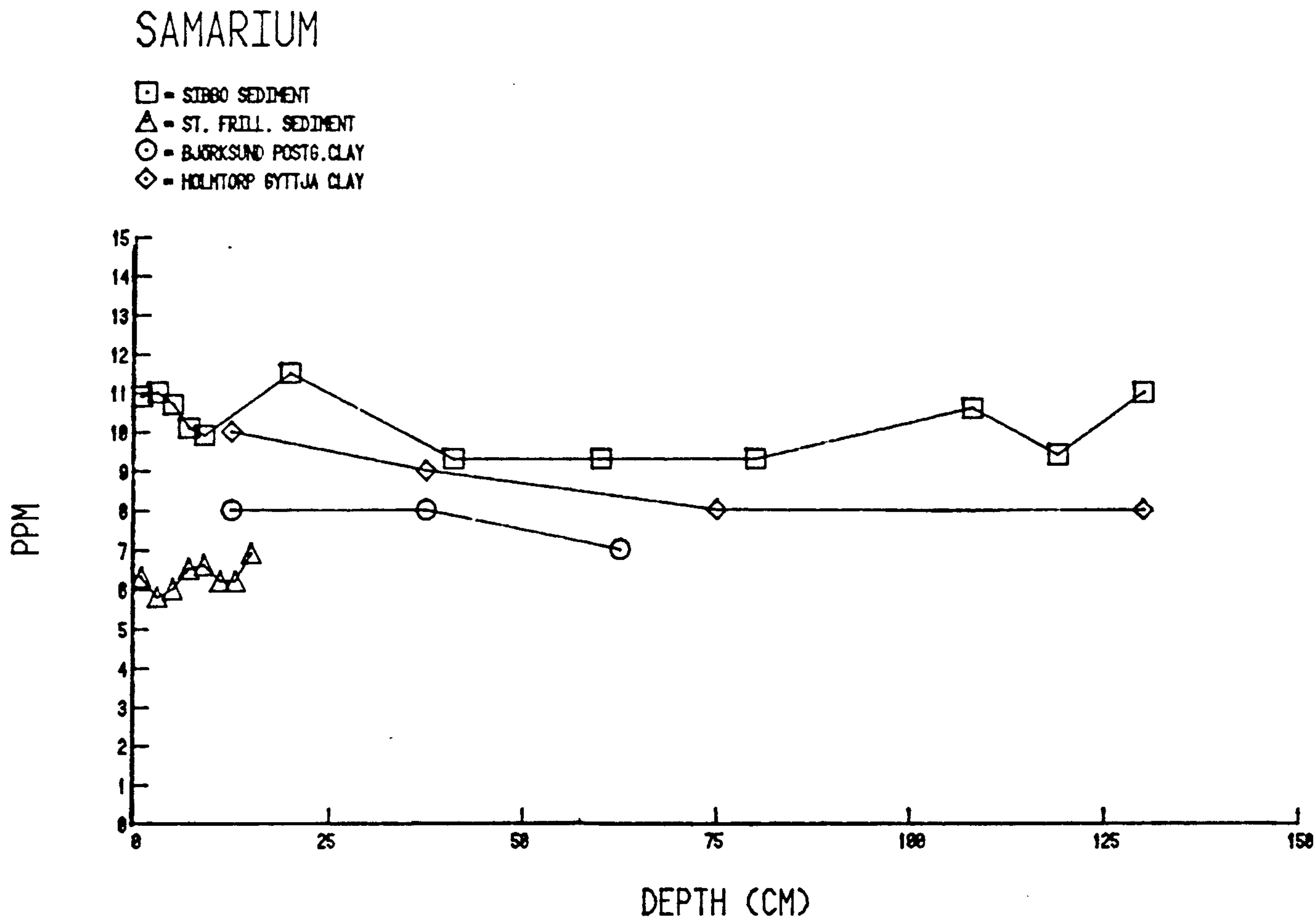


FIGURE 35 AND 36



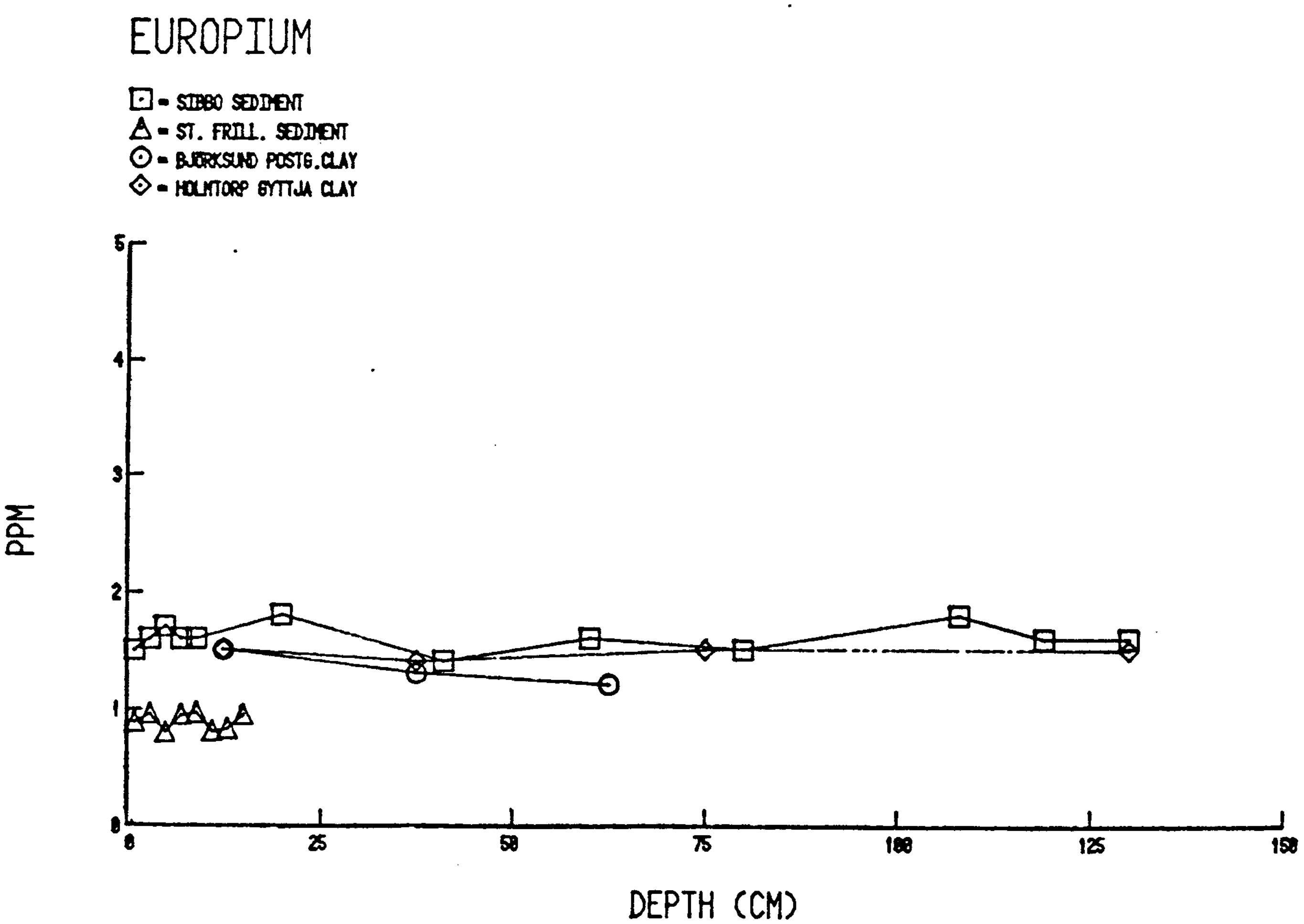
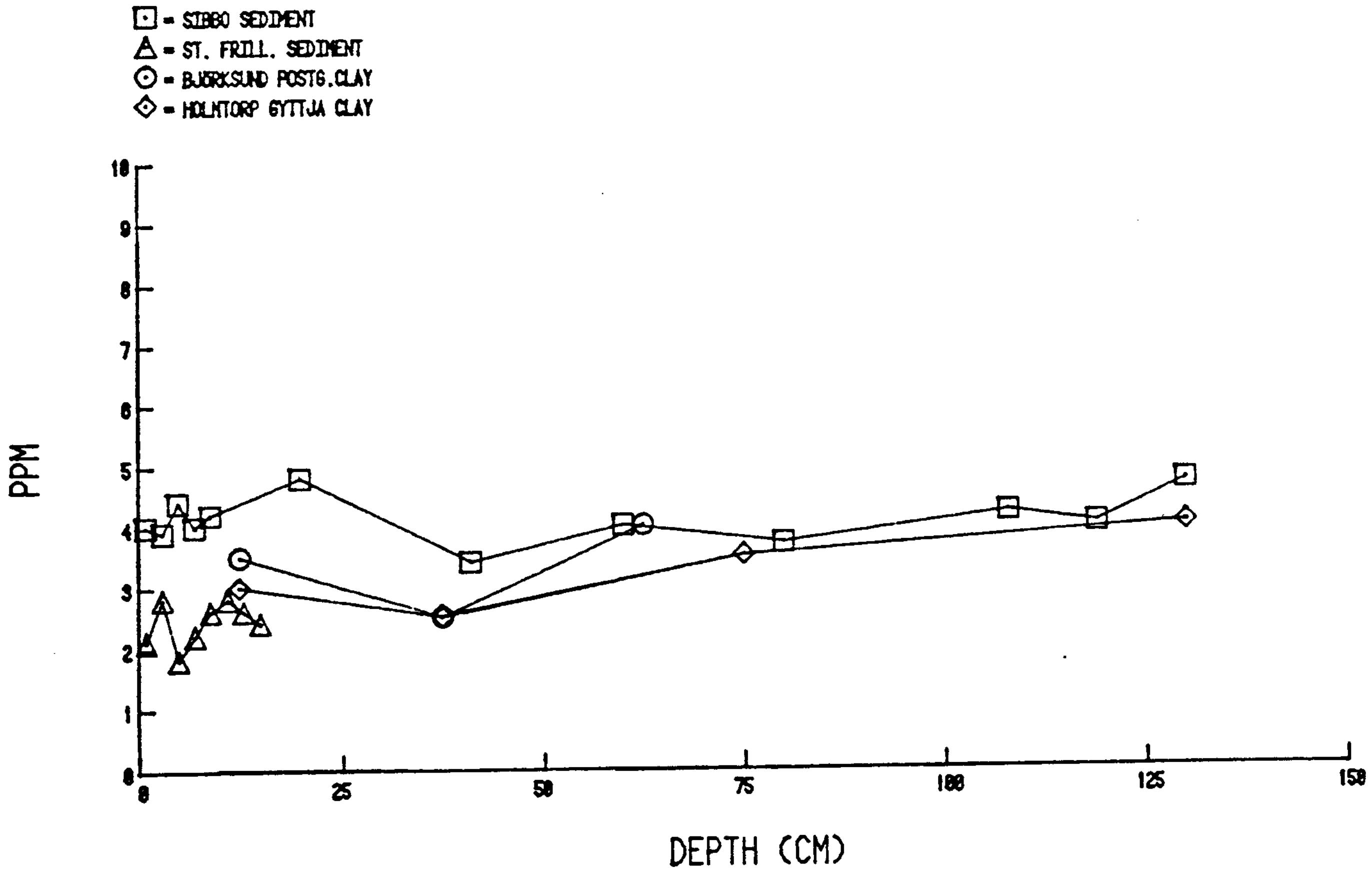


FIGURE 37 AND 38

YTTERBIUM



LUTETIUM

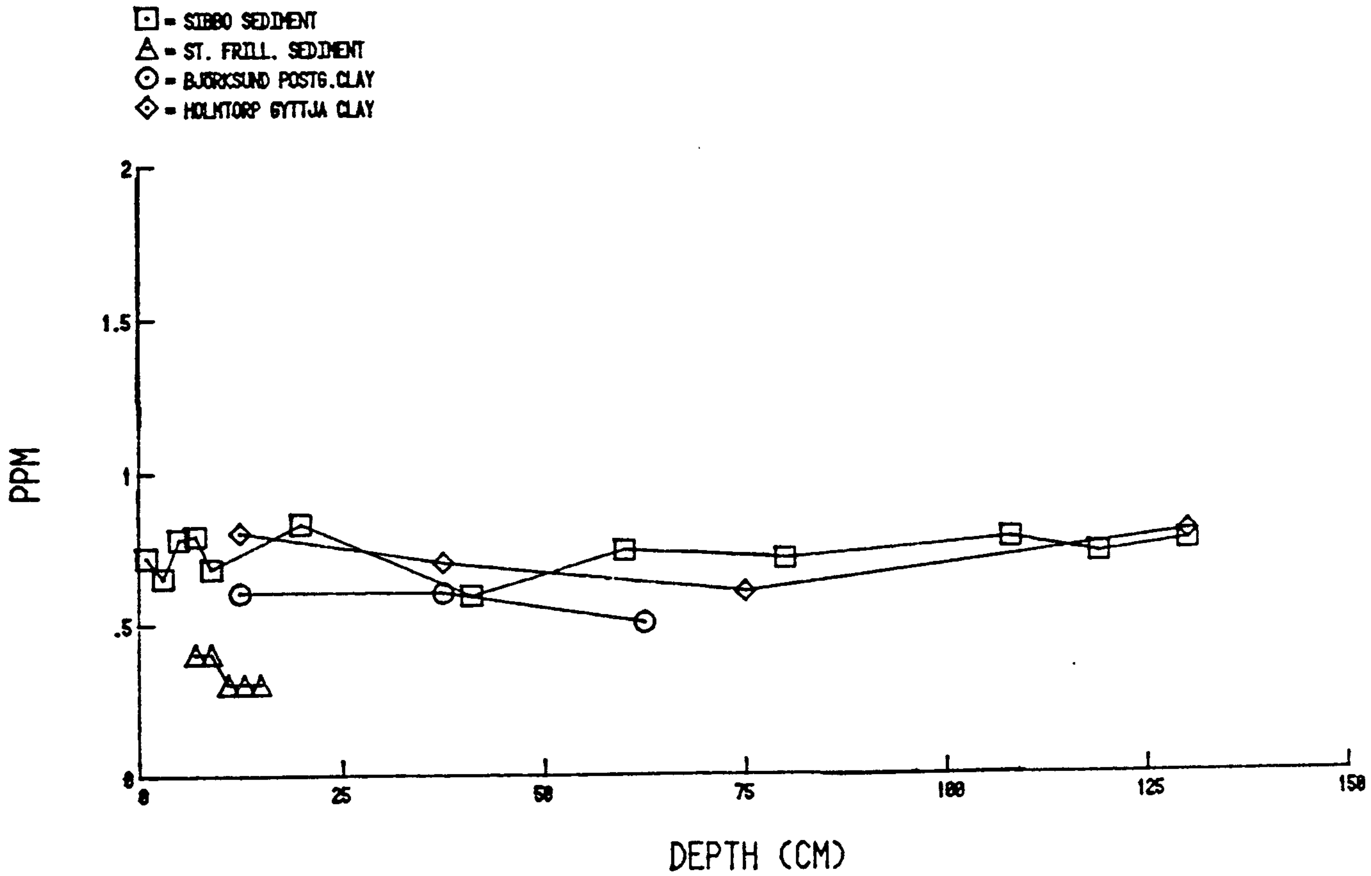
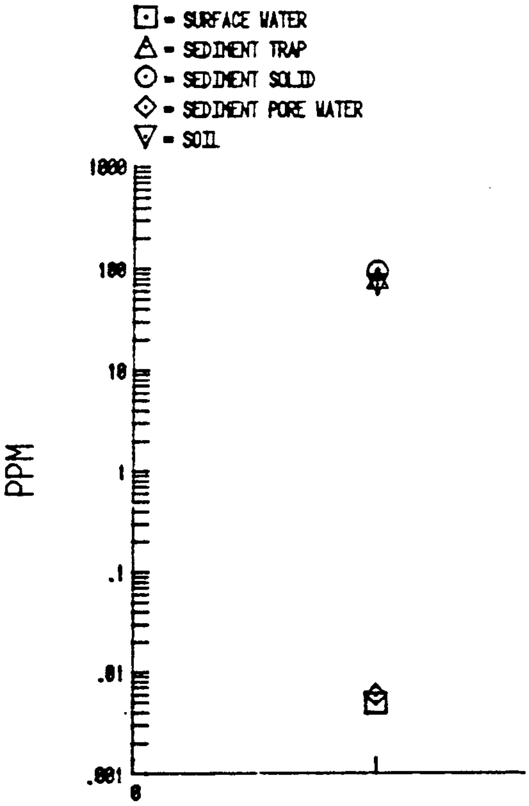
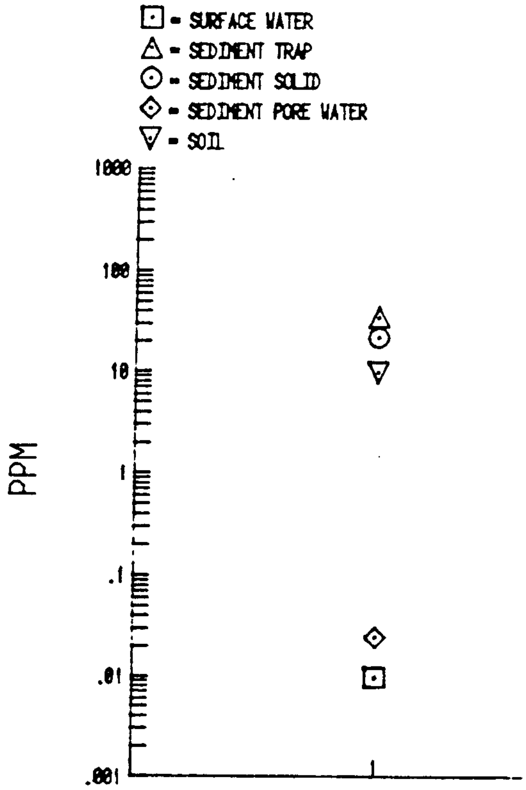


FIGURE 39 AND 40

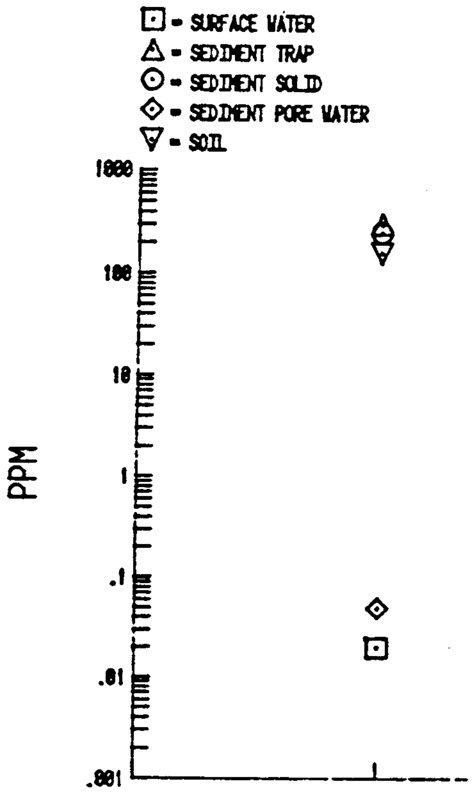
TROBBO CHROMIUM



TROBBO COBALT



TROBBO ZINC



TROBBO LANTHANUM

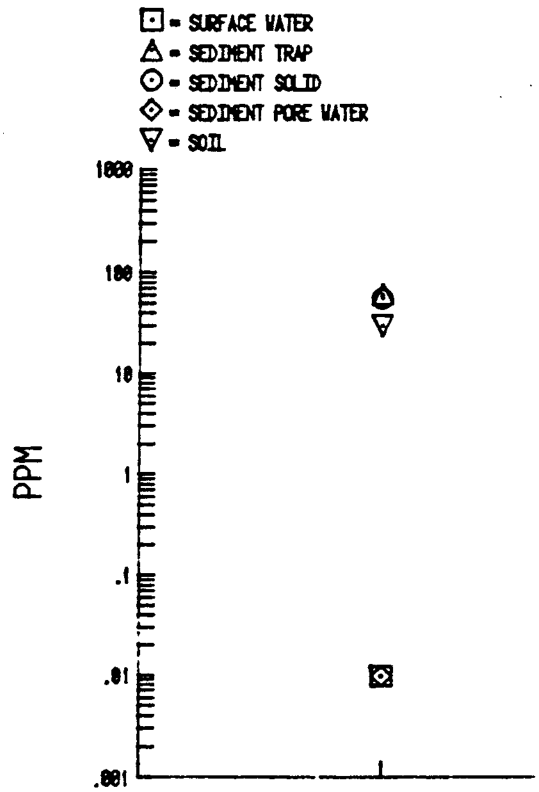


FIGURE 41 AND 44

List of SKB reports

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TR 121
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Summaries. Stockholm, May 1979.

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KBS Technical Reports 79-01 – 79-27.
Summaries. Stockholm, March 1980.

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KBS Technical Reports 80-01 – 80-25.
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The KBS Annual Report 1983.
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Annual Research and Development Report 1984
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Stockholm June 1985.

1985
TR 85-20
Annual Research and Development Report 1985
Including Summaries of Technical Reports Issued during 1985. (Technical Reports 85-01-85-19)
Stockholm May 1986.

Technical Reports

1986

TR 86-01
I: An analogue validation study of natural radionuclide migration in crystalline rock using uranium-series disequilibrium studies
II: A comparison of neutron activation and alpha spectroscopy analyses of thorium in crystalline rocks
J A T Smellie, Swedish Geological Co, A B MacKenzie and R D Scott, Scottish Universities Research Reactor Centre
February 1986

TR 86-02
Formation and transport of americium pseudocolloids in aqueous systems
U Olofsson
Chalmers University of Technology, Gothenburg, Sweden
B Allard
University of Linköping, Sweden
March 26, 1986

TR 86-03
Redox chemistry of deep groundwaters in Sweden
D Kirk Nordstrom
US Geological Survey, Menlo Park, USA
Ignasi Puigdomenech
Royal Institute of Technology, Stockholm, Sweden
April 1, 1986

TR 86-04
Hydrogen production in alpha-irradiated bentonite
Trygve Eriksen
Royal Institute of Technology, Stockholm, Sweden
Hilbert Christensen
Studsvik Energiteknik AB, Nyköping, Sweden
Erling Bjergbakke
Risö National Laboratory, Roskilde, Denmark
March 1986

TR 86-05
Preliminary investigations of fracture zones in the Brändan area, Finnsjön study site
Kaj Ahlbom, Peter Andersson, Lennart Ekman, Erik Gustafsson, John Smellie, Swedish Geological Co, Uppsala
Eva-Lena Tullborg, Swedish Geological Co, Göteborg
February 1986

TR 86-06
Geological and tectonic description of the Klipperås study site
Andrzej Olkiewicz
Vladislav Stejskal
Swedish Geoloaical Company
Uppsala, October, 1986

TR 86-07
Geophysical investigations at the Klipperås study site
Stefan Sehlstedt
Leif Stenberg
Swedish Geological Company
Luleå, July 1986

TR 86-08
Hydrogeological investigations at the Klipperås study site
Bengt Gentzschein
Swedish Geological Company
Uppsala, June 1986

TR 86-09
Geophysical laboratory investigations on core samples from the Klipperås study site
Leif Stenberg
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TR 86-10
Fissure fillings from the Klipperås study site
Eva-Lena Tullborg
Swedish Geological Company
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Hydraulic fracturing rock stress measurements in borehole Gi-1, Gideå Study Site, Sweden
Bjarni Bjarnason and Ove Stephansson
Division of Rock Mechanics,
Luleå University of Technology, Sweden
April 1986

TR 86-12
PLAN 86— Costs for management of the radioactive waste from nuclear power production
Swedish Nuclear Fuel and Waste Management Co
June 1986

TR 86-13
Radionuclide transport in fast channels in crystalline rock
Anders Rasmuson, Ivars Neretnieks
Department of Chemical Engineering
Royal Institute of Technology, Stockholm
March 1985

TR 86-14
Migration of fission products and actinides in compacted bentonite
Börje Torstenfelt
Department of Neclear Chemistry, Chalmers
University of Technology, Göteborg
Bert Allard
Department of water in environment and society, Linköping university, Linköping
April 24, 1986

TR 86-15
Biosphere data base revision
Ulla Bergström, Karin Andersson, Björn Sundblad, Studsvik Energiteknik AB, Nyköping
December 1985

TR 86-16
Site investigation
Equipment for geological, geophysical, hydrogeological and hydrochemical characterization
Karl-Erik Almén, SKB, Stockholm
Olle Andersson, IPA-Konsult AB, Oskarshamn
Bengt Fridh, Bengt-Erik Johansson,
Mikael Sehlstedt, Swedish Geological Co, Malå
Erik Gustafsson, Kenth Hansson, Olle Olsson,
Swedish Geological Co, Uppsala
Göran Nilsson, Swedish Geological Co, Luleå
Karin Axelsen, Peter Wikberg, Royal Institute of Technology, Stocholm
November 1986

TR 86-17
Analysis of groundwater from deep boreholes in Klipperås
Sif Laurent
IVL, Swedish Environmental
Research Institute
Stockholm, 1986-09-22

TR 86-18
Technology and costs for decommissioning the Swedish nuclear power plants.
Swedish Nuclear Fuel and Waste Management Co
May 1986

TR 86-19
Correlation between tectonic lineaments and permeability values of crystalline bedrock in the Gideå area
Lars O Ericsson, Bo Ronge
VIAK AB, Vällingby
November 1986

TR 86-20
A Preliminary Structural Analysis of the Pattern of Post-Glacial Faults in Northern Sweden
Christopher Talbot, Uppsala University
October 1986

TR 86-21
Steady-State Flow in a Rock Mass Intersected by Permeable Fracture Zones. Calculations on Case 2 with the GWHRT-code within Level 1 of the HYDROCOIN Project.
Björn Lindbom, KEMAKTA Consultants Co, Stockholm
December 1986

TR 86-22
Description of Hydrogeological Data in SKBs Database Geotab
Bengt Gentzschein, Swedish Geological Co, Uppsala
December 1986

TR 86-23
Settlement of Canisters with Smectite Clay Envelopes in Deposition Holes
Roland Pusch
Swedish Geological Co
December 1986

TR 86-24
Migration of Thorium, Uranium, Radium and Cs—137 in till Soils and their Uptake in Organic Matter and Peat
Ove Landström, Björn Sundblad
Studsvik Energiteknik AB
October 1986

TR 86-25
Aspects of the Physical State of Smectite-adsorbed Water
Roland Pusch, Ola Karnland
Swedish Geological Co, Lund
Engineering Geology
December 1986

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