Research Papers

No. 25

PALAEOECOLOGICAL EVALUATION OF THE RECENT ACIDIFICATION OF WELSH LAKES

9. Llyn Llagi, Gwynedd

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Summary

i) Core studies of diatoms, pollen, chemistry, carbonaceous particles and magnetics together with a land use study have been conducted at Llyn Llagi, Gwynedd. An upland, oligotrophic lake situated on the south side of Snowdonia.

ii) Sediment accumulation rates at the core site for the last 150 years were approximately stable (0.015 g cm^{-2} yr^{-1}) The CRS model indicates periods of accelerated sedimentation around 1900 and 1968-1975.

iii) The diatom based pH reconstructions (pre-1850) suggest that the pH of Llyn Llagi was 5.9 - 6.2. Planktonic diatoms were absent from the lake and the data suggest a fairly stable flora of attached circumneutral and acidophilous taxa. Acidification of Llyn Llagi is marked by the decline in *Achnanthes minutissima* and expansion of *Frustulia rhomboides*, *Tabellaria flocculosa*, *Eunotia veneris* and *Achnanthes marginulata* and the first appearance of *Tabellaria quadriseptata*. The greatest change is from 6 cm (1960) with the tremendous expansion of *T.quadriseptata* and smaller increases in *Navicula heimansii* and *Melosira lirata*. The data suggest a pH decline of 1.0 pH unit between 1850 and 1985.

iv) The core chemistry record demonstrates that trace metal contamination of the lake sediments began at 24 cm (ca. 1800) for Pb and Zn and 22 cm for Cu.

v) The contamination of the sediments by carbonaceous particles commences at 22 cm, concomitant with the beginnings of trace metal contamination, but concurrent with lake acidification. The concentration of these particles increase rapidly from 9 cm (1940's).

vi) The pollen diagram identifies a shift in the local vegetation from *Calluna* domination to domination by members of the Gramineae, presumably *Nardus*, *Molinia* & *Agrostis*. This change is the reverse of what would normally be expected if the land-use hypothesis as supported by Rosenqvist *et al*. 1980 & Krug & Frink (1983) were in operation.

vii) No appreciable land use change has occurred within the catchment since the introduction of sheep by the Cistercian monastery. While sheep numbers have increased in the area in recent years the documentary evidence is not precise enough to assess whether the catchment has experienced a significant increase in grazing pressure. No liming has taken place within the catchment and burning has not been a significant management practice.

viii) The acidification cannot be accounted for by land use changes. Instead, all the data indicate acid deposition as the cause of acidification. The timing of the changes and trends of the atmospheric pollution indicators (trace metals, magnetics, carbonaceous particles), indicating local deposition of atmospheric pollutants, are consistent with this view.

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A. Full diatom diagrams for the Llyn Llagi 1 core
B. Full pollen diagrams for the Llyn Llagi 1 core

Explanation of Abbreviations

ADAS	Agricultural and Development Advisory Service.
MAFF	Ministry of Agriculture, Fisheries and Food.
NCC	Nature Conservancy Council
NLW	National Library of Wales
PAH	Polyaromatic Hydrocarbons
PRO	Public Record Office
WWA	Welsh Water Authority
SSSI	Site of Special Scientific Interest
UCNW	University College North Wales

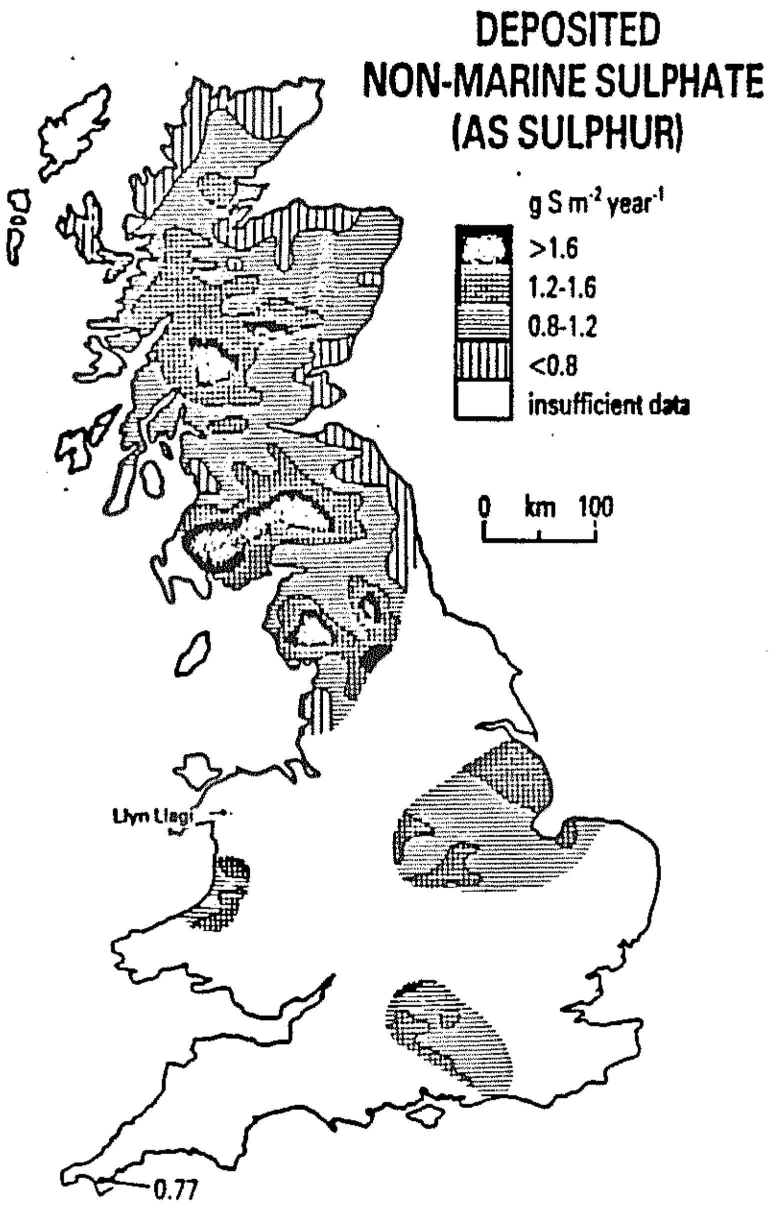
1.0 Introduction

Surface water acidification is recognised as one of the most important environmental problems in Europe and North America, yet despite the pioneering work of Gorham on precipitation chemistry in Cumbria (Gorham 1958) the extent of acidification in the UK is still not known. In earlier papers Flower and Battarbee 1983, Battarbee _et al._ 1985, Jones _et al._ 1986, Flower _et al_ 1987) we established that lakes on granitic rocks in Galloway, South West Scotland, were strongly acidified, and that the most likely cause of the acidification was acid deposition. We have now extended our enquiry to acid lakes in Wales and other parts of Scotland to test the general hypothesis that clearwater lakes with pH values less than 5.5 occurring within areas of high acid deposition are acidified due to an increase in acid deposition over recent decades.

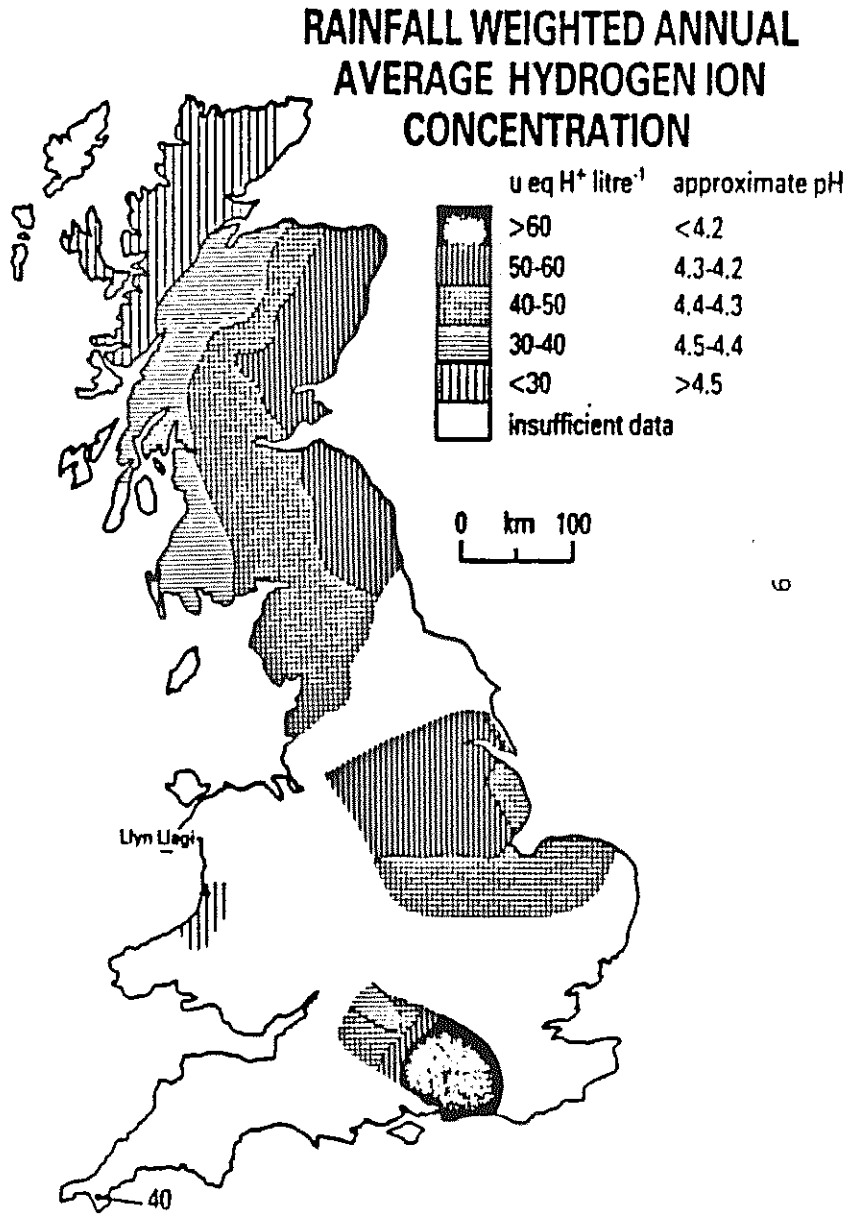
Llyn Llagi (Fig. 1), located on the southern edge of the Snowdonia was the sixth site chosen in Wales. While there are no site records of acid deposition, records from Aberystwyth reveal that the mean pH of precipitation is ca. 4.5 and the annual wet sulphate loading is 1.2 - 1.6 g m^{-2} yr^{-1} (Figs. 2 & 3). The catchment is largely undisturbed, comprising upland moorland and rough grazing for sheep. Sediment cores were obtained in August 1985.

Our approach involves the use of diatom analysis to reconstruct past pH values; ^{210}Pb analysis to establish a lake sediment chronology; geochemical, magnetic and "soot" analysis to trace the history of atmospheric contamination; and pollen analysis and land-use history studies to evaluate the influence of catchment changes on the past ecology of the lake.

1. Llyn Llagi location map



Average annual deposition of non-marine sulphate for the U.K. (Redrawn from Barrett et al 1983)



2. Average annual rainfall weighted hydrogen ion concentration deposition for the U.K. (Redrawn from Barrett et al 1983)

2.0 Site details

2.1 Lake

Llyn Llagi, lying at over 360 m and receiving rainfall in excess of 2000 mm yr^{-1}, occupies a broad almost circular, deep basin (16.5 m), surrounded by an extensive 1m deep shallow rim to the north east (Fig. 4). Overall the lake has a volume of 331,734 m^3 and a mean depth of 5.8 m and displays minimal variation in water level. The lake is chiefly fed by a stream from Llyn yr Adar, and groundwater flows. Llyn Llagi is drained by a northerly flowing river into the Nanmor.

Table 1 Lake characteristics

Area	56771 m^2
Volume	331734 m^3
Maximum depth	16.5 m
Mean depth	5.8 m

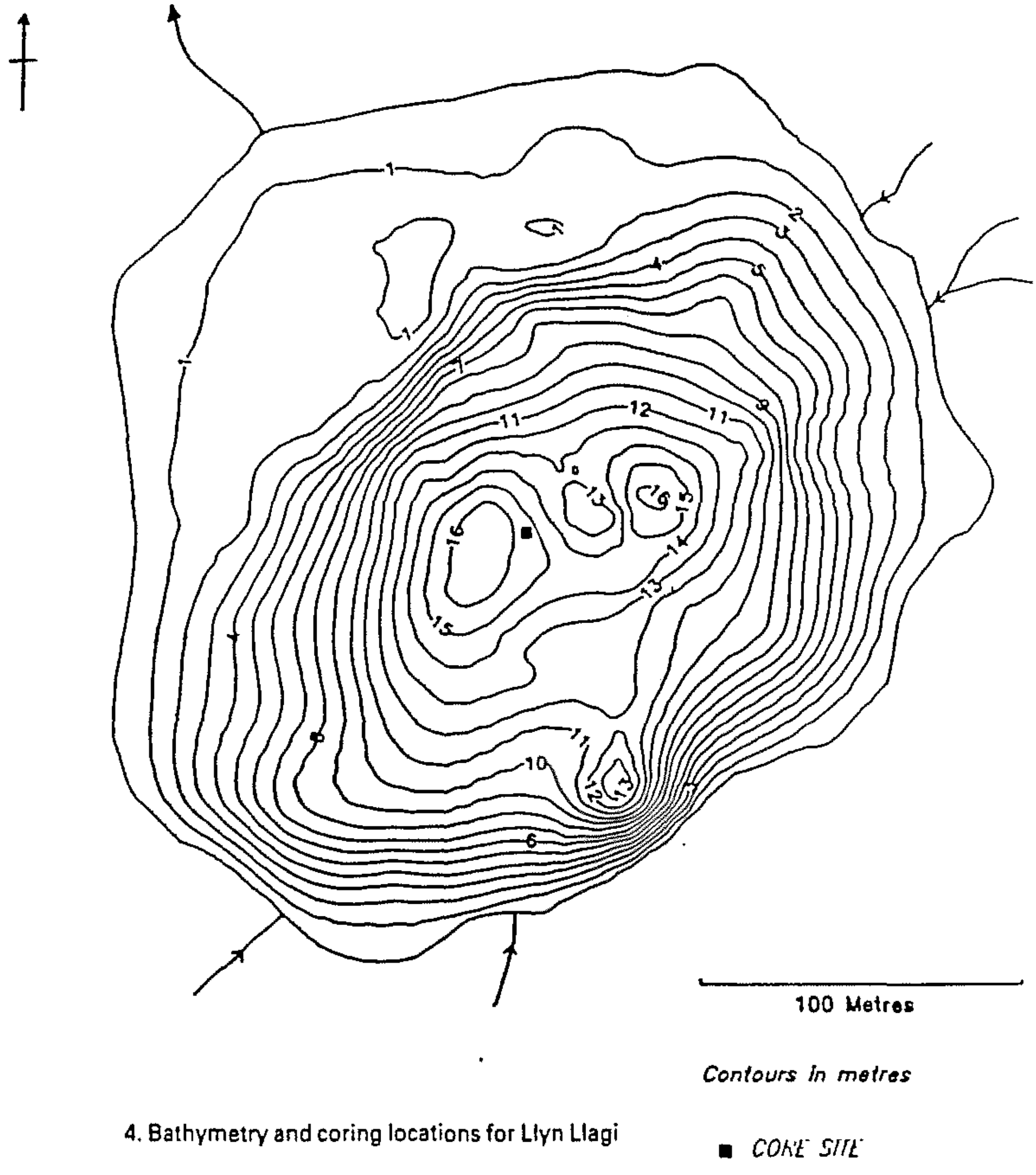
2.1.1 Water chemistry

Available water chemistry from the lake is limited and is restricted to eight spot samples taken in the course of the present study in 1985 and 1986 (Table 2). Lake pH varies from 5.0-5.3 and has a low calcium levels.

2.1.2 Lake Vegetation

Fringing and littoral vegetation were mapped from the shoreline on the 31st May and 15 sublittoral Ekman grab samples were taken on the 23rd August 1985 (Fig. 5).

The marshy fringes of the western and northern shores are dominated by rushes (*Juncus* spp.). By contrast the rocky eastern fringes supported only mosses and liverworts. *Lobelia dortmanna* dominates the littoral flora adjacent to the marshy fringes (Fig. 5), while *Isoetes lacustris* is abundant in deeper waters although it does not extend beyond ca. 3.0m depth (Tables 3 & 4). Filamentous algae and leafy liverworts are locally frequent in shallow rocky areas but *Sphagnum* moss was not recovered from the lake. *Juncus bulbosus* var. *fluitans* and *Sparganium angustifolium* which were recorded by Seddon (1972) 25 years previously, were not present in the lake in 1985.



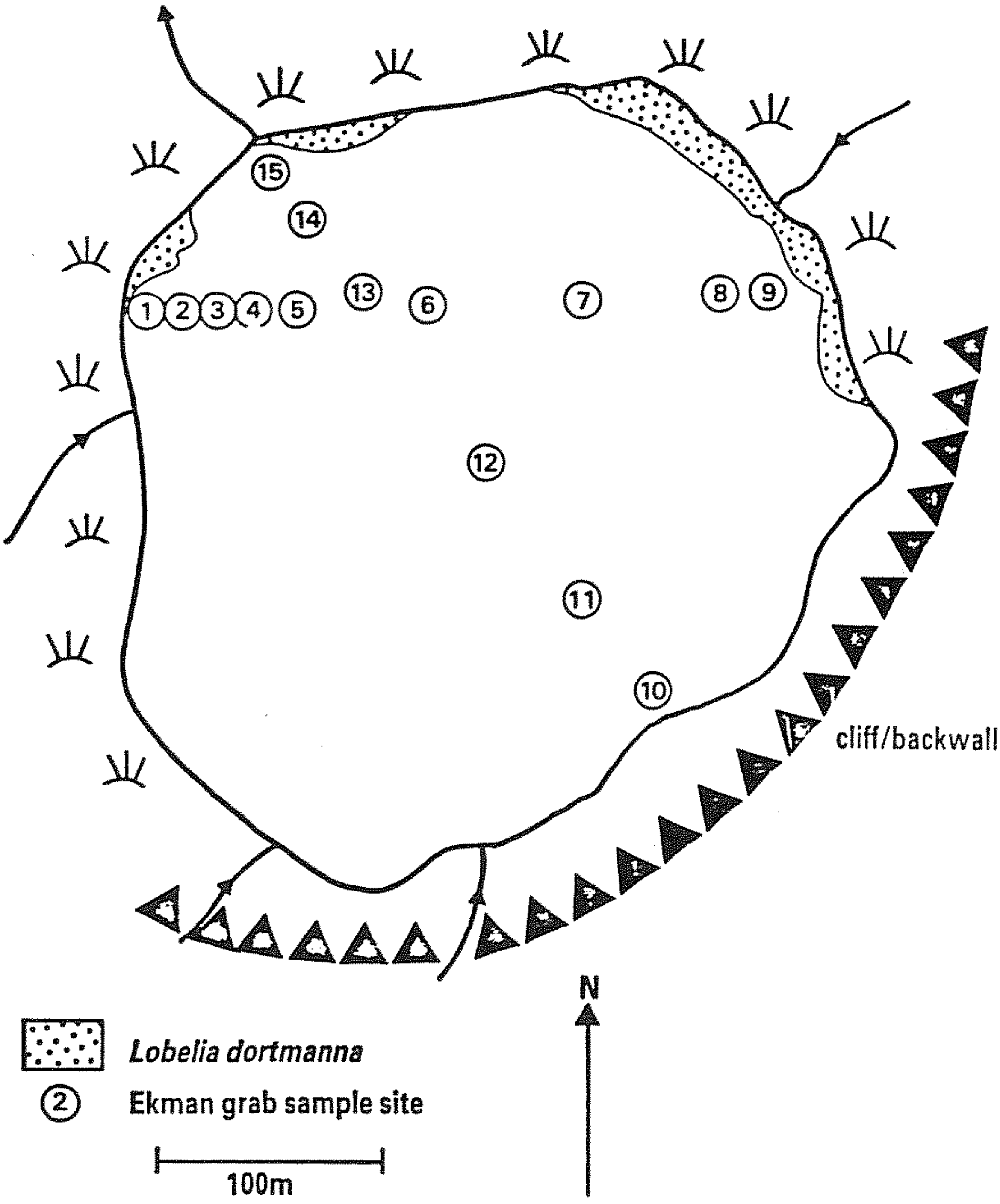
4. Bathymetry and coring locations for Llyn Llagi

Table 2 Water chemistry for Llyn Llagi

Date	pH	Total Oxidised Nitrogen mg l^{-1}	Total Alkalinity mg l^{-1}	Chloride mg l^{-1}	Dissolved Silicate mg l^{-1}	Dissolved Sulphate mg l^{-1}	Dissolved Sodium mg l^{-1}
27/03/84	4.0	0.14	1.0	10.0	0.193	5.0	5.0
12/06/84	-	0.14	2.0	11.0	0.107	5.0	4.8
07/08/84	5.1	0.05	1.0	10.0	0.107	5.0	4.7
09/10/84	4.8	0.03	1.0	6.0	0.791	5.0	4.0
12/12/84	3.5	2.30	1.0	6.4	0.856	5.0	3.7
06/02/85	5.2	0.10	3.2	6.1	0.100	5.04	-
23/04/86	5.2	0.27	2.6	8.9	0.370	--	4.0
02/12/86	5.0	0.10	1.1	6.0	0.300	2.31	3.3

Date	Dissolved Potassium	Dissolved Calcium	Dissolved Magnesium	Dissolved Zinc mg l^{-1}	Dissolved Copper	Dissolved Lead	Dissolved Manganese	Dissolved Iron
27/03/84	1.0	1.26	0.70	0.016	0.005	0.01	0.06	0.04
12/06/84	1.0	1.54	0.77	0.050	0.005	0.01	0.07	0.03
07/08/84	1.0	1.41	0.73	0.026	0.005	--	0.06	0.07
09/10/84	1.0	1.27	0.63	0.021	0.005	--	0.07	0.16
12/12/84	1.0	1.95	0.58	0.120	0.008	--	0.05	0.12
06/02/85	1.0	--	--	0.100	---	--	--	--
23/04/86	0.3	1.00	0.69	0.150	0.006	--	0.06	0.05
02/12/86	0.1	0.82	0.46	0.009	0.002		0.04	0.06

Date	Conductivity us	Aluminium mg l^{-1}	DOC mg l^{-1} C
23/04/86	43	0.09	
02/12/86	32	0.043 as non-labile and 0.081 as a labile fraction	2.0



5. Macrophyte vegetation for Llyn Llagi

Table 3: The fringing and aquatic vegetation of Llyn Llagi, August 1985
(A= abundant; lf= locally frequent; r= rare)

i) Fringes
Juncus acutifloris, *J.articulatus* & *J.effusus*(A)

ii) Littoral zone
Filamentous algae including *Mougeotia* spp. (lf); leafy liverworts including *Jungermannia* spp. (lf); *Littorella uniflora* (r); *Lobelia dortmanna* (lf); *Subularia aquatica*.

iii) Sublittoral zone
Isoetes echinospora (r); *I.lacustris* (A).

Table 4: Ekman grab samples
(site; depth; substrate; plants)

1. 1.0m; mud; *Isoetes* (A), *Lobelia* (r)
2. 1.2m; mud; *Isoetes* (A)
3. 1.2m; mud; *Isoetes* (A)
4. 1.0m; mud; *Isoetes* (A)
5. 1.0m; mud; *Isoetes* (A)
6. 2.5m; mud; *Isoetes* (A)
7. 4.2m; mud; -----
8. 3.5m; mud; -----
9. 0.8m; mud; *Isoetes* (A), *Lobelia* (A)
10. 10.0m; mud; -----
11. 10.0m; mud; -----
12. 11.0m; mud; -----
13. 2.0m; mud; *Isoetes* (A)
14. 1.0m; mud; *Isoetes* (A)
15. 1.0m; mud; *Isoetes* (A)

2.1.3 Fishing history

Little is known of the contemporary fishery status of Llyn Llagi. Some decline in fishing quality has been recognised in the last 20 years (R. Hemsworth & T.Rowlands pers. comms.).

Cliffe (1860) reported that the lake was rarely visited by angling, but that the trout in it were 'large and free'. He suggested that trout from Llyn Llagi were used to stock the previously fishless Llyn yr Adar in the early 19th century.

Ward (1931) described the lake as having numerous trout, averaging 0.25 lbs.

2.2 Catchment

Table 5 Catchment characteristics

Total catchment area	1,681,408 m^2
Area of land in catchment	1,570,586 m^2
Area of lake	56771 m^2
Catchment/lake ratio	27.7
Maximum relief	90 m

2.2.1 Geology

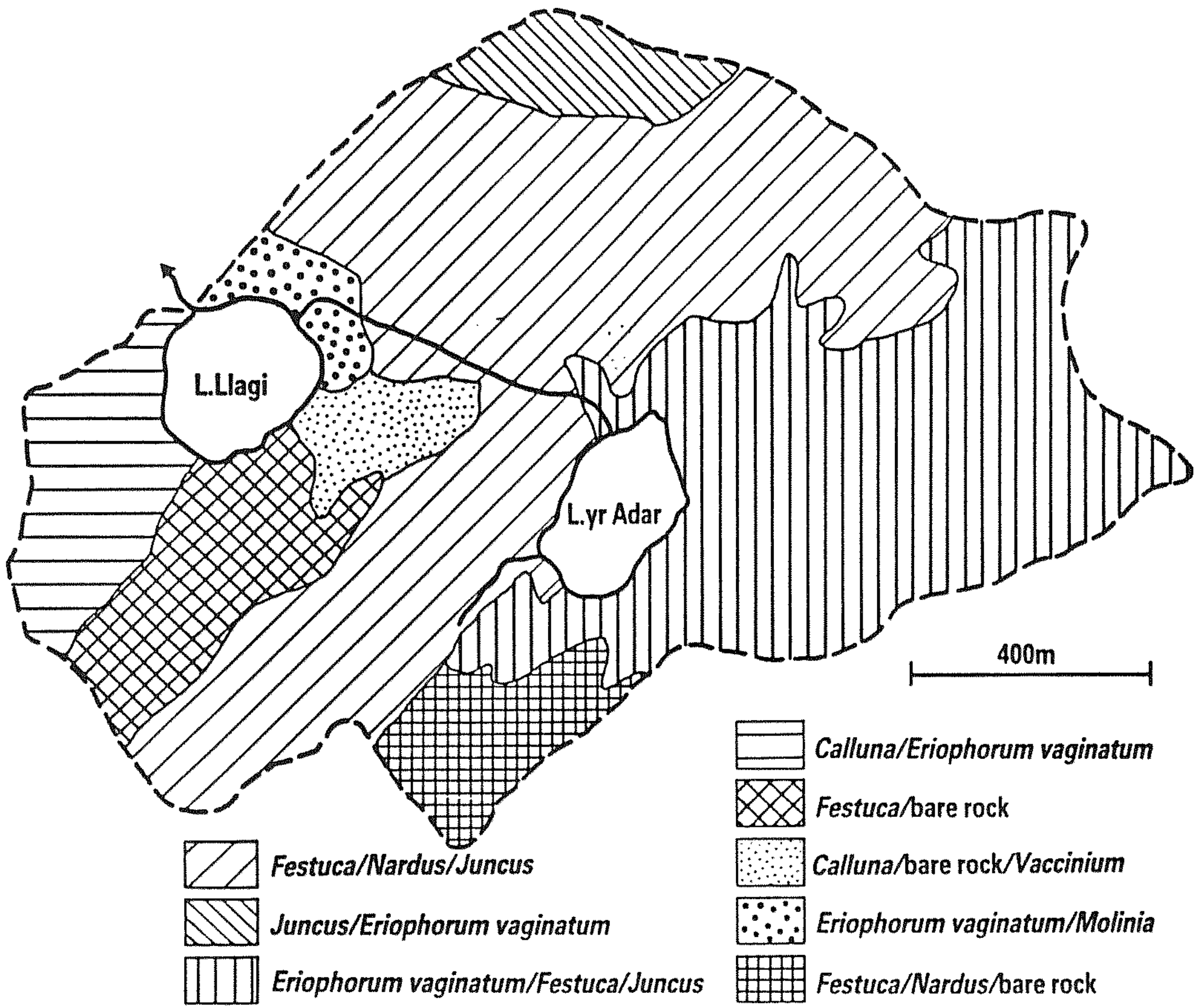
Ordivician slates and shales of the Glanarfon series dominate the catchment geology. The backwall is composed of a large Doleritic intrusion and small igneous intrusions of fine microgranites and volcanic tuff also occur.

2.2.2 Soils

Soils of the catchment are chiefly stagnopodsols and stagnohumic gleys of the Hafren association (654a) and amorphous blanket peats belonging to the Crowdy association (1013a) (Rudeforth et al 1984).

2.2.3 Present Vegetation

The present vegetation of Llyn Llagi (Fig. 6) consists of a sparse Festuca community to the south west on the corrie back wall which grades into a sparse Calluna community. To the north around the outflow a Calluna/ Eriophorum vaginatum community dominates while the wetter easterly slopes consist of an extensive Eriophorum /Molinia community. The catchment around the top lake Llyn yr Adar consists of an extensive Eriophorum / Molinia / Juncus marshland.



6. The catchment vegetation of Llyn Llagi

3.0 Methods

3.1 Surveying

The lake was surveyed using the techniques described in Stevenson *et al.* (1987). Shore surveying stations were located by the inflow and outflows.

3.2 Collection of sediment cores and routine laboratory measurement of sediment characteristics

Cores were taken using a wide diameter piston corer operated from a mini raft supported by two inflatable boats. Sampling was carried out during August 1985. Llagi 1 was used for dating and analysis and Llagi 4 for PAH.

Core Llagi 1 (92 cm) was extruded in the laboratory and the top 20cm sliced into 1/2 cm slices and the remaining core at 1cm intervals. The sediment was then sub-sampled for dry weight, loss on ignition (at 550°C) and wet density measurements.

Analyses for dating, magnetics, chemistry, soot, diatoms & pollen were all conducted according to the standard methods set out in Stevenson *et al.* (1987).

4.0 Results

4.1 Lake history

4.1.1 Sediment Description

The core constitution (Fig. 7) from 92 - 26 cm is a dark brown organic mud ($Ld^3 4$). Within this section the wet density is stable while the loss on ignition profile shows a continual decline except for a small increase between 50 and 40 cm. A silt inwash occurs between 26 and 24 cm with the sediment changing to a dark grey/brown organic mud with some silt ($Ld^3 4$, Ag+). This inwash is recorded in the loss on ignition profile as a sharp drop. From 24 to 10 cm the sediment constitution returns to the compostion of the basal unit. From 10 cm the sediment contains identifiable detritus and the dry weight values fall slightly at the very top of the core.

4.1.2 ^{210}Pb dating

Sediments from Llagi 1 were analysed for ^{210}Pb, ^{226}Ra and ^{137}Cs by gamma spectrometry (Appleby et al. 1986). The ^{210}Pb and ^{226}Ra results are given in Table 6, and shown graphically in Fig. 8 & 9 . The ^{137}Cs results are given in Table 7 and Fig. 10. The gamma spectra also indicated the presence of ^{241}Am in the top-most sediments, and these activities are given in Table 8. Fig. 11 plots both the ^{137}Cs and ^{241}Am profiles of the core. Table 9 gives values of a range of other radioisotopes determined from the gamma spectra.

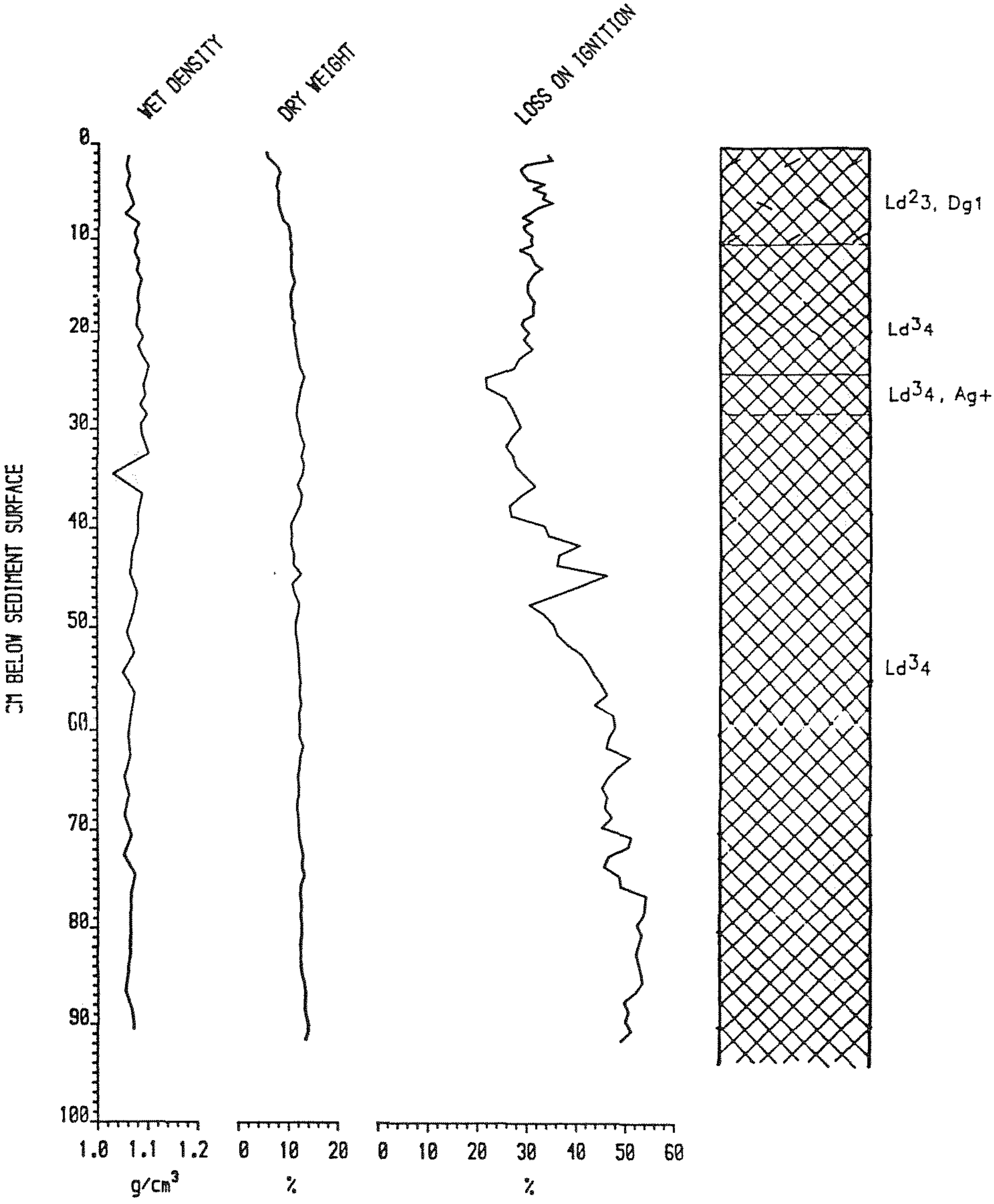
The ^{210}Pb inventory of the core is 21.2 pCi cm^{-2}, and represents a mean ^{210}Pb supply rate of 0.66 pCi cm^{-2} yr^{-1}. This is within the range of values expected for this region, and supports the use of the CRS ^{210}Pb dating model (Appleby & Oldfield 1983). Fig. 11 shows both the CRS and CIC model ^{210}Pb chronologies for core LAG 1. There is relatively little divergence between the two sets of dates, and both models indicate a mean sediment accumulation rate over the past 150 years of ca. 0.015 g cm^{-2} yr^{-1}. The CRS model indicates episodes of accelerated sedimentation around 1900, and 1968-1975. The CRS model chronology is given in Table 10.

The ^{137}Cs and ^{241}Am activities both have well defined peaks at 4.25 cm. Assuming that these profiles reflect atmospheric fall out this level should be dated to ca. 1963. Fig. 10 shows that date is in quite good agreement with the ^{210}Pb chronology. ^{210}Pb indicates that the 1954 onset of ^{137}Cs and ^{241}Am fall out should occur at ca. 7 cm. There is no detectable ^{241}Am beneath this level. There are, however, significant ^{137}Cs concentrations down to the ^{210}Pb equilibrium level, indicating once again the extent to which ^{137}Cs diffusion occurs.

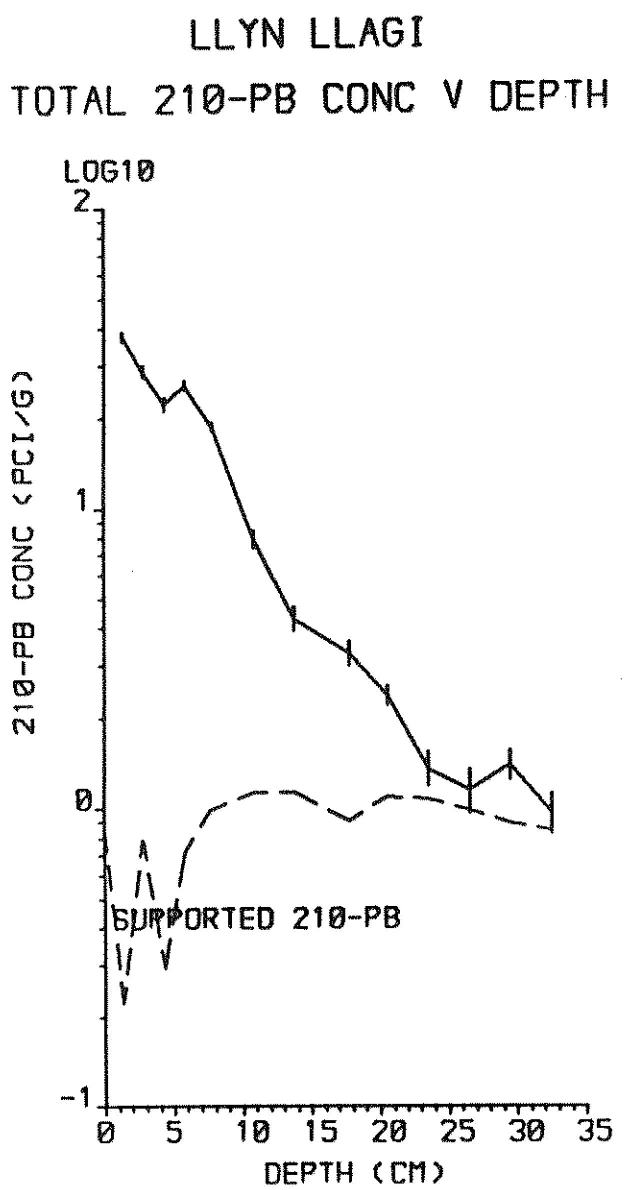
The radioisotope data (Table 9) shows that sediments in the top 5 cm have low ^{226}Ra and ^{40}K activities, and may indicate a change of sediment composition over the last 20 years.

4.1.3 Diatoms and pH reconstruction

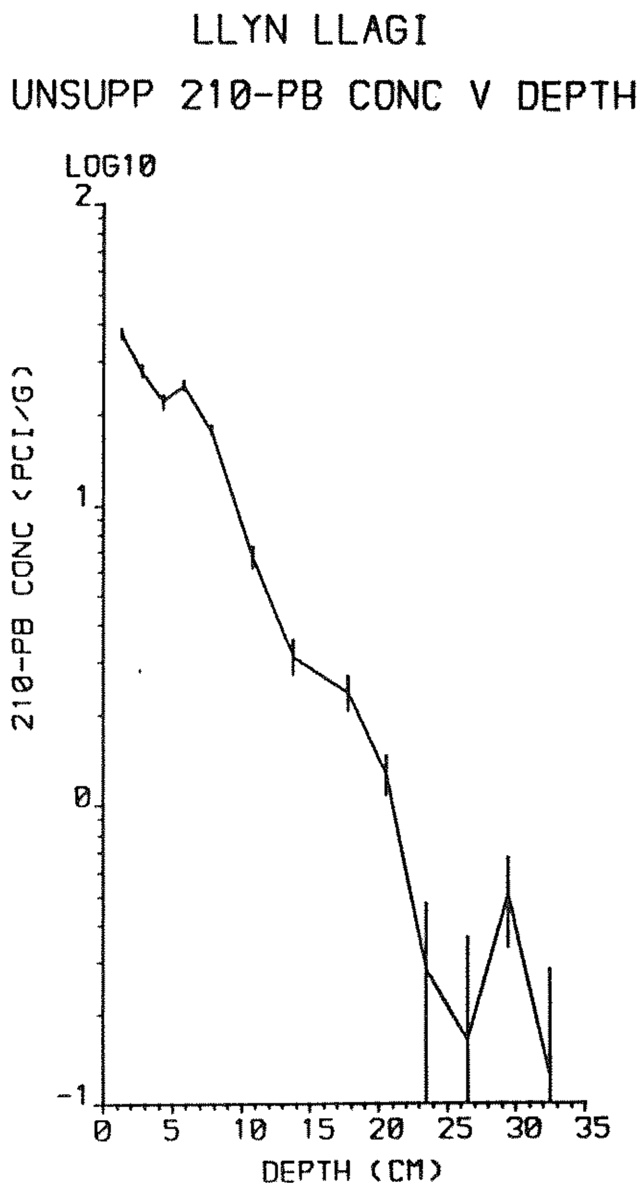
Diatoms were analysed from the uppermost 61 cm of core LAG 1. The top 22 cm includes the ^{210}Pb dated portion of the core. A summary diagram of the relative abundance of major taxa in the Llyn Llagi sediments is shown in Fig. 12. Diagrams showing the stratigraphy of all taxa are included in



7. Profiles of variation in dry weight, wet density and loss - on - ignition for the Llyn Llagi core



8. Total ^{210}Pb profile for the Llyn Llagi core



9. Unsupported ^{210}Pb profile for the Llyn Llagi core

Table 6. ^{210}Pb Data for Core Llagi 1.

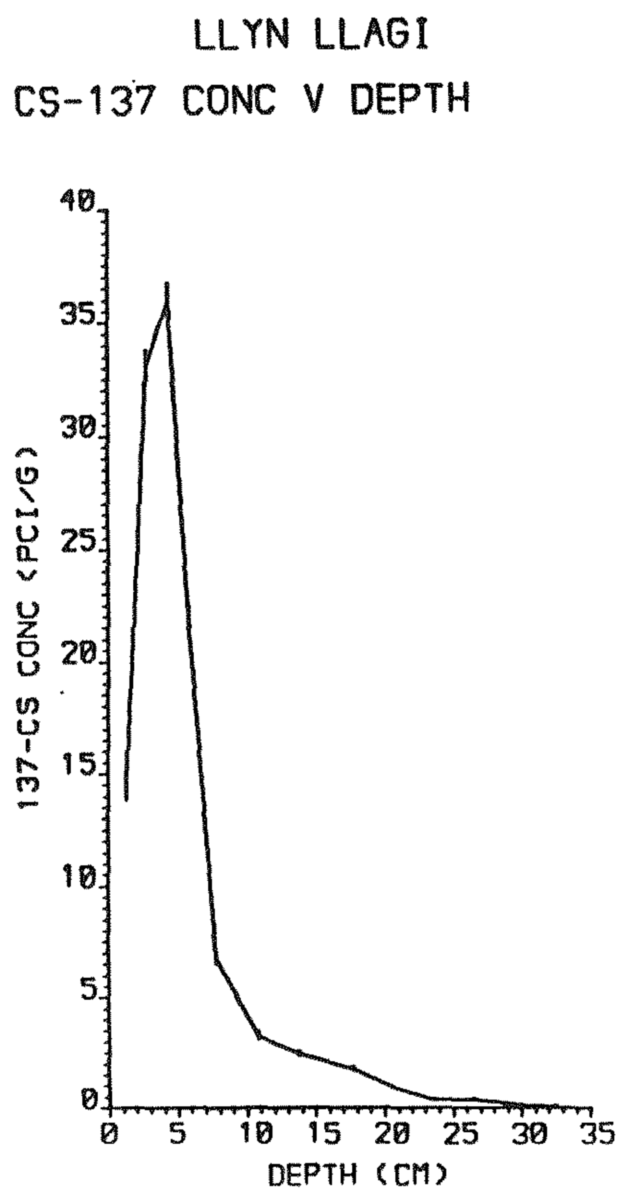
Depth cm	Dry Mass g cm^{-2}	^{210}Pb Concentration Total pCi g^{-1}	Unsupported pCi g^{-1}	Standard Errors Concent. Total	Uns.	^{226}Ra concentration pCi g^{-1}	+/-
1.25	0.0685	37.44	37.22	1.53	1.57	0.22	0.34
2.75	0.1837	28.57	27.79	1.38	1.41	0.78	0.31
4.25	0.3087	22.28	21.99	1.27	1.30	0.29	0.27
5.75	0.4334	25.56	24.86	1.03	1.05	0.70	0.22
7.75	0.6101	18.69	17.69	0.69	0.71	1.00	0.16
10.75	0.9386	7.82	6.69	0.57	0.60	1.13	0.18
13.75	1.2815	4.25	3.12	0.40	0.42	1.13	0.14
17.75	1.7462	3.26	2.35	0.30	0.32	0.91	0.10
20.50	2.0741	2.36	1.27	0.19	0.20	1.09	0.07
23.50	2.4614	1.35	0.28	0.18	0.19	1.07	0.07
26.50	2.8792	1.14	0.16	0.19	0.20	0.98	0.07
29.50	3.2684	1.39	0.50	0.16	0.17	0.89	0.06
32.50	3.6849	0.96	0.12	0.15	0.16	0.84	0.06

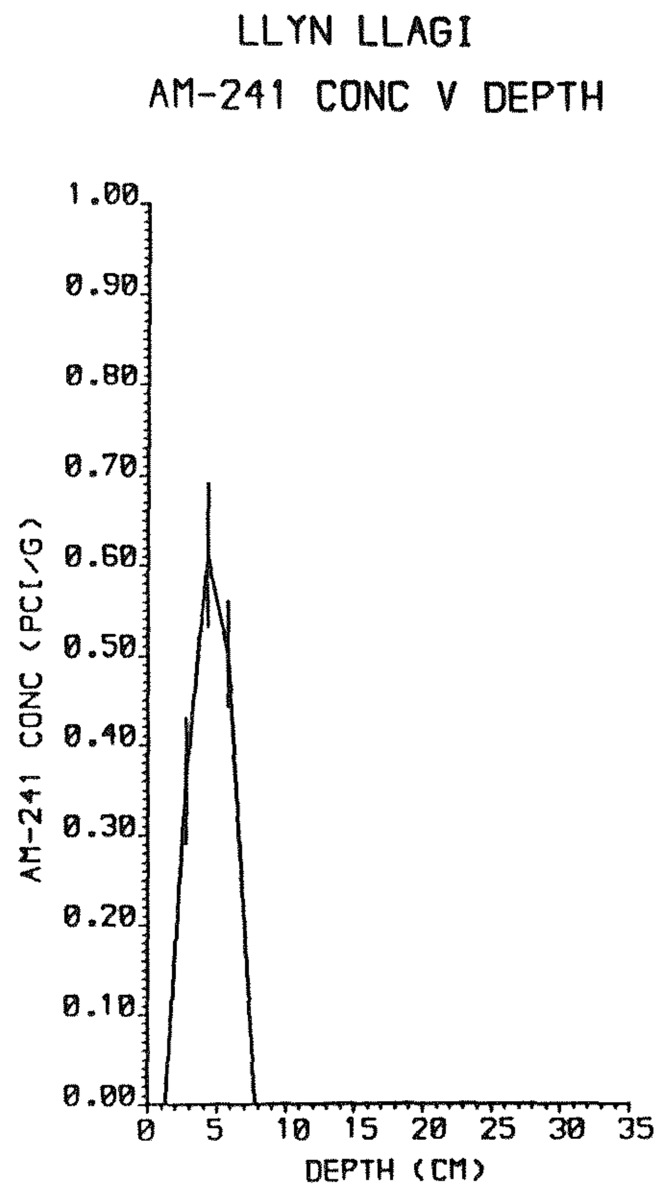
Table 7. ^{137}Cs data for Core Llagi 1

Depth cm	Dry Mass g cm^{-2}	^{137}Cs concentration pCi g^{-1}	+/-	Cumulative ^{137}Cs pCi cm^{-2}	+/-	Fract
1.25	0.0685	14.42	0.62	0.99	0.07	0.054
2.75	0.1837	32.98	0.80	3.57	0.17	0.196
4.25	0.3087	35.95	0.80	7.88	0.29	0.433
5.75	0.4334	21.95	0.55	11.42	0.36	0.628
7.75	0.6101	6.74	0.26	13.69	0.39	0.753
10.75	0.9386	3.25	0.21	15.26	0.40	0.840
13.75	1.2815	2.43	0.15	16.23	0.41	0.893
17.75	1.7462	1.78	0.11	17.20	0.42	0.946
20.50	2.0741	0.95	0.06	17.64	0.42	0.970
23.50	2.4614	0.39	0.05	17.88	0.42	0.983
26.50	2.8792	0.37	0.06	18.04	0.42	0.992
29.50	3.2684	0.16	0.04	18.14	0.42	0.998
32.50	3.6849	0.07	0.04	18.18	0.42	1.000

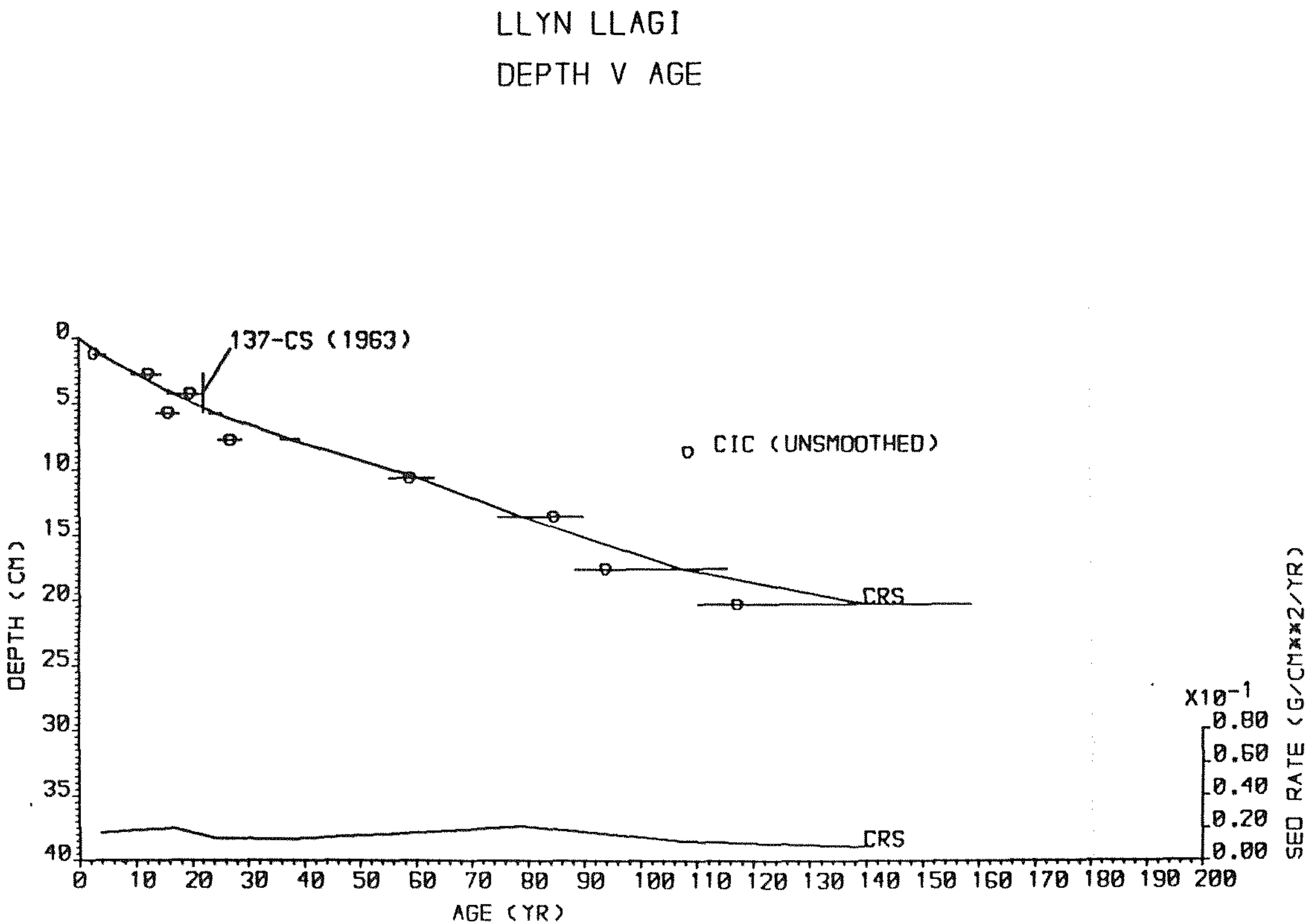
Table 8. ^{241}Am data for Core Llagi 1

Depth cm	Dry Mass g cm^{-2}	^{241}Am concentration pCi g^{-1}	+/-	Cumulative ^{241}Am pCi cm^{-2}	+/-	Fract
1.25	0.0685	0.00	0.00	0.00	0.00	0.000
2.75	0.1837	0.36	0.07	0.02	0.00	0.106
4.25	0.3087	0.61	0.08	0.08	0.01	0.418
5.75	0.4334	0.50	0.06	0.15	0.01	0.773
7.75	0.6101	0.00	0.00	0.19	0.02	1.000
10.75	0.9386	0.00	0.00	0.19	0.02	1.000
13.75	1.2815	0.00	0.00	0.19	0.02	1.000
17.75	1.7462	0.00	0.00	0.19	0.02	1.000
20.50	2.0741	0.00	0.00	0.19	0.02	1.000
23.50	2.4614	0.00	0.00	0.19	0.02	1.000
26.50	2.8792	0.00	0.00	0.19	0.02	1.000
29.50	3.2684	0.00	0.00	0.19	0.02	1.000
32.50	3.6849	0.00	0.00	0.19	0.02	1.000





10. ^{137}Cs profile for the Llyn Llagi core



11. CRS and CIC ^{210}Pb age/depth chronology for the Llyn Llagi core

Table 9. Other radioisotope data for Core Llagi 1.

Depth cm	^{226}Ra	^{238}U	^{235}U pCi g^{-1}	^{228}Ac	^{228}Th	^{40}K
1.25	0.22	0.00	0.00	2.60	0.00	1.78
2.75	0.78	0.00	0.46	0.47	1.28	4.89
4.25	0.29	0.00	0.24	0.00	0.00	3.31
5.75	0.70	0.10	0.19	0.53	0.92	9.75
7.75	1.00	0.02	0.01	0.69	0.06	12.10
10.75	1.13	0.39	0.25	0.25	0.00	9.12
13.75	1.13	0.34	0.08	0.16	0.75	12.50
17.75	0.91	0.55	0.16	0.93	0.79	11.74
20.50	1.09	0.81	0.15	0.62	0.40	12.83
23.50	1.07	0.70	0.17	0.71	1.16	12.40
26.50	0.98	0.73	0.20	0.78	0.52	12.08
29.50	0.89	0.47	0.13	0.71	1.06	11.98
32.50	0.84	0.31	0.13	0.67	1.07	12.33

Table 10. CRS Model ^{210}Pb chronology

Depth	Dry Mass	Cumul. Unsupp. ^{210}Pb	Chronology			Sedimentation Rate		
			Date	Age	Std.			Std. Error
cm	g cm^{-2}	pCi cm^{-2}	AD	Yr	Error	g cm^{-2}	cm yr^{-1}	%
0.00	0.0000	21.17	1985	0				
1.00	0.0548	19.30	1982	3	1	0.0174	0.262	5.2
2.00	0.1261	17.07	1978	7	2	0.0182	0.248	5.7
3.00	0.2045	14.95	1974	11	2	0.0191	0.237	6.3
4.00	0.2879	13.07	1970	15	2	0.0195	0.236	7.0
5.00	0.3710	11.23	1965	20	2	0.0167	0.198	6.6
6.00	0.4555	9.48	1959	26	2	0.0136	0.156	6.1
7.00	0.5438	7.71	1953	32	2	0.0132	0.139	6.4
8.00	0.6375	6.22	1946	39	2	0.0132	0.129	7.0
9.00	0.7470	4.90	1938	47	3	0.0146	0.137	8.7
10.00	0.8565	3.86	1930	55	3	0.0160	0.146	10.3
11.00	0.9672	3.08	1923	62	3	0.0174	0.155	11.9
12.00	1.0815	2.54	1917	68	4	0.0188	0.166	13.6
13.00	1.1958	2.10	1911	74	4	0.0203	0.177	15.3
14.00	1.3105	1.72	1904	81	5	0.0207	0.180	17.1
15.00	1.4267	1.38	1897	88	6	0.0183	0.158	19.6
16.00	1.5429	1.10	1890	95	7	0.0159	0.137	22.1
17.00	1.6591	0.89	1883	102	8	0.0135	0.116	24.6
18.00	1.7760	0.68	1875	110	10	0.0115	0.097	27.0
19.00	1.8952	0.47	1863	122	13	0.0104	0.087	29.1
20.00	2.0145	0.33	1851	134	17	0.0093	0.076	31.2

^{210}Pb Flux = 0.66 +/- 0.02 pCi cm^{-2}
90% Equilibrium Depth = 13.1 cm. or 1.21 g cm^{-2}
99% Equilibrium Depth = 21.5 cm. or 2.20 g cm^{-2}

Appendix A.

The diatom assemblage in the basal 40 cm of analysed sediments is dominated by acidophilous and circumneutral periphytic diatoms including the dominant Achnanthes minutissima and moderate percentages of Eunotia veneris, Anomoeoneis vitrea, Tabellaria flocculosa and Fragilaria virescens. Alkaliphilous taxa are present in very low percentages. This flora is most similar to the early flora of Llyn y Bi (Fritz et al. 1987) although Achnanthes minutissima is more strongly dominant in Llyn Llagi in comparison with Llyn y Bi. The absence of planktonic diatom taxa and the low percentage of alkaliphilous taxa indicates that Llyn Llagi has been moderately acidic throughout the period represented by the analysed sediments.

Beginning at 20 cm (ca. 1851) precentages of the circumneutral taxon Achnanthes minutissima begin to decline, with subsequent increases in the acidophilous Frustulia rhomboides, Tabellaria flocculosa, Eunotia veneris and Achnanthes marginulata, the circumneutral Anomoeoneis vitrea, and the first appearance of Tabellaria quadriseptata. The greatest change in the diatom assemblage occurs in the uppermost 6 cm (post-1960), with the tremendous expansion of Tabellaria quadriseptata and smaller increases in the relative abundance of Navicula heimansii and Melosira lirata.

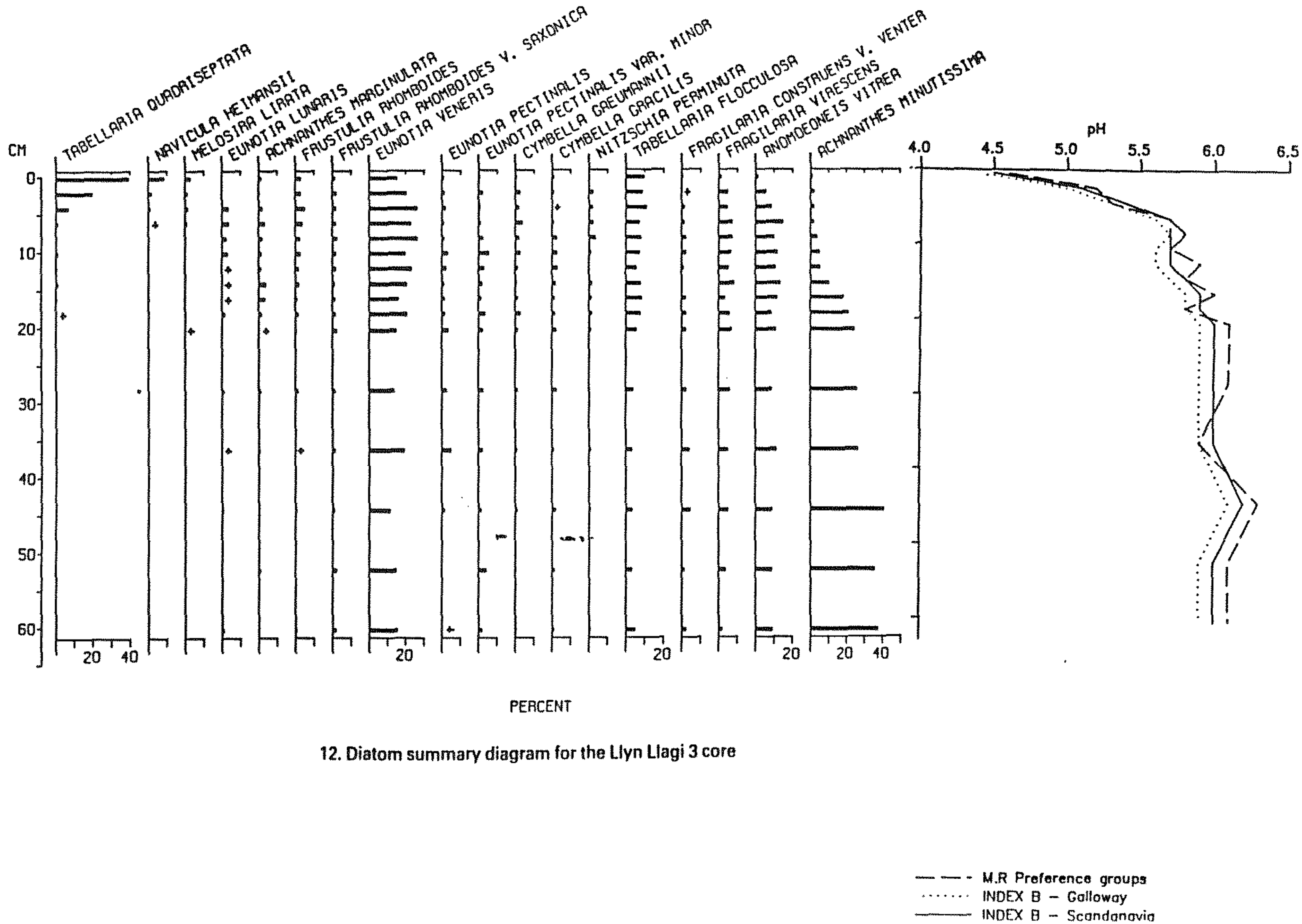
pH reconstruction using index B-Scandinavia, index B-Galloway, and multiple regression of pH groups (Galloway) (Flower 1986) indicate a fairly stable pH of 5.9 - 6.2 below 20 cm (pre-1850). The index B reconstruction models suggest a slight decline of 0.3 pH units between 20 and 6 cm, associated with the decline of Achnanthes minutissima. The multiple regression model suggests no net decline until 12 cm (1917). All 3 reconstruction techniques show a sharp drop in lakewater pH above 6 cm (1959), with a pH declining over 1.1 units to the surface. Reconstructed pH values at the sediment surface range from 4.4 - 4.6. The multiple regression of pH preference groups model comes closest to predicting the present mean pH of 4.6, but all model predictions fall within the present range of lakewater pH (4.0 - 5.2).

These data suggest that Llyn Llagi may have undergone a slight (0.3 units) decline in lakewater pH beginning late in the 19th century (index B models) or early in the 20th century (multiple regression model). Major acidification of the lake, marked by the expansion of Tabellaria quadriseptata, however, did not occur until after 1960 and continued sharply until the present, despite the post-1970 decline in sulphur emissions. The late onset of major acidification at Llyn Llagi suggest a small source of alkalinity in the lake catchment capable of neutralising acidic inputs.

4.1.4 Sediment chemistry

Major cations

All the Welsh lakes examined so far have had changes in their sediment constitution along the core. In comparison the changes in Llyn Llagi are small. The loss on ignition is fairly constant and the dry weight only drops a little above 30 cm (Fig. 7).



12. Diatom summary diagram for the Llyn Llagi 3 core

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The sodium, magnesium and potassium concentrations also change little. They decrease above 20 cm (Fig. 13). The sodium and magnesium concentrations also increase a little from the base of the core to 30 cm but this disappears when the concentrations are expressed per gramme of minerals (Fig. 14).

As the sedimentary calcium concentrations are fairly constant there are no large changes in the basic sediment constitution in the Llyn Llagi core. The trace metal concentration-depth profiles should therefore reflect changes in the level of contamination.

Trace metals

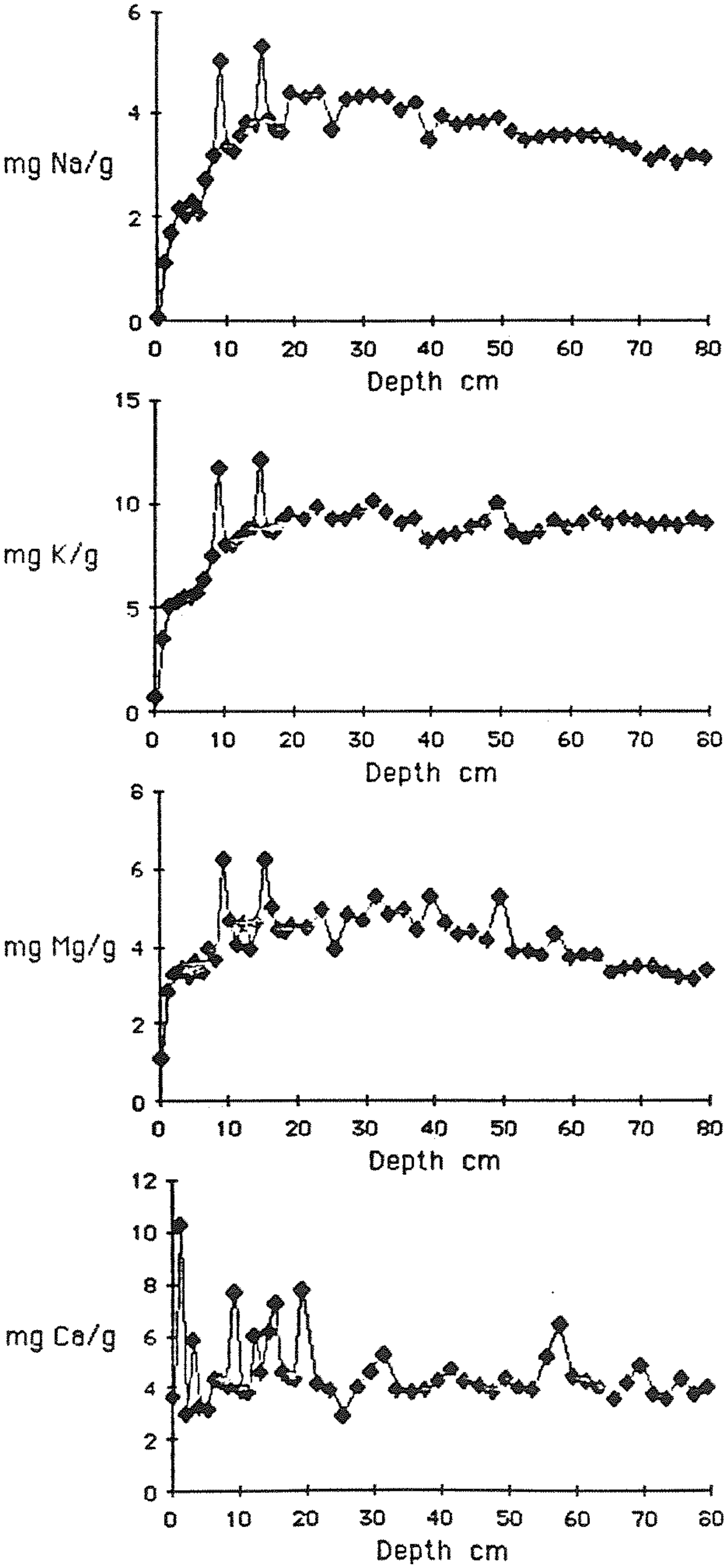
There is lead and zinc contamination above 24 cm and copper above 22 cm (Fig. 15 & 16). The nickel concentration drops above 20 cm and so shows no sign of contamination (Fig. 16). The 24 cm depth for the start of the contamination is confirmed by plots of the trace metal concentrations against the major cations (Patrick et al. 1987) and also when the concentrations are expressed per gramme minerals (Fig. 17). This depth is a little below the dated part of the core but it extrapolates to 1800 A.D. (assuming 0.076 cm yr^{-1}, Table 10). The contamination as in all the other Welsh lakes is probably from the atmosphere. Contamination from wastewater sources in these remote lakes is very unlikely and there has been no mining activity in the catchment.

The total amount of zinc and lead accumulated in the Llyn Llagi core since 1900 is compared to that in other Welsh lakes in Table 11. Llyn Berwyn is omitted as there is a hiatus in the core and it is not possible to construct a reliable chronology. The lakes divide into two groups with either a lower or higher dry mass accumulation. Llyns Gynon and Hir in central Wales and Llagi in the north-west have higher accumulation rates than Dulyn, Eiddew Bach and Llyn y Bi. The lakes with higher accumulation rates have also higher amounts of lead and zinc. As the position of the lake does not influence the amount of lead and zinc accumulation it seems reasonable to assume that there is roughly the same contamination flux of trace metals from the atmosphere in central and north-west Wales.

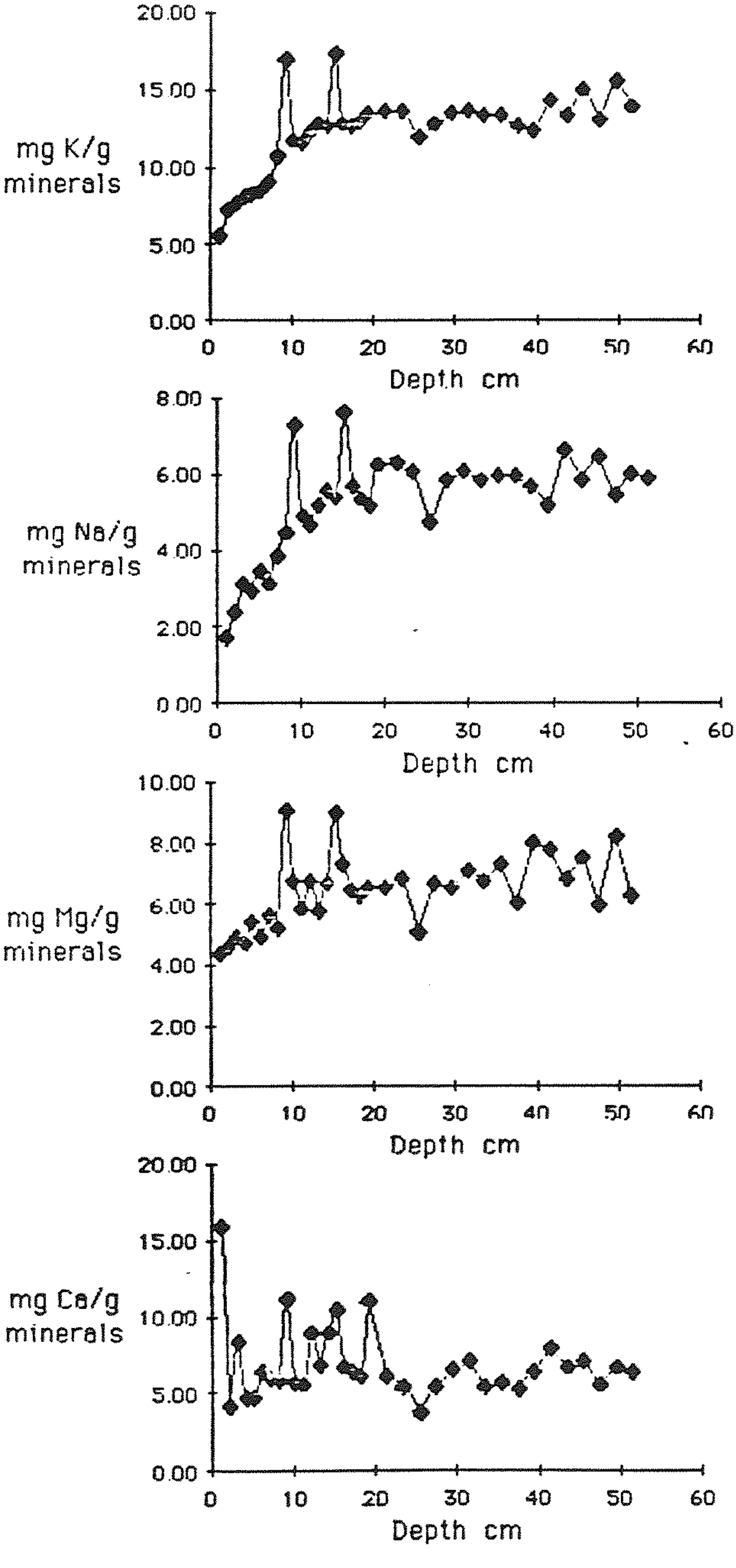
The correspondence between lower or higher amounts of trace metals with lower or higher sediment accumulation rates implies that the efficiency of trapping of the trace metals is controlled by the amount of sediment deposited. When there is a low amount there is not enough material falling through the water column to carry with it all the trace metals. The sedimentation efficiency is thus low. Greater amounts of material are needed to sediment out most of the extra trace metals derived from the atmosphere. If the sedimentary record is to be used to construct a map of the variation of trace metal contamination from the atmosphere then lakes with sufficiently high dry mass accumulation rates will have to be used.

Sulphur

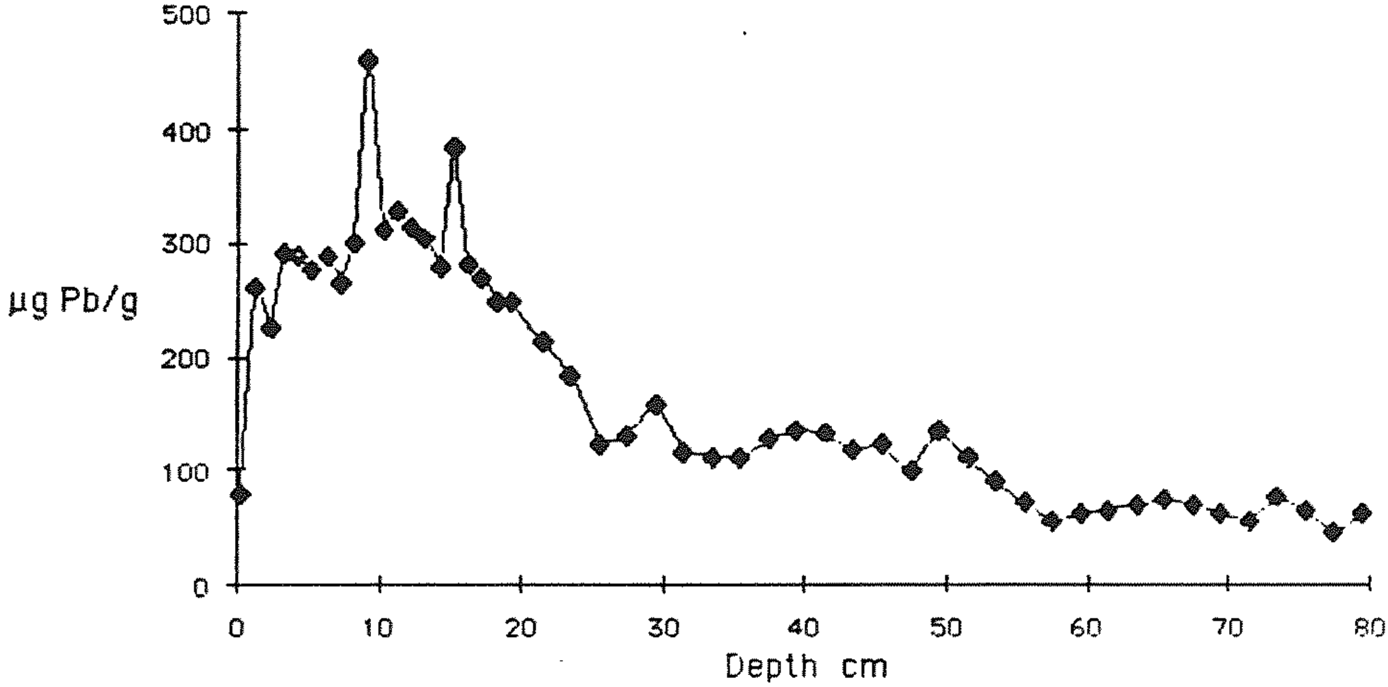
There was not enough sample for sulphur analysis

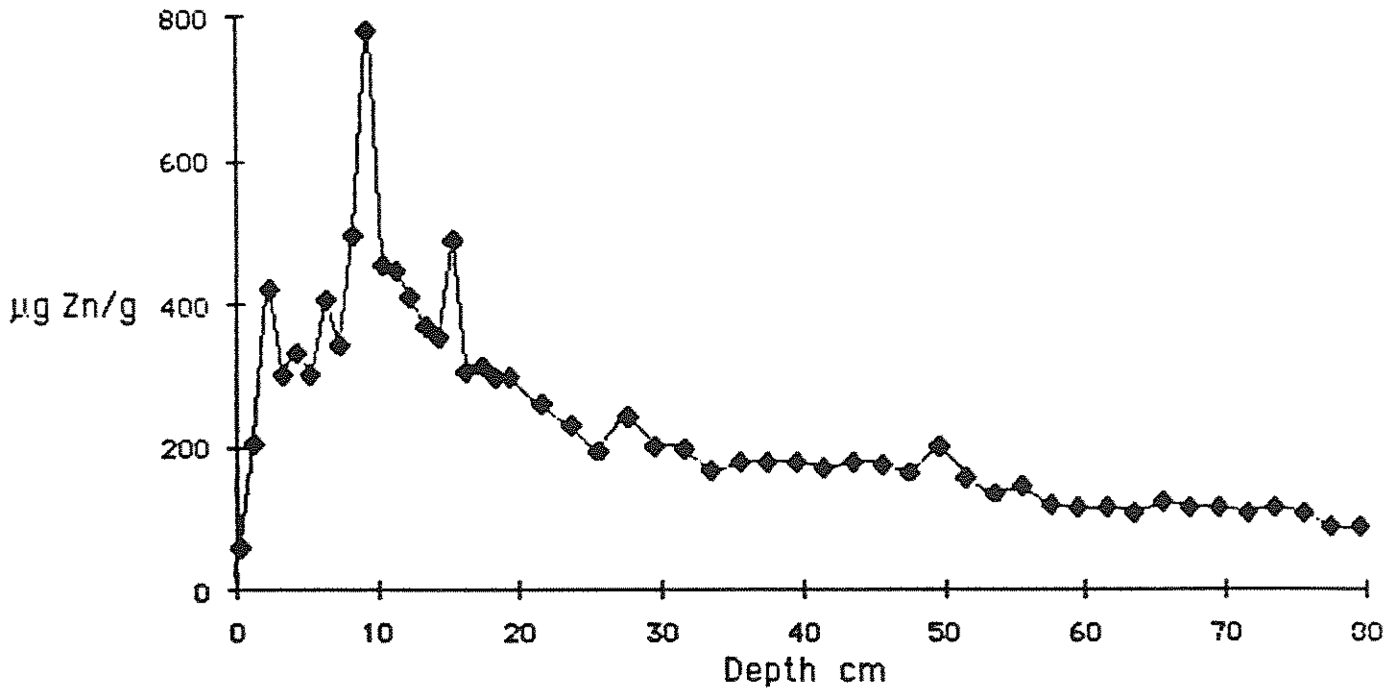


13. Variations in Na, K, Mg & Ca gdw^{-1} for the Llyn Llagi core

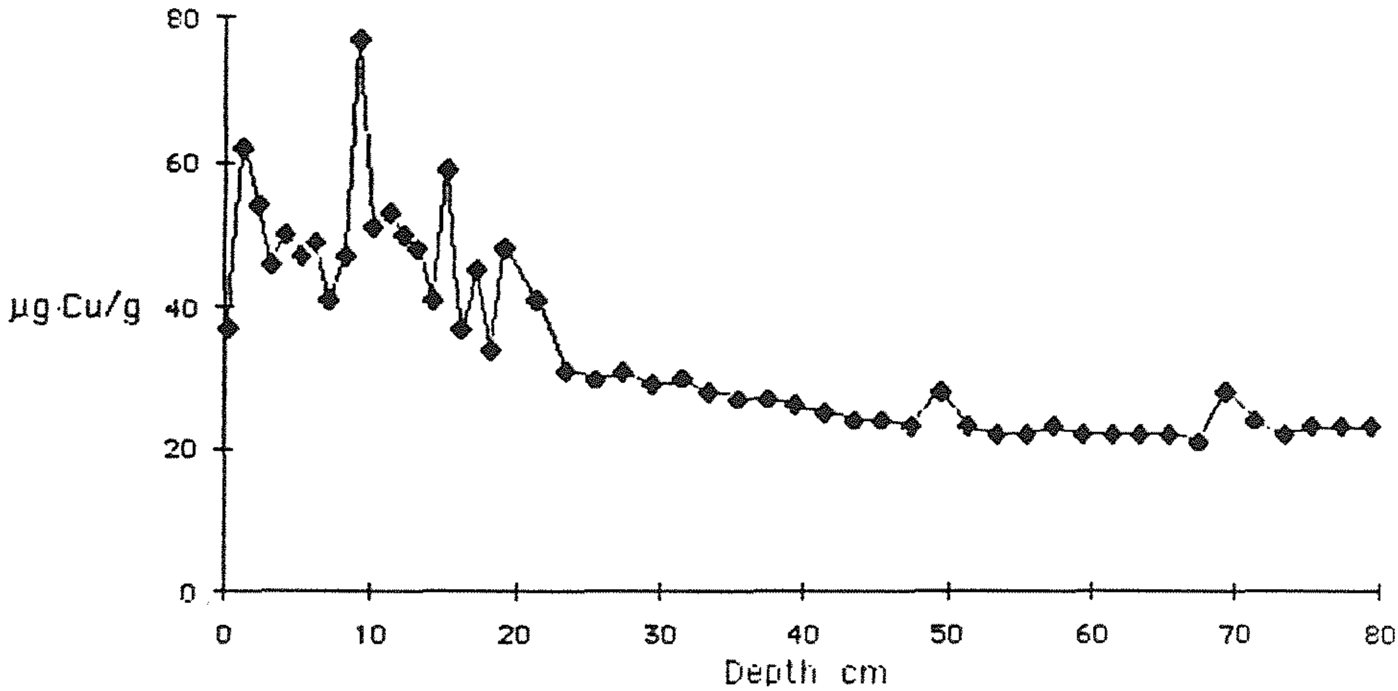


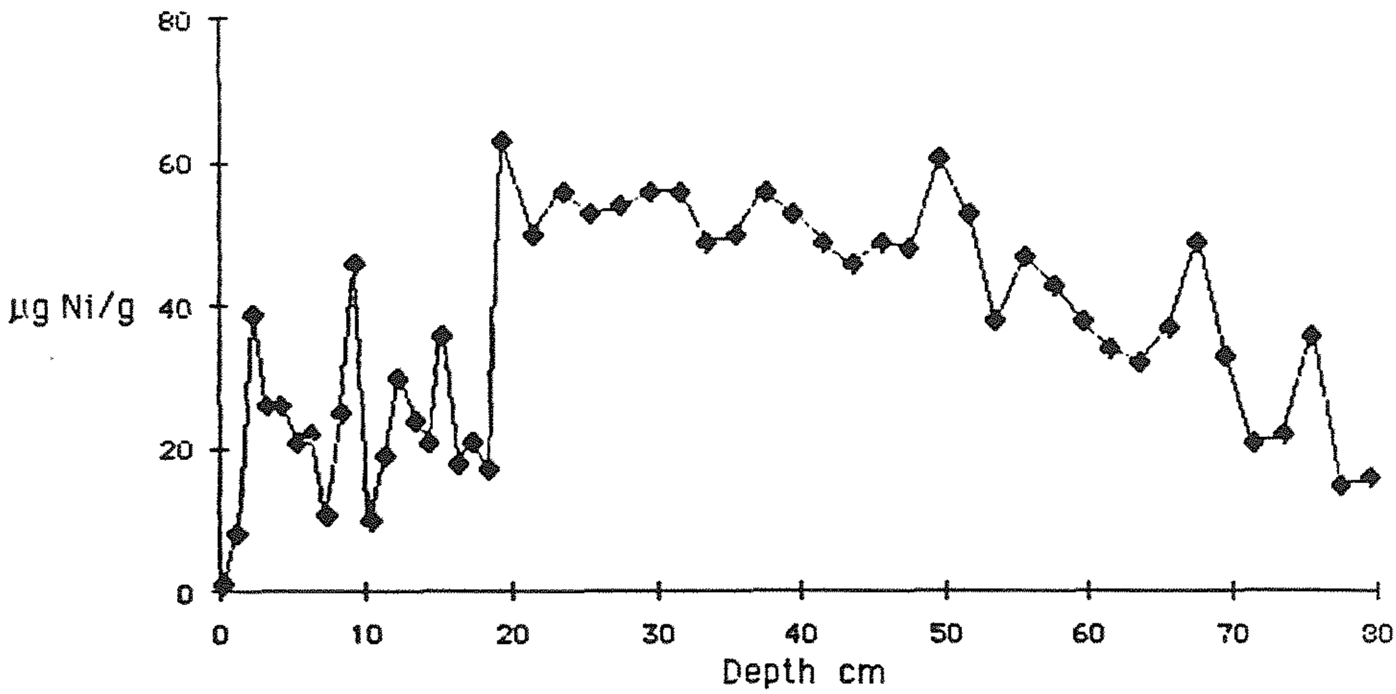
14. Variations in Na, K, Mg & Ca per gram mineral dry weight for the Llyn Llagi core



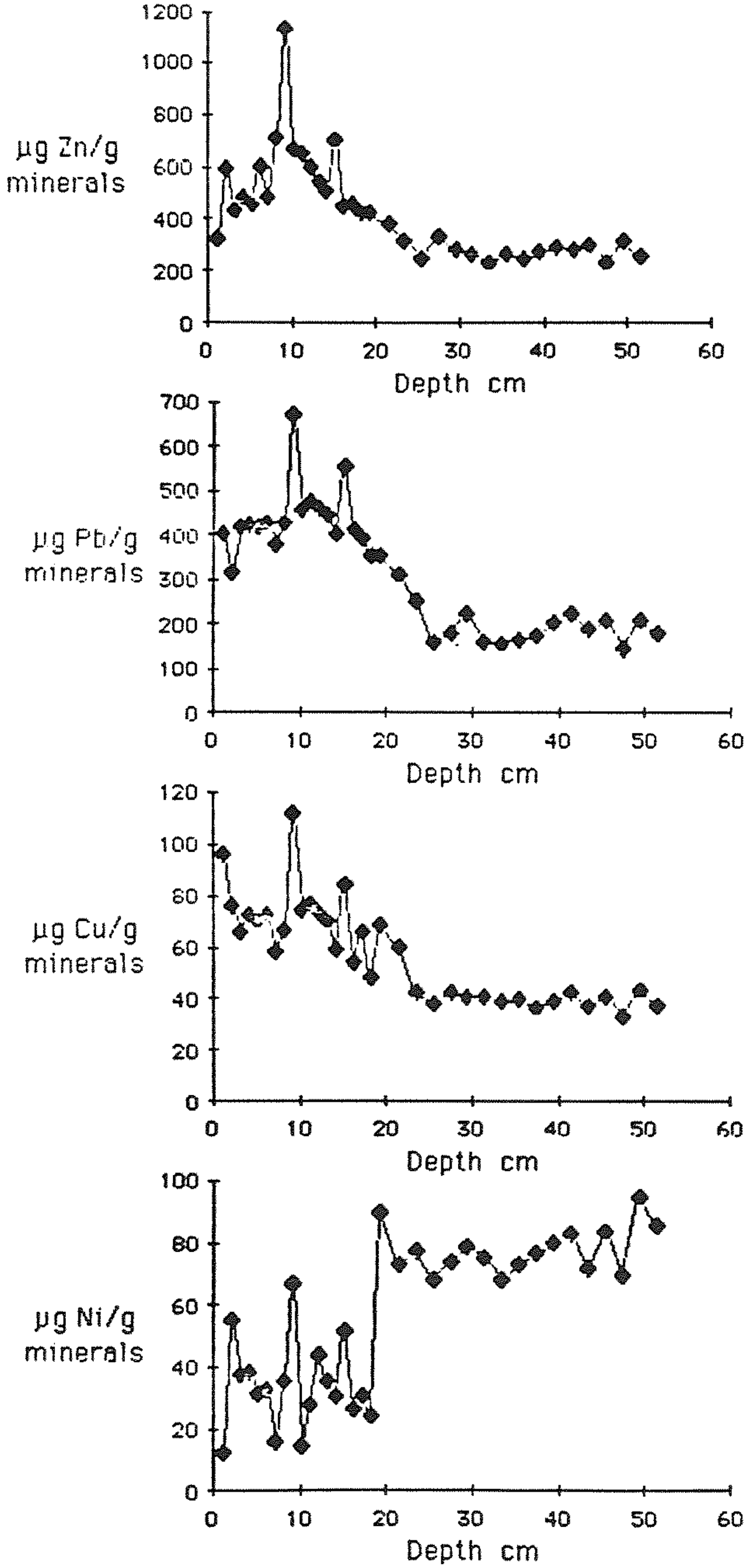


15. Variations in Pb & Zn gdw^{-1} for the Llyn Llagi core





16. Variations in Ni & Cu gdw^{-1} for the Llyn Llagi core



17. Variation of trace metal concentrations with depth for Llyn Llagi expressed as per gram minerals

Table 11 Comparison of the amounts of sedimentary lead and zinc deposited in Welsh lakes since 1900. The amount of dry sediment accumulated in the same period is also given.

Lake	Depth equivalent to 1900	Amount deposited since 1900 Zinc $mg\ m^{-2}$	Lead $mg\ m^{-2}$	Dry sediment $mg\ cm^{-2}$
Central Wales				
Gynon	16	8383	4854	2655
Hir	8	2707	1738	616
North-west Wales				
Dulyn	10	1283	728	628
Eiddew Bach	6	1681	509	600
Llagi	16	6245	4623	1543
Y Bi	5.25	677	406	250

4.1.5. Carbonaceous particles

The carbonaceous particle pattern for Llyn Llagi, illustrating the number of particles per gram dry sediment is given in Fig. 18 & Table 12. It shows the presence of carbonaceous particles in small numbers at a depth of 22 cm (ca. 1800 AD). A smooth rise in particles then occurs to 9 cm (1940's) subsequently followed by a very steep rise in concentration to the top.

The pattern for the carbonaceous particle count in terms of the organic content of dry sediment is given in Fig. 19. Carbonaceous particle patterns expressed in terms of the organic fraction of sediment (using LOI) may be considered to be more precise than expression per gram dry weight as the supply of organic material to the sediment tends to be more uniform over time than the input of mineral matter, which can vary widely. Using LOI as a base has the effect of 'smoothing' the soot pattern, and this can be observed for Llyn Llagi. Otherwise, the pattern is very similar to that in Fig. 18.

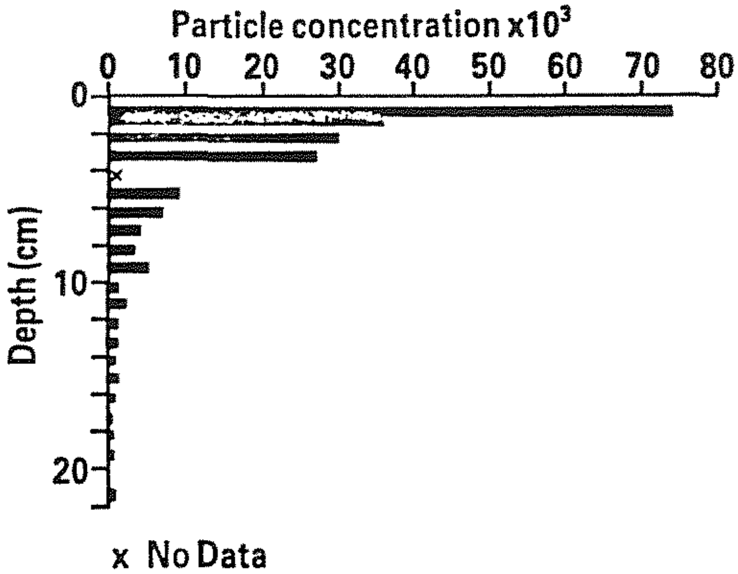
4.1.6 Magnetic Measurements

Sediments from Llyn Llagi Core 1 were packed into previously screened styrene pots and subject to the following sequence of magnetic measurements:-

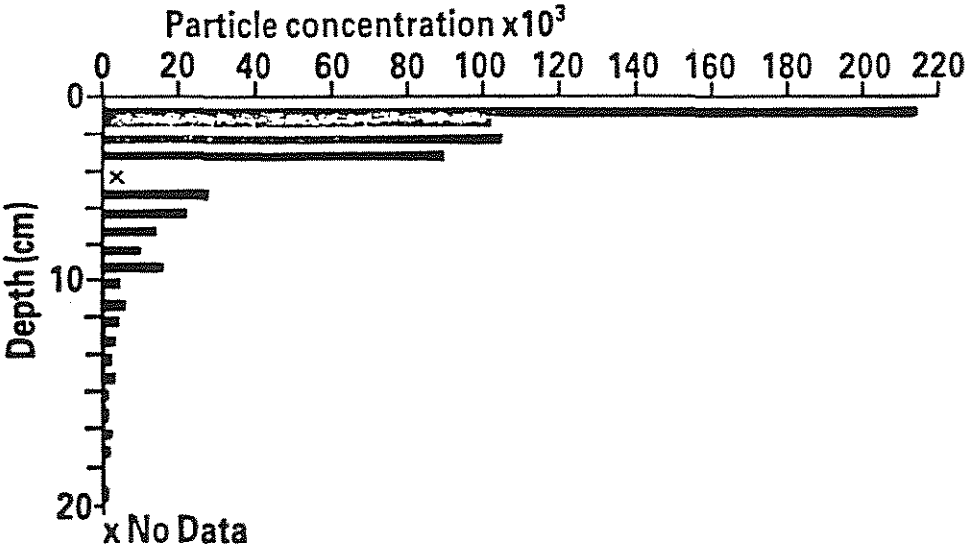
1. Anhysteritic Remnanent Magnetization (ARM) using a Molspin AF Demagnetizer set with a peak AF field of 100mT and a DC bias of 0.04mT. Some of the measurements between 11 and 22 cm were too close to the instrumental noise level to encourage confidence in between sample variations in calculated values.

2. 'Saturation' Isothermal Remanent Magnetization (SIRM) using a Molspin Pulse Magnetizer with a maximum DC field of 850mT.

3. Isothermal Remanence (IRM) measured at each step in a sequence of reverse field DC demagnetization at -20mT, -40mT, -100mT and -300mT for samples from 0 - 30 cm.



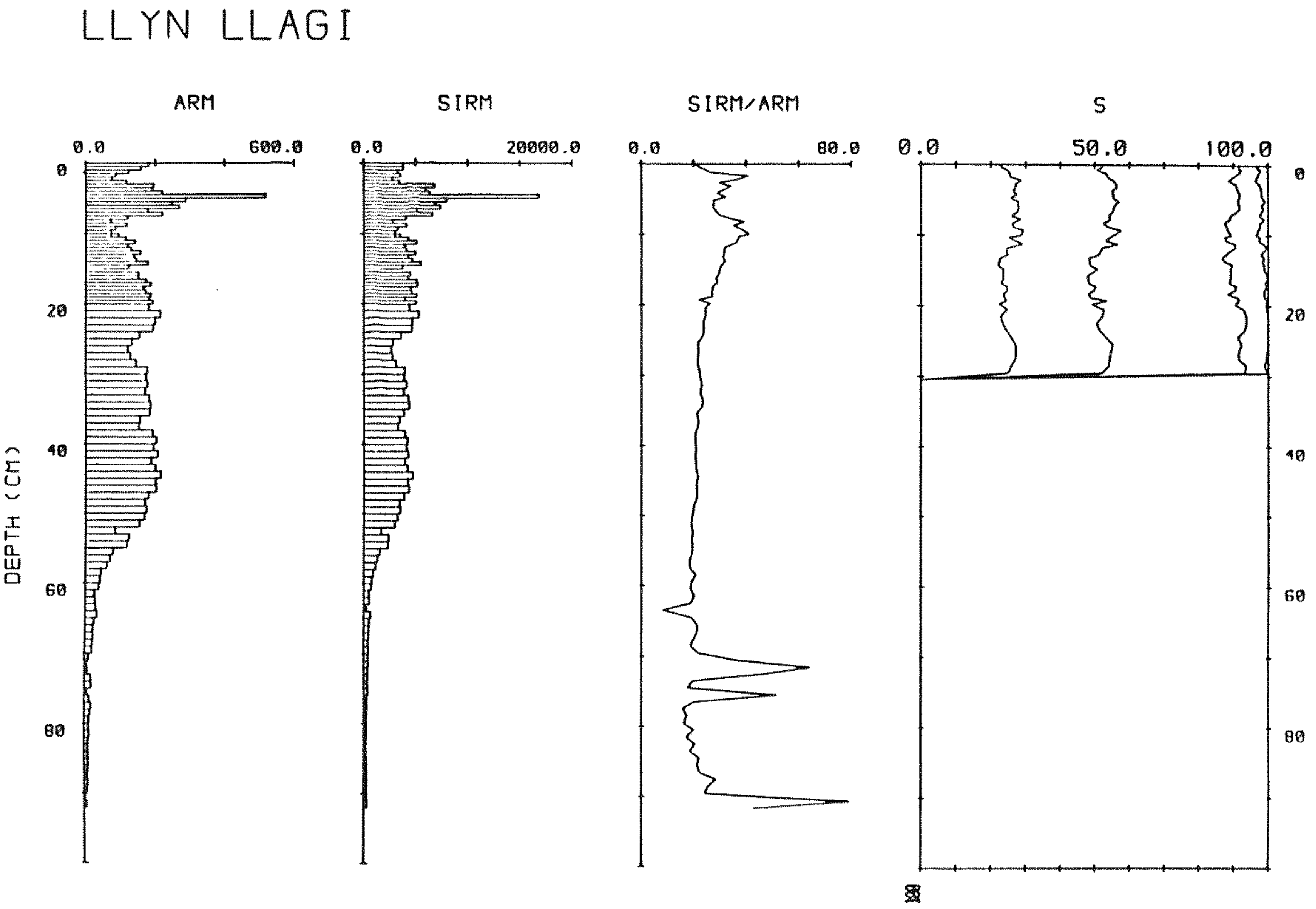
18. Carbonaceous particle record gdw⁻¹ for the Llyn Llagi core



19. Carbonaceous particle record per gram mineral dry weight for the Llyn Llagi core

Table 12: Carbonaceous particle analysis for Llyn Llagi 1

Depth (cm)	No. Carbonaceous Particles per g dry sed x 10^3	per g organic content x 10^3
0.0 - 0.5	73.74	214.1
1.0 - 1.5	36.18	102.3
2.0 - 2.5	30.23	104.5
3.0 - 3.5	37.74	89.6
4.0 - 4.5	---	----
5.0 - 5.5	9.23	27.7
6.0 - 6.5	7.28	22.4
7.0 - 7.5	4.23	14.4
8.0 - 8.5	2.64	9.0
9.0 - 9.5	4.61	14.7
10.0 - 10.5	1.30	4.1
11.0 - 11.5	1.59	5.1
12.0 - 12.5	0.88	2.8
13.0 - 13.5	0.69	2.2
14.0 - 14.5	0.54	1.8
15.0 - 15.5	0.81	2.7
16.0 - 16.5	0.34	1.1
17.0 - 17.5	0.07	0.2
18.0 - 18.5	0.28	0.9
19.0 - 19.5	0.20	0.7
21.0 - 22.0	0.13	0.4
25.0 - 26.0	0	0



20. ARM, SIRM and SIRM/ARM versus depth, 0-92 cm. Reverse field ratios (see text) are plotted for the top 30 cm only

All remanences were measured on a Minispin Slow-speed spinner Fluxgate Magnetometer. Susceptibilities were not measured as the combination of small sample size and relatively weak magnetization made the samples unsuitable.

Fig. 20 plots the magnetic measurements for this core. The right hand graph shows reverse field ratios (IRM_{-n}/SIRM) plotted against a horizontal scale of percentage reverse-saturation. Thus 50 represents the point during DC demagnetization at which IRM is zero and 100 represents the point at which IRM/SIRM is -1.

Peak SIRM and ARM values are over an order of magnitude higher than would be expected from atmospheric deposition. Moreover, the changing magnetic concentrations do not follow patterns potentially interpretable in those terms. Below 60 cm, ARM values are low and where minimal, contribute to high and variable SIRM/ARM quotients as a result of the effects of instrumental noise. The increase in both SIRM and ARM above 60 cm leads to a consistently higher range of magnetic mineral concentrations throughout the upper part of the core. From 60 cm to ca. 12 cm, changes in concentration and in interparametric ratios are modest. Above 12 cm there are sharper fluctuations in ARM and SIRM, culminating in peak concentrations at 4.5 - 5 cm. Between 0 and 12 cm there are also greater variations in interparametric ratios indicating significant shifts in magnetic mineralogy and/or grain size. All the magnetic changes recorded in the core are probably the effect of catchment processes or changes in lake level.

4.1.7 Pollen

Fig. 21 presents a summary pollen diagram of the Llyn Llagi core. Appendix B contains the full pollen diagram.

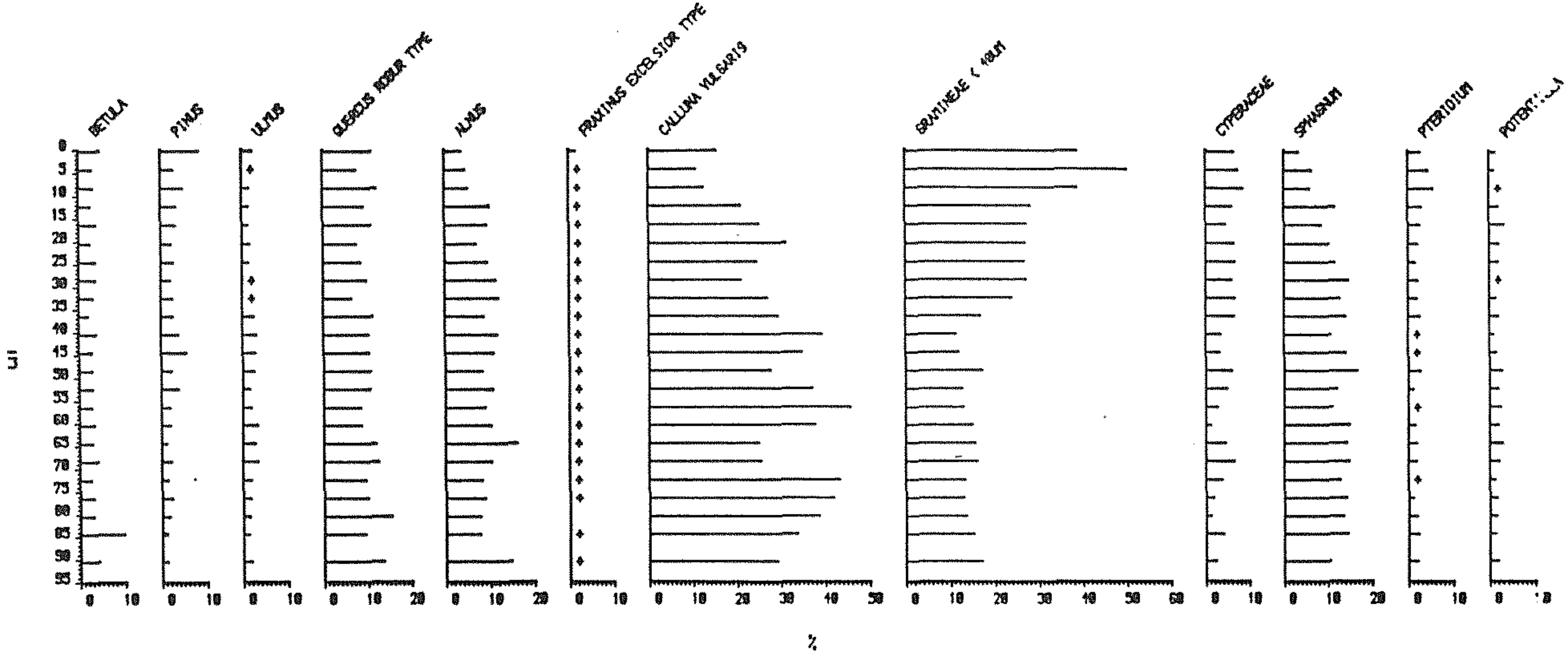
The diagram has not been zoned since only the major catchment changes will be disussed.

The pollen record indicates that a continuous sedimentary record appears to have been preserved unlike some of the other lakes studied within the project (Stevenson et al. 1987a, Stevenson et al. 1987b, Fritz et al. 1987a

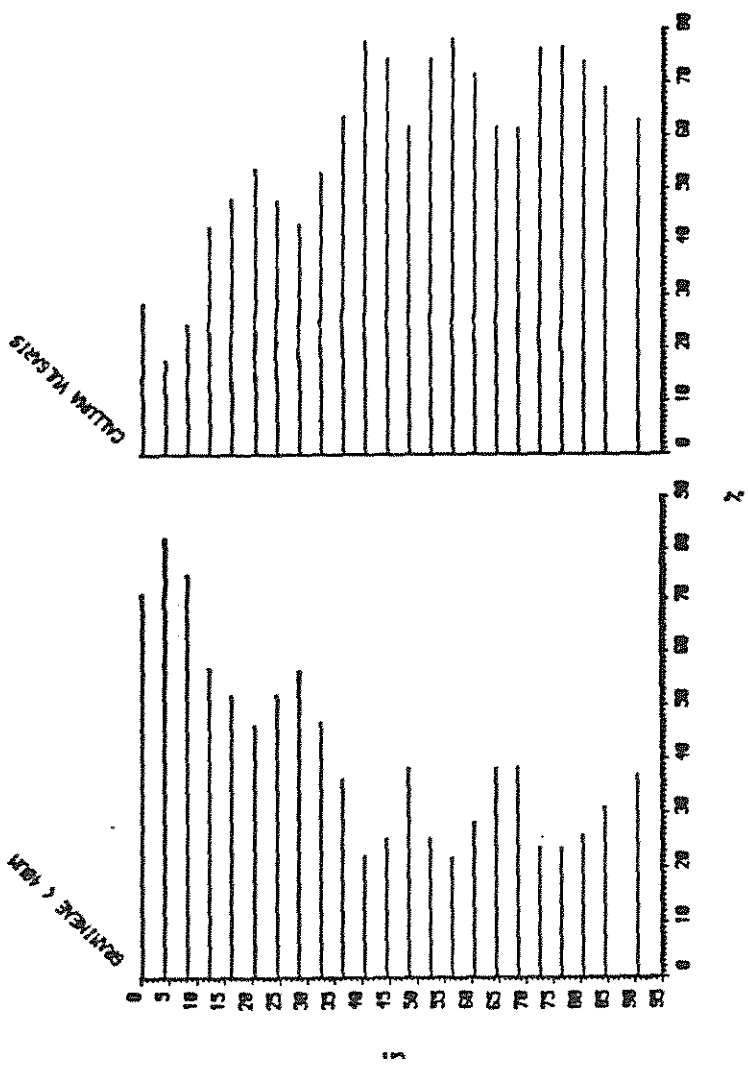
The tree spectrum reveals little change within the regional vegetation except for the normal rise in Pinus values associated with the afforestation of much of upland Wales starting in the 1900's.

The most noticeable feature of the pollen spectra derived from the catchment is the major change in the Calluna to Gramineae ratio. It can be seen that Calluna is predominant for the first half of the diagram but then undergoes a massive decline associated with a large increase in Gramineae pollen values. This change indicates that for a long period of time the catchment was dominated by an extensive Calluna vulgaris community and within the last 200- 300 years has been converted by fire and grazing to a Molinia/Nardus dominated community reflecting the present vegetational composition of the catchment.

This change from Calluna to Gramineae domination is not what would be expected under the land-use hypothesis as propounded by Krug & Frink (1983) and Rosenqvist (1980), who suggest that since upland sheep grazing has declined dramatically over the last 150 years the reverse change should be



21. Summary pollen diagram for the Llyn Llagi core. All taxa expressed as a percentage of the arboreal pollen + peatland indicators sum


CALLUNA VULGARIS

expected which is then thought to provide a mechanism to acidify the lake water.

4.2 Land use and management (2)

4.2.1 Land use

The Llyn Llagi catchment lies on acidic soils at an altitude mostly in excess of 400m. The catchment comprises unimproved moorland utilised for rough grazing. In terms of its vegetational composition (see Section 2.1.3) it may be categorised predominantly as 'grassy heath' (eg. King 1977, Ball *et al*. 1982).

In terms of the ADAS (2) land capability classification the catchment comprises land of categories H3 - 'improvements generally severely limited but of moderate or high grazing value' and H4 - 'generally not improvable and of low grazing value' (MAFF 1980).

Land immediately adjacent to the lake and below the steep cwm wall is 'enclosed' with rough dry stone walls. The date of this enclosure is unknown but the notation 'Ffridd y Llyn' on Ordnance Survey maps and the absence of enclosure Acts relating to this locality, suggests that the enclosure(s) may have been established before the more expansive moorland enclosures of the early 19th century (Bowen 1914, Dodd 1927, Morgan 1959, Thomas 1965).

According to a map produced by Hays (1963) the Llyn Llagi catchment occupied the south-east most extremity of the Nanhwynain grange of the Cistercian abbey of Aberconway. The uppermost ('mountain') wall may therefore date from as early as the late 12th century.

Within the 'enclosed' area two or three shallow drains run downslope for a short distance from the lake. The date of this 'drainage' is unknown. Only a few metres of 'drain' actually lie within the catchment.

Although 'enclosure' and 'drainage' may have represented an attempt to improve the grazing quality of the land and have inevitably affected its management (cf. Section 4.1.2), there is no evidence that the small section of the catchment involved, experienced a change in land use as a result.

The altitude, soil acidity, wetness and exposed position of the catchment determine that the land would be extremely difficult to improve. There is no evidence from documentary sources (see below), from air photographs, or on the ground to suggest that the catchment has ever supported a land use other than rough moorland grazing.

It is unreasonable to expect any attempt to have been made towards improving the acid moorland with lime. Merioneth is almost entirely devoid of limestone deposits and in the 19th century the high price of imported lime together with the cost of carriage over poor roads, ensured that it was rarely used in remoter areas (Davies 1813) (3). Contemporary farmers (P. Williams pers. comm.) and authorities (T. Rowlands pers. comm.) confirm that agricultural lime has not been applied to the catchment in living memory.

Documentary evidence (4)

The tithe maps and schedule of Beddgelert (1840) (5) only provide information on the land use of the catchment for the north-western sector, describing it as sheepwalk.

The description of the locality by Cliffe (1860) as 'a wild sequestered scene' with 'barren verdureless precipices dividing the llyns' (Llagi and Yr Adar), suggests the unimproved nature of the land.

The first and subsequent editions of the six inch ordnance survey map of the area (6) show the catchment to consist of 'rough or heathy pasture'.

The First Land Utilisation Survey six inch manuscript map of 1937 (7) places the entire catchment in the 'moorland/rough grazing category. The Second Land Utilisation Survey six inch manuscript map of 1970 (8) indicates a vegetation cover and distribution very similar to the present situation (Fig. 6).

The catchment lies within the north Snowdonia National Park region that was studied in the Moorland Change Project of Parry _et al_. 1982. Analysis of original project data (9) confirmed that the Llyn Llagi catchment has experienced no change in land use since 1887.

Non agricultural land use

Llyn Llagi lies just 2 km north and west of the major Croesor quarrying and mining region. The remains of at least two small 'excavations' can be seen on the northern slope of the catchment. However, there is no evidence from documentary sources to suggest that any mineral was ever actively exploited within the lake catchment.

4.2.2 Land management

Pastoralism

Until the mid 19th century black cattle were an important component of the pastoral economy of north Wales (Roberts 1959, Emery 1965, Hughes _et al_. 1973). Goats also ranged the hills in significant numbers (Evans 1812, Roberts 1959, Emery 1965, Hughes _et al_. 1973), as did young ponies.

Cattle were grazed on and occasionally above ffridd land in summer (refs), but at over 350 m the ffridd within the LLagi catchment was probably too high for that activity. The central issues of pastoral management in the catchment concern its utilisation for sheep grazing.

As grangeland of Aberconway abbey the lower catchment probably has a long history of sheep grazing. The Cistercians introduced sheep earlier and in larger numbers to their land than was the case on surrounding moorland. Hughes _et al_. (1973) suggest that in the 13th century Aberconway grange land supported a sheep density of some 0.6 ewe units ha^{-1} and a sheep:cattle ratio of 7.7:1.

The only quantitative data relating to sheep numbers in the vicinity of Llyn Llagi are those of the annual parish agricultural returns of Beddgelert (10). These were analysed at quinquennial intervals and are presented in Fig. 22.

Although they represent the source of information most applicable to the

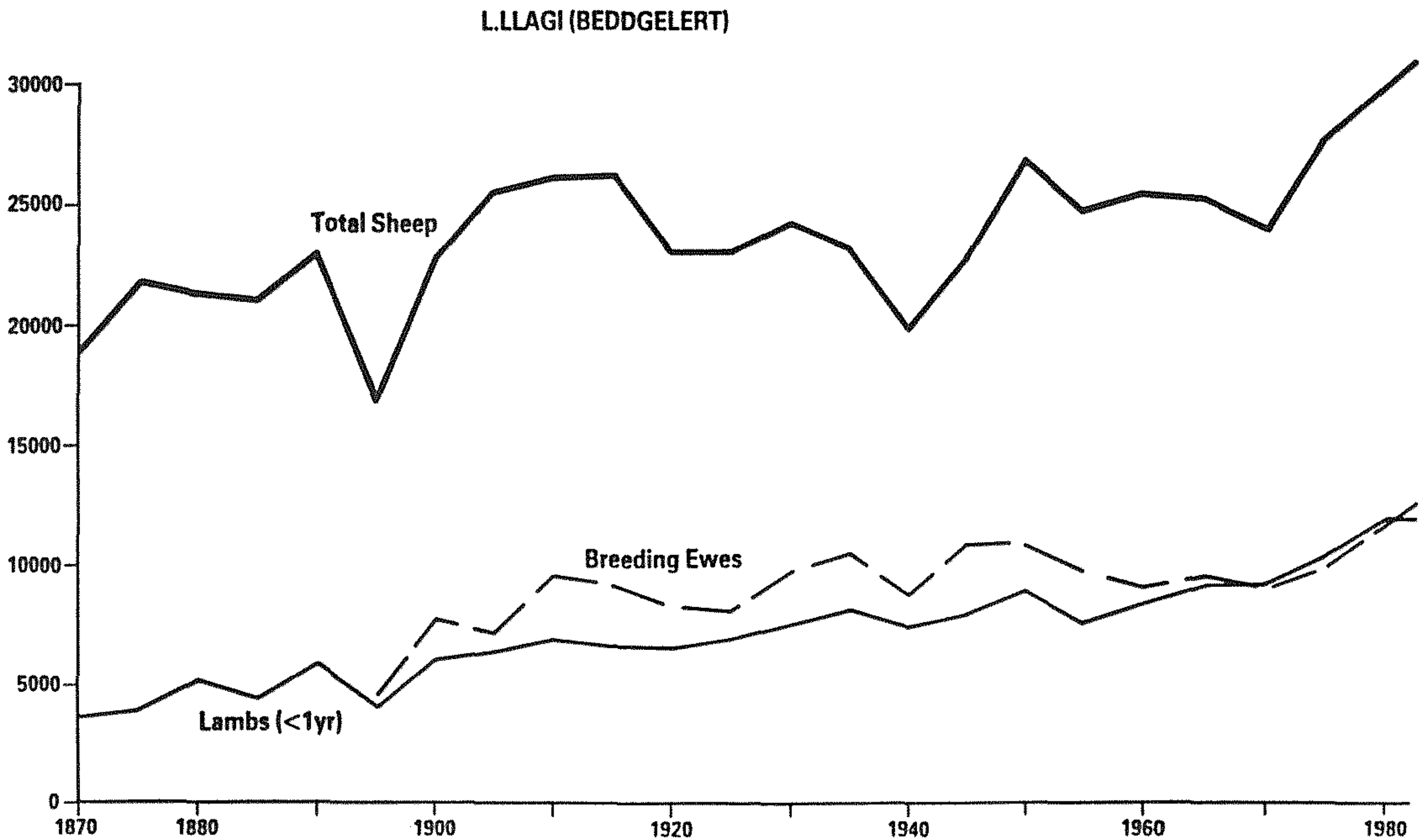


Fig. 22. Sheep numbers in Llanddwywe-is-y-Graig (1895-1983)

Llyn Llagi catchment, the spatial resolution of these data do not permit catchment-specific assertions to be drawn and their interpretation is hindered by several other constraints. In particular they take only a limited account of changes in sheep type and no account of changes in grazing regime (Patrick 1987).

Sheep numbers have fluctuated between 1867-1983 but the overall trend in the parish has been for numbers to rise, particularly at the beginning and end of this period (Fig. 22). The increasing significance of ewes and lambs at the expense of wether sheep over the last century, is also suggested from Fig. 22.

Within the Llyn Llagi catchment a broad increase in sheep numbers has been recognised in recent years (P. Williams, T. Rowlands pers. comms.).

A change in grazing regime has been apparent through the late 19th and 20th centuries. The transition from hardy wethers to ewes and lambs, the declining viability and eventual abandonment of the higher farms and the greater availability of winter grazing on lower land, has resulted in fewer sheep over-wintering on the high hills and a shortening of the grazing season at these altitudes (Patrick 1987). Ffridd land was frequently employed to graze sheep in winter but at over 350m it is doubtful that the land immediately adjacent to Llyn Llagi was ever put to such use.

Fig. 22 suggests that although grazing densities have risen since 1940. These trends are not catchment-specific and they assume that all sheep are turned on to the hills (not an unreasonable assumption in summer). Furthermore they take no account of the changing impact on grazing intensity consequent upon the replacement of larger wethers by ewes and lambs.

The Llyn Llagi catchment lies in the Snowdonia National Park and is designated as a SSSI. The NCC have a consultative but little practical role in the management of the catchment.

The catchment is infrequently burnt (T. Rowlands, P. Williams pers. comms.) with the 'enclosed' area adjacent to the lake being burnt more often than the upper catchment. The spatial irregularity of burning between the upper and lower catchment is apparent from aerial photographs taken in 1946 (11).

Professor R.E. Hughes (pers. comm.) reports that in the 1950s the Molinia within the enclosed area adjacent to the lake was cut in summer as hay to provide winter fodder on lower land. That practice is no longer undertaken.

A (now disused) sheep pen on the north-eastern shore of the lake (12) was utilised during the process of washing sheep in the lake prior to shearing (P. Williams pers. comm.)

The different intensity of land management between the upper and lower catchments is a theme that runs through the land management of the catchment. The lower catchment has been 'enclosed', partly 'drained', cut for hay and more regularly burnt. It is probable that grazing intensities were (and are) higher than on the exposed upper catchment.

Subsidiary management practices

There is no evidence that the catchment has ever been managed for game. Nor that the peat deposits of the upper catchment were ever exploited as a turbary.

5.0 Conclusions

i) Sediment accumulation rates at the core site for the last 150 years were approximately stable (0.015 g cm^{-2} yr^{-1}) The CRS model indicates periods of accelerated sedimentation around 1900 and 1968-1975.

ii) The diatom based pH reconstructions (pre 1850) suggest that the pH of Llyn Llagi was 5.9 - 6.2. Planktonic diatoms were absent from the lake and the data suggest a fairly stable flora of attached circumneutral and acidophilous taxa. Acidification of Llyn Llagi is marked by the decline in Achnanthes minutissima and expansion of Frustulia rhomboides, Tabellaria flocculosa, Eunotia veneris and Achnanthes marginulata and the first appearance of Tabellaria quadriseptata. The greatest change is from 6 cm (1960) with the tremendous expansion of T.quadriseptata and smaller increases in Navicula heimansii and Melosira lirata. The data suggest a pH decline of 1.0 pH unit between 1850 and 1985.

iii) The core chemistry record demonstrates that trace metal contamination of the lake sediments began at 24 cm (ca. 1800) for Pb and Zn and 22 cm for Cu.

iv) The contamination of the sediments by carbonaceous particles commences at 22 cm, concomitant with the beginnings of trace metal contamination, but concurrent with lake acidification. The concentration of these particles increase rapidly from 9 cm (1940's).

v) The pollen diagram identifies a shift in the local vegetation from Calluna domination to domination by members of the Gramineae, presumably Nardus, Molinia & Agrostis. This change is the reverse of what would normally be expected if the land-use hypothesis as supported by Rosenqvist et al. 1980 & Krug & Frink (1983) were in operation.

vi) No appreciable land use change has occurred within the catchment since the introduction of sheep by the Cistercian monastery. While sheep numbers have increased in the area in recent years the documentary evidence is not precise enough to assess whether the catchment has experienced a significant increase in grazing pressure. No liming has taken place within the catchment and burning has not been a significant management practice.

vii) The acidification cannot be accounted for by land use changes. Instead, all the data indicate acid deposition as the cause of acidification. The timing of the changes and trends of the atmospheric pollution indicators (trace metals, magnetics, carbonaceous particles), indicating local deposition of atmospheric pollutants, are consistent with this view.

6.0 References

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1. See Patrick (1987) for definitions of 'land use' and 'land management'.

2. ADAS - Agricultural Development Advisory Service (MAFF). Manuscript 1:25,000 maps accessed at ADAS Aberystwyth.

3. The Tithe Commissioners (Beddgelert tithe file, PRO (Kew) IR18 14095) attributed the 'general unimprovability' of land in the parish to the scarcity of lime.

4. See Patrick (1987) with regards to sources (and their interpretation) used in documenting land use and land management change.

5. Tithe map and schedule for the parish of Beddgelert, 1840. PRO (Kew) IR30 48/5.

6. First edition surveyed 1887, published 1891.
Second edition surveyed 1899, published 1900.
Third edition ammended 1913, published 1920.
Provisional edition ammended 1949, published 1953.

The area was not surveyed at 25 inches to a mile.

7. Held at the London School of Economics archive.

8. Held at King's College London Geography Department. Sheet no. 552.

9. Field data accessed on computer files and 1:25,000 maps at Department of Geography, University of Birmingham.

10. PRO (Kew) Class MAF 68.

11. Air Photograph Office, Welsh Office, Cardiff. 1:10,000.
279: 3121, 3122. May 7th 1946.

12. The first cartographic record of this structure is from the first edition Ordnance Survey 6 inch map (see note 6).

ALGAE SPECIES LIST

12A ACHNANTHES LINEARIS	W. SMITH
2C ACHNANTHES LINEARIS V PUSILLA	GRUN.
6B ACHNANTHES CLEVEI V ROSTRATA	HUST.
3A ACHNANTHES MINUTISSIMA	KUTZ.
4A ACHNANTHES AUSTRIACA	HUST.
2A ACHNANTHES MARGINULATA	GRUN.
8A ACHNANTHES SAXONICA	KRASSKE
0A ACHNANTHES UNARA	CARTER
2A ACHNANTHES HUNGARICA	GRUN.
2A ACHNANTHES DETHA	
97 ACHNANTHES CF LAPIDOSA	
99 ACHNANTHES SP	
99 AMPHORA SP	
3B ANOMOEONEIS SERIANS V BRACHYSIRA	(BREB.) CLEVE
4A ANOMOEONEIS VITREA	(GRUN.) ROSS
2A CALONEIS BACILLUM	(GRUN.) MERESCHKOWSKY
1A CYMBELLA VENTRICOSA	KUTZ.
4A CYMBELLA MICROCEPHALA	GRUN.
0A CYMBELLA PERPUSILLA	A. CLEVE
5A CYMBELLA CESATII	(RABH.) GRUN.
7A CYMBELLA HEBRIDICA	(GREGORY) GRUN.
8A CYMBELLA GRACILIS	(RABH.) CLEVE
0A CYMBELLA GAEUMANNI	MEISTER
1B CYMBELLA HETEROPLEURA V MINOR	CLEVE
1A CYMBELLA MINUTA	HILSE EX RABH.
92 CYMBELLA SP 1	PIRLA
99 CYMBELLA SP.	
1C COCCONEIS PLACENTULA V LINEATA	(EHR.) CLEVE
1A EUNOTIA VENERIS	(KUTZ.) O. MULLER
2A EUNOTIA PECTINALIS	(KUTZ.) RABH.
2B EUNOTIA PECTINALIS V MINOR	(KUTZ.) RABH.
2D EUNOTIA PECTINALIS V UNDULATA	(RALFS) RABH.
3A EUNOTIA PRAERUPTA	EHR.
4A EUNOTIA TENELLA	(GRUN). HUST.
5A EUNOTIA ALPINA	(NAEGELI) HUST.
6A EUNOTIA LUNARIS	(EHR.) GRUN.
6B EUNOTIA LUNARIS V SUBARCUATA	(NAEGELI) GRUN.
7A EUNOTIA BIDENTULA	W. SMITH
8C EUNOTIA MONODON V MAIOR	(W. SMITH) RABH.
9A EUNOTIA EXIGUA	(BREB.) RABH.
10A EUNOTIA FABA	(EHR.) GRUN.
10B EUNOTIA FABA V INTERMEDIA	
11A EUNOTIA RHOMBOIDEA	HUST.
12A EUNOTIA ROBUSTA	RALFS
13A EUNOTIA ARCUS	EHR.
17A EUNOTIA TAIFIAENSIS	FOGED
20A EUNOTIA MEISTERI	HUST.
25A EUNOTIA FALLAX	CLEVE
26A EUNOTIA PRAERUPTA-NANA	BERG
27A EUNOTIA MICROCEPHALA	KRASSKE EX HUST.
993 EUNOTIA SP 1	L.HIR (SF)
999 EUNOTIA SP	
01A FRAGILARIA PINNATA	EHR.
02A FRAGILARIA CONSTRUENS	(EHR.) GRUN.
02C FRAGILARIA CONSTRUENS V VENTER	(EHR.) GRUN.
05A FRAGILARIA VIRESCENS	RALFS
06A FRAGILARIA BREVISTRIATA	GRUN.
FR007A FRAGILARIA VAUCHERIAE	(KUTZ.) LANGE PETERSEN
FR009A FRAGILARIA CAPUCINA	DESMAZIERES
FR9995 FRAGILARIA CF SINNATA V LANCETTULA	L.HIR (SF)
FR9999 FRAGILARIA SP	
FU002A FRUSTULIA RHOMBOIDES	(EHR.) DE TONI
FU002B FRUSTULIA RHOMBOIDES V SAXONICA	(RABH.) DE TONI
GO004A GOMPHONEMA GRACILE	EHR.
GO006A GOMPHONEMA ACUMINATUM	EHR.
GO013A GOMPHONEMA PARVULUM	KUTZ.
GO020A GOMPHONEMA AFFINE	KUTZ.
GO023A GOMPHONEMA TRUNCATUM	EHR.
GO9999 GOMPHONEMA SP	
HA001A HANTZSCHIA AMPHIOXYS	(EHR.) GRUN.
ME004A MELOSIRA LIRATA	(EHR.) KUTZ.
ME005A MELOSIRA DISTANS	(EHR.) KUTZ.
ME005E MELOSIRA DISTANS V NIVALIS	(W.SM.) KIRCHNER
ME010A MELOSIRA PERGLABRA	OESTRUP
ME010B MELOSIRA PERGLABRA V FLORINIAE	CAMBURN
NA002A NAVICULA JAERNEFELTII	HUST.
NA003B NAVICULA RADIOSA V TENELLA	(BREB.) GRUN.
NA005A NAVICULA SEMINULUM	GRUN.
NA006A NAVICULA MEDIOCRIS	KRASSKE
NA013A NAVICULA PSEUDOSCUTIFORMIS	HUST.
NA014A NAVICULA PUPULA	KUTZ.
NA016A NAVICULA INDIFFERENS	HUST.
NA032A NAVICULA COCCONEIFORMIS	GREGORY
NA036A NAVICULA PERPUSILLA	GRUN.
NA037A NAVICULA ANGUSTA	GRUN.
NA038A NAVICULA ARVENSIS	HUST.
NA041A NAVICULA HEIMANSII	VAN DAM & KOOY.
NA042A NAVICULA MINIMA	GRUN.
NA043A NAVICULA SUBATOMOIDES	HUST.
NA045A NAVICULA BRYOPHILA	PETERSEN
NA046A NAVICULA CONTENTA	GRUN.
NA082A NAVICULA MURALIS	GRUN.
NA129A NAVICULA SEMINULOIDES	HUST.
NA142A NAVICULA MEDIOCONVEXA	HUST.
NA158A NAVICULA CUMBRIENSIS	HAWORTH
NA9944 NAVICULA SP 13	EIDDAW BACH (SF)
NA9950 NAVICULA SP 9	PIRLA
NA9955 NAVICULA CF VITIOSA	L.HIR (SF)
NA9958 NAVICULA SP 24	PIRLA
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NA9962 NAVICULA SP 2	L.HIR (SF)
NA9963 NAVICULA SP 1	L.HIR (SF)
NA9964 NAVICULA CF SPIRATA	L.HIR (SF)
NA9965 NAVICULA PELLICULOSA/PERMITIS	L.HIR (SF)
NA9999 NAVICULA SP	
NE003B NEIDIUM AFFINE V LONGICEPS	(GREGORY) CLEVE
NE004A NEIDIUM BISULCATUM	(LAGERSTEDT) CLEVE
NE9999 NEIDIUM SP	
NI005A NITZSCHIA [illegible]	GRUN.
NI009A NITZSCHIA PALEA	(KUTZ.) W. SMITH
NI025A NITZSCHIA RECTA	HANTZSCH
NI9989 NITZSCHIA CF FONTICOLA	L.HIR (SF)
NI9999 NITZSCHIA SP	
PE002A PERONIA FIBULA	[illegible]
PI005A PINNULARIA MAJOR	(KUTZ.) [illegible]
PI017F PINNULARIA VIRIDIS V [illegible]	[illegible] CLEVE
PI020A PINNULARIA DIVERGENS	[illegible]
PI112A PINNULARIA BOREALIS	EHR.
PI013A PINNULARIA APPENDICULATA	(AGARDH) CLEVE
PI015A PINNULARIA ABAUJENSIS	(PANT.) ROSS
PI018A PINNULARIA BICEPS	GREGORY
PI021A PINNULARIA HILSEANA	(JANISCH) EHR.
PI022A PINNULARIA SUBCAPITATA	GREGORY
PI023A PINNULARIA TERORATA	(GRUN.) HUST.
PI033B PINNULARIA BRAUNII V AMPHICEPHALA	(A. MAYER) HUST.
PI049A PINNULARIA SUBSIOMATOPHORA	HUST.
PI9993 PINNULARIA SP 11	PIRLA
PI9992 PINNULARIA CF TERMITINA	L.HIR (SF)
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SA001B STAURONEIS ANCEPS F GRACILIS	(EHR.) CLEVE
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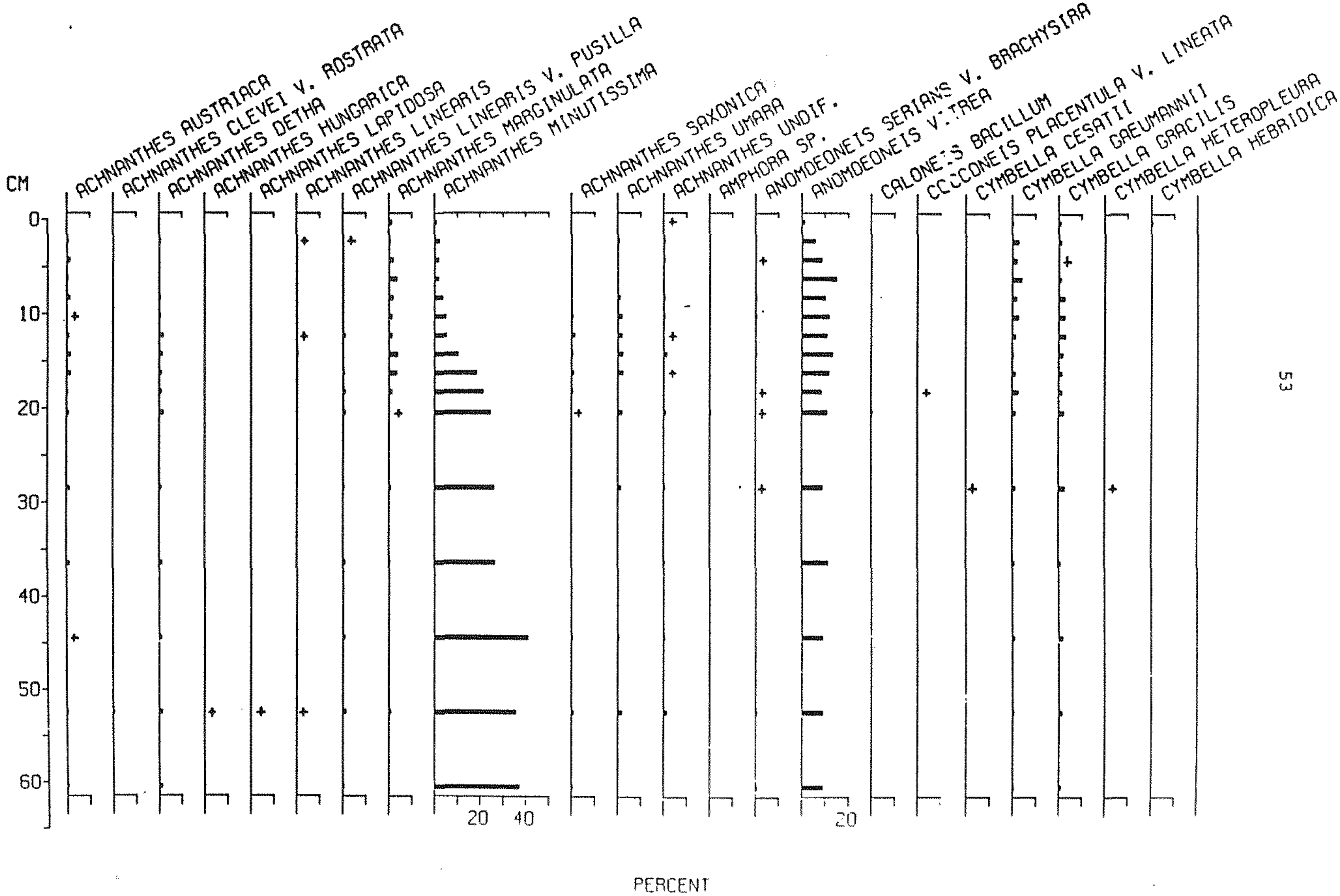
SA9998 STAURONEIS ANCEPS V 1	L.HIR (SF)
SA9999 STAURONEIS SP	
SP001A STENOPTEROBIA INTERMEDIA	LEWIS
SU9999 SURIRELLA SP	
SY004B SYNEDRA PARASITICA V SUBCONSTRICTA	GRUN.
SY011B SYNEDRA DELICATISSIMA V ANGUSTISSIMA	GRUN.
SY9999 SYNEDRA SP	
TA001A TABELLARIA FLOCCULOSA	(ROTH) KUTZ.
TA004A TABELLARIA QUADRISEPTATA	KNUDSON
TA9999 TABELLARIA SP	
TE001A TETRACYCLUS LACUSTRIS	RALFS
UN9996 PERIPHYTON	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ACHNANTHES SAXONICA
ACHNANTHES UMARA
ACHNANTHES UNDIF.
AMPHORA SP.
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ANOMOEONEIS V. TREA
CALONEIS BACILLUM
COCCONEIS PLACENTULA V. LINEATA
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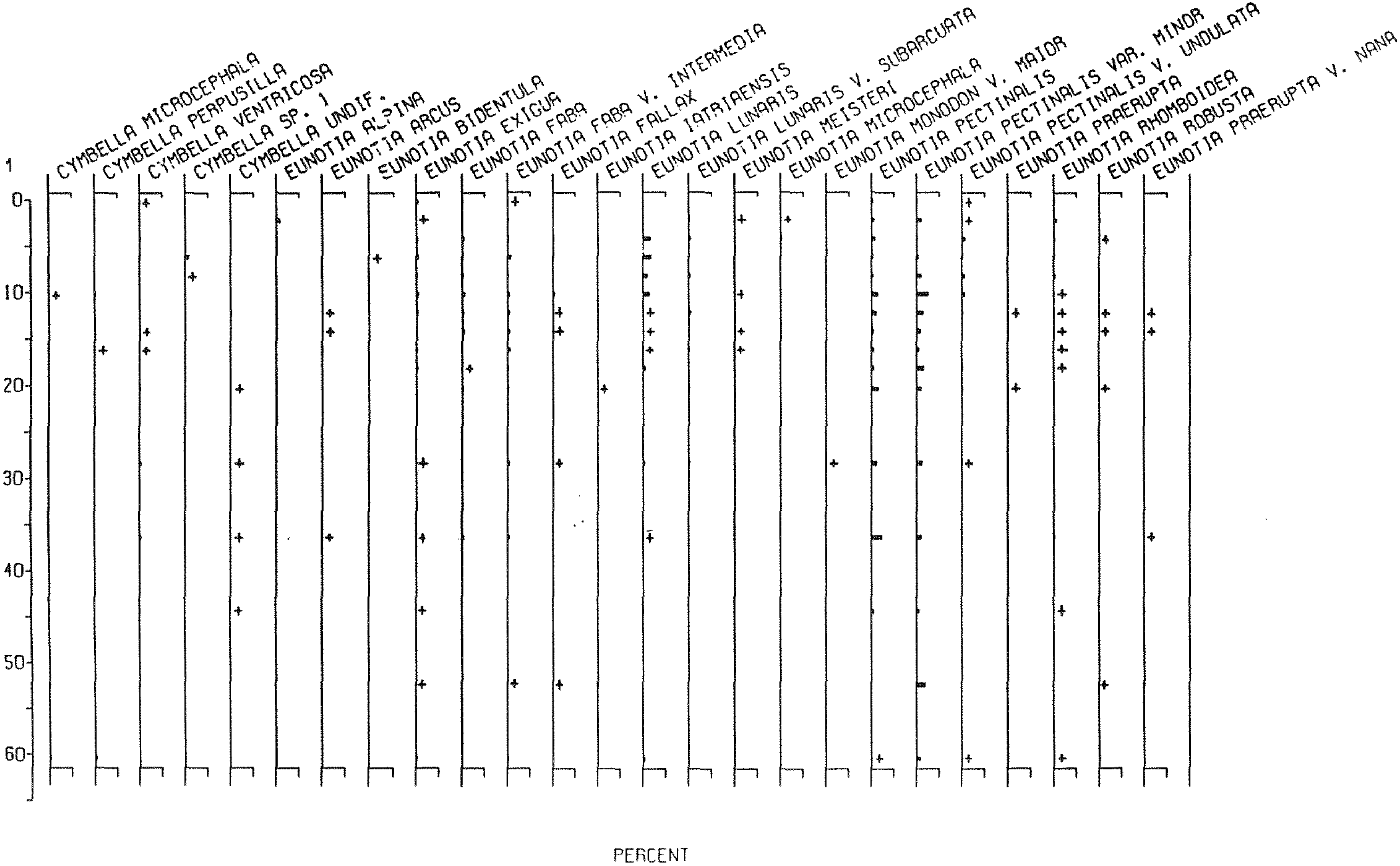
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EUNOTIA EXIGUA
EUNOTIA FABA
EUNOTIA FABA V. INTERMEDIA
EUNOTIA FALLAX
EUNOTIA IATRIAENSIS
EUNOTIA LUNARIS
EUNOTIA LUNARIS V. SUBARCUATA
EUNOTIA MEISTERI
EUNOTIA MICROCEPHALA
EUNOTIA MONODON V. MAIOR
EUNOTIA PECTINALIS
EUNOTIA PECTINALIS VAR. MINOR
EUNOTIA PECTINALIS V. UNDULATA
EUNOTIA PRAERUPTA
EUNOTIA RHOMBOIDEA
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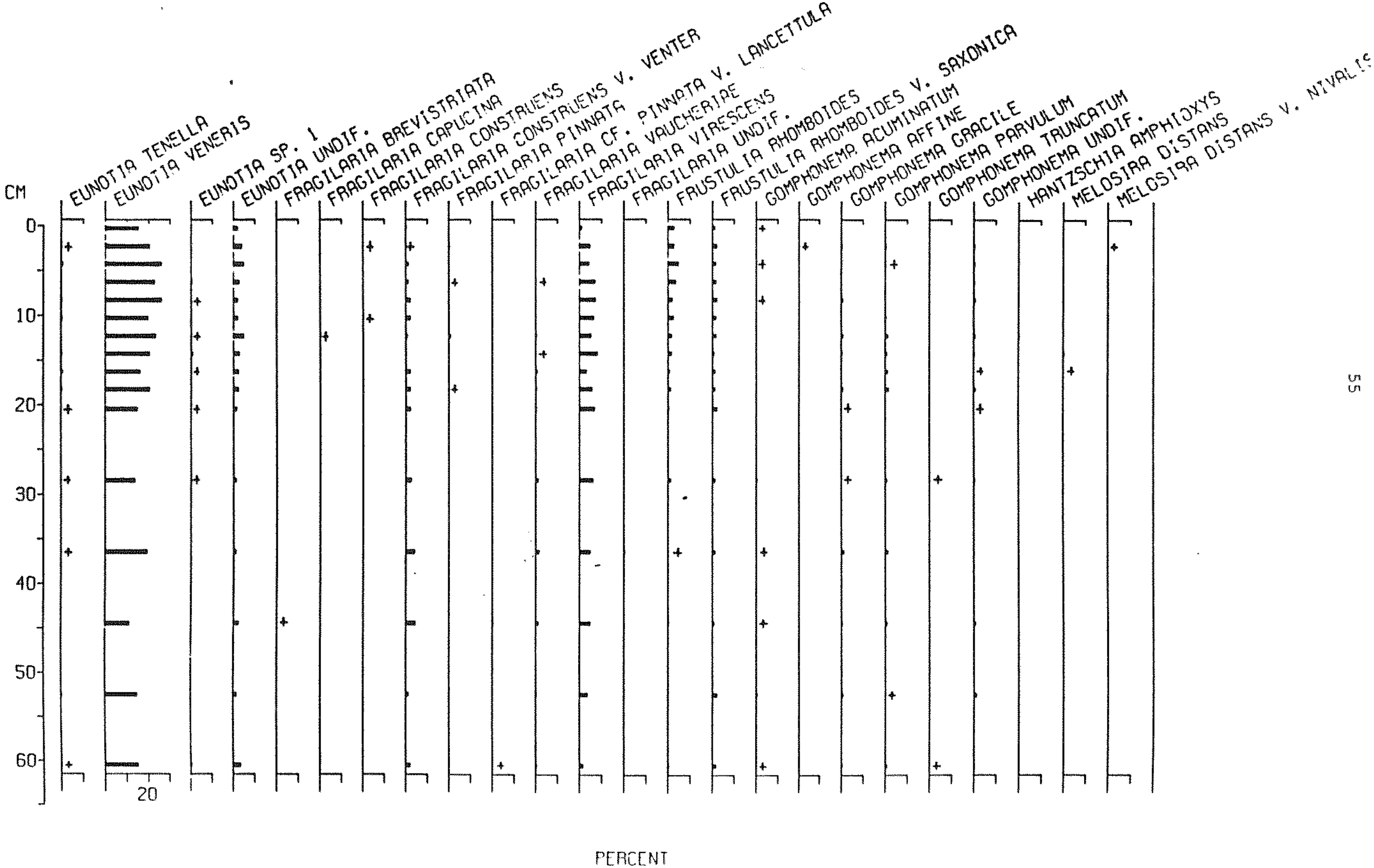

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EUNOTIA VENERIS
EUNOTIA SP. 1
EUNOTIA UNDIF.
FRAGILARIA BREVISTRIATA
FRAGILARIA CAPUCINA
FRAGILARIA CONSTRUENS
FRAGILARIA CONSTRUENS V. VENTER
FRAGILARIA PINNATA
FRAGILARIA CF. PINNATA V. LANCETTULA
FRAGILARIA VAUCHERIAE
FRAGILARIA VIRESCENS
FRAGILARIA UNDIF.
FRUSTULIA RHOMBOIDES
FRUSTULIA RHOMBOIDES V. SAXONICA
GOMPHONEMA ACUMINATUM
GOMPHONEMA AFFINE
GOMPHONEMA GRACILE
GOMPHONEMA PARVULUM
GOMPHONEMA TRUNCATUM
GOMPHONEMA UNDIF.
HANTZSCHIA AMPHIOXYS
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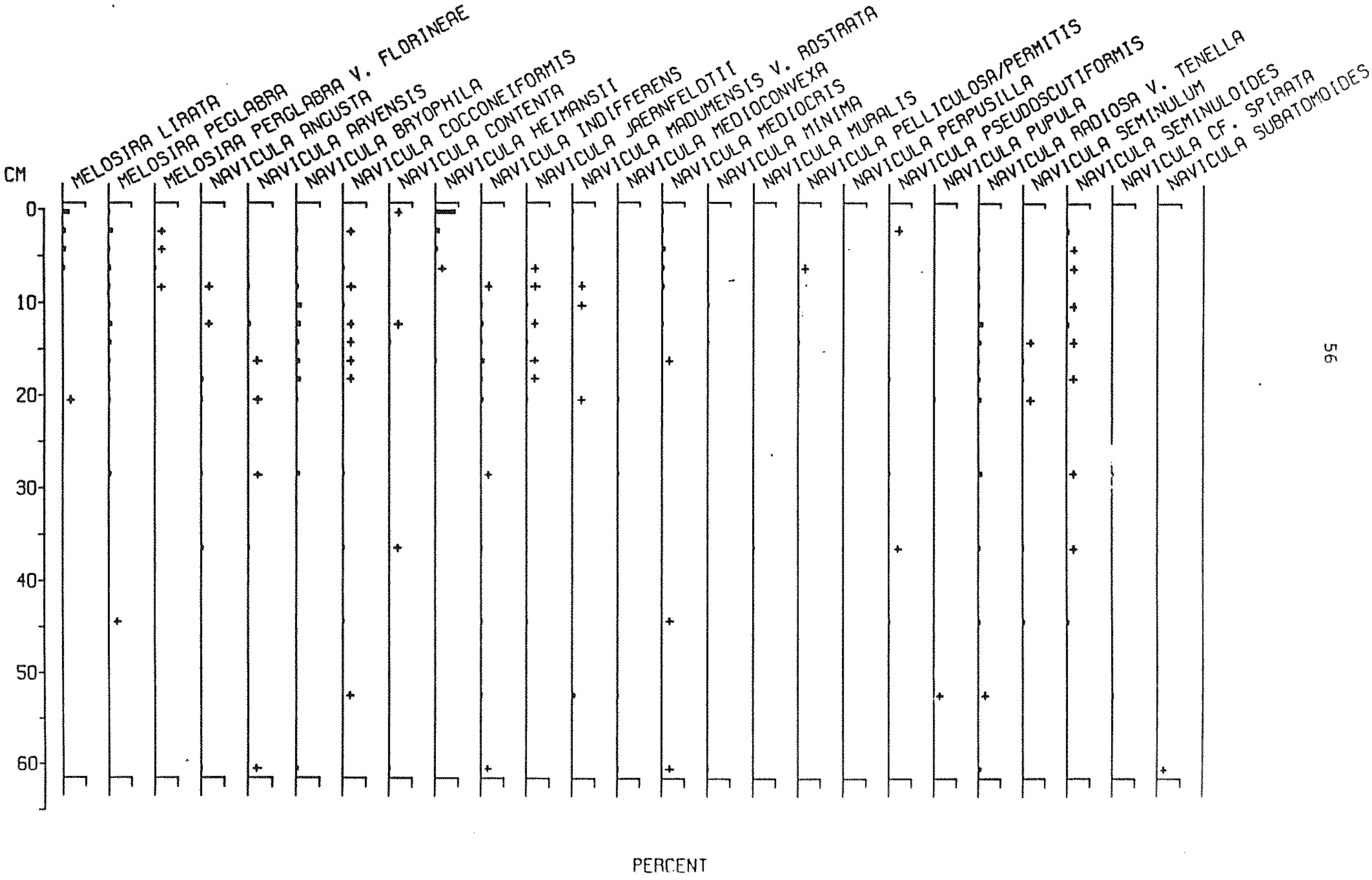
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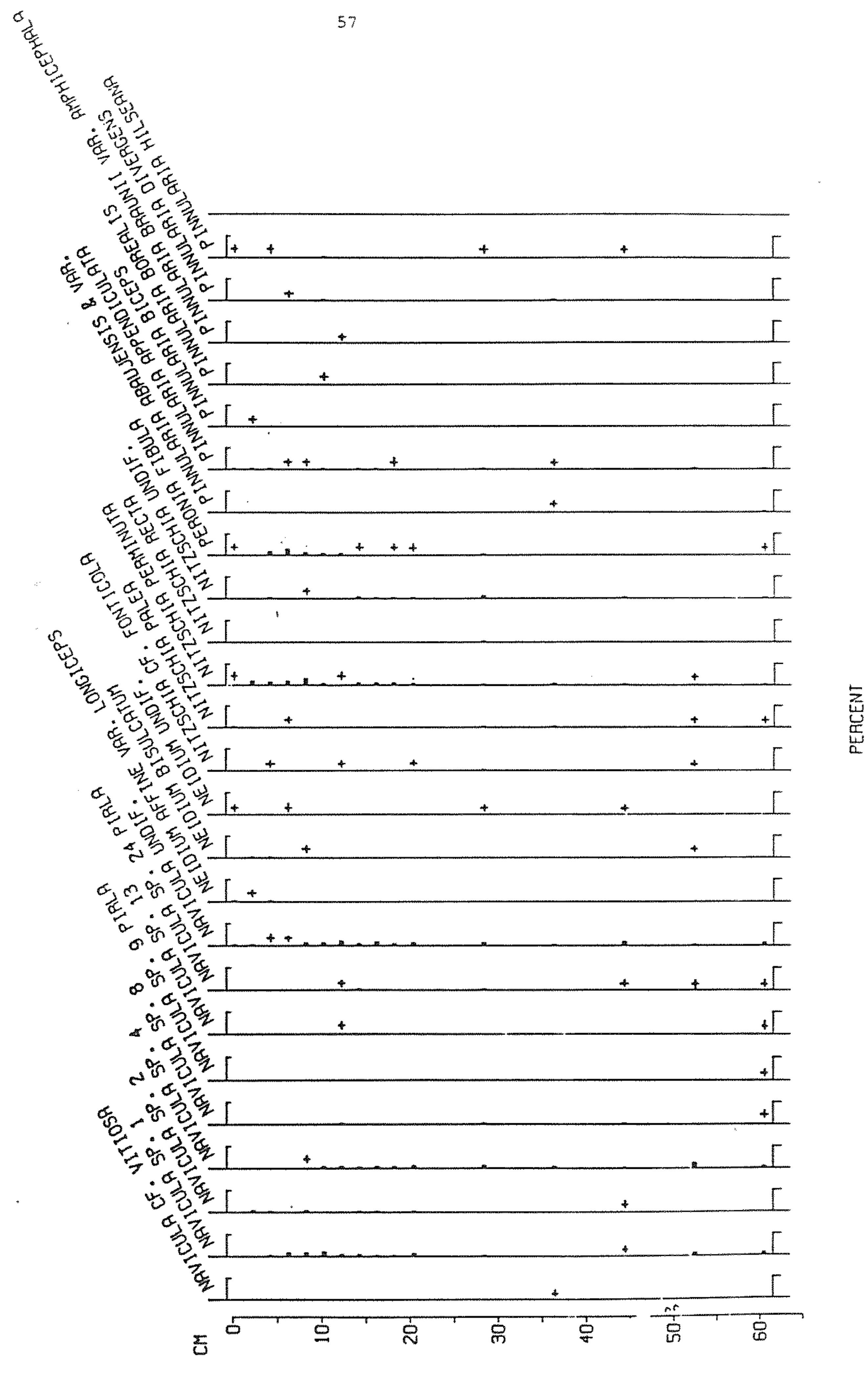
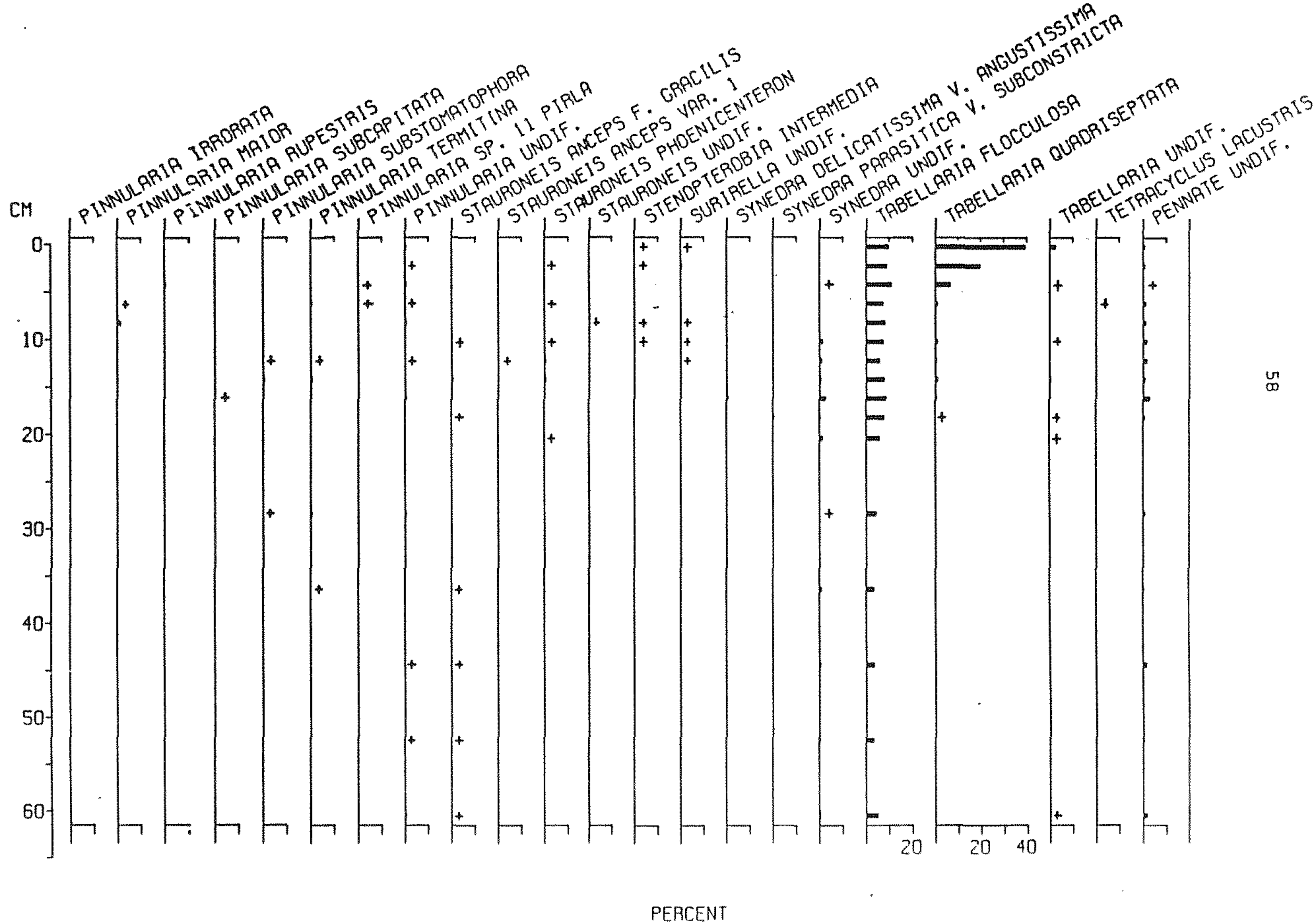
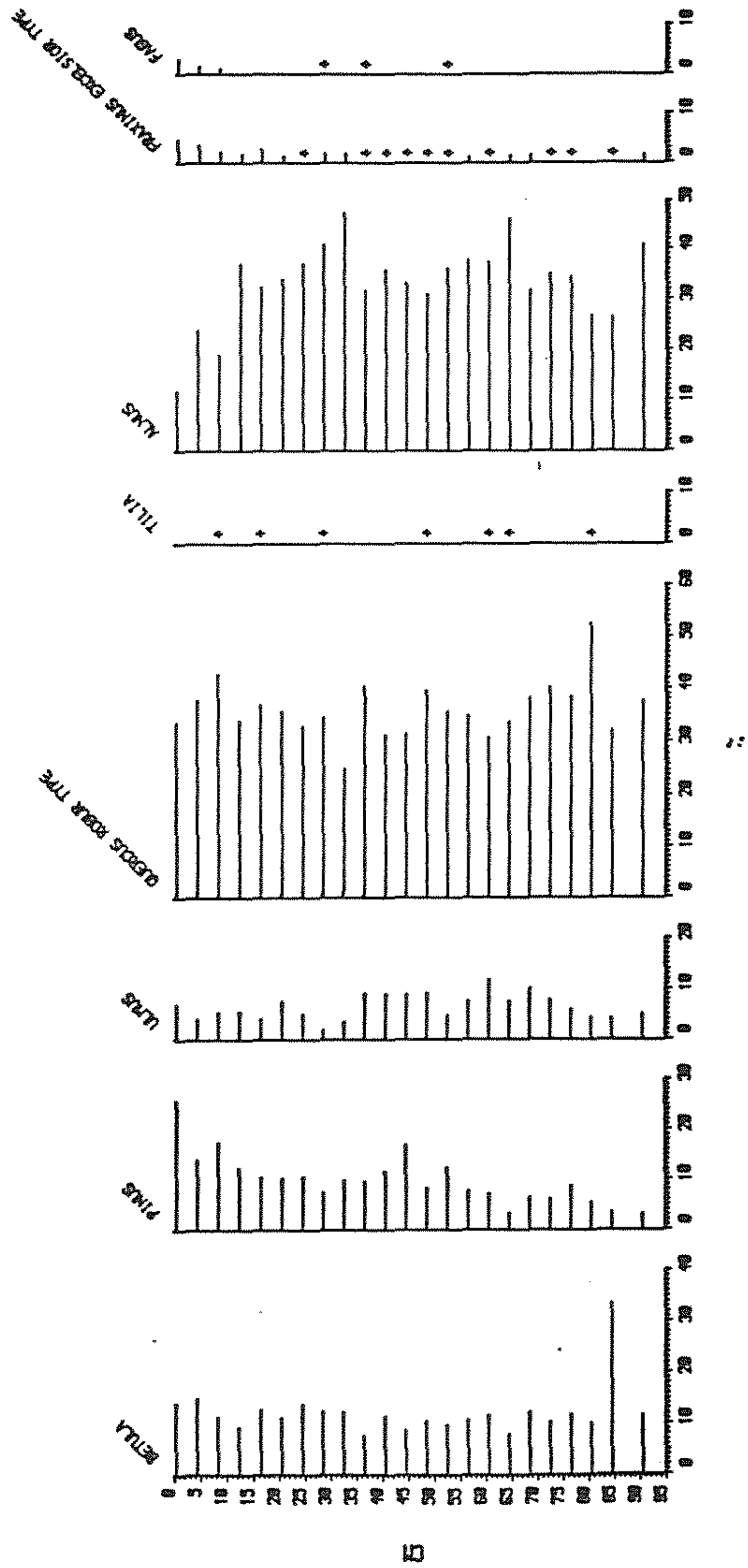
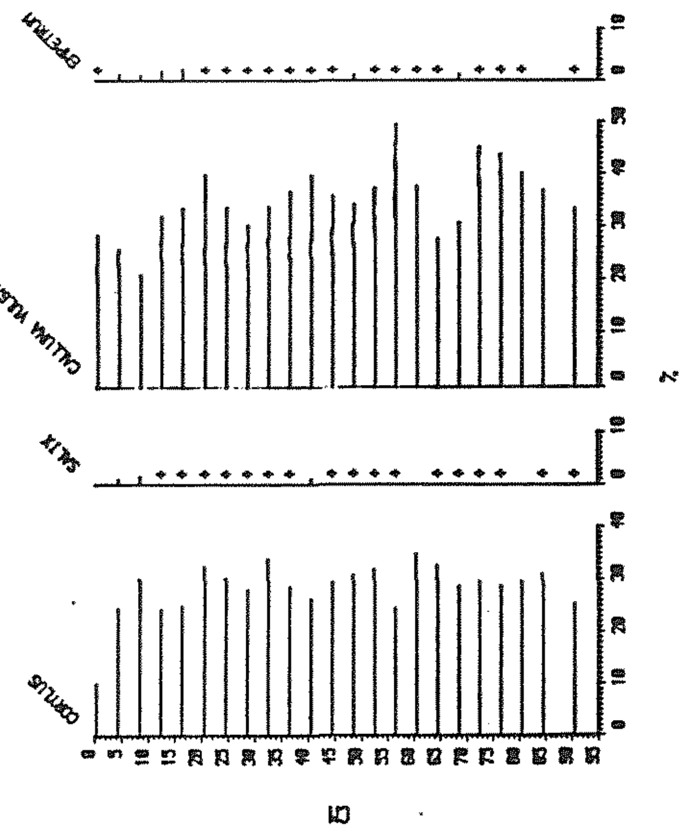
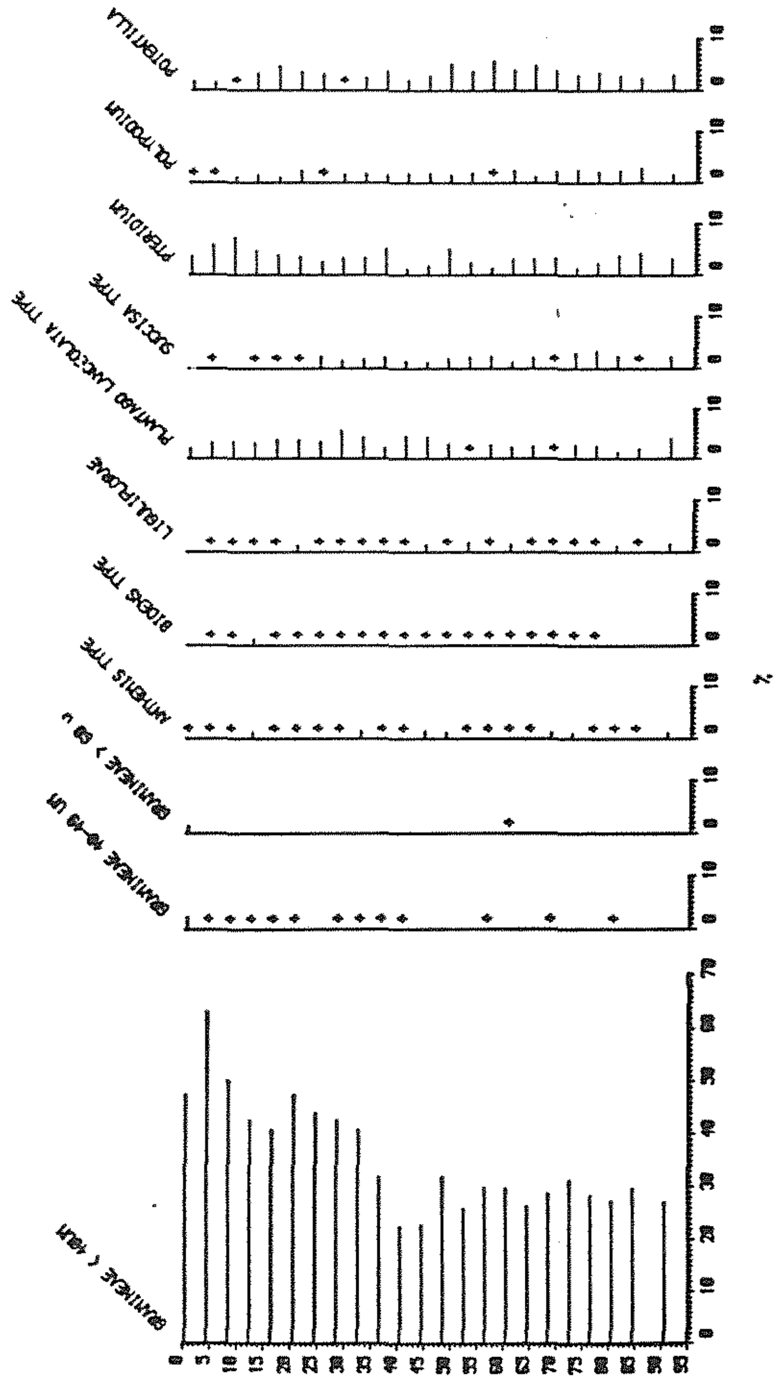
MELOSIRA LIRATA
MELOSIRA PEGLABRA
MELOSIRA PERGLABRA V. FLORINEAE
NAVICULA ANGUSTA
NAVICULA ARVENSIS
NAVICULA BRYOPHILA
NAVICULA COCCONEIFORMIS
NAVICULA CONTENTA
NAVICULA HEIMANSII
NAVICULA INDIFFERENS
NAVICULA JAERNFELDTII
NAVICULA MADUMENSIS V. ROSTRATA
NAVICULA MEDIOCONVEXA
NAVICULA MEDIOCRIS
NAVICULA MINIMA
NAVICULA MURALIS
NAVICULA PELLICULOSA/PERMITIS
NAVICULA PERPUSILLA
NAVICULA PSEUDOSCUTIFORMIS
NAVICULA PUPULA
NAVICULA RADIOSA V. TENELLA
NAVICULA SEMINULUM
NAVICULA SEMINULOIDES
NAVICULA CF. SPIRATA
NAVICULA SUBATOMOIDES
0
10
20
30
40
50
60
PERCENT


NAVICULA CF. VITIOSA
NAVICULA SP. 1
NAVICULA SP. 2
NAVICULA SP. 4
NAVICULA SP. 8
NAVICULA SP. 9 PIRLA
NAVICULA SP. 13
NAVICULA SP. 24 PIRLA
NAVICULA UNDIF.
NEIDIUM AFFINE VAR. LONGICEPS
NEIDIUM BISULCATUM
NEIDIUM UNDIF.
NITZSCHIA CF. FONTICOLA
NITZSCHIA PALEA
NITZSCHIA PERMINUTA
NITZSCHIA RECTA
NITZSCHIA UNDIF.
PERONIA FIBULA
PINNULARIA ABAUJENSIS & VAR.
PINNULARIA APPENDICULATA
PINNULARIA BICEPS
PINNULARIA BOREALIS
PINNULARIA BRAUNII VAR. AMPHICEPHALA
PINNULARIA DIVERGENS
PINNULARIA HILSEANA
CM
0
10
20
30
40
50
60
PERCENT

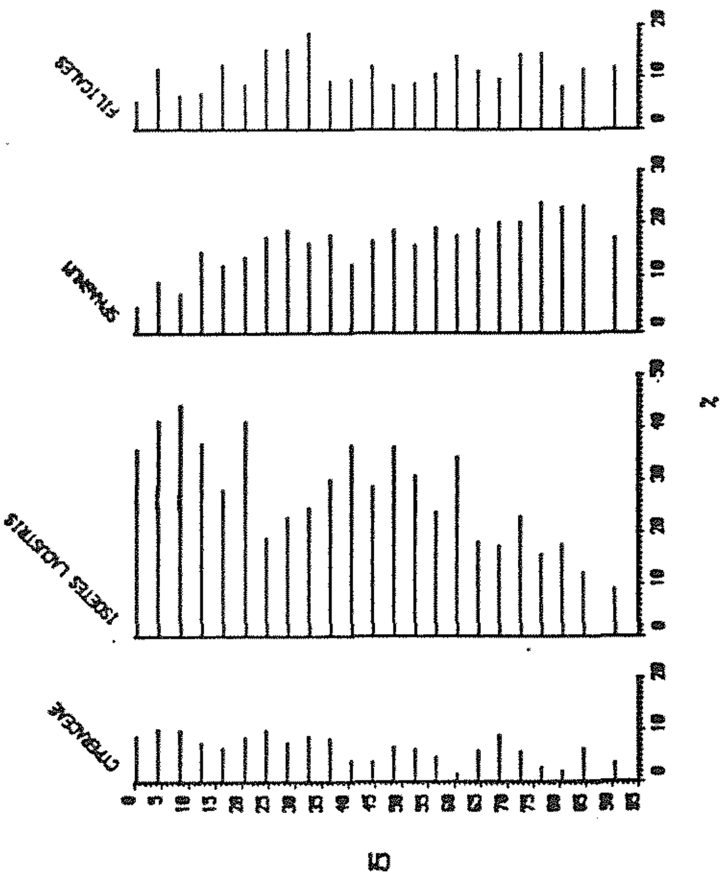

PINNULARIA IRRORATA
PINNULARIA MAIOR
PINNULARIA RUPESTRIS
PINNULARIA SUBCAPITATA
PINNULARIA SUBSTOMATOPHORA
PINNULARIA TERMITINA
PINNULARIA SP. 11 PIRLA
PINNULARIA UNDIF.
STAURONEIS ANCEPS F. GRACILIS
STAURONEIS ANCEPS VAR. 1
STAURONEIS PHOENICENTERON
STAURONEIS UNDIF.
STENOPTEROBIA INTERMEDIA
SURIRELLA UNDIF.
SYNEDRA DELICATISSIMA V. ANGUSTISSIMA
SYNEDRA PARASITICA V. SUBCONSTRICTA
SYNEDRA UNDIF.
TABELLARIA FLOCCULOSA
TABELLARIA QUADRISEPTATA
TABELLARIA UNDIF.
TETRACYCLUS LACUSTRIS
PENNATE UNDIF.
CM
0
10
20
30
40
50
60
20
20
40
PERCENT


BETULA
PINUS
ULMUS
QUERCUS ROBUR TYPE
TILIA
ALNUS
FRAXINUS EXCELSIOR TYPE
FAGUS
cm


CORYLUS
SALIX
CALLUNA VULGARIS
EMPETRUM
%
cm


POTENTILLA
POLYPODIUM
PTERIDIUM
SUCCISA TYPE
PLANTAGO LANCEOLATA TYPE
LIGULIFLORAE
BIDENS TYPE
ANTHEMIS TYPE
%

15


FILICALES
SPHAGNUM
ISOETES LACUSTRIS
CYPERACEAE
%

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