Research Papers

No.23

PALAEOECOLOGICAL EVALUATION OF THE RECENT ACIDIFICATION OF WELSH LAKES

7. Llyn y Bi, 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 y Bi, Gwynedd. An upland, oligotrophic lake situated on the eastern side of the Rhinog plateau.

ii) Sediment accumulation rates at the core site appear to have accelerated above 2.75 cm (ca. 1940). Before 1940 there appears to have been a constant accumulation rate of 0.033 g cm^{-2} yr^{-1}.

iii) The diatom based pH reconstructions suggest that the pH of Llyn y Bi was 5.8 - 6.1 throughout most of the history recorded in the core (until 4 cm ca. 1903). Above 4 cm pH declines rapidly, dropping over 1.2 units between 1903 and 1985. Acidification of Llyn y Bi is marked by the expansion of *Tabellaria binalis*, *Navicula subtilissima*, *N. heimansii*, *Eunotia denticulata* & *E. alpina*.

iv) The core chemistry record demonstrates that trace metal contamination of the lake sediments began between 7 and 8 cm (ca. 1800) with lead followed by strong contamination by zinc at 4 cm (1903).

v) The contamination of the sediments by carbonaceous particles commences at 6 cm (ca. 1840's). The rapid rise in carbonaceous particles from 4 cm (1903) is concurrent with lake acidification. A similar trend is shown by the magnetic data.

vi) The recent portion of the pollen diagram identifies a shift in the local vegetation from *Gramineae* domination to domination by *Calluna* at a depth of 10 - 15 cm a century or more before lake acidification began. A period of catchment erosion is identified by an *Isoetes* decline from 20 cm to 10 cm and matches a period of increased cation concentrations in the lake sediments.

vii) No land use change has occurred within the catchment. However, the cessation of burning has occurred in recent years with a concomitant decrease in sheep numbers and grazing pressure. No liming has taken place within the catchment.

ix) While the pollen evidence suggests that a vegetation change towards *Calluna* heathland took place in the local area in the 18th and 19th centuries the timing of the changes and trends of the atmospheric pollution indicators (trace metals, magnetics, carbonaceous particles). indicate acid deposition as the cause of acidification. The extent to which acidification might have been exacerbated by land-use management practices cannot be assessed. Moreover, this is the only lake site in central Wales & north-west Wales where a potentially acidifying land-use change is indicated.

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Explanation of Abbreviations

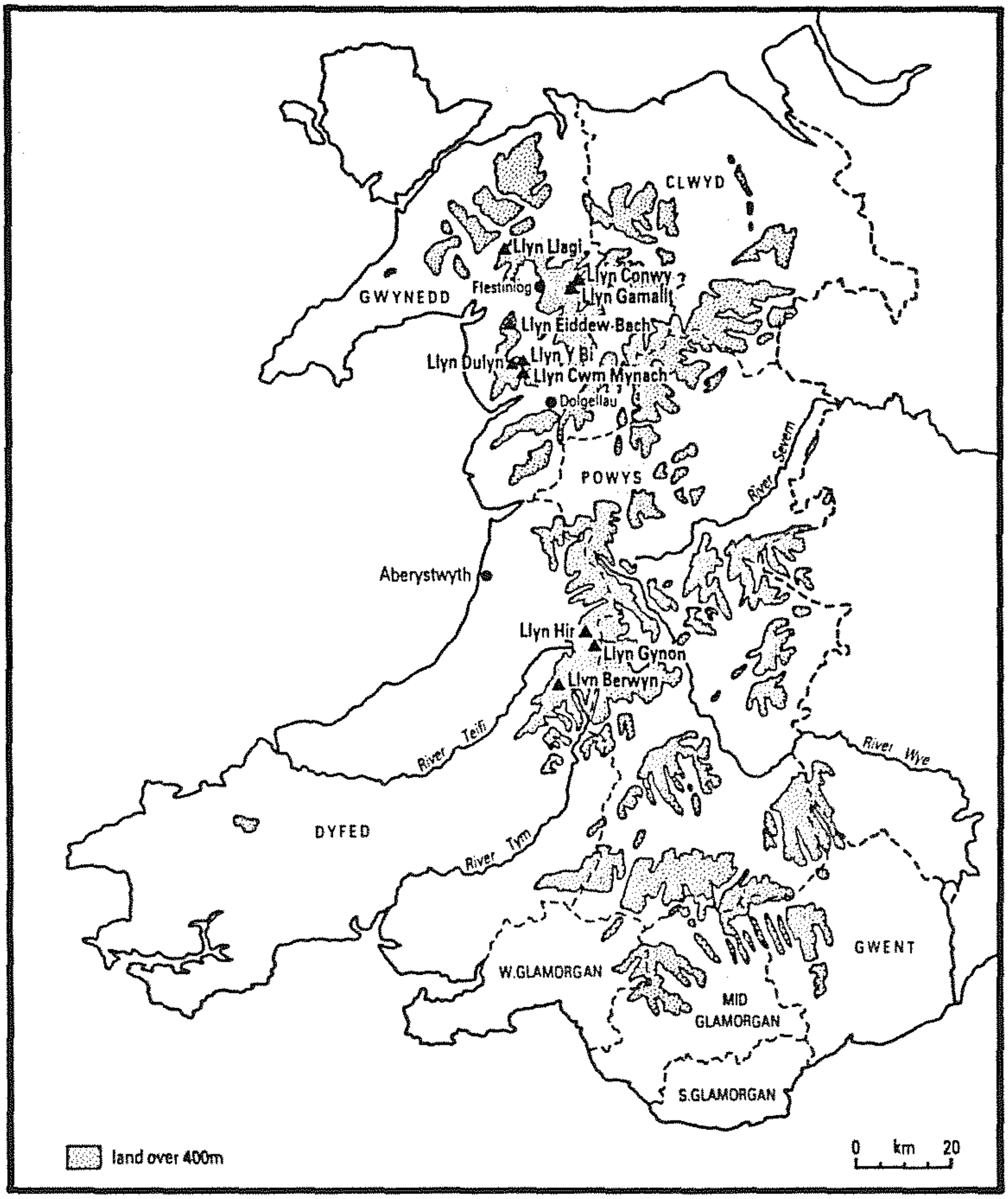
ADAS	Agricultural and Development Advisory Service.
MAFF	Ministry of Agriculture, Fisheries and Food.
NCC	Nature Conservancy Council.
NLW	National Library of Wales.
PAH	Polyaromatic Hydrocarbons.
PRO	Public Record Office.
WWA	Welsh Water Authority.
SSSI	Site of Special Scientific Interest.
UCNW	University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

1.0 Introduction

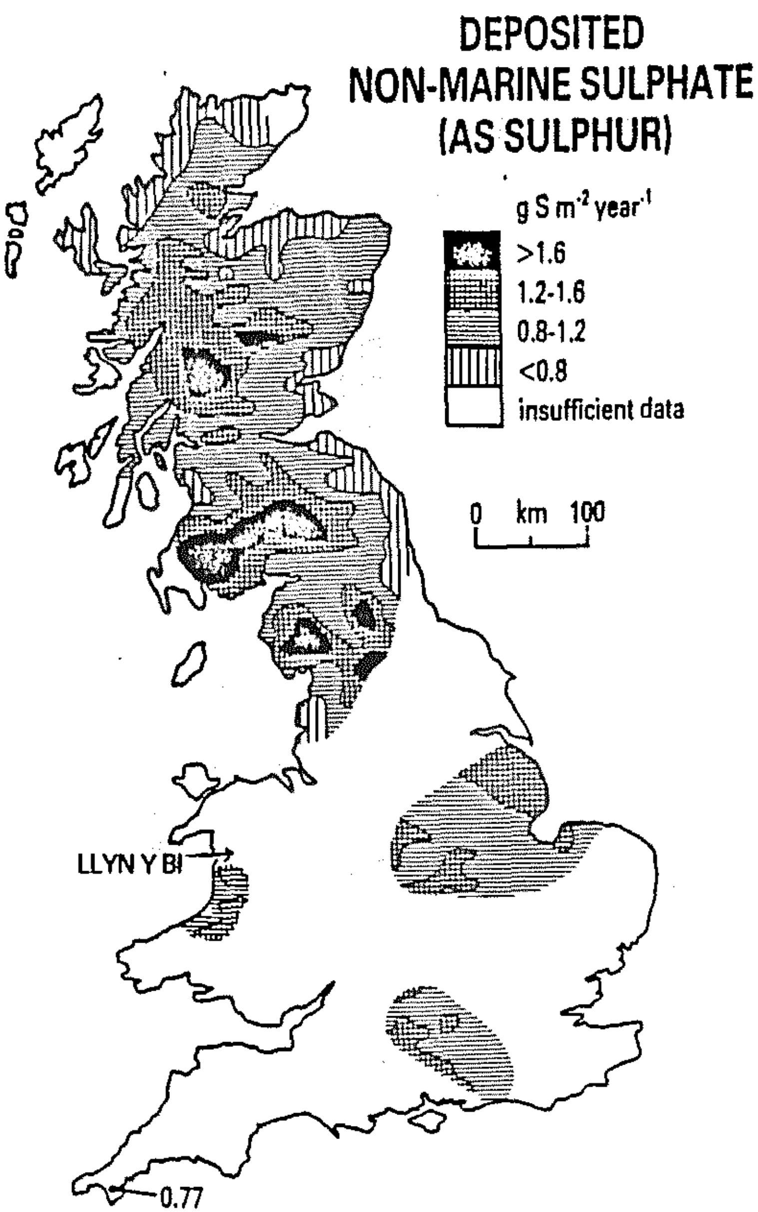
Surface water acidification is recognised as one of the most important environmental problems in Europe and North America, yet despite the pioneering work of Gorham on precipitation chemistry in Cumbria (Gorham 1958) the extent of acidification in the UK is still not known. In earlier papers (Flower and Battarbee 1983, Battarbee et al. 1985, Jones, Stevenson and Battarbee 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 y Bi, located on the eastern side of the Rhinog plateau, Gwynedd (Fig. 1), was the fourth site chosen in Wales. While no site details of acid deposition exist, records from the nearby monitoring station at Aberystwyth reveal that in general 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 May 1985.

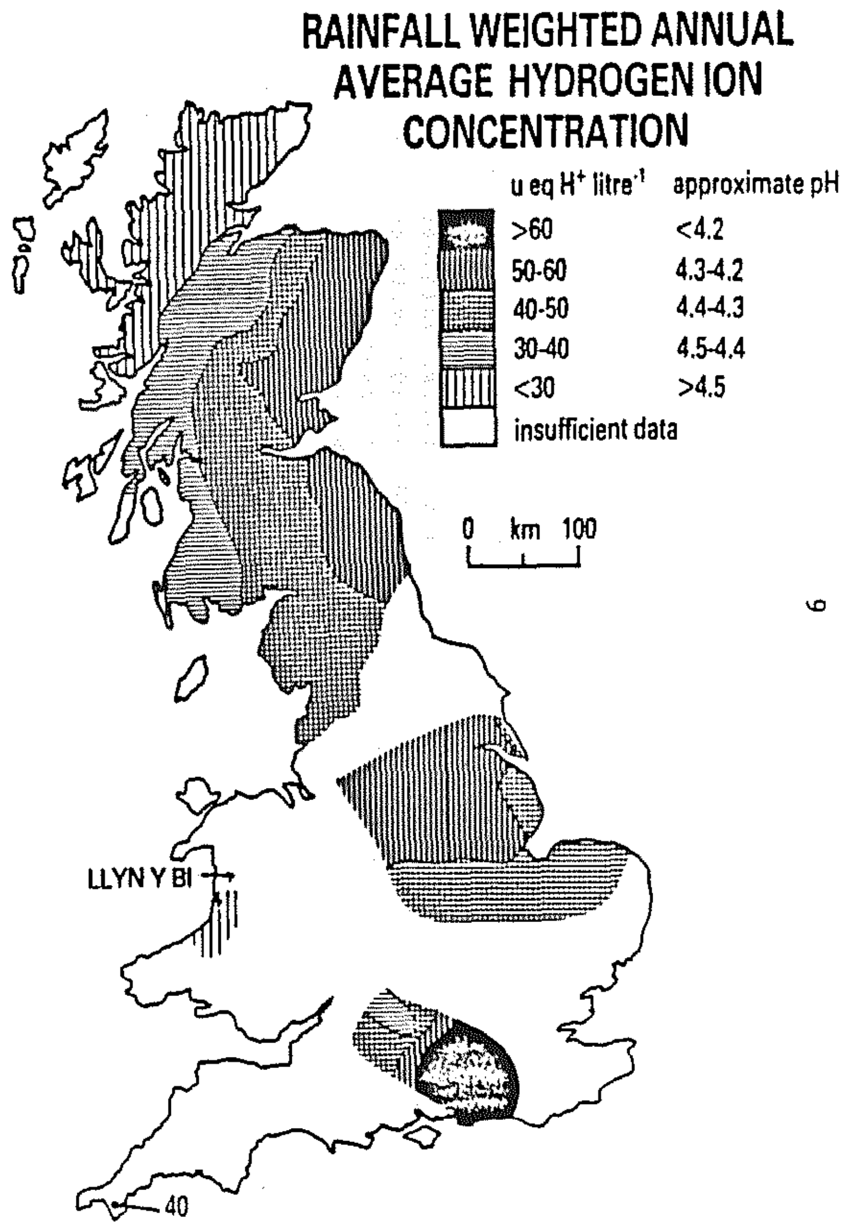
Our approach involves the use of diatom analysis to reconstruct past pH values; ^{210}Pb analysis to establish a lake sediment chronology; geochemical, magnetic and "soot" analysis to trace the history of atmospheric contamination; and pollen analysis and land-use history studies to evaluate the influence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



1. Llyn y Bi location map



3. 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 y Bi lies at an altitude of 445 m in an area which receives rainfall in excess of 2000 mm yr^{-1}. The lake is a small, almost circular, upland corrie lake of 27,063 m^2 and a volume of 42,638 m^3. The detailed bathymetry (Fig. 4) reveals that the lake is very shallow with an average depth of 1.58 m. No inflows exist and the lake is fed chiefly by groundwater and surface flows. Llyn y Bi is drained by an outflow running eastwards into the Afon Gamlan north of Dolgellau.

Table 1 Lake characteristics

Area	27063 m^2
Volume	42638 m^3
Maximum depth	3.0 m
Mean depth	1.58 m
Approximate residence time	16 days

2.1.1 Water chemistry

In common with most of the upland acid lakes examined in this study water chemistry measurements by the WWA (Table 2) reveal that the lake has a low mean pH of 4.74 (Fritz *et al*. 1986, Kreiser *et al*. 1986, Stevenson *et al*. 1987a, Stevenson *et al*. 1987b, Patrick *et al* 1987).

2.1.2 Lake vegetation

On May 2nd 1985, major stands of littoral vegetation were mapped from the shoreline. 15 Ekman grab samples were taken from a boat to determine the distribution of sublittoral plants.

Along rocky parts of the shore, a rich variety of liverworts and algae abound, while rushes (eg. *Juncus acutiflorus** and *J.articulatus*) dominate the peaty stretches. *Lobelia dortmanna* is locally frequent in shallow water along the southern shore and there is an extensive stand of *Equisetum fluviatile* at the west end of the lake (Fig. 5). Except for the rocky eastern end, the lake floor is largely covered with *Juncus fluitans*. *Sphagnum* moss was recovered in 4 of the Ekman samples. Otherwise, the macrophyte flora is species poor (Table 3).

Table 3. Plants growing within Llyn y Bi, May 1985.
(A= abundant; lf= locally frequent; o= occasional; r= rare)

Shoreline	Littoral zone	Sublittoral zone
Leafy liverworts	Lobelia dortmanna	Isoetes lacustris
filamentous algae (lf)	Littorella uniflora (r)	Juncus fluitans (A)
Carex spp. (r)	Potamogeton natans (o)	Sphagnum sp. (o)
Juncus acutiflorus (lf)	Equisetum fluviatile (lf)	
Juncus articulatus (lf)	Juncus fluitans (lf)	
Menyanthes trifoliata (r)		

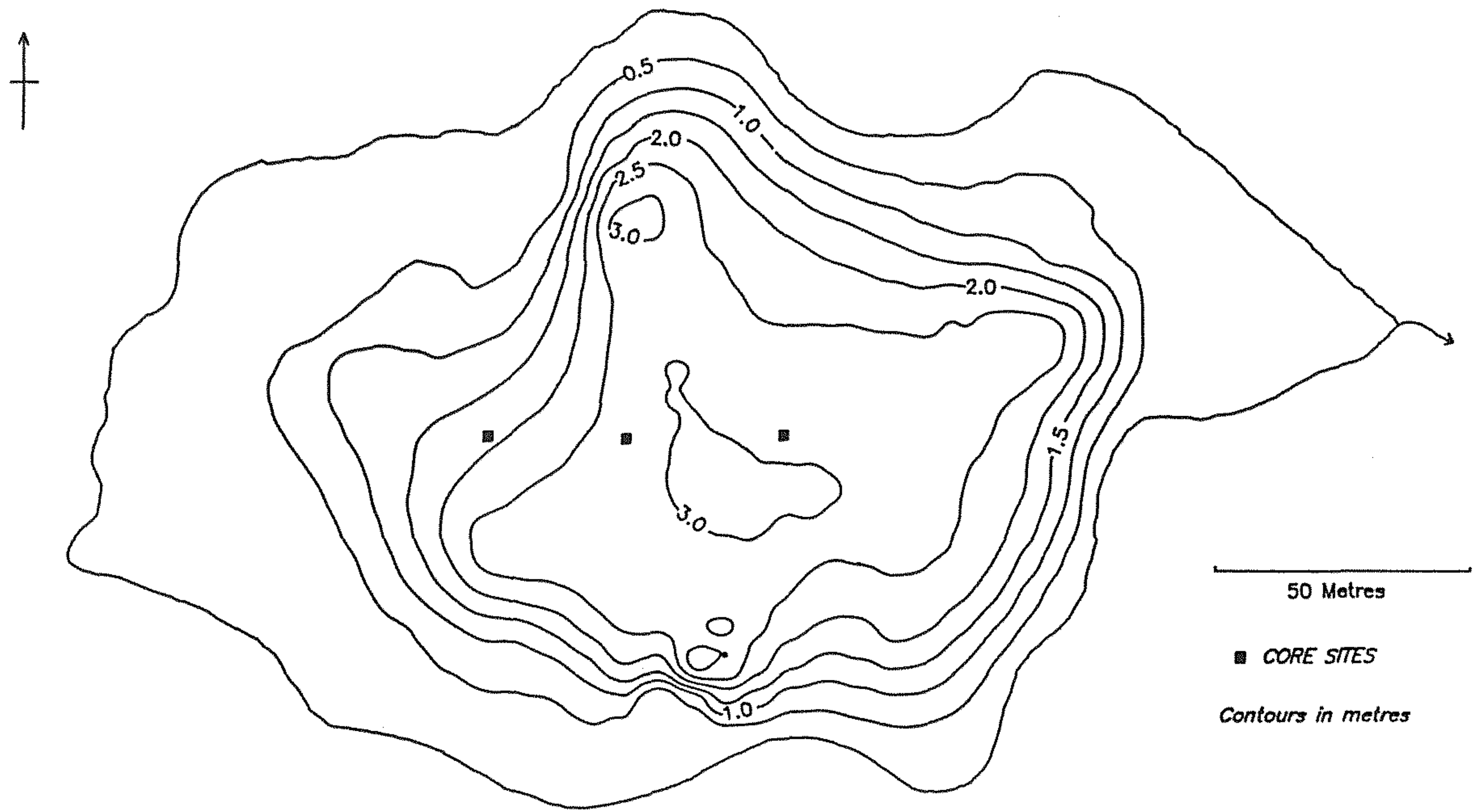
*Nomenclature follows Tutin et al. 1964-1980.

able 2: Lake water chemistry results for Llyn y Bi.

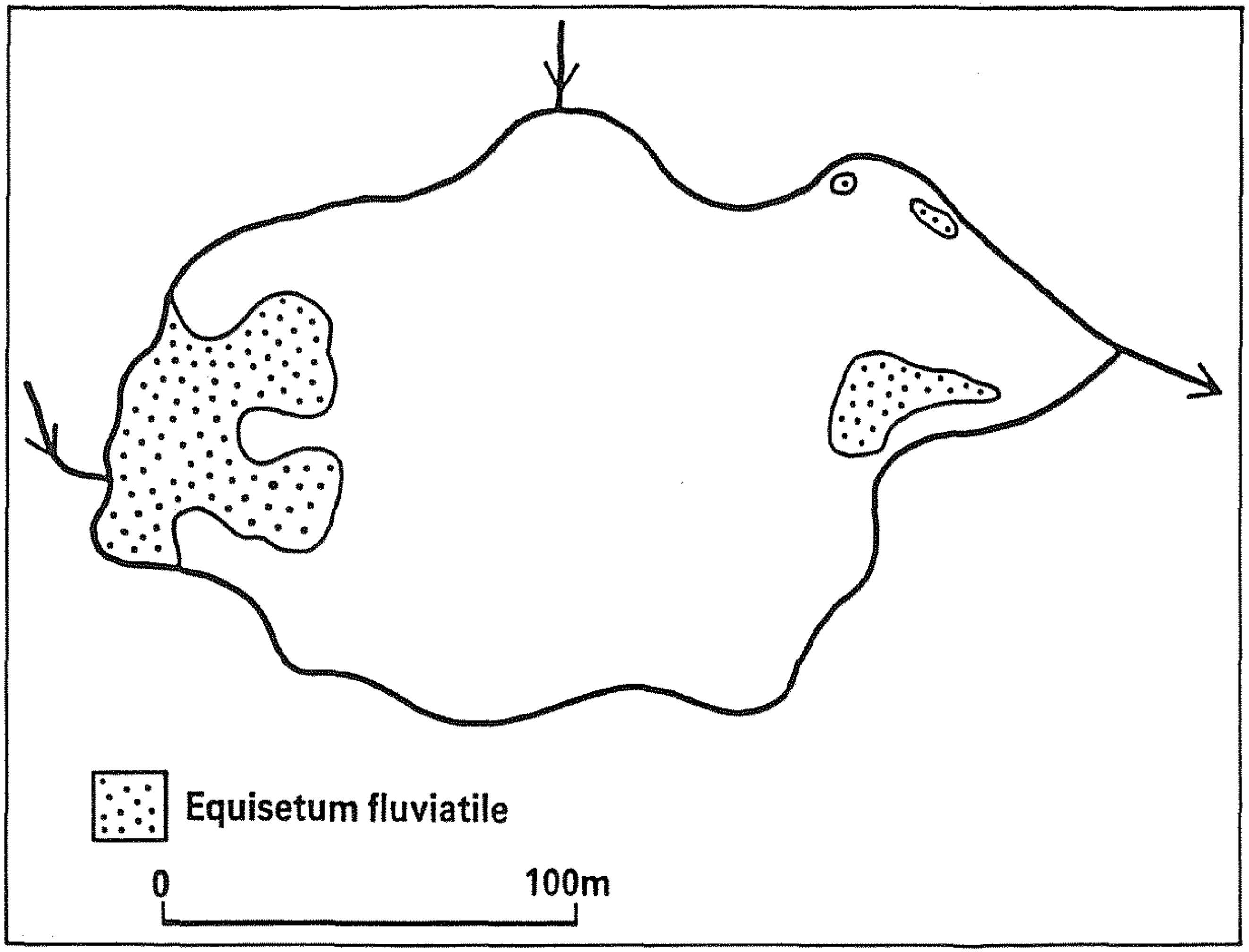
Date	pH	Total Oxidised Nitrogen	Total Alkalinity	Chloride	Silicate	Sulphate	Sodium
			mg l^{-1}				
28/03/84	4.8	0.12	1.0	12.0	0.898	5.0	5.5
13/06/84	4.6	0.04	1.0	11.0	0.107	7.0	5.5
08/08/84	4.3	0.11	1.0	11.0	0.641	5.0	5.2
10/10/84	4.7	0.15	3.0	8.0	0.856	5.0	4.8
10/12/84	5.3	0.20	1.0	6.5	1.711	5.0	4.3
05/02/85	-	0.70	2.8	9.4	0.200	4.84	-
23/04/86	5.1	0.33	2.3	10.0	0.710	----	4.3
02/12/86	4.9	0.15	0.9	7.0	0.800	3.23	4.0

Date	Potassium	Calcium	Magnesium	Zinc mg l^{-1}	Copper	Lead	Manganese	Iron
28/03/84	1.0	1.23	1.02	0.011	0.005	0.01	0.07	0.02
13/06/84	1.0	1.43	0.89	0.013	0.005	0.01	0.11	0.03
08/08/84	1.0	1.36	0.64	0.013	0.005	--	0.10	0.04
10/10/84	1.0	0.99	0.73	0.015	0.005	--	0.06	0.03
10/12/84	1.0	0.99	--	0.019	0.005	--	0.05	0.02
05/02/85	1.0	--	--	0.130	--	--	--	--
23/04/86	0.4	0.70	0.84	0.027	0.005	--	0.05	0.04
02/12/86	0.5	0.77	0.59	0.006	--	--	0.04	0.01

	Conductivity us cm^{-1}	Aluminium mg l^{-1}
23/04/86		0.190
02/12/86	43	0.149



4. Bathymetry and coring locations for Llyn y Bi



5. Vegetation map for Llyn y Bi

2.1.3 Fishing history

The contemporary fishery status of Llyn y Bi is uncertain. The lake is privately owned and only irregularly fished by anglers. It was reputed to contain arctic char and good stocks of heavy trout, but a WWA survey in 1985 was unable to verify this (N. Milner pers. comm.). Two local communicants suggest that the lake is now virtually fishless (G. Edwards, J. Jones pers. comm.).

Cliffe (1860) reported that the trout in Llyn y Bi were superb fish, both in appearance and quality and that specimens in excess of 5 lbs had been caught. Paradoxically the fishing at that time was so good that it was spoiled for the angler by poachers using 'otter boards'.

Ward (1931) affirmed the presence of 'fine' trout and char in the lake.

The ruins of a boat house may still be seen on the north-east shore of the lake. The date of this construction is unknown, but its presence suggests that in a former era the lake supported a viable fishery.

2.2 Catchment

Llyn y Bi has a large catchment, 477,116 m^2, and has a large catchment:lake ratio (16.6).

Table 4 Catchment characteristics

Total catchment area	477116 m^2
Area of land in catchment	450053 m^2
Area of lake	27063 m^2
Catchment/lake ratio	16.6
Maximum relief	120 m

2.2.1 Geology

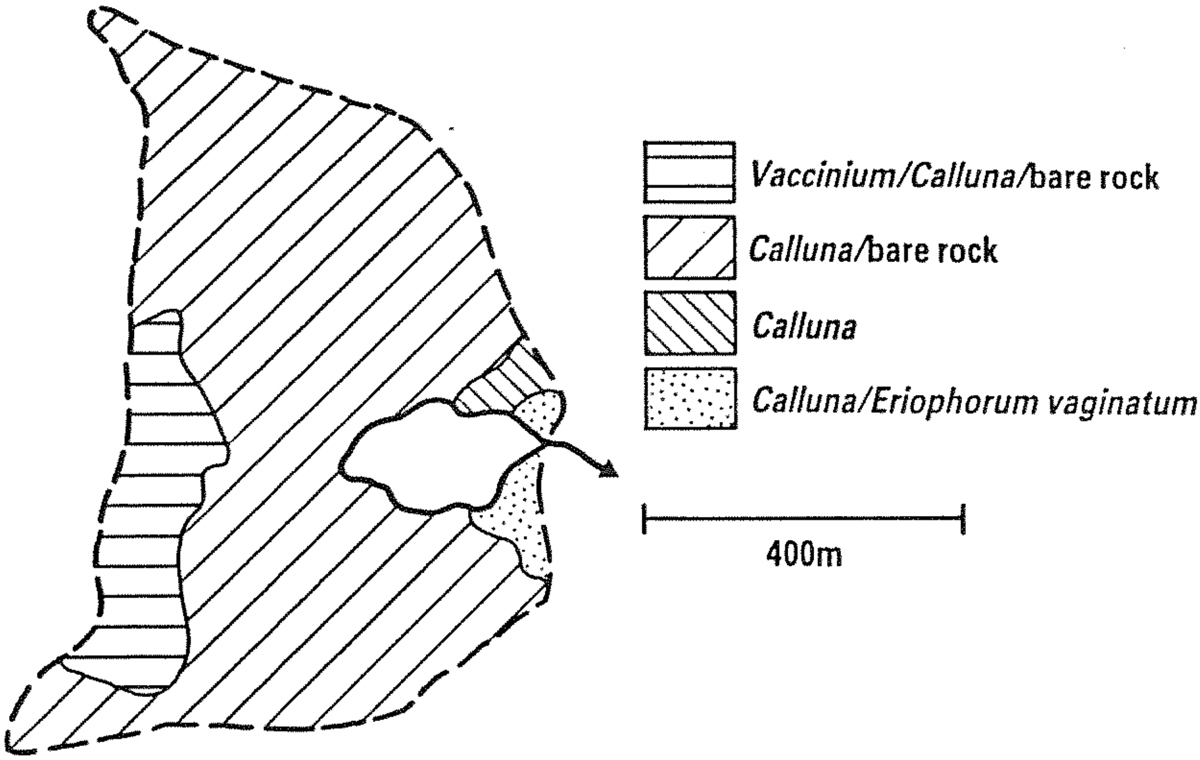
The solid geology of Llyn y Bi consists of Cambrian, coarse grained/pebbly greywackes of the Rhinog formation of the Harlech grits group (Allen & Jackson 1985). The drift geology is restricted to areas of scree beneath the corrie backwall and a small area of overlying boulder clay to the south-south-east.

2.2.2 Soils

Acid, humic rankers belonging to the Revidge Association (311a) dominate the catchment soils (Rudeforth *et al.* 1984).

2.2.3 Present Vegetation

The corrie backwall is dominated by bare rock, *Vaccinium* and small amounts of *Calluna vulgaris*. The remainder of the gentler slopes are covered in extensive, mature *Calluna vulgaris* communities with the underlying bare rock occasionally exposed (Fig. 6). Small amounts of *Eriophorum vaginatum* and *Calluna vulgaris* occur in the wetter areas around the outflow.



6. The catchment vegetation of Llyn y Bi

3.0 Methods

3.1.1. Surveying

The lake was surveyed using the techniques described in Stevenson *et al.* (1987). Shore surveying stations were located on opposite shores.

3.1.2. Collection of sediment cores and routine laboratory measurements of sediment characteristics

Cores were taken using a modified Livingstone corer operated from a mini-raft supported by two inflatable boats. Sampling was carried out during May 1985.

Core Llyn y Bi 2 (65 cm) was extruded in the laboratory and the top 20 cm sliced into 1/2cm slices. The remaining sediment was sliced at 1cm intervals. The sediment was subsequently 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

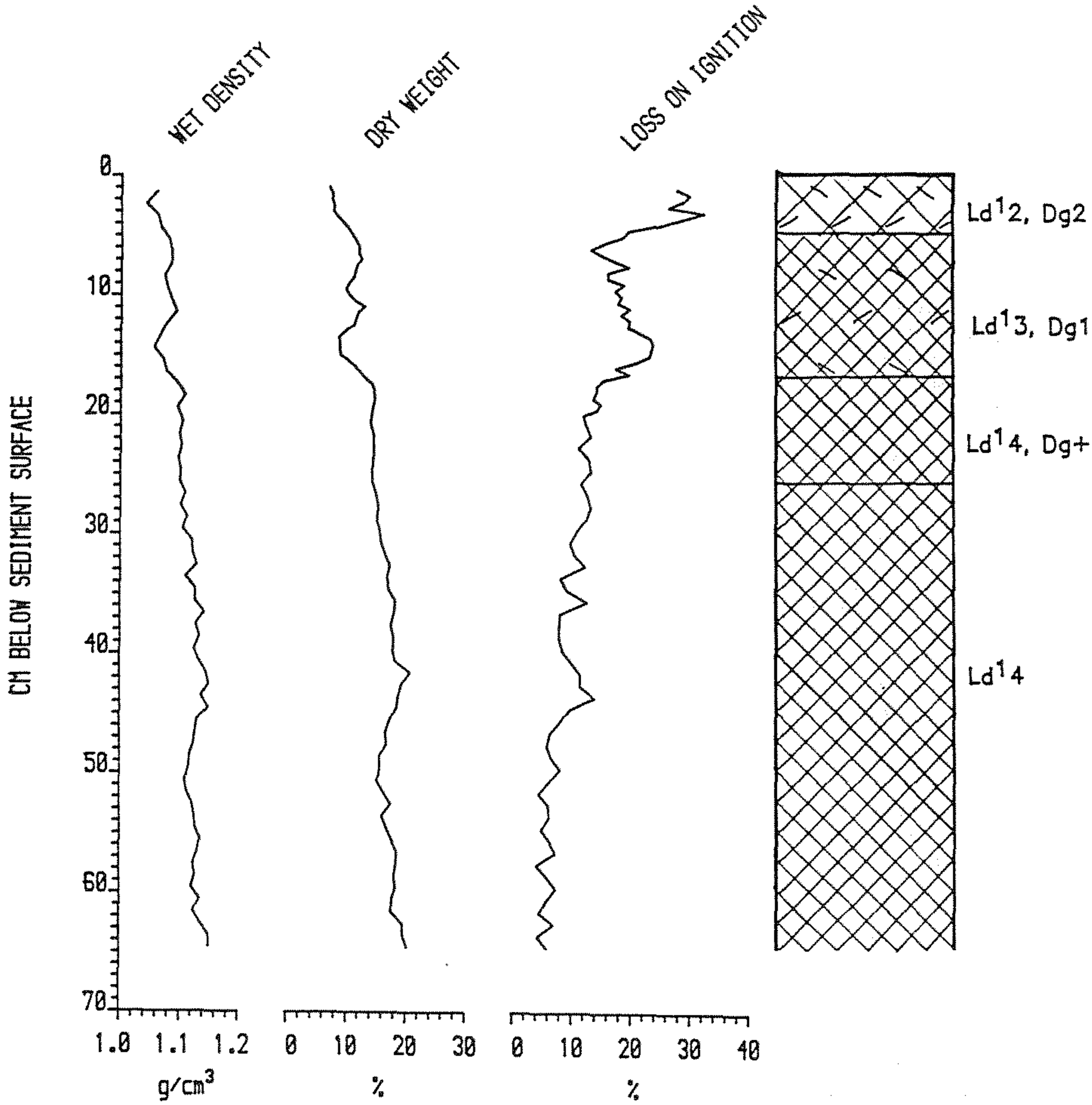
The lithostratigraphy of the core is given in Fig. 7 and is divided into 4 main units. The basal unit consists of an olive-grey organic mud with occasional black iron concretions (Ld[1]4). The organic content of the sediment throughout this section is extemely low (approx. 8%) with high wet density and dry weight. A general trend to higher loss on ignition and lower dry weight and wet density values is observed throughout the section. From 26 - 17 cm the sediment changes to a light grey/brown organic mud with some fine detritus (Ld[1]4, Dg+) and gradual increases in loss on ignition and declines in wet density and dry weight values. Above 17 cm and until 5 cm the sediment undergoes a more marked change as loss on ignition values rise appreciably and wet density and dry weight values fall. The topmost section of the core consists of a dark brown organic sediment of low humic content with fine detritus (Ld[1]2, Dg2) and is associated with a large rise in loss on ignition values to 30% and consequent drops in dry weight and wet density values.

4.1.2. ^{210}Pb dating

Sediments from core YBI 2 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 5 and shown graphically in Figs. 8 & 9. The ^{137}Cs results are given in Table 6 and Fig. 10. Table 7 gives values of a range of other radioisotopes determined from the gamma spectra. The ^{210}Pb inventory of the core is 5.55pCi cm^{-2}, and represents a mean ^{210}Pb flux of 0.17 pCi cm^{-2} yr^{-1}. This is comparable with the value for the adjacent Llyn Dulyn (Stevenson et al. 1987b).

The reduced slope of the ^{210}Pb profile above 2.75 cm appears to be associated with an acceleration in the rate of sedimentation. The well defined ^{137}Cs peak at 1.25 cm would appear to preclude mixing. Fig. 11 shows the ^{210}Pb chronologies for core YBI 2, given by the CRS and CIC ^{210}Pb dating models (Appleby and Oldfield 1978). If the ^{137}Cs peak is associated with the peak ^{137}Cs fallout from nuclear weapons testing, 1963 should occur at some point between 0.5 cm and 2.5 cm. These limits are in this case consistent with the CRS model, which puts 1963 at a depth of 1.5 cm. The CIC model on the other hand gives much younger dates, and puts 1963 at 3 cm. In view of the reasonable ^{210}Pb flux and the consistency with the ^{137}Cs date, it would seem preferable to use the CRS model chronology, and this is given in Table 8. It should be noted, however, that consistency with ^{137}Cs does not extend to the 1954 onset date. There are significant ^{137}Cs concentrations down to the ^{210}Pb equilibrium depth, indicating significant downwards diffusion.

The CRS model dates the acceleration in accumulation rate to some time between 1940 and 1970. Before 1940 there appears to have been a constant sedimentation rate of 0.033 g cm^{-2} yr^{-1}. The ^{210}Pb profile (Fig. 8) shows reduced ^{226}Ra concentrations between 4.75 cm and 2.75 cm, i.e. between 1880 and 1940. The decline at 4.75 cm is also marked by a decline in the ^{40}K concentration (Table 7), and may indicate a change in sediment type. The values of the other radioisotopes are too low to give a consistent pattern.


WET DENSITY
DRY WEIGHT
LOSS ON IGNITION
CM BELOW SEDIMENT SURFACE
0
10
20
30
40
50
60
70
1.0 1.1 1.2
g/cm3
0 10 20 30
%
0 10 20 30 40
%
Ld12, Dg2
Ld13, Dg1
Ld14, Dg+
Ld14

4.

Table 5. ^{210}Pb Data for Core YBI2

Depth	Dry Mass	^{210}Pb Concentration Total		Unsupp.		^{226}Ra Concentration	
cm	g cm^{-2}	pCi g^{-1}	±	pCi g^{-1}	±	pCi g^{-1}	±
0.25	0.0137	21.15	1.20	21.15	1.20	0.00	0.00
1.25	0.0903	21.34	1.28	20.40	1.33	0.94	0.36
2.75	0.2096	14.16	0.66	13.73	0.68	0.43	0.16
3.75	0.2994	5.17	0.57	4.81	0.59	0.36	0.17
4.75	0.4075	2.02	0.40	1.65	0.42	0.37	0.13
5.75	0.5303	1.13	0.16	0.46	0.17	0.67	0.06
6.75	0.6600	1.35	0.37	0.23	0.40	1.13	0.16
7.75	0.7877	0.66	0.28	-0.48	0.30	1.14	0.12

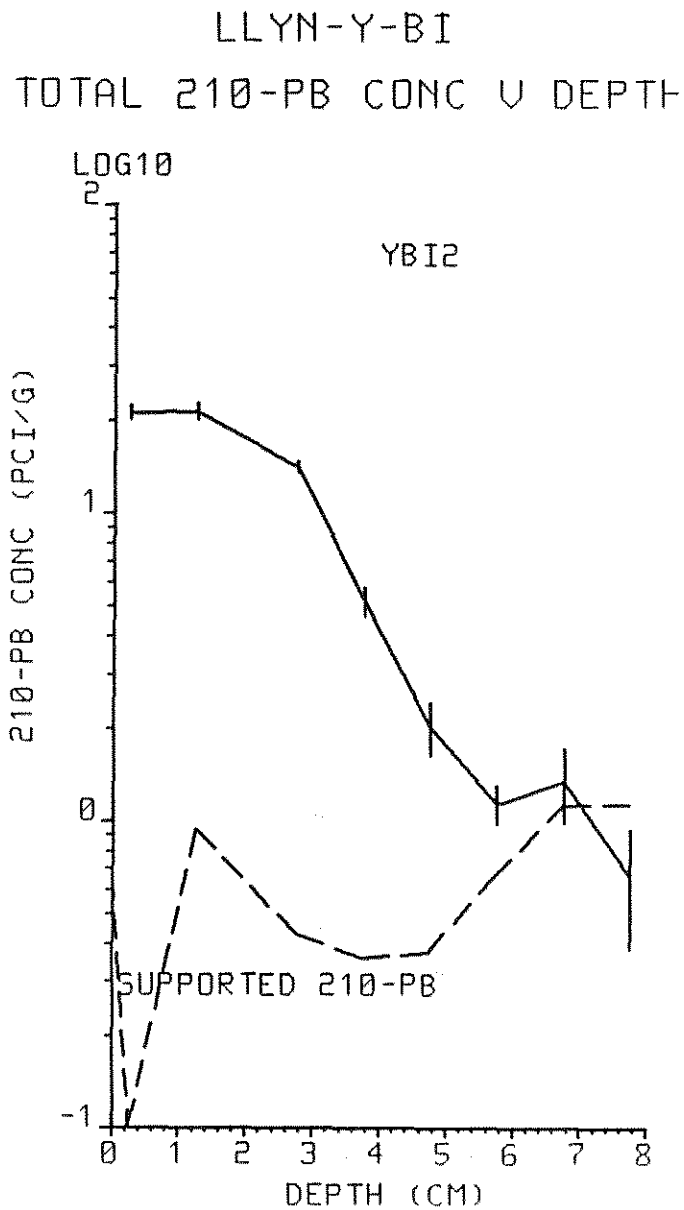
Table 6. ^{137}Cs data for Core YBI2

Depth cm	Dry Mass g cm^{-2}	^{137}Cs concentration pCi g^{-1}	+/-	Cumulative ^{137}Cs pCi cm^{-2}	+/-	Fract
0.25	0.0137	4.77	0.40	0.07	0.01	0.046
1.25	0.0903	5.51	0.44	0.46	0.03	0.321
2.75	0.2096	2.96	0.21	0.95	0.06	0.662
3.75	0.2994	1.98	0.21	1.17	0.06	0.817
4.75	0.4075	0.79	0.14	1.31	0.07	0.914
5.75	0.5303	0.36	0.05	1.37	0.07	0.961
6.75	0.6600	0.21	0.12	1.41	0.07	0.987
7.75	0.7877	0.10	0.09	1.43	0.07	1.000

Table 7. Other radioisotope data for Core YBI2.

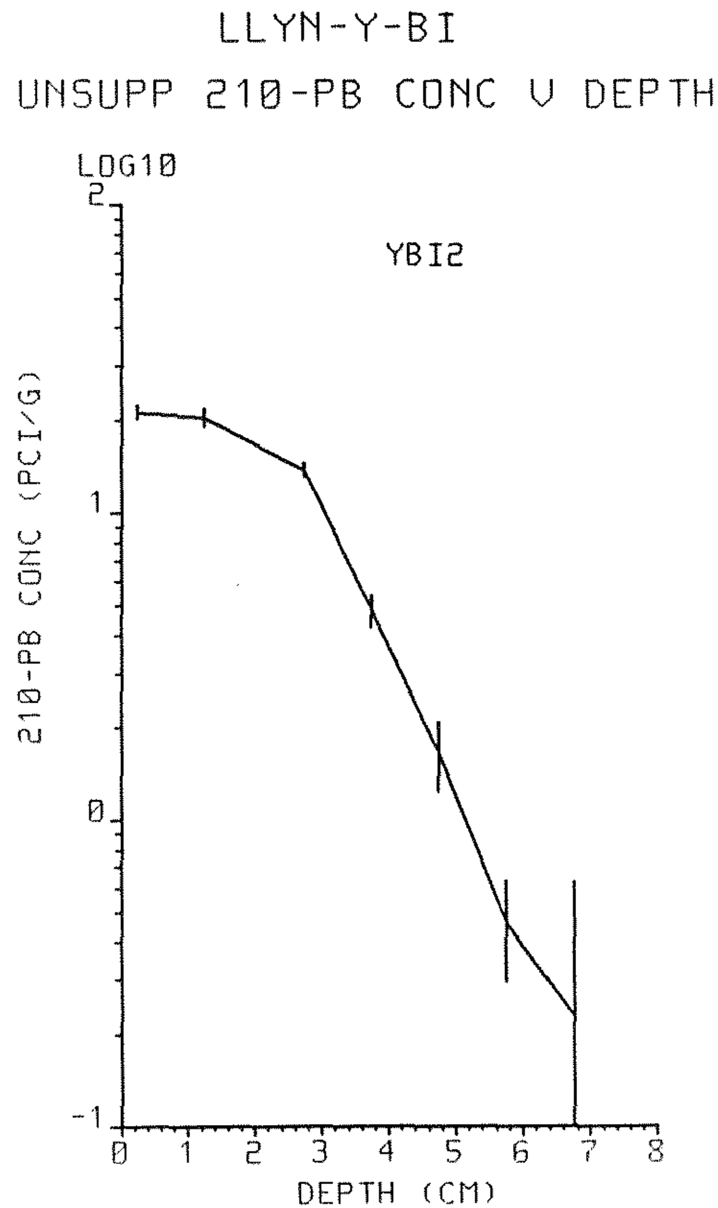
Depth cm	^{226}Ra	^{238}U	^{235}U pCi g^{-1}	^{228}Ac	^{228}Th	^{40}K
0.25	0.00	0.00	0.00	2.42	0.00	4.90
1.25	0.94	0.91	0.00	0.89	0.45	3.45
2.75	0.43	0.00	0.17	0.93	0.22	2.68
3.75	0.36	0.56	0.05	0.54	0.00	5.33
4.75	0.37	0.00	0.21	0.49	0.20	9.34
5.75	0.67	0.43	0.15	0.50	0.33	11.11
6.75	1.13	0.00	0.22	0.46	0.00	10.93
7.75	1.14	0.68	0.18	0.36	0.30	16.67

Fig. 8



8. Total ^{210}Pb profile for the Llyn y Bi 2 core

Fig. 9



9. Unsupported ^{210}Pb profile for the Llyn y Bi 2 core

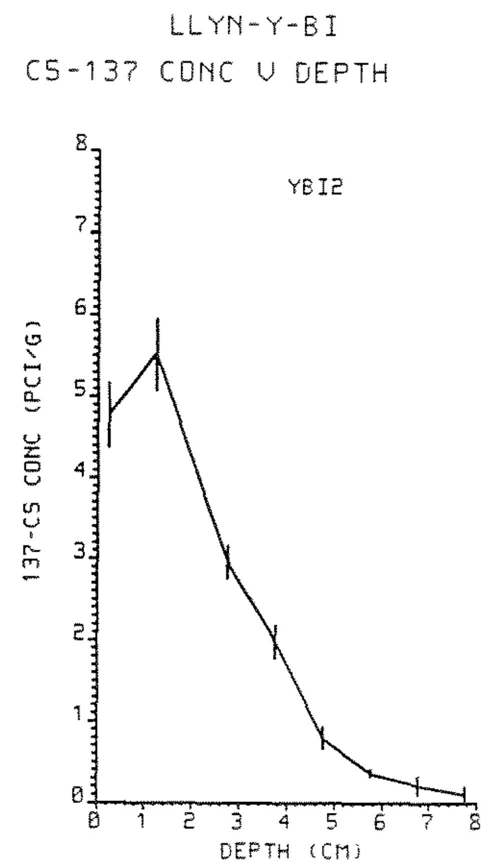
Table 8. CRS Model ^{210}Pb chronology

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	5.55	1985	0				
0.50	0.0329	4.71	1980	5	2	0.0067	0.091	6.2
1.00	0.0711	3.87	1973	12	2	0.0056	0.073	6.1
1.50	0.1102	3.00	1965	20	2	0.0047	0.059	6.3
2.00	0.1499	2.19	1955	30	2	0.0040	0.049	6.8
2.50	0.1897	1.60	1945	40	2	0.0033	0.040	7.4
3.00	0.2320	1.09	1933	52	3	0.0030	0.035	9.0
3.50	0.2769	0.69	1918	67	4	0.0032	0.034	11.9
4.00	0.3264	0.43	1903	82	5	0.0034	0.033	15.7
4.50	0.3805	0.26	1887	98	7	0.0035	0.031	20.5
5.00	0.4382	0.15	1869	116	10	0.0035	0.030	25.2
5.50	0.4996	0.09	1851	134	15	0.0035	0.028	30.0

^{210}Pb Flux = 0.17 +/- 0.01 pCi cm^{-2}
90% Equilibrium Depth = 3.7cm. or 0.30 g cm^{-2}
99% Equilibrium Depth = 5.9cm. or 0.55 g cm^{-2}

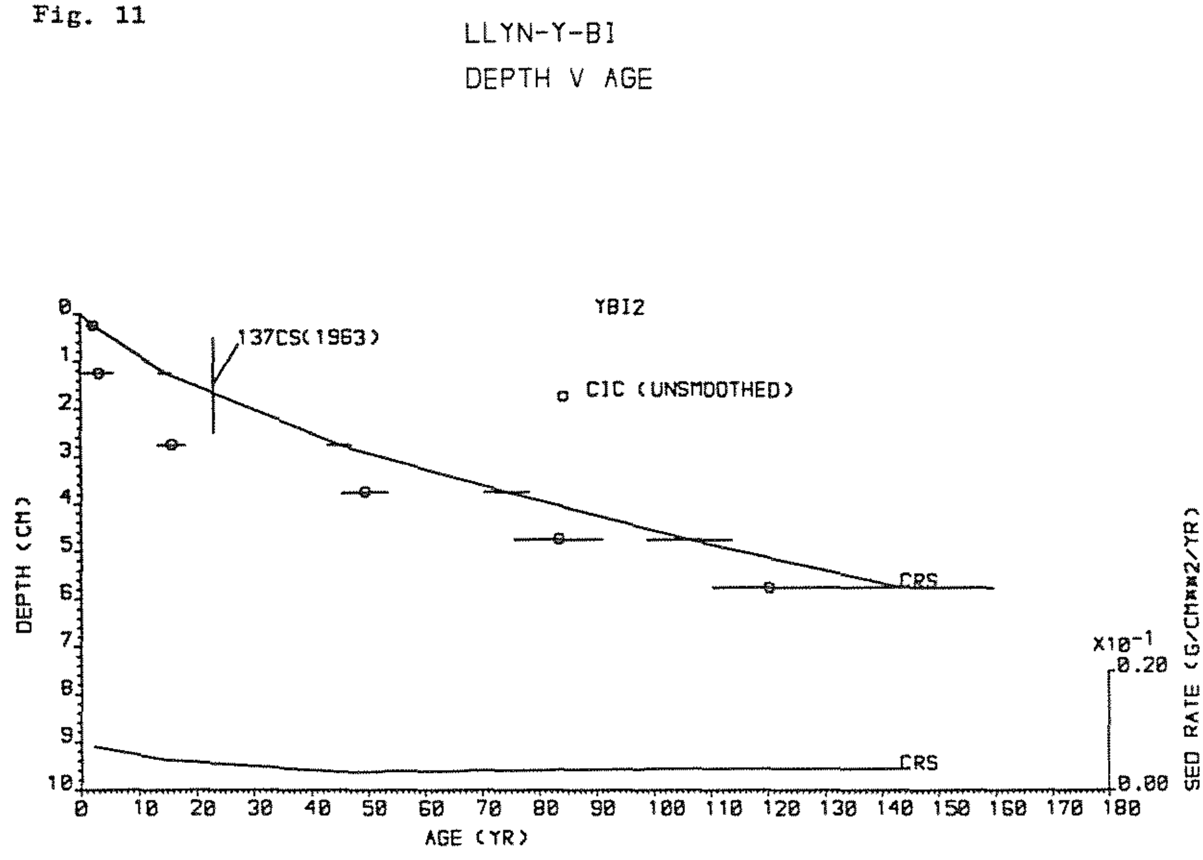
1700 = 9.73

Fig. 10



10. ^{137}Cs profile for the Llyn y Bi 2 core

Fig. 11



11. CRS and CIC ^{210}Pb age/depth chronology for the Llyn y Bi 2 core

4.1.3. Diatoms and pH reconstruction

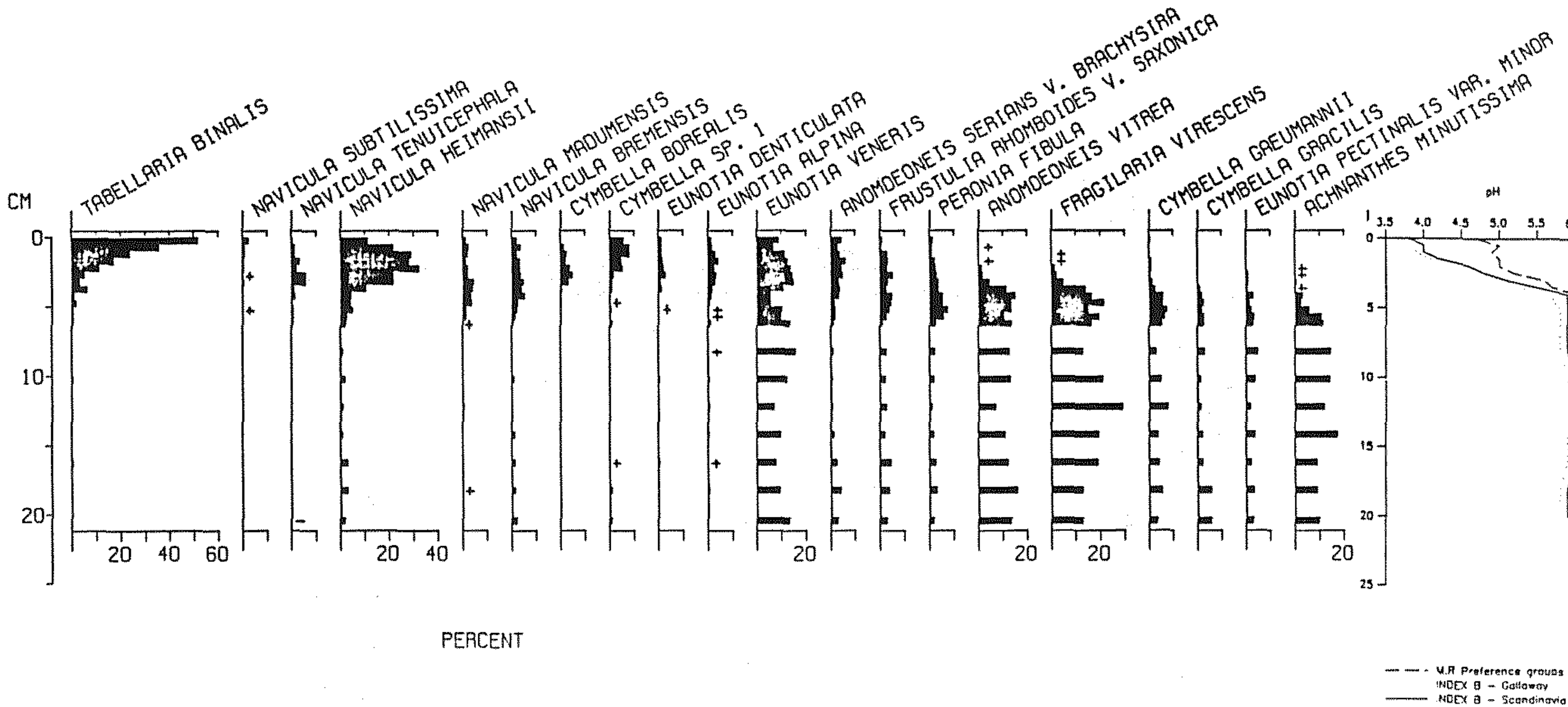
Diatoms were analysed from the uppermost 20 cm of core YBI 2. The top 6 cm includes the ^{210}Pb-dated portion of the core. Fig. 12 is a summary diagram of the relative abundance of major taxa in the Llyn y Bi sediments. Diagrams showing the stratigraphy of all taxa are included in Appendix A.

Periphytic taxa make up the diatom flora throughout the analysed sediments. Below 5 cm the flora is dominated by the circumneutral and acidophilous taxa *Achnanthes minutissima*, *Anomoeoneis vitrea*, *Fragilaria virescens* and *Eunotia veneris*. Other common taxa include *Cymbella gaeumannii*, *Cymbella gracilis*, *Eunotia pectinalis* var. *minor*, *Frustulia rhomboides* var. *saxonica*, *Navicula mediocris*, *Peronia fibula* and *Tabellaria flocculosa*. This assemblage is somewhat similar to the early floras of the nearby Llyn Dulyn (Stevenson *et al*. 1987b), excepting significant percentages of acidophilous *Melosira* species in Llyn Dulyn, and of Llyn Gynon (Stevenson *et al*. 1987a), which has higher percentages of the alkaliphilous *Fragilaria construens* var. *pumila*. The absence of planktonic species suggests that Llyn y Bi has been moderately acidic throughout the period represented by these sediments.

The first floristic changes occur in the Llyn y Bi core at 5 cm (ca. 1869) with the expansion of *Navicula madumensis* and subsequently *Navicula bremensis* and the initial decline of *Achnanthes minutissima*. More dramatic floristic changes begin above 4 cm (1903), with the expansion of the acidobiontic taxa *Tabellaria binalis* and *Navicula subtilissima*, the acidophilous taxa *Navicula heimansii*, *Eunotia denticulata* and *Eunotia alpina*, as well as the pH-undesignated *Navicula tenuicephala* and *Cymbella borealis*. Several circumneutral taxa including *Anomoeoneis vitrea*, *Cymbella gracilis* and *Fragilaria virescens* decline concurrently. The progressive expansion of *Tabellaria binalis* and decline of *Achnanthes minutissima*, *Fragilaria virescens* and *Anomoeoneis vitrea* is similar to the pattern seen in the uppermost sediments of several Galloway lochs (Flower *et al*. 1987) and clearly indicates a progressive decline in lake pH. Llyn y Bi is the only Welsh where *Tabellaria binalis* has been found, and in contrast to several of the other acidified Welsh sites, *Tabellaria quadriseptata* is rare. Percentages of *Tabellaria binalis* are considerably higher in the uppermost 2 cm of Llyn y Bi than in any Galloway sites, where relative abundances do not exceed 10%.

pH reconstructions for Llyn y Bi (Fig. 12) using index B-Galloway, index B-Scandinavia, and multiple regression of pH groups (Flower 1986) all suggest a stable pH of 5.8 - 6.1 below 4 cm (1903). Above 4 cm pH declines rapidly, dropping over 1.2 units between 1903 and 1985. The initial pH decline at Llyn y Bi is approximately synchronous with that at nearby Llyn Dulyn (Stevenson *et al*. 1987b) and at Llyn Hir (Fritz *et al*. 1986), although at Llyn Hir the pH decline is less rapid early in the 20th century and then accelerates in the 1940's.

The pH reconstruction using multiple regression of pH categories accurately predicts the mean lakewater pH at the sediment surface. pH reconstruction models using index B, however, predict a surface pH considerably lower (3.7 - 3.8) than the actual lakewater pH. This large discrepancy in measured vs predicted pH is somewhat difficult to explain. It is clear that the pH



12. Diatom summary diagram for the Llyn y Bi 2 core

reconstructions are being driven by the tremendous representation of the acidobiontic Tabellaria binalis whose relative abundance in Llyn y Bi greatly exceeds that in any of the Scandinavian or Galloway sites used to construct the indices. We are presently developing a calibration data set for pH reconstruction (see Flower 1986) using surface samples from Welsh lakes (including Llyn y Bi). This regionally based data set should provide more accurate pH reconstructions for the Welsh lakes which differ floristically in several respects from the Galloway and Scandinavian lakes (eg. Fritz et al. 1986). Nonetheless the agreement of the three extant models in reconstructing pre-20th century pH values of Llyn y Bi and a early 20th century onset of pH decline suggests that the pattern and timing of pH change suggested by these models is real and that the magnitude of 20th-century pH change is indeed considerable. Subsequent pH models using a Welsh data set will hopefully allow an accurate modelling of the true magnitude and rate of the 20th century pH decline.

4.1.4. Sediment chemistry

Major cations

The sediment constitution in Llyn y Bi, as in all the Welsh lakes studied so far, is not constant along the core. Both density and dry weight decrease up the core (with shoulders at 5 and 18 cm) while the loss on ignition generally increases (with minor peaks also at 5 and 18 cm) (Fig. 7).

The behaviour of magnesium, sodium and potassium is similar (Fig. 13). The concentrations are fairly constant to 20 cm and then after a small drop they increase to 8.25 cm and finally drop towards the sediment surface. A comparison of the cation profiles with that of loss on ignition shows that the changes in cation concentration are not due to changes in the organic content of the sediment. This is also supported by the similar shape of the cation concentration-depth profiles and the same profiles when the concentrations are expressed per gramme minerals (Fig. 14).

These changes in sediment constitution indicate that there have been changes in the erosion rate of material from the catchment (Engstrom & Wright 1984, pp27-34, Mackereth 1966). The changes are before the dated part of the core but the higher concentrations between 5 and 15 cm coincide with pollen evidence (4.1.7) for a period of higher erosion of material from the catchment.

The calcium concentration is fairly constant and its behaviour is dissimilar to the other cations.

Trace metals

Even though the concentrations of magnesium, sodium and potassium all drop in the upper 8 cm of sediment the concentrations of zinc, lead and copper increase (Figs. 15 & 16) The increases in lead and zinc are large. The lead concentration increases above 8 cm, zinc above 4 cm (with a large subsiduary peak at 15 cm) and copper above 5 cm. The nickel concentration-depth behaviour is less clear but it does have a peak at 4 cm. The profiles are similar when the concentrations are expressed per gramme minerals (Fig. 17).

There is contamination of the Llyn y Bi sediments, particularly by lead and

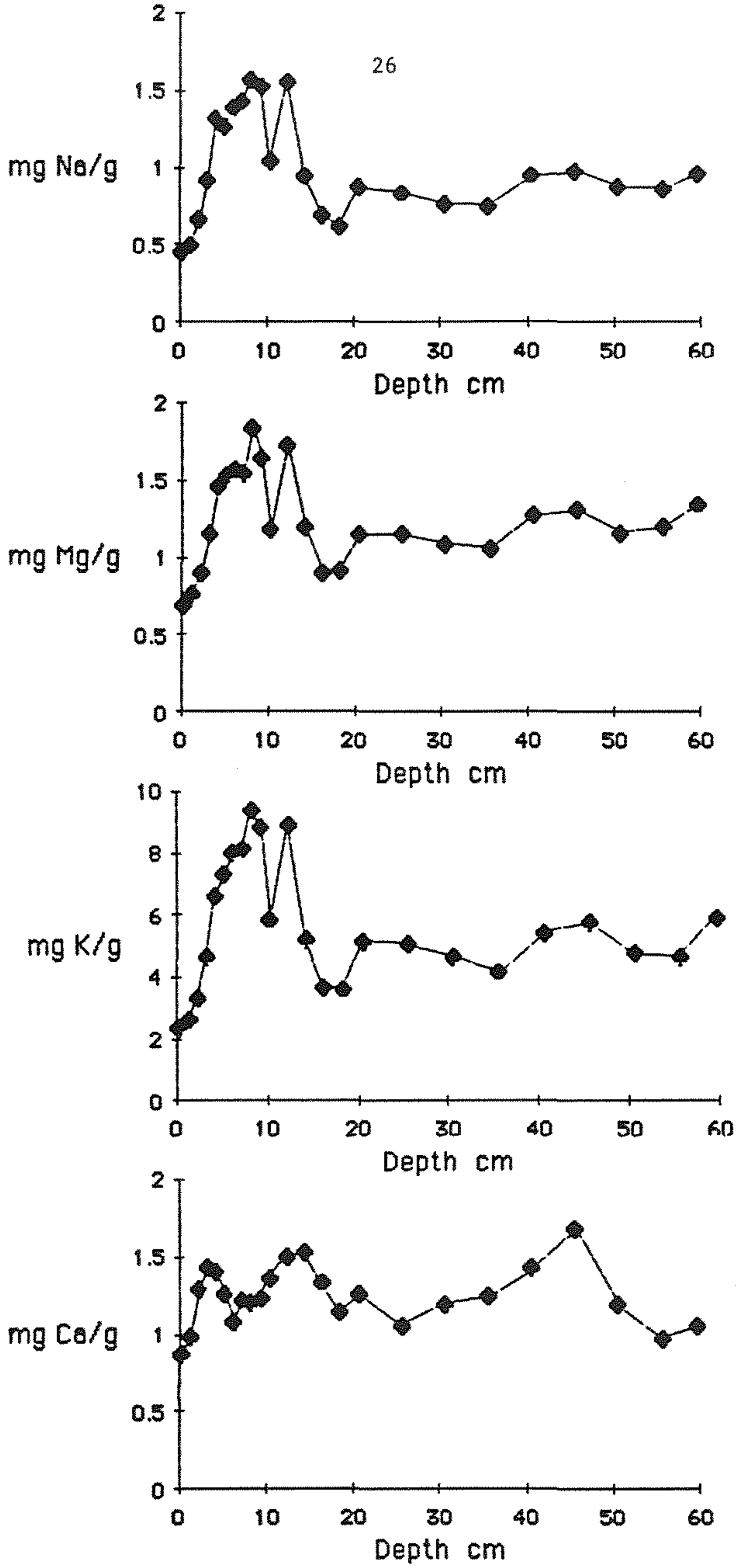


Fig. 13 The variation of sodium, magnesium, potassium and calcium concentration in Llyn-Y-Bi

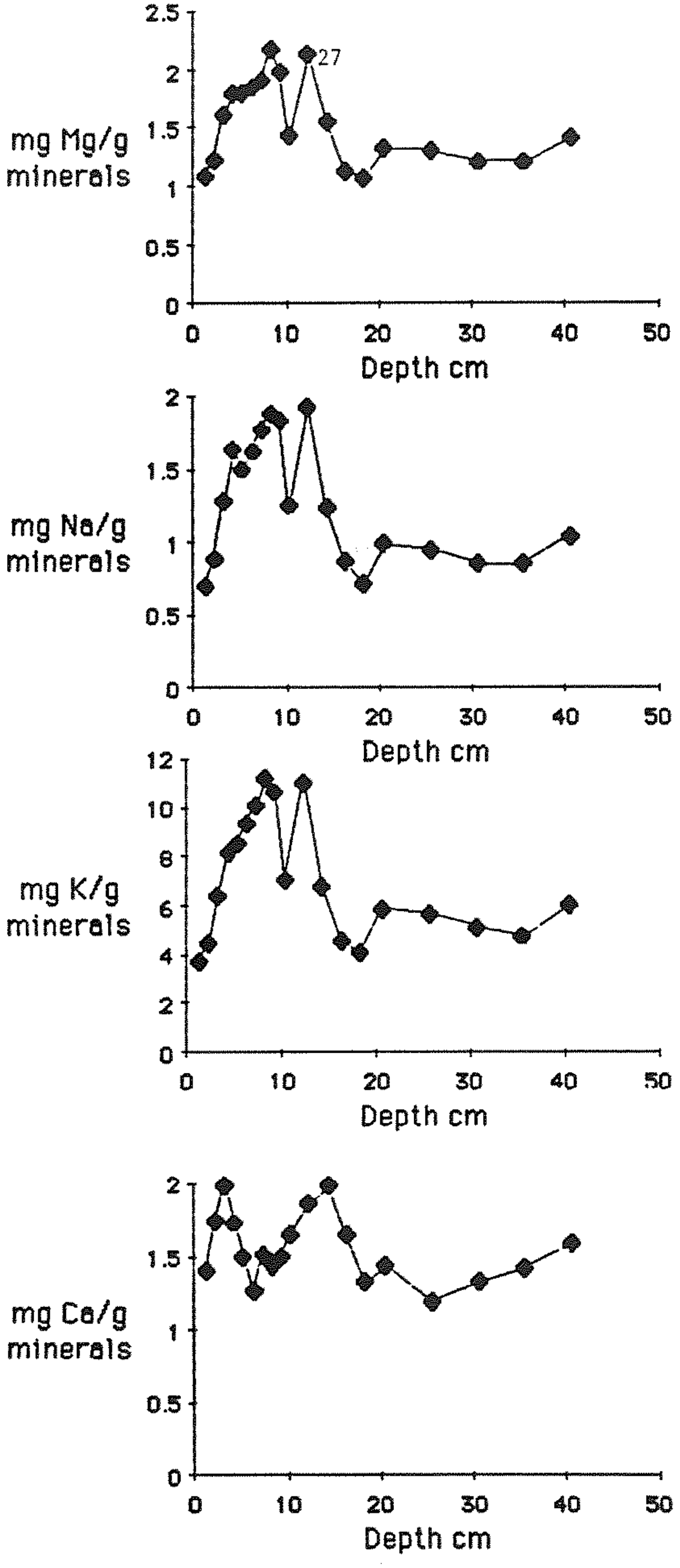


Fig 14 Variation of magnesium, sodium, potassium and calcium concentration in Llyn-Y-Bi expressed per gramme minerals

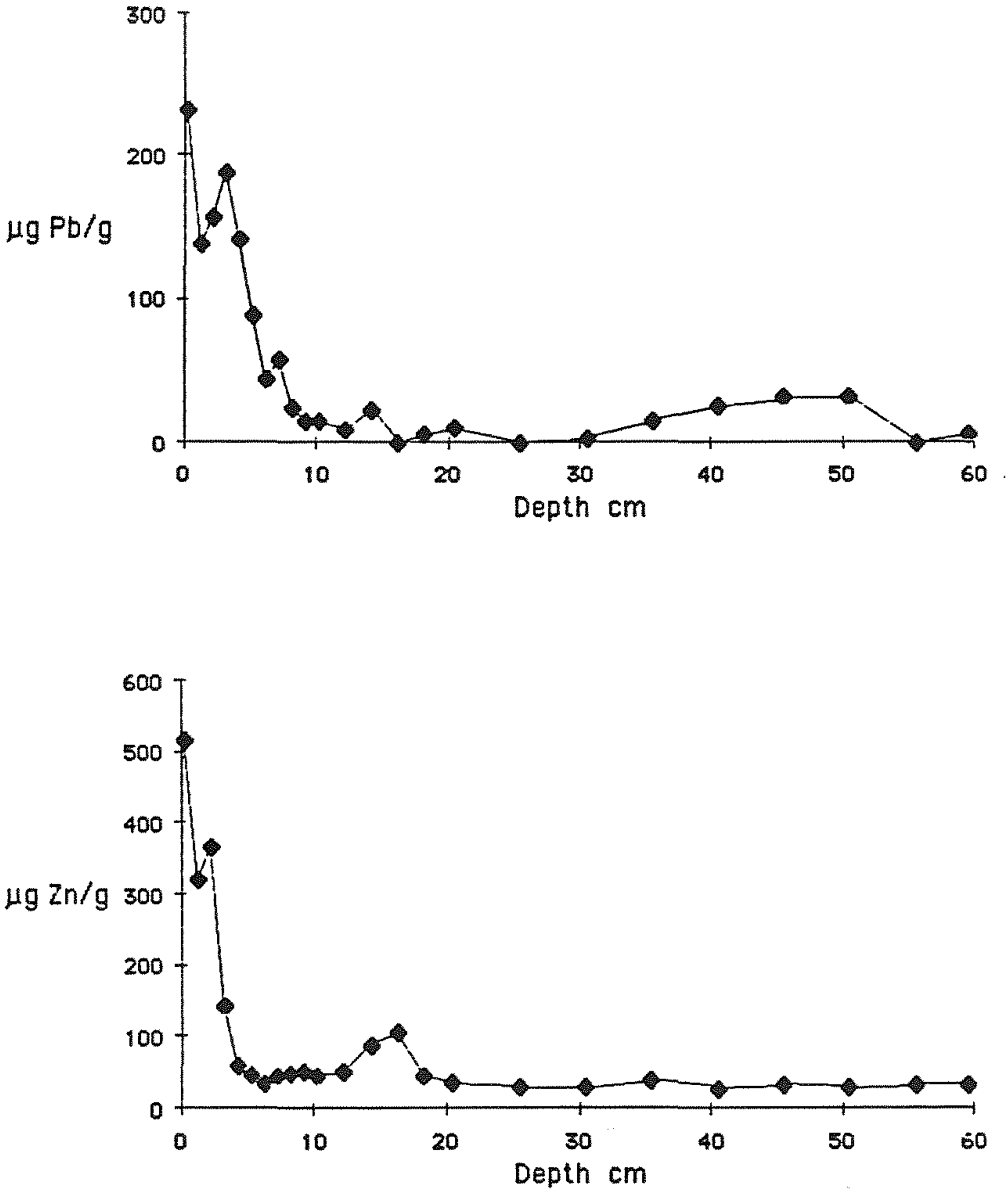
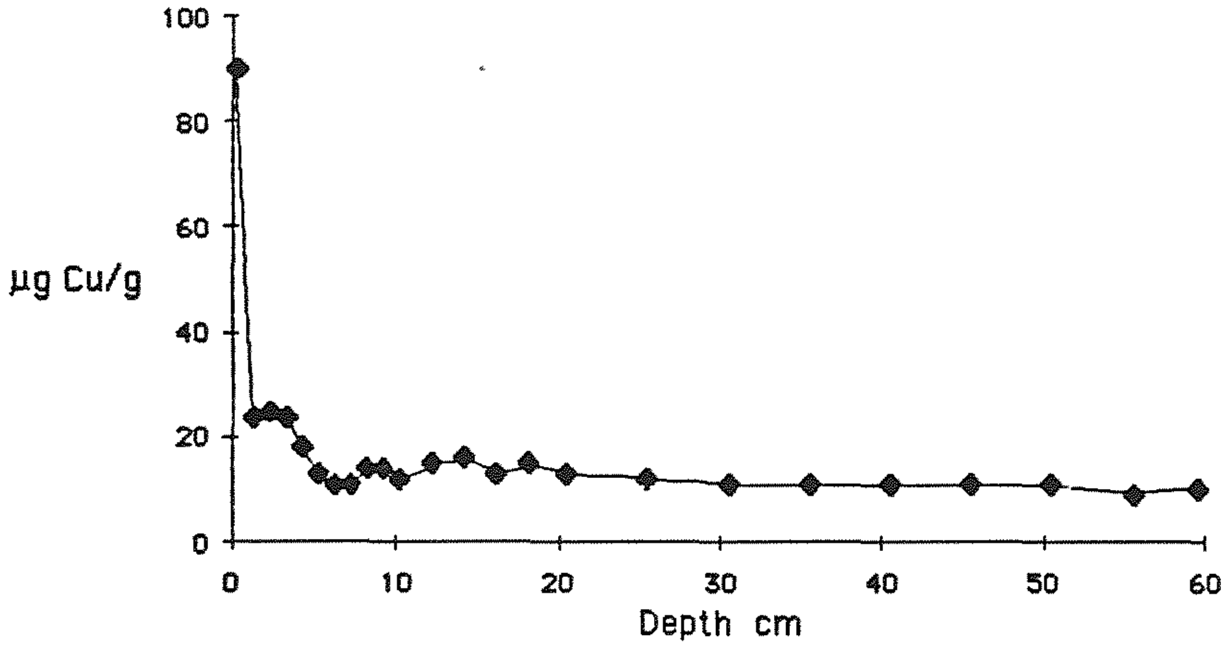


Fig. 15 Variation of lead and zinc concentrations in Llyn-Y-Bi



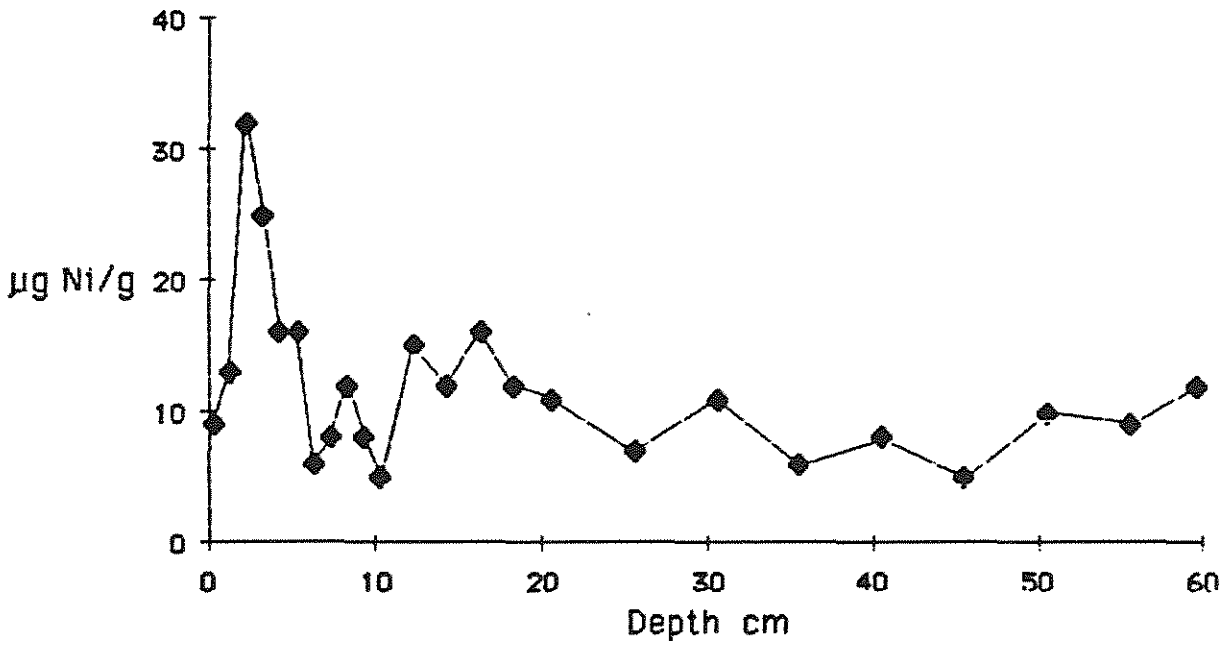


Fig. 16 Variation of copper and nickel concentrations in Llyn-Y-Bi

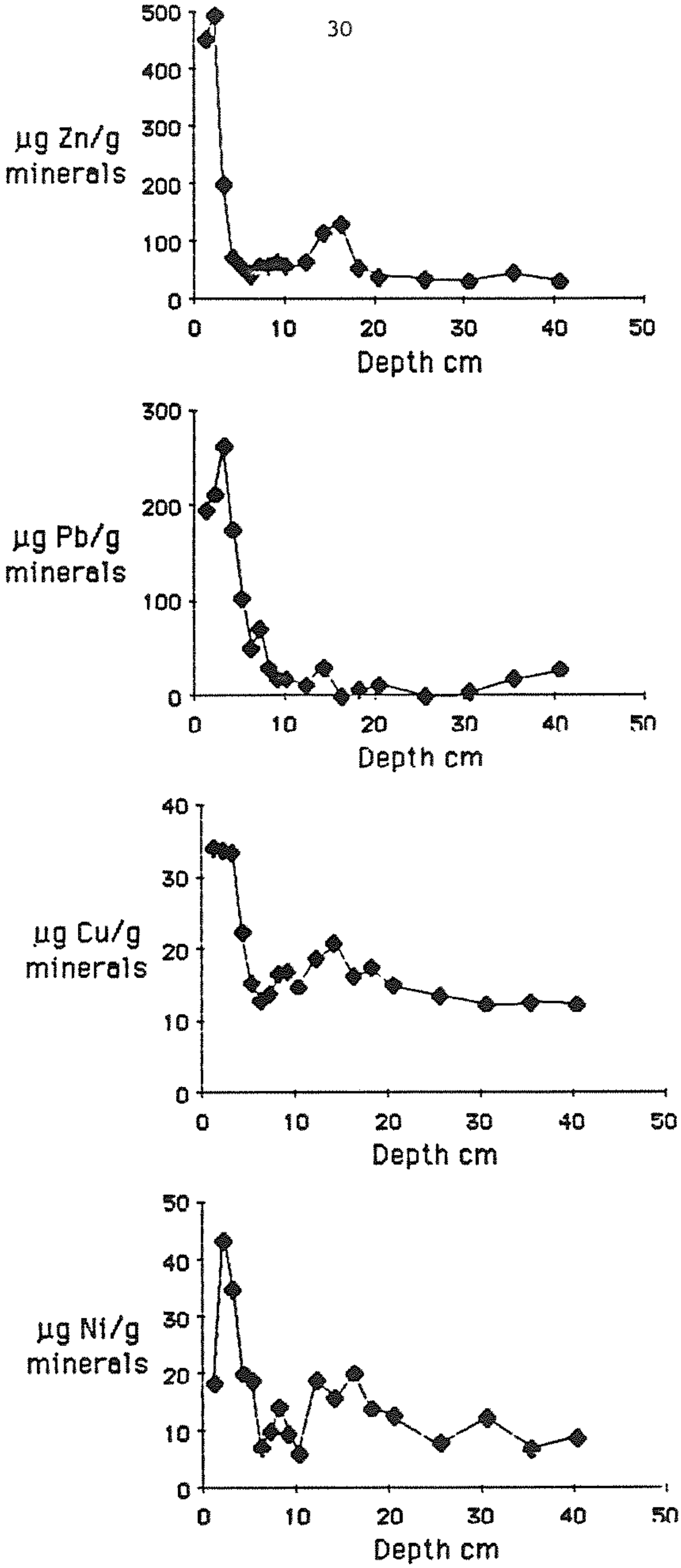


Fig 17 Variation of zinc, lead, copper and nickel concentrations in Llyn-Y-Bi expressed per gramme minerals

zinc, starting at 1903 (4 cm) with zinc and around 1800 (8 cm) with lead. This contamination, like in all the Welsh lakes so far studied, is from the atmosphere (Fritz et al. 1986, Kreiser et al. 1986, Stevenson et al 1987a, Stevenson et al 1986b). Wastewater sources in this remote lake are very unlikely.

The trace metal (and cation) fluxes in Llyn y Bi (Fig. 18) are low compared to the Galloway lakes (Battarbee et al. 1985) and the other lakes in central Wales (Stevenson et al 1987a). They are, however, similar to all but one of the lakes in north-west Wales. The low trace metal fluxes in Llyn y Bi and those other Welsh lakes are in sediments with low dry mass accumulation rates. It is probable that the low sedimentary fluxes are because of reduced trace metal sedimentation efficiencies due to low dry mass accumulation rates or short residence times.

Sulphur

The sulphur profile is shown along with loss on ignition in Fig. 19. At first glance the sulphur profile follows that of the loss on ignition. However, closer visual inspection and the correlation coefficient (0.371) show that there are factors other than changes in the organic content which influence the sulphur profile.

It may be that the sulphur peak at 16 cm is associated with the land-use changes which give rise to the loss on ignition and major cation variations around this depth. Above 5 cm the rapid rise in concentration may be due to contamination from the atmosphere. Sulphur, unlike the major cations and the trace metals, is involved in (micro)biological cycles in lakes. This complicates interpreting concentration-depth profiles as a direct reflection of inputs to the lake. Changes in lake productivity, thermal stratification and chemical environment all influence this cycling and so the net sedimentary concentrations. Without some information about the sulphur cycle in a lake it is difficult to evaluate its influence on the sulphur profiles.

4.1.5. Carbonaceous particles

The carbonaceous particle pattern for Llyn y Bi, illustrating the number of particles per gram dry sediment is given in Fig. 20 & Table 9 . It shows the presence of particles in small numbers at a depth of 6 -7 cm. The onset of a trend of rapidly increasing counts commences at 5 cm (ca. 1869), continuing to the surface.

The pattern for the carbonaceous particle count in terms of the organic content of dry sediment is given in Fig. 21. Carbonaceous particle patterns in terms of the organic fraction of sediment (using LOI) may be considered to be more precise 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 y Bi. Otherwise, the pattern is very similar to that in Fig. 20.

4.1.6. Magnetic Measurements

Sediments from Llyn y Bi 2 were packed into previously screened styrene pots and subject to the following sequence of magnetic measurements:-

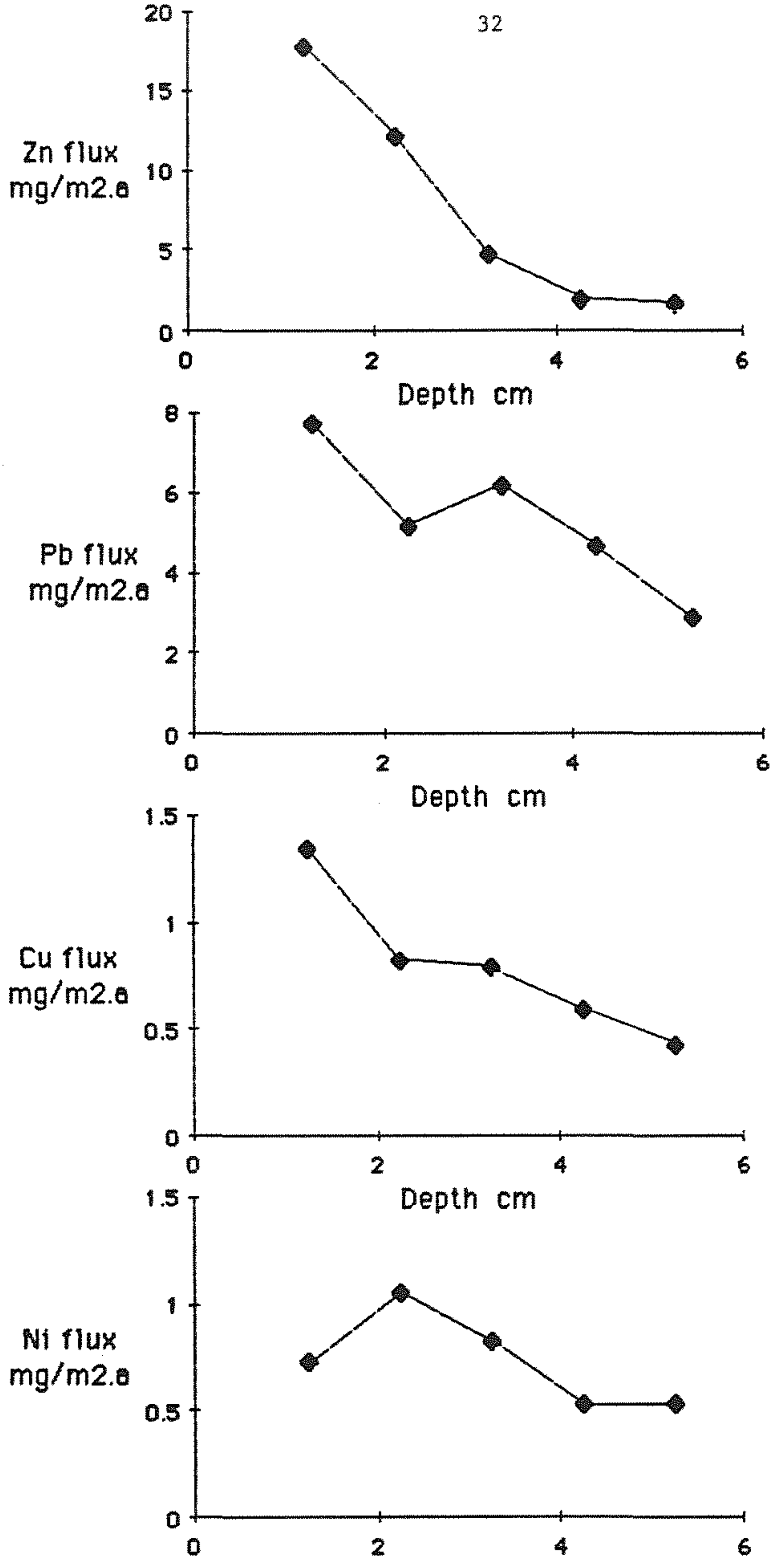


Fig. 18 Variation of zinc, lead, copper and nickel fluxes with depth in Llyn-Y-Bi

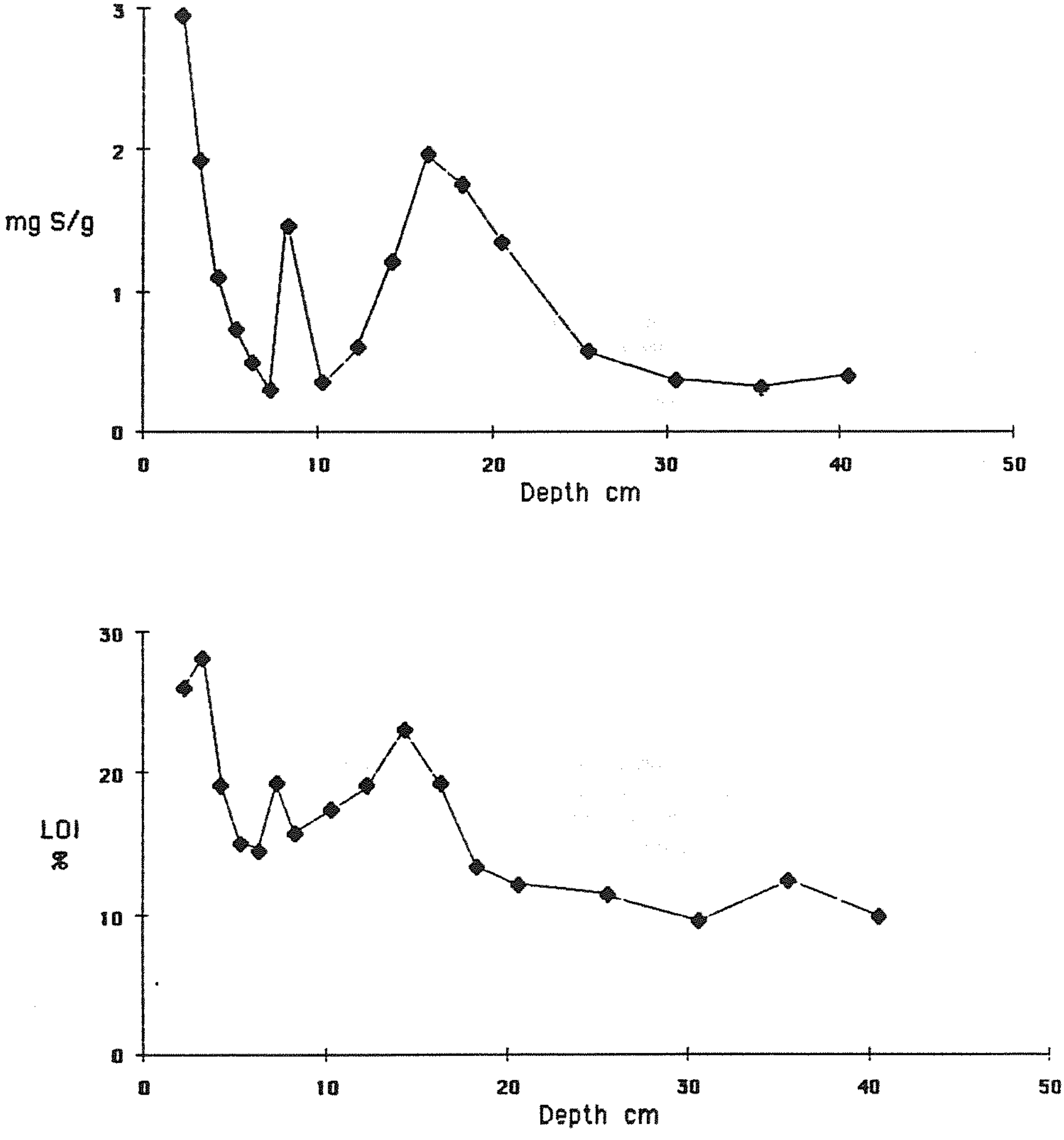
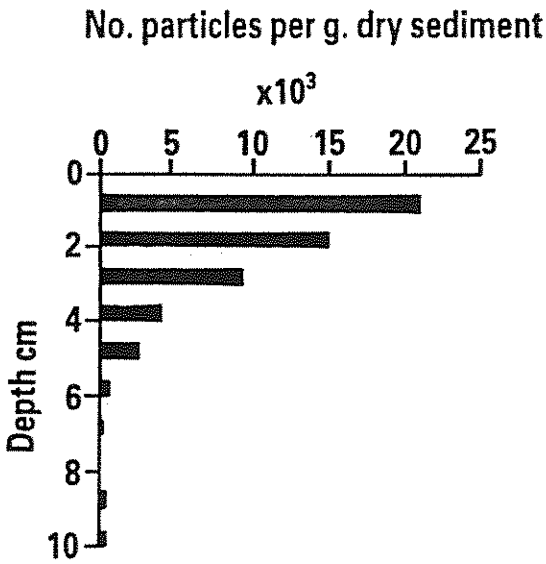


Fig. 19 Variation of sulphur with depth in Llyn-Y-Bi
The loss on ignition profile is included for comparison



20. Carbonaceous particle record gdw⁻¹ for the Llyn y Bi 2 core

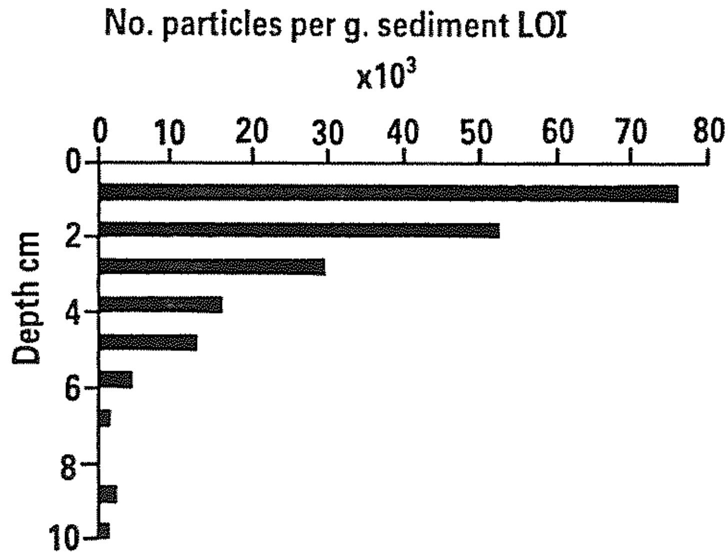


Table 9: Carbonaceous particle analysis for Llyn y Bi 2

Depth (cm)	No. Carbonaceous Particles per g dry sed x 10^3	No. Carbonaceous Particles per g organic content x 10^3
0.5 - 1.0	20.58	75.5
1.5 - 2.0	14.86	52.3
2.5 - 3.0	9.28	29.1
3.5 - 4.0	3.88	15.8
4.5 - 5.0	2.20	12.1
5.5 - 6.0	0.52	4.0
6.5 - 7.0	0.15	0.9
7.5 - 8.0	0.00	0.0
8.5 - 9.0	0.38	2.1
9.5 - 10.0	0.15	0.8

1. Anhysteritic Remanent Magnetization (ARM) using a Molspin AF Demagnetizer set with a peak AF field of 100mT and a DC bias of 0.04mT.

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.

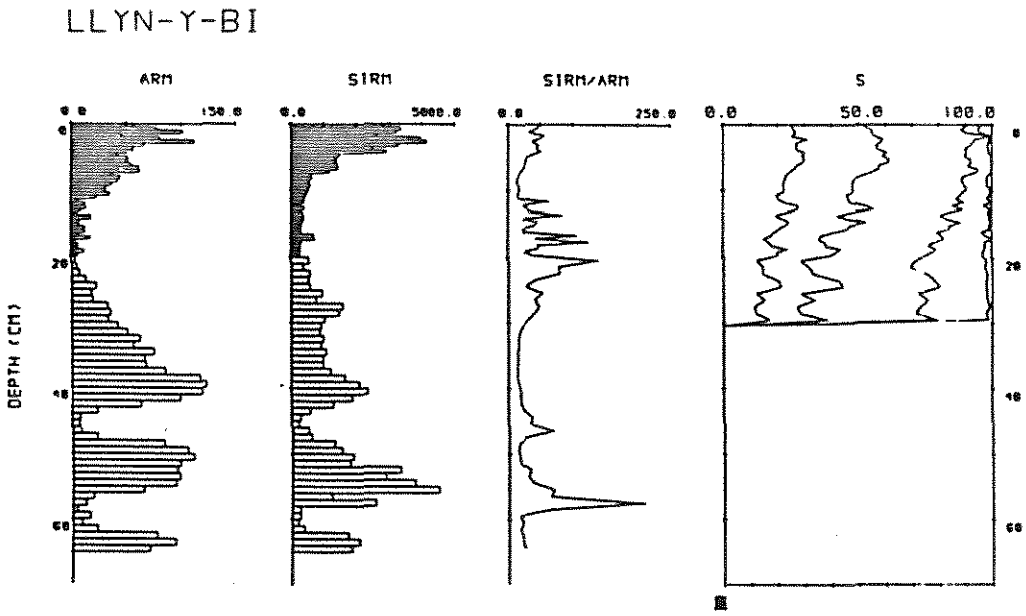
All remanences were measured on a Minispin Slow-speed spinner Fluxgate Magnetometer. Susceptibilities were not measured as the combination of small sample size and relatively weak magnetization made the samples unsuitable.

Fig. 22 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. Fig. 23 plots SIRM-IRM_{-20mT} as a mass specific remanence versus depth. This is the best available (albeit imperfect) estimate of the changing concentration of multidomain 'magnetite' in the core. Our unpublished evidence indicates that this is often the best single 'magnetic' indicator of recent anthropogenically derived atmospheric deposition. Fig. 24 plots SIRM + IRM_{-300mT} also as a mass specific remanence versus depth. This is the best available estimate of the changing concentration of 'haematite' in the core.

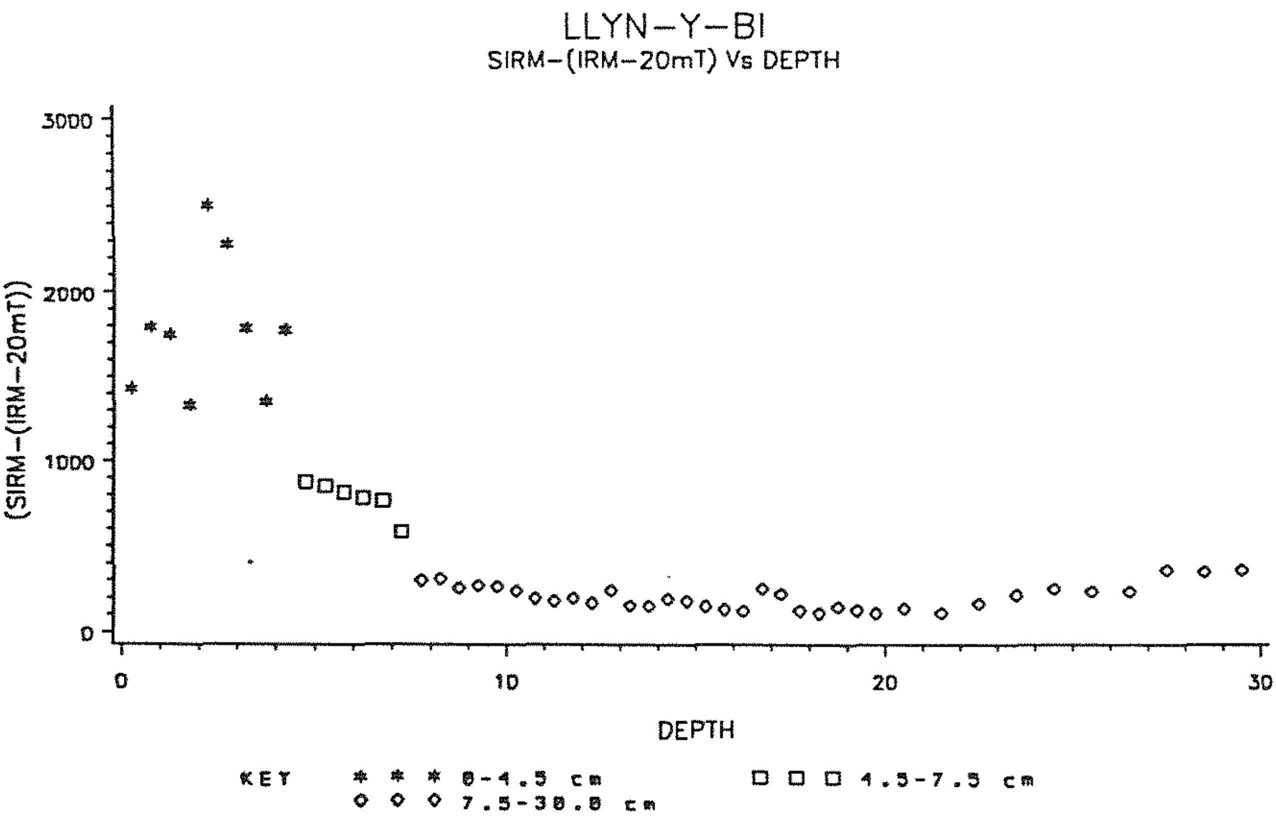
Both SIRM and $SIRM_{-20mT}$ increase steeply above 7.5 cm. The SIRM values below that depth down to 22 cm range between 250 and 700 x 10^{-6} Am^2 kg^{-1}, some 5 to 10 times the values found in most pre-industrial ombrotrophic peats. Below 22 cm there are major shifts in both SIRM and ARM with peak values exceeding those in the top 5 cm of the core. These lower variations are probably attributable to changes in allochthonous, catchment derived sediment input. Extrapolation downwards of the roughly constant ^{210}Pb derived sedimentation rates found below ca. 4 cm suggests that the period of low magnetic concentration begins in the 14th century A.D. The first increase in magnetic concentrations at 7.5 cm dates to the late 18th century and the main increase at 4 cm dates from ca. 1880 A.D.

In view of the extremely low values of ARM between 11.5 cm and 22 cm, cross plots have been compiled only for samples above 11.5 cm and detailed interpretation is restricted to this uppermost part of the core. Values for 'hard' IRM (SIRM + IRM_{-300mT}) are so low below 4.5 cm that this parameter has not been used in cross plots.

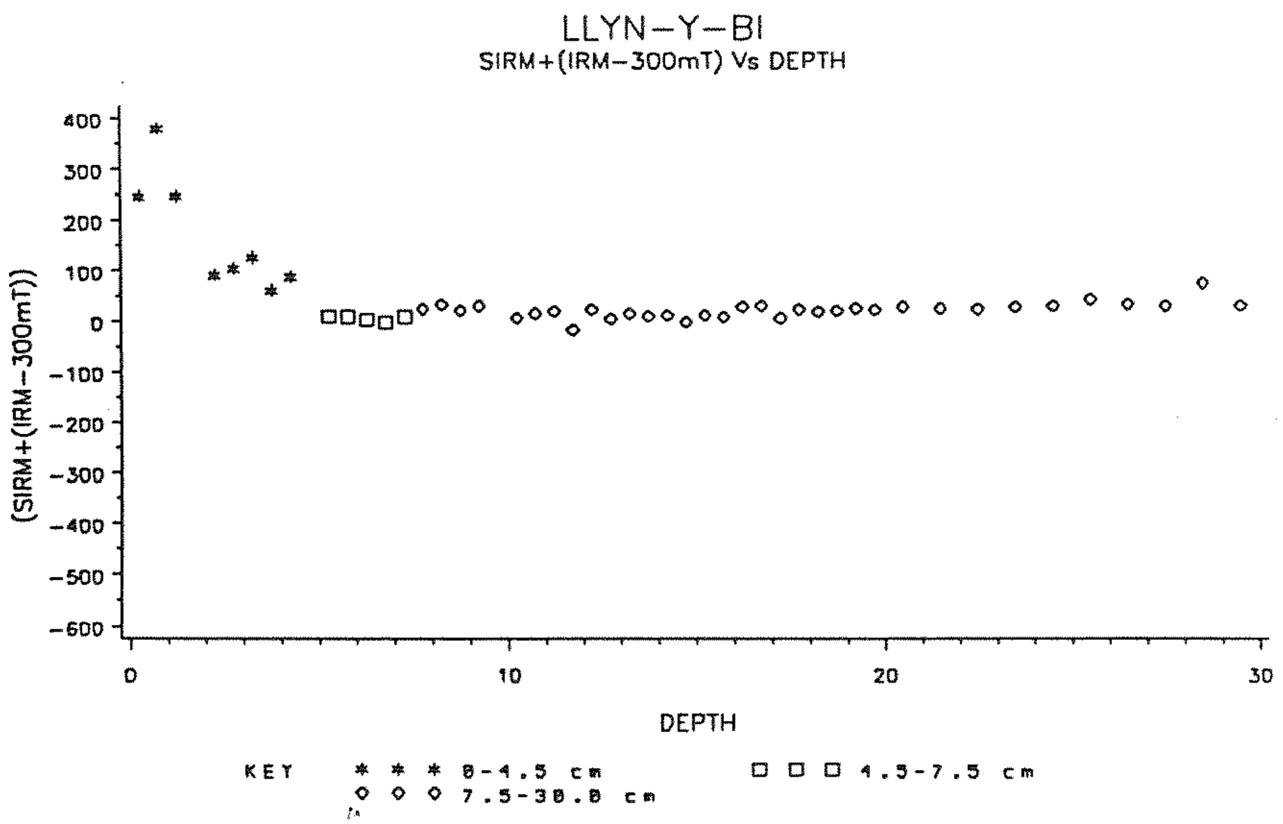
'Soft' IRM values increase in two steps at 7.5 cm and 4.5 cm (Fig. 23) and 'hard' IRM values in a single step at 4.5 cm (Fig. 24). Both on a mass specific and a normalized basis, soft IRM:ARM ratios differentiate the same sample groups below 7.5 cm, from 7.5 - 4.5 cm and above 4.5 cm, into more or less discrete envelopes of values (Figs 25 & 26). The magnetic accumulation rates shown in Fig. 27 show an increase in both 'soft' and total IRM accumulation from the late-19th century onwards, with peak deposition since 1965. The peak rates are ca. 4 times those recorded for the mid-19th century. The calculated accumulation rates parallel and are comparable in



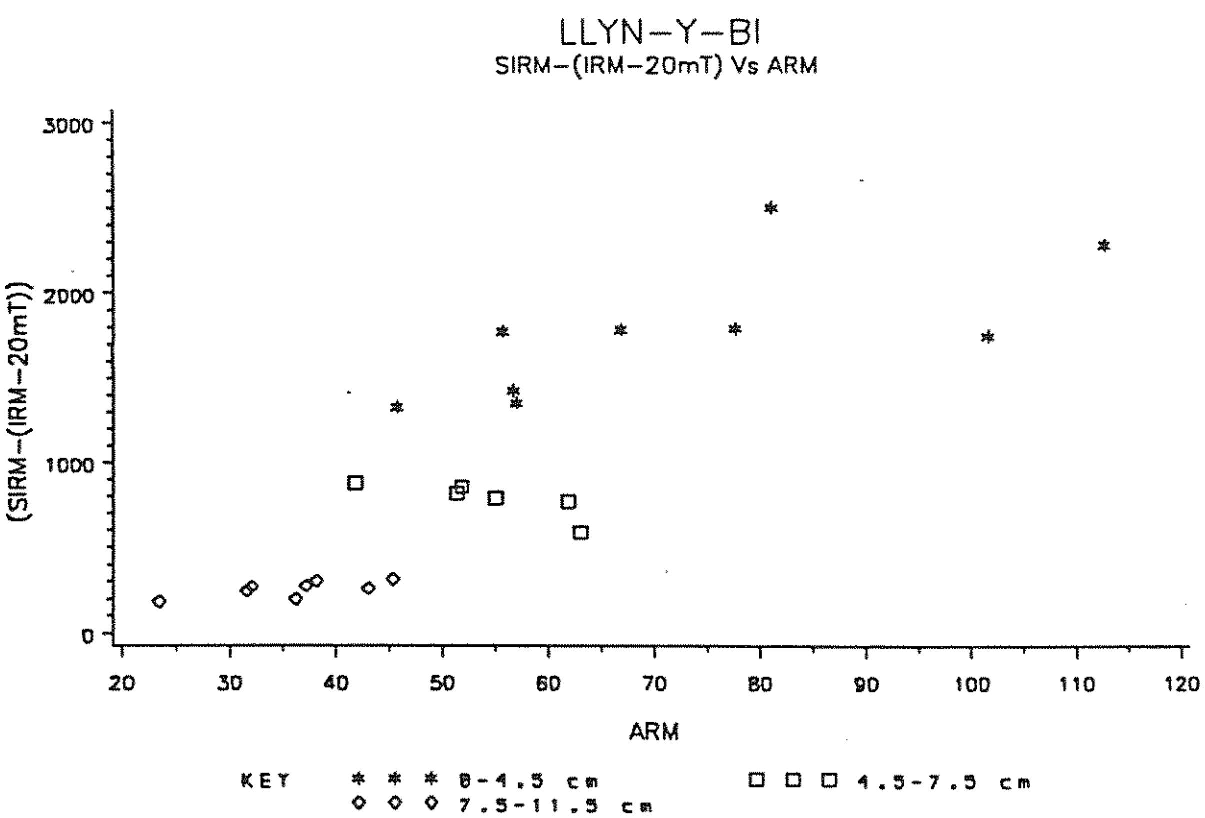
22. ARM, SIRM and SIRM/ARM versus depth, 0-80cm. Reverse field ratios (see text) are plotted for the top 23 cm only



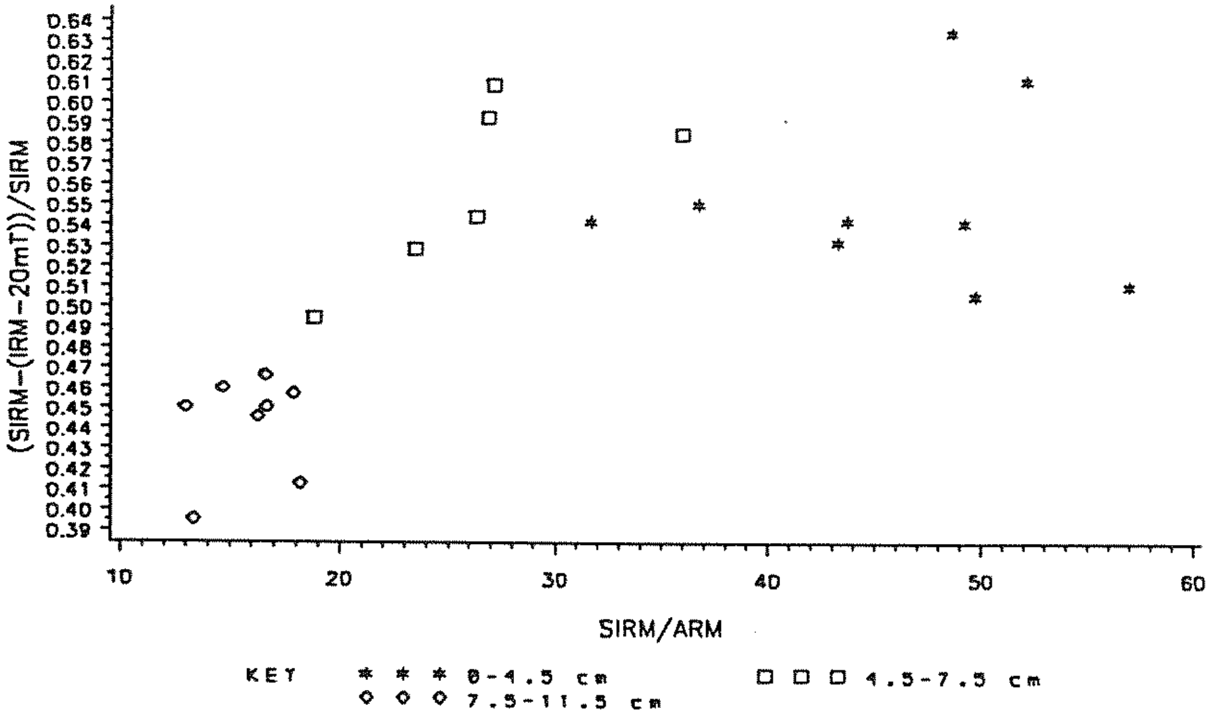
23. SIRM - (IRM_{20mT}) versus depth for the Llyn y Bi 2 core



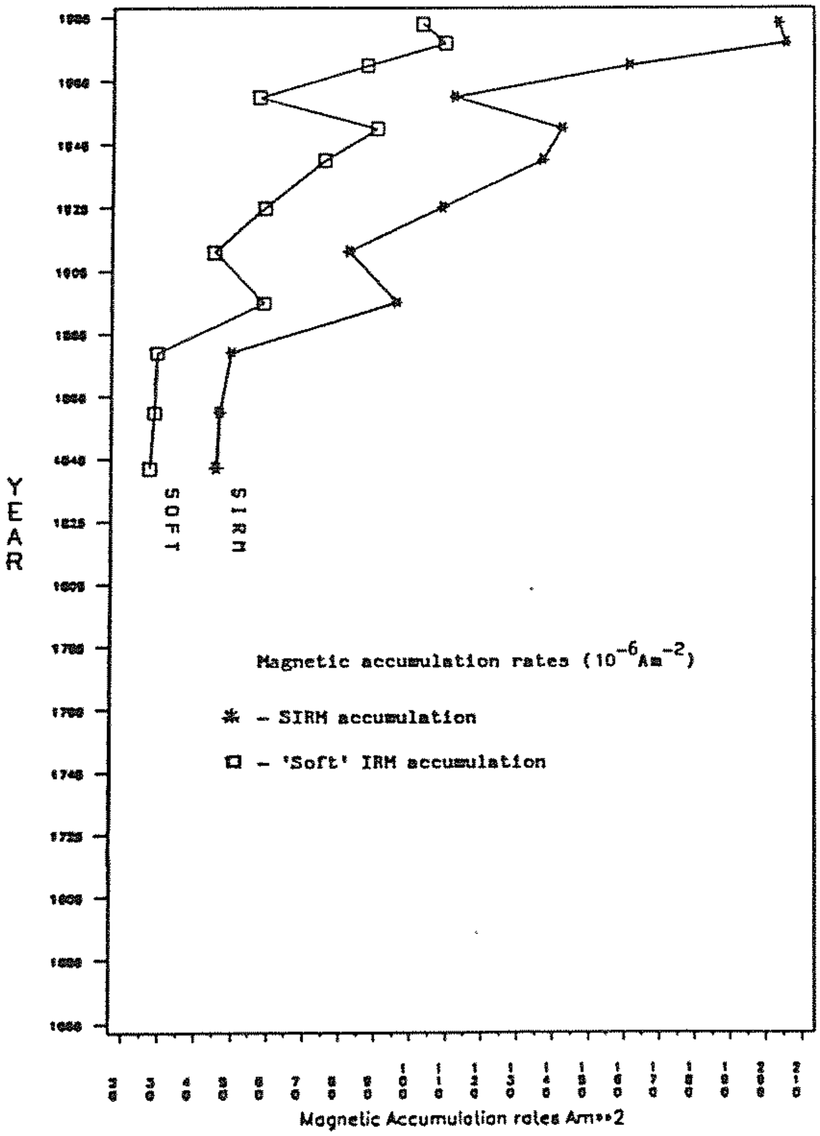
24. SIRM + (IRM_{-300mT}) versus depth for the Llyn y Bi 2 core



25. SIRM - (IRM_{-20mT}) versus ARM for the Llyn y Bi 2 core



26. (SIRM - (IRM $_{-20mT}$))/SIRM versus SIRM/ARM for the Llyn y Bi 2 core



27. Magnetic accumulation rate for the Llyn y Bi 2 core

quantitative terms to those calculated for nearby Llyn Dulyn (Stevenson et al. 1987b). All the magnetic properties of the most recent samples are compatible with atmospheric sources.

4.1.7. Pollen

Figs. 28 & 29 present summary pollen diagrams of the Llyn y Bi core. Appendix B contains the full pollen diagram. The pollen diagrams have not been zoned because of their short depth.

The pollen diagram for Llyn y Bi 2 has been truncated because of the extremely low pollen concentrations found in the sediments below 36 cm. Above this depth the core presents a picture of an open moorland dominated by *Calluna* and Gramineae. The pine increase at the top of the core along with a *Picea* increase reflects the extensive planting of the Coed y Brenin forest lying some 2 km to the east.

The catchment vegetation while now dominated by *Calluna vulgaris* and reflected in the very high *Calluna* pollen values has in the past been dominated mainly by Gramineae and *Sphagnum*. The change from this wetter type of moorland community to a drier *Calluna* dominated system is probably associated with the changing land use and management pattern (4.2.1). It is interesting to note that this is the only lake catchment within the Welsh and Scottish sites studied so far where a potentially acidifying land-use change can be identified (cf. Rosenqvist 1980, Krug & Frink 1983).

A marked erosion feature in the sediments is indicated by the dramatic collapse in *Isoetes* values at 12 & 8 cm followed by a subsequent recovery and is also indicated by a small peak in the loss on igntion record during this period and an increase in the major cation concentrations (4.1.4).

4.2 Land use and Management (1)

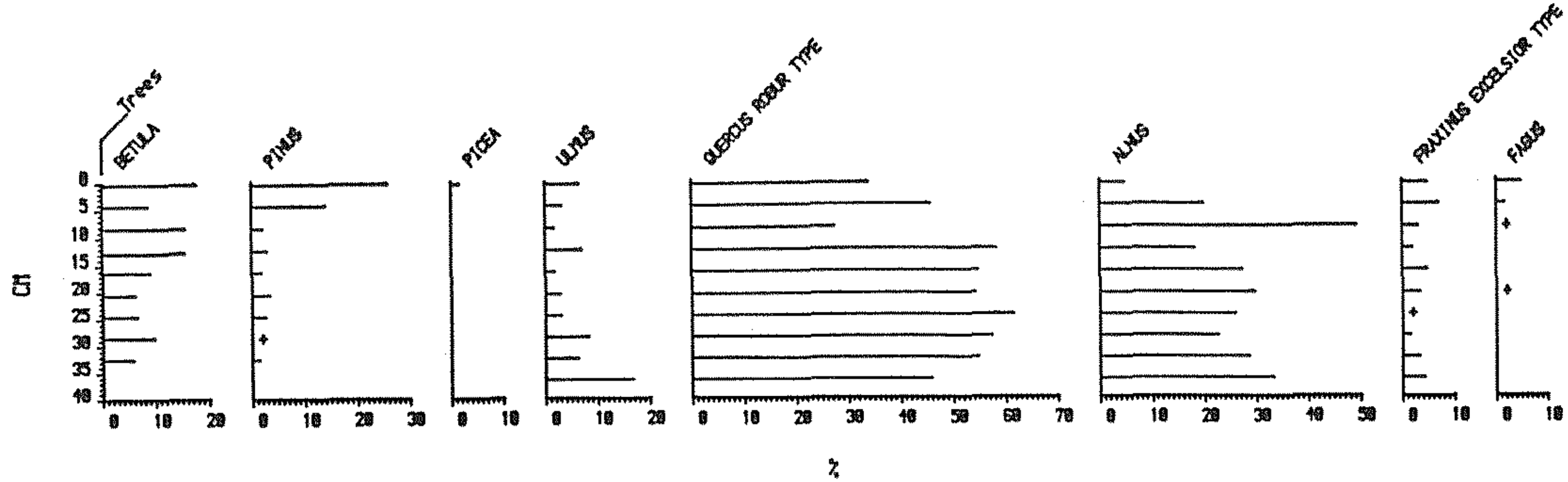
4.2.1 Land use

At over 400 m on acidic soils the Llyn y Bi catchment consists of unimproved enclosed moorland utilised for rough grazing. In terms of its vegetational composition (see Section 2.2.3) it may be categorised as 'shrubby heath' (eg. King 1977, Ball et al. 1982).

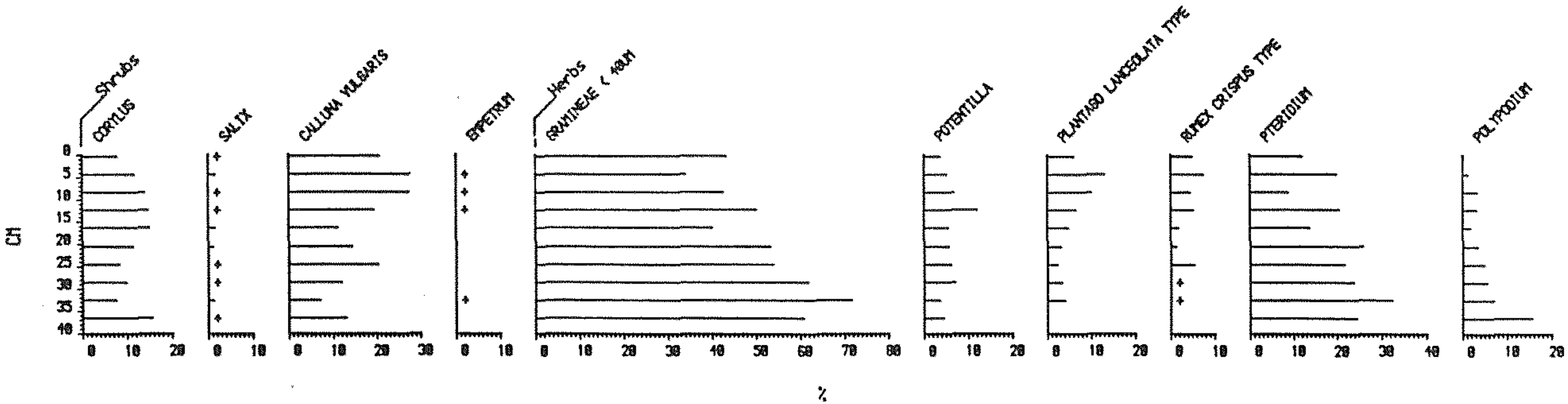
In terms of the ADAS (2) land capability classification the catchment comprises land of category H4 - 'generally not improvable and of low grazing value' (MAFF 1980).

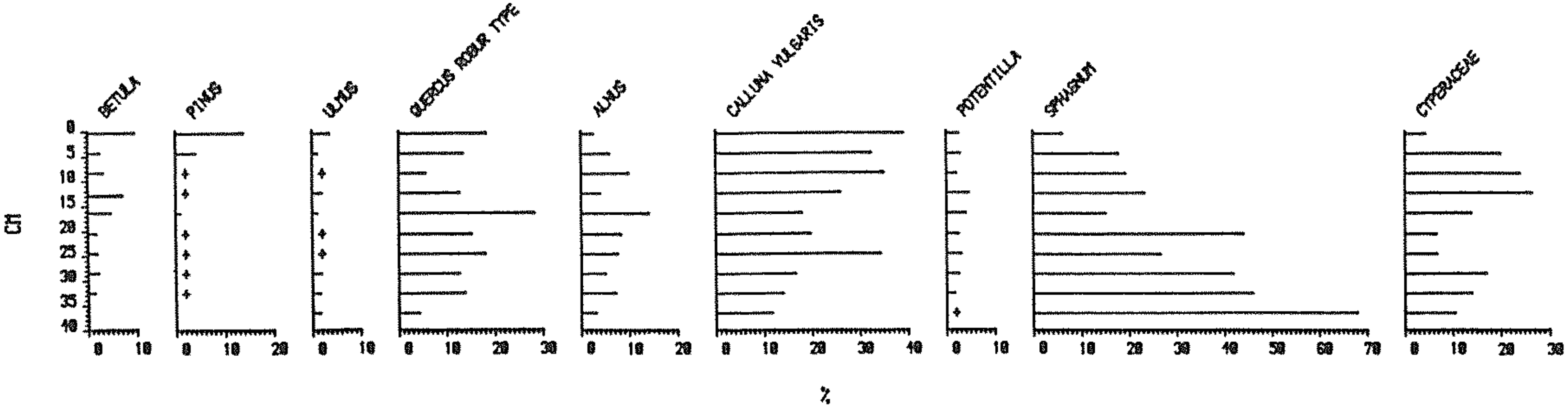
The Llyn y Bi catchment comprises the northernmost of four adjacent blocks of land enclosed by dry stone walls. The date of enclosure is uncertain. It is possible that the wall high on the western ridge is an older boundary and that enclosure into blocks took place at a later date. Locally the enclosure is attributed to the early 19th century (J. Howell pers. comm.). This was the high period of moorland enclosure in Wales coinciding with the stimulated agricultural economy of the Napoleonic wars (Bowen 1914, Dodd 1927, Morgan 1959, Thomas 1965).

Whether the enclosure was accomplished by a private or (if after 1801) a

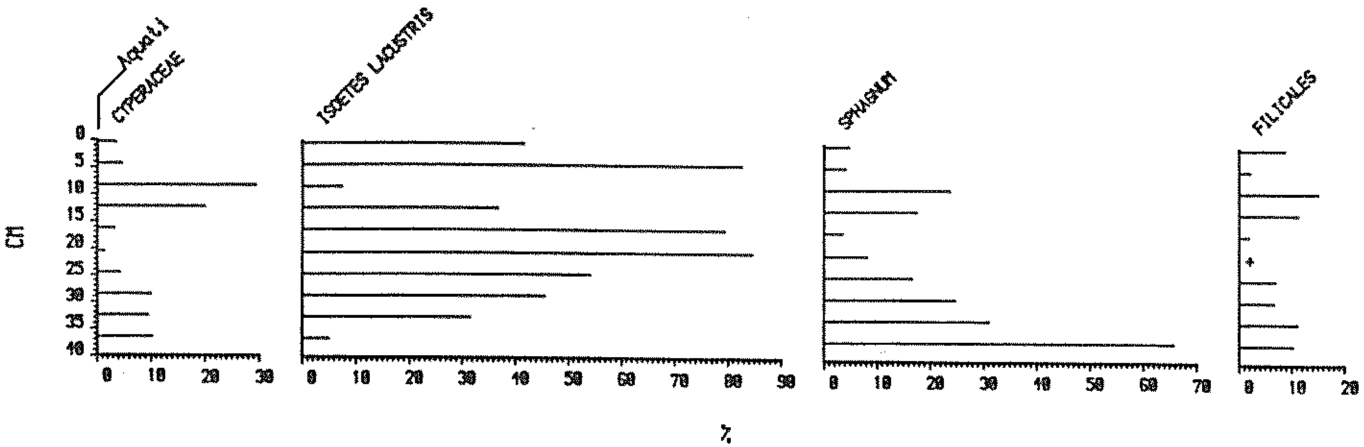


28. Summary pollen diagram for the Llyn y Bi 2 core. Trees expressed as a percentage of the arboreal pollen. All other groupings as a percentage of the arboreal pollen + the respective grouping





29. Summary pollen diagram for the Llyn y Bi 2 core. All taxa expressed as a percentage of the arboreal pollen + peatland indicators sum



parliamentary Act, or whether it represented an unauthorised encroachment by the estate (the Dolmelynllyn estate possessed the grazing rights in this area) on to the Crown Waste, is unknown. The catchment lies in the parishes of Llanddwywe-uwch-y-Graig and Llanelltyd. Some land in Llanelltyd was enclosed in 1809 (3) and some in Llanddwywe in 1810 (4) (Bowen 1914). Precise details of the area(s) involved are not known (5). A 19th century map and survey describe the 'allotments' in question but are undated (6). Ordnance Survey surveyor's drawings made in 1819 (7) give no indication of any enclosure around Llyn y Bi, but the accuracy of these plans is uncertain.

Enclosure in the vicinity of Llyn y Bi probably represented a 'land grab' by the estate and not an attempt to actively improve the rough moorland grazing (cf. Morgan 1959, Thomas 1965, Dodd 1968). Although enclosure inevitably affected the management of the land and possibly its vegetational composition (cf. Section 2.2.3), there is no evidence, nor likelihood, that the catchment has experienced a change in land use as a result.

Aside from the altitude, soil acidity and wetness of the catchment, the rocky terrain and particularly the precipitous back wall are inherently unimprovable. 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). Contemporary farmers (I. Edwards, J. Howell, J. Jones pers. comm.) and authorities (D. Jarrett pers. comm.) confirm that agricultural lime has not been applied to the catchment in living memory.

Documentary evidence (7)

The tithe maps and schedules of Llanddwywe (Llanddwywe-uwch-y-Graig and Llanddwywe-is-y-Graig) (8) and Llanelltyd (9) provide somewhat inconclusive evidence as to the land use of the catchment in the mid-19th century. The section in Llanddwywe is described as 'allotment' attached to the holding 'Ty Cerrig'. The notation 'pasture' does not necessarily indicate improved grazing land (cf. Morgan 1959, Kain and Prince 1985). The section in Llanelltyd is described as 'unenclosed sheepwalk'. This suggests that enclosure occurred after the tithe survey (1841) or, more probably, that the survey was inaccurate, the information being derived from an earlier map (Kain and Prince 1985).

The first and subsequent editions of the six inch ordnance survey map of the area (10) show the catchment to consist of 'rough or heathy pasture'.

The First Land Utilisation Survey six inch manuscript map of 1937 (11) places the entire catchment in the 'moorland/rough grazing' category. The Second Land Utilisation Survey six inch manuscript map of 1970 (12) indicates a vegetation cover and distribution very similar to the present situation (Fig. 6).

Non agricultural land use

Although it lies close to the Cefn Cam slate quarry which functioned in the 19th and early 20th centuries, and north of the Diphwys manganese mines, there is no evidence from documentary sources or on the ground to suggest that any mineral was ever exploited or prospected for 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). It has been suggested that the name 'Llyn y Bi' is derived from 'Llyn y Bu' which is translated 'lake of the cattle' (J. Howell pers. comm.). Goats also ranged the hills in significant numbers (13) (Evans 1812, Roberts 1959, Emery 1965, Hughes et al. 1973), as did young ponies which Merioneth was renowned for rearing and which stayed on the hills year round (Davies 1813). However, the central issues of pastoral management in the catchment concern its utilisation for sheep grazing.

The only quantitative data relating to sheep numbers in the vicinity of Llyn y Bi are those of the annual parish agricultural returns of Llanddwywe-uwch-y-Graig and Llanelltyd (14). These were analysed at quinquennial intervals and are presented in Fig. 30.

Although they represent the source of information most applicable to the Llyn y Bi 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).

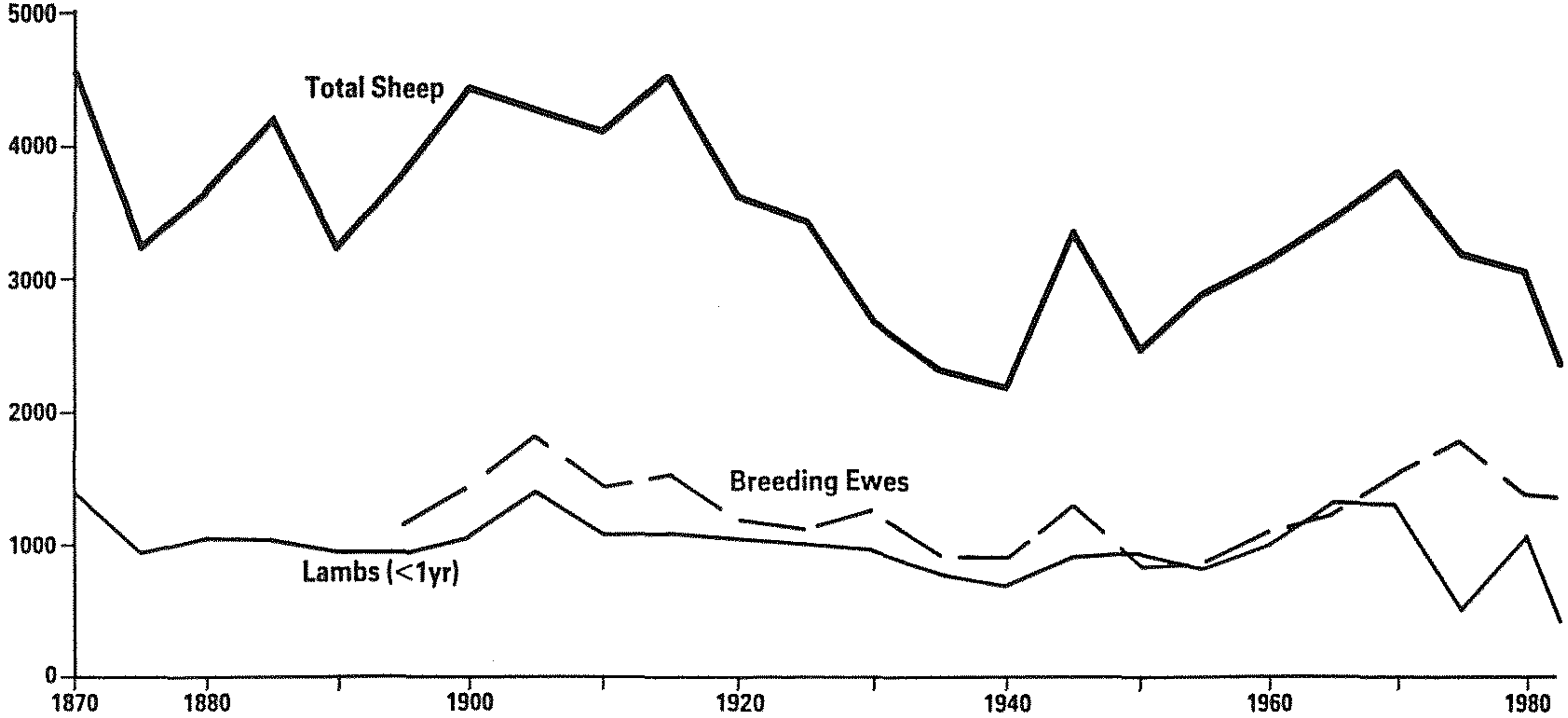
Sheep numbers have fluctuated between 1867-1983 but the overall trend in both parishes has been for numbers to fall (Fig. 30). The increasing significance of ewes and lambs at the expense of wether sheep over the last century, is also suggested from Fig. 30.

Within the Llyn y Bi catchment a broad decrease in sheep numbers has been recognised since ca. 1930 (G. Edwards, I. Edwards, J. Howell, D. Jarrett pers. comm.), although the present tenant maintains a slightly larger flock (ca. 200) than his predecessor (ca. 140) on the land in and surrounding the catchment (I. Edwards, J. Howell pers. comm.).

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 (15) 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) (16).

Fig. 30 probably overestimates the grazing intensity in the Llyn y Bi catchment. Much of the catchment is unsuited for sheep grazing. Until the National Trust purchased the area in ca. 1930 it was managed for grouse not sheep. The long, rangy Calluna of the catchment is indicative of low

LLYN Y BI (LLANDDWYWE-UWCH-Y-GRAIG)



30. Sheep numbers in Llanddywye-uwch-y-Graig & Llanelltyd parishes 1895-1983

intensity management and grazing pressure. This is particularly apparent when compared with the two enclosures immediately to the south of the catchment. Here the continued maintenance of a higher sheep population and more regular burning has resulted in vegetation dominated by short Calluna and grassy species.

The Llyn y Bi catchment lies in the Snowdonia National Park but has been owned by the National Trust since ca. 1930. The trust negotiate maximum stocking levels with their tenant farmers (17) and require to be consulted over management practices such as burning.

Burning

When managed primarily for grouse (mid-19th century - ca. 1930) the catchment was regularly burnt in small patches (I. Edwards, J. Howell, J. Jones pers. comm.). Since that date the frequency and extent of burning declined. Aerial photographs show no evidence of 'recent' burning in the catchment in 1946 and 1962 (18). A combination of National Trust policy, the proximity of the Rhinog National Nature Reserve immediately to the north and extensive tracts of forest 2 km. to the south-east and 3 km. to the east, determine that the catchment is now burnt very infrequently.

Management for game

The moorland in the vicinity of Llyn y Bi was actively managed for game (primarily grouse) through the 19th and early 20th centuries (J. Aylett, J. Howell, D. Jarrett pers. comm.). A shooting 'box' was constructed about 1.5 km. to the south of the Llyn y Bi catchment for the benefit of 'sportsmen'. Shooting ceased in the Llyn y Bi catchment when the National Trust purchased the land surrounding the lake. Gamekeepers ceased to patrol the moors in the area in the 1920s (G. Edwards, J. Howell pers. comm.) since when grouse numbers have substantially declined.

5.0 Conclusions

i) Sediment accumulation rates at the core site appear to have accelerated above 2.75 cm (ca. 1940). Before 1940 there appears to have been a constant accumulation rate of 0.033 g cm^{-2} yr^{-1}.

ii) Planktonic diatoms were absent from the lake and the data suggest a fairly stable flora of attached circumneutral and acidophilous taxa. Acidification of Llyn y Bi is marked by the expansion of Tabellaria binalis, Navicula subtilissima, N. heimansii, Eunotia denticulata & E. alpina. The diatom based pH reconstructions suggest that the pH of Llyn y Bi was 5.8 - 6.1 throughout most of the history recorded in the core (until 4 cm ca. 1903). Above 4 cm pH declines rapidly, dropping over 1.2 units between 1903 and 1985.

iii) The core chemistry record demonstrates that trace metal contamination of the lake sediments began between 7 and 8 cm (ca. 1800) with lead followed by strong contamination by zinc at 4 cm (1903). The low trace metal fluxes are thought to be the result of low dry mass accumulation rates and hence reduced sedimentation efficiencies.

iv) The contamination of the sediments by carbonaceous particles commences at 6 cm (ca. 1840's). The rapid rise in carbonaceous particles from 4 cm (1903) is concurrent with lake acidification. A similar trend is shown by the magnetic data.

v) The recent portion of the pollen diagram identifies a shift in the local vegetation from Gramineae domination to domination by Calluna at a depth of 10 - 15 cm a century or more before lake acidification began. A period of catchment erosion is identified by an Isoetes decline from 20 cm to 10 cm and matches a period of increased cation concentrations in the lake sediments.

vi) No land use change has occurred within the catchment. However, a cessation of burning has occurred in recent years with a concomitant decrease in sheep numbers and grazing pressure. No liming has taken place within the catchment.

vii) While the pollen evidence suggests that a vegetation change towards Calluna heathland took place in the local area in the 18th and 19th centuries the timing of the changes and trends of the atmospheric pollution indicators (trace metals, magnetics, carbonaceous particles). indicate acid deposition as the cause of acidification. The extent to which acidification might have been exacerbated by land-use management practices cannot be assessed. Moreover, this is the only lake site in central Wales & north-west Wales where a potentially acidifying land-use change is indicated.

6.0 References

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7.0 Acknowledgments

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8.0 Notes

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. 49 Geo. 3, C.66.

4. 50 Geo. 3, C.56.

5. Of the nine Acts of enclosure concerning lands in Merioneth passed between 1801-1850, only six awards are extant (Thomas 1965).

6. UCNW Mostyn Collection 8677. 'Map and survey of allotments in the township of Uwch-Craig and the parish of Llanddwywe. No date.

7. British Museum Map Library, Ordnance Survey Surveyor's Drawings sheet 302, drawn 1819, published 1837-1840.

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

9. Tithe map and schedule for the parish of Llanddwywe. PRO (Kew) IR

10. Tithe map and schedule for the parish of Llanelltyd. PRO (Kew) IR

11. First edition surveyed 1887, published 1890.
    Second edition surveyed 1900, published 1901.
    Third edition ammended 1949, published 1953.
    There was no 25 inch survey of this area.

12. Held at the London School of Economics archive.

13. Held at King's College London Geography Department. Sheet no. 509.

14. A herd of feral goats roams the moorland of the Rhinog National Nature Reserve which abuts the Llyn y Bi catchment to the north.

15. PRO (Kew) Class MAF 68.

16. Abandonment of the highest farms in the Llyn-y-Bi region set in after ca. 1850.

17. Recently this trend has been partially reversed in the catchment as the current tenant maintains his sheep on the hill for a longer period than his predecessor who generally brought them to lower ground in early November (I. Edwards, J. Howell, J. Jones pers. comms.).

18. Actual numbers of sheep on the catchment are considerably below the maximum of 500 ewes which the present agreement would permit (J. Aylett, J. Howell pers. comms.).

19. Air Photograph Office, Welsh Office, Cardiff. 1:10,000.
369: 1225, 1226. May 4th 1946.
2074: 0085, 0086. June 6th 1962.

LLYN-Y-BI SPECIES LIST

AC002A	ACHNANTHES LINEARIS	W. SMITH
AC002C	ACHNANTHES LINEARIS V PUSILLA	GRUN.
AC003A	ACHNANTHES MICROCEPHALA	KUTZ.
AC013A	ACHNANTHES MINUTISSIMA	KUTZ.
AC014A	ACHNANTHES AUSTRIACA	HUST.
AC022A	ACHNANTHES MARGINULATA	GRUN.
AC024A	ACHNANTHES DEPRESSA	(CLEVE) HUST.
AC030A	ACHNANTHES UMARA	CARTER
AC042A	ACHNANTHES DETHA	
AC9999	ACHNANTHES SP	
AN003A	ANOMOEONEIS SERIANS	(BREB.) CLEVE
AN003B	ANOMOEONEIS SERIANS V BRACHYSIRA	(BREB.) CLEVE
AN004A	ANOMOEONEIS VITREA	(GRUN.) ROSS
AN9998	ANOMOEONEIS SP A	EG HORSESHOE L. (RWB)
AS003A	ASTERIONELLA RALFSII	W. SMITH
CM001A	CYMBELLA VENTRICOSA	KUTZ.
CM004A	CYMBELLA MICROCEPHALA	GRUN.
CM009A	CYMBELLA NAVICULIFORMIS	AUERSWALD
CM010A	CYMBELLA PERPUSILLA	A. CLEVE
CM017A	CYMBELLA HEBRIDICA	(GREGORY) GRUN.
CM018A	CYMBELLA GRACILIS	(RABH.) CLEVE
CM020A	CYMBELLA GAEUMANNI	MEISTER
CM046A	CYMBELLA BOREALIS	HUST.
CM9992	CYMBELLA SP 1	PIRLA
CM9999	CYMBELLA SP.	
CY016A	CYCLOTELLA ARENTII	KOLBE
DS001A	DS001A DESMOGONIUM RABENHORSTIANUM	
EU001A	EUNOTIA VENERIS	(KUTZ.) O. MULLER
EU002A	EUNOTIA PECTINALIS	(KUTZ.) RABH.
EU002B	EUNOTIA PECTINALIS V MINOR	(KUTZ.) RABH.
EU003A	EUNOTIA PRAERUPTA	EHR.
EU004A	EUNOTIA TENELLA	(GRUN). HUST.
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EU006A	EUNOTIA LUNARIS	(EHR.) GRUN.
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EU007A	EUNOTIA BIDENTULA	W.SMITH
EU008C	EUNOTIA MONODON V MAIOR	(W.SMITH) RABH.
EU009A	EUNOTIA EXIGUA	(BREB.) RABH.
EU010A	EUNOTIA FABA	(EHR.) GRUN.
EU010B	EUNOTIA FABA V INTERMEDIA	
EU011A	EUNOTIA RHOMBOIDEA	HUST.
EU012A	EUNOTIA ROBUSTA	RALFS
EU013A	EUNOTIA ARCUS	EHR.
EU014A	EUNOTIA BACTRIANA	EHR.
EU015A	EUNOTIA DENTICULATA	(BREB.) RABH.
EU017A	EUNOTIA FLEXUOSA	KUTZ.
EU019A	EUNOTIA IATRIAENSIS	FOGED
EU020A	EUNOTIA MEISTERI	HUST.
EU025A	EUNOTIA FALLAX	CLEVE
EU027A	EUNOTIA TRINACRIA	KRASSKE
EU029A	EUNOTIA VALIDA	HUST.
EU043A	EUNOTIA ELEGANS	OSTRUP
EU9983	EUNOTIA SP 1	L.HIR (SF)
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FR002A	FRAGILARIA CONSTRUENS	(EHR.) GRUN.
FR002C	FRAGIALRIA CONSTRUENS V VENTER	(EHR.) GRUN.
FR005A	FRAGILARIA VIRESCENS	RALFS
FR007A	FRAGILARIA VAUCHERIAE	(KUTZ.) BOYE PETERSON
FR010A	FRAGILARIA CONSTRICTA	EHR.
FR9999	FRAGILARIA SP	
FU002A	FRUSTULIA RHOMBOIDES	(EHR.) DE TONI
FU002B	FRUSTULIA RHOMBOIDES V SAXONICA	(RABH.) DE TONI
FU9998	FRUSTULIA CF MAGALIESMONTANA	PIRLA
GO003A	GOMPHONEMA ANGUSTATUM	(KUTZ.) RABH.
GO004A	GOMPHONEMA GRACILE	EHR.
GO013A	GOMPHONEMA PARVULUM	KUTZ.
GO9994	GOMPHONEMA SP (MONTANUM)	L.HIR (SF)
GO9999	GOMPHONEMA SP	
HA001A	HANTZSCHIA AMPHIOXYS	(EHR.) GRUN.
ME005A	MELOSIRA DISTANS	(EHR.) KUTZ.
ME005E	MELOSIRA DISTANS V NIVALIS	(W.SM.) KIRCHNER
ME010A	MELOSIRA PERGLABRA	OSTRUP
ME010B	MELOSIRA PERGLABRA V FLORINIAE	CAMBURN
ME9999	MELOSIRA SP	
NA002A	NAVICULA JARNEFELTII	HUST.
NA003A	NAVICULA RADIOSA	KUTZ.
NA003B	NAVICULA RADIOSA V TENELLA	(BREB.) GRUN.
NA005A	NAVICULA SEMINULUM	GRUN.
NA006A	NAVICULA MEDIOCRIS	KRASSKE
NA014A	NAVICULA PUPULA	KUTZ.
NA017A	NAVICULA VENTRALIS	KRASSKE
NA032A	NAVICULA COCCONEIFORMIS	GREGORY
NA033A	NAVICULA SUBTILISSIMA	CLEVE
NA037A	NAVICULA ANGUSTA	GRUN.
NA038A	NAVICULA ARVENSIS	HUST.
NA041A	NAVICULA HEIMANSII	VAN DAM & KOOY.
NA045A	NAVICULA BRYOPHILA	PETERSEN
NA046A	NAVICULA CONTENTA	GRUN.
NA099A	NAVICULA BREMENSIS	HUST.
NA129A	NAVICULA SEMINULOIDES	HUST.
NA135A	NAVICULA TENUICEPHALA	HUST.
NA140A	NAVICULA MADUMENSIS	JORGENSEN
NA142A	NAVICULA MEDIOCONVEXA	HUST.
NA9943	NAVICULA SP 29	PIRLA
NA9944	NAVICULA SP 13	EIDDAW BACH (SF)
NA9954	NAVICULA MADUMENSIS V 1	HAWORTH (NARROW FORM)
NA9963	NAVICULA SP 1	L.HIR (SF)
NA9999	NAVICULA SP	
NE004A	NEIDIUM BISULCATUM	(LAGERSTEDT) CLEVE
NI005A	NITZSCHIA PERMINUTA	GRUN.
NI009A	NITZSCHIA PALEA	(KUTZ.) W. SMITH
NI9989	NITZSCHIA CF FONTICOLA	L.HIR (SF)
NI9999	NITZSCHIA SP	
PE002A	PERONIA FIBULA	(BREB. ex KUTZ.) ROSS
PI002A	PINNULARIA ACUMINATA	SMITH SYN.PI003A
PI005A	PINNULARIA MAIOR	KUTZ.
PI007A	PINNULARIA VIRIDIS	(NITZSCH) EHR.
PI008A	PINNULARIA DIVERGENS	W. SMITH
PI011A	PINNULARIA MICROSTAURON	(EHR.) CLEVE
PI014A	PINNULARIA APPENDICULATA	(AGARDH) CLEVE
PI015A	PINNULARIA ABAUJENSIS	(PANT.) ROSS
PI018A	PINNULARIA BICEPS	GREGORY
PI021A	PINNULARIA HILSEANA	(JANISCH) MULL.
PI023A	PINNULARIA IRRORATA	(GRUN.)HUST.
PI033B	PINNULARIA BRAUNII V AMPHICEPHALA	(A. MAYER) HUST.
PI9933	PINNULARIA SP 11	PIRLA
PI9992	PINNULARIA CF TERMITINA	L.HIR (SF)
PI9999	PINNULARIA SP	
SA001B	STAURONEIS ANCEPS F GRACILIS	(EHR.) CLEVE
SA006A	STAURONEIS PHOENICENTERON	(NITZSCH) EHR.
SA9998	STAURONEIS ANCEPS V 1	L.HIR (SF)
SP001A	STENOPTEROBIA INTERMEDIA	LEWIS
SU9999	SURIRELLA SP	
SY002A	SYNEDRA RUMPENS	KUTZ.
SY9995	SYNEDRA SP 1	L. Y BI (SF)
SY9999	SYNEDRA SP	
TA001A	TABELLARIA FLOCCULOSA	(ROTH) KUTZ.
TA002A	TABELLARIA FENESTRATA	(LYNGBYE) KUTZ.
TA003A	TABELLARIA BINALIS	(EHR.) GRUN.
TA004A	TABELLARIA QUADRISEPTATA	KNUDSON
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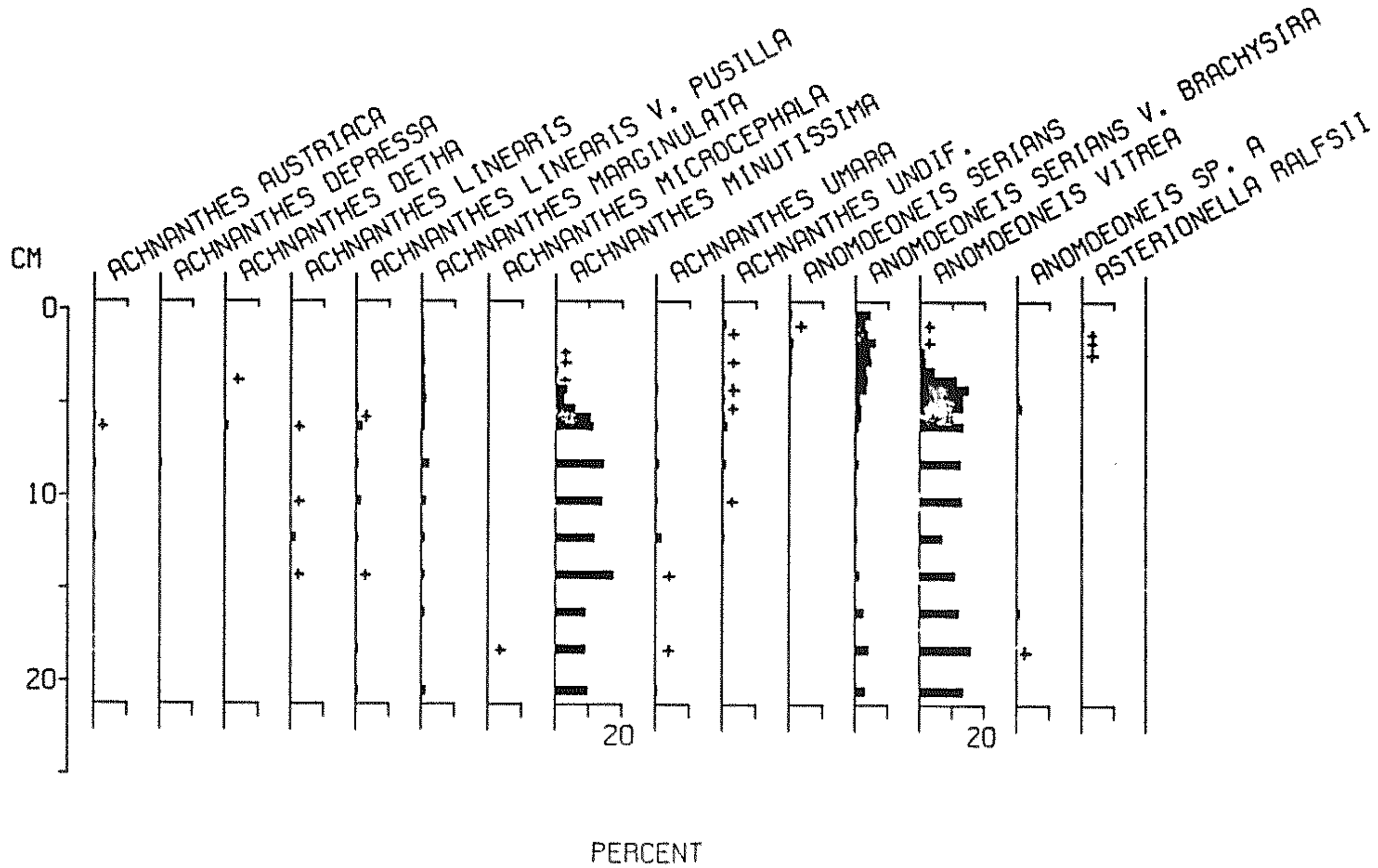
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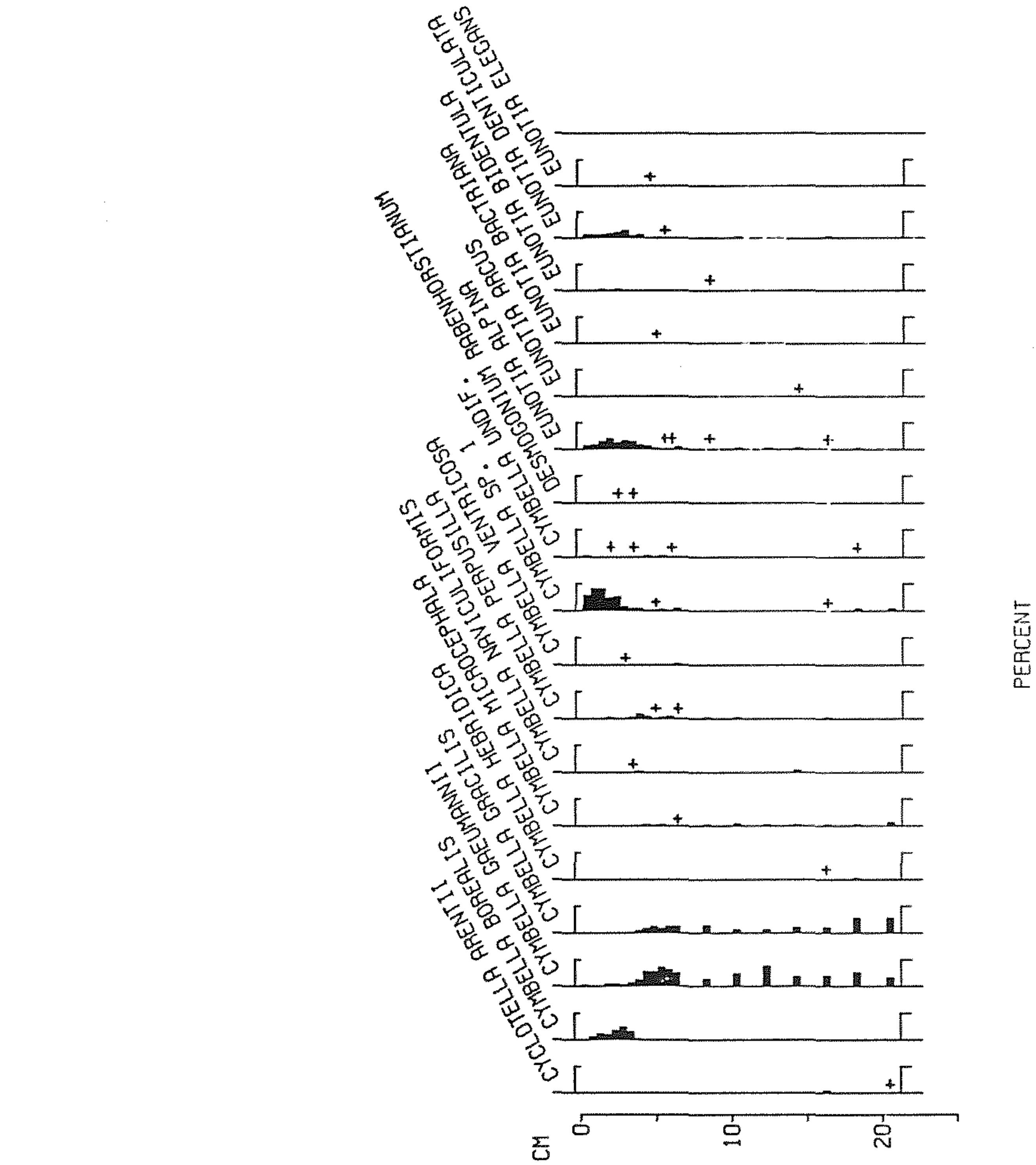
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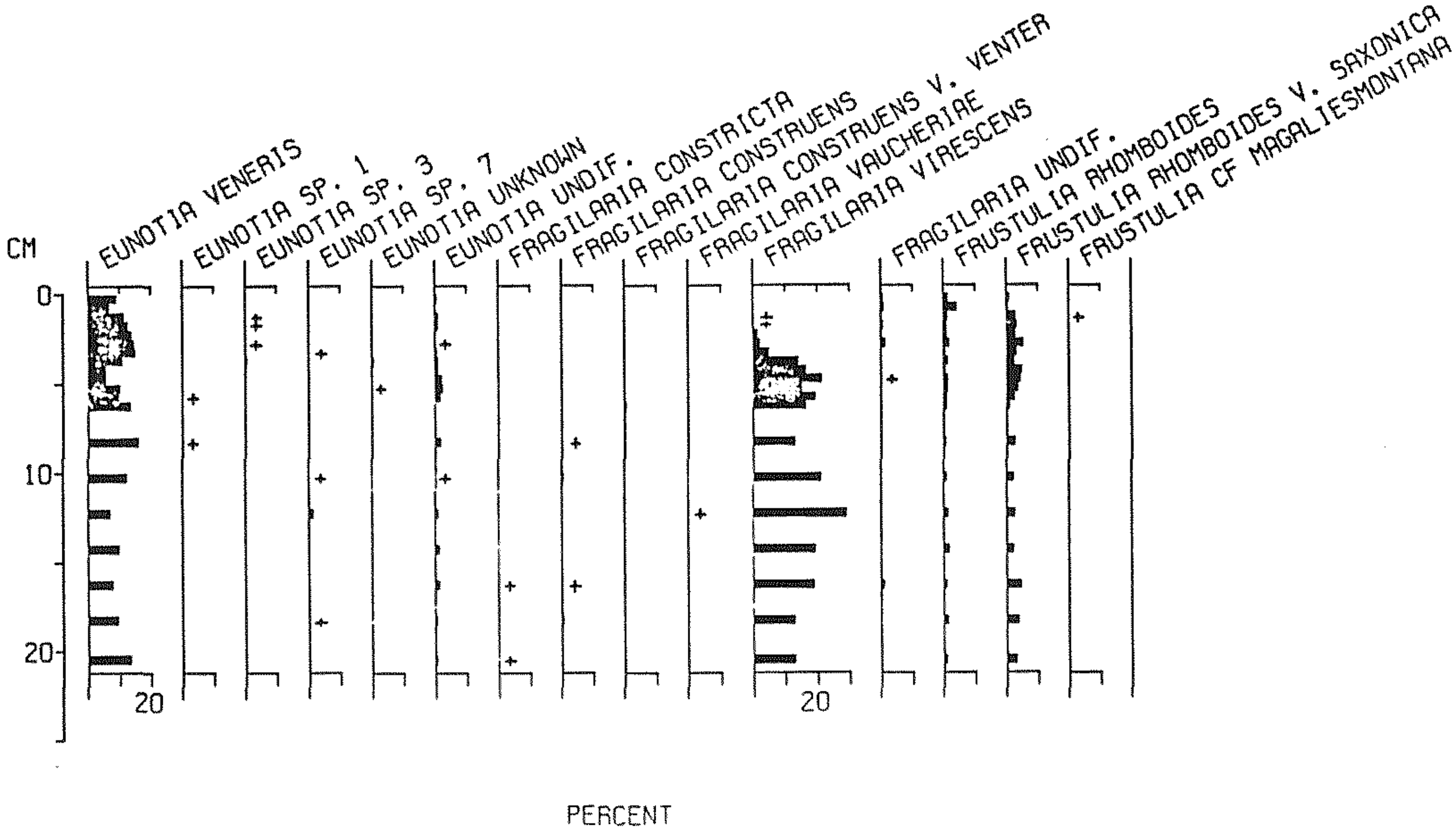
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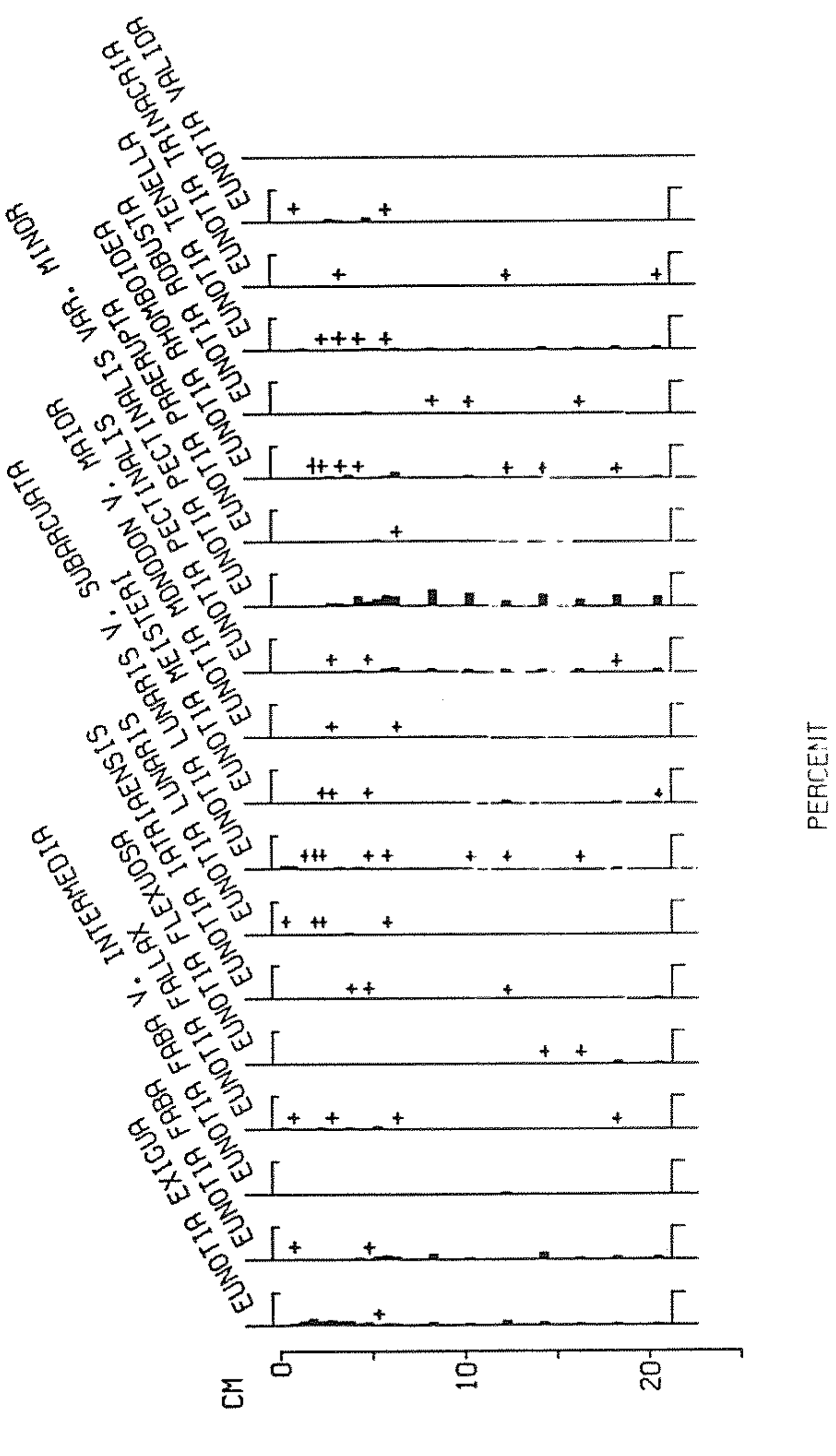
FRAGILARIA CONSTRUENS
FRAGILARIA CONSTRUENS V. VENTER
FRAGILARIA VAUCHERIAE
FRAGILARIA VIRESCENS
FRAGILARIA UNDIF.
FRUSTULIA RHOMBOIDES
FRUSTULIA RHOMBOIDES V. SAXONICA
FRUSTULIA CF MAGALIESMONTANA
20
20
PERCENT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EUNOTIA FLEXUOSA
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EUNOTIA LUNARIS
EUNOTIA LUNARIS V. SUBARCUATA
EUNOTIA MEISTERI
EUNOTIA MONODON V. MAIOR
EUNOTIA PECTINALIS
EUNOTIA PECTINALIS V. MINOR
EUNOTIA PRAERUPTA
EUNOTIA RHOMBOIDEA
EUNOTIA ROBUSTA
EUNOTIA TENELLA
EUNOTIA TRINACRIA
EUNOTIA VALIDA
CM
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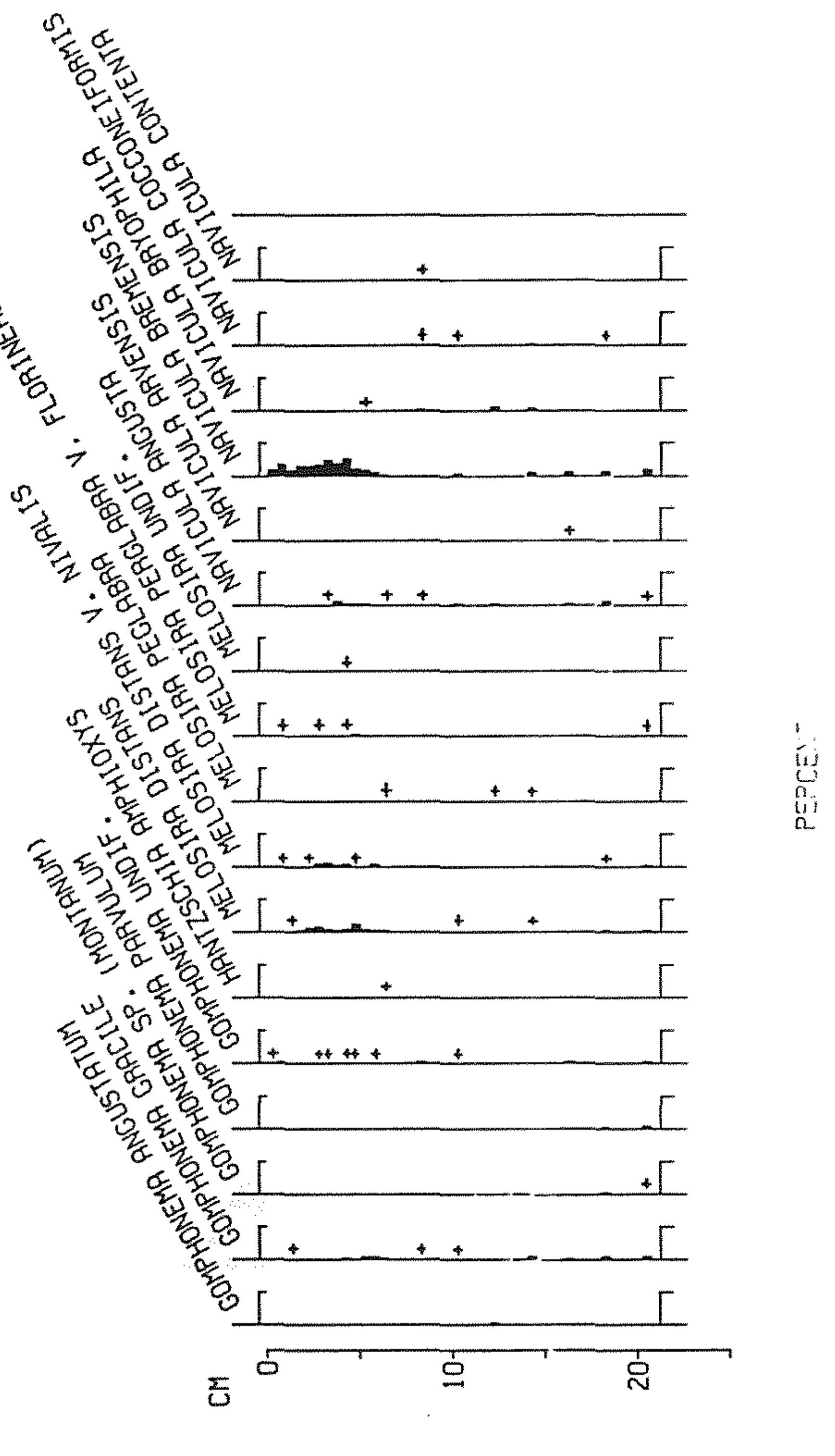
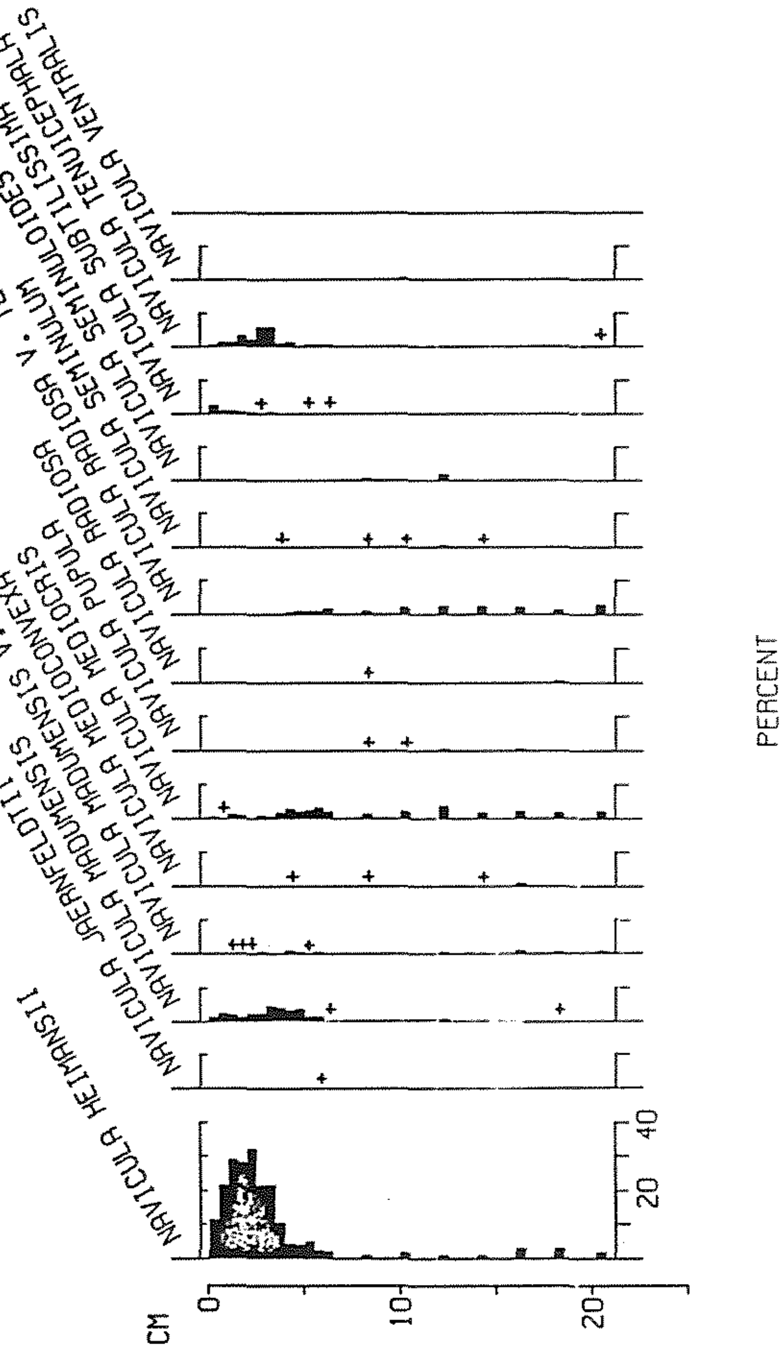
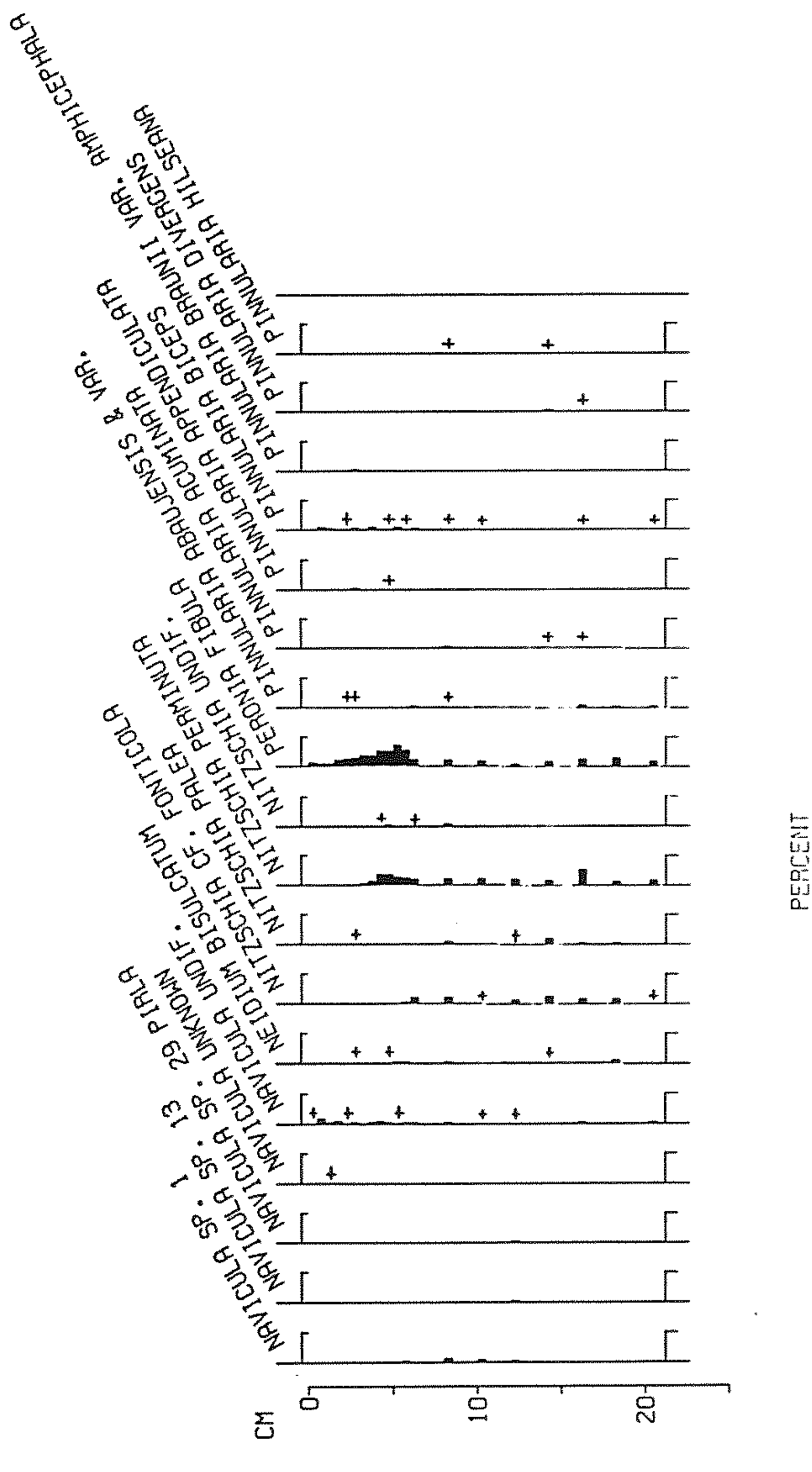
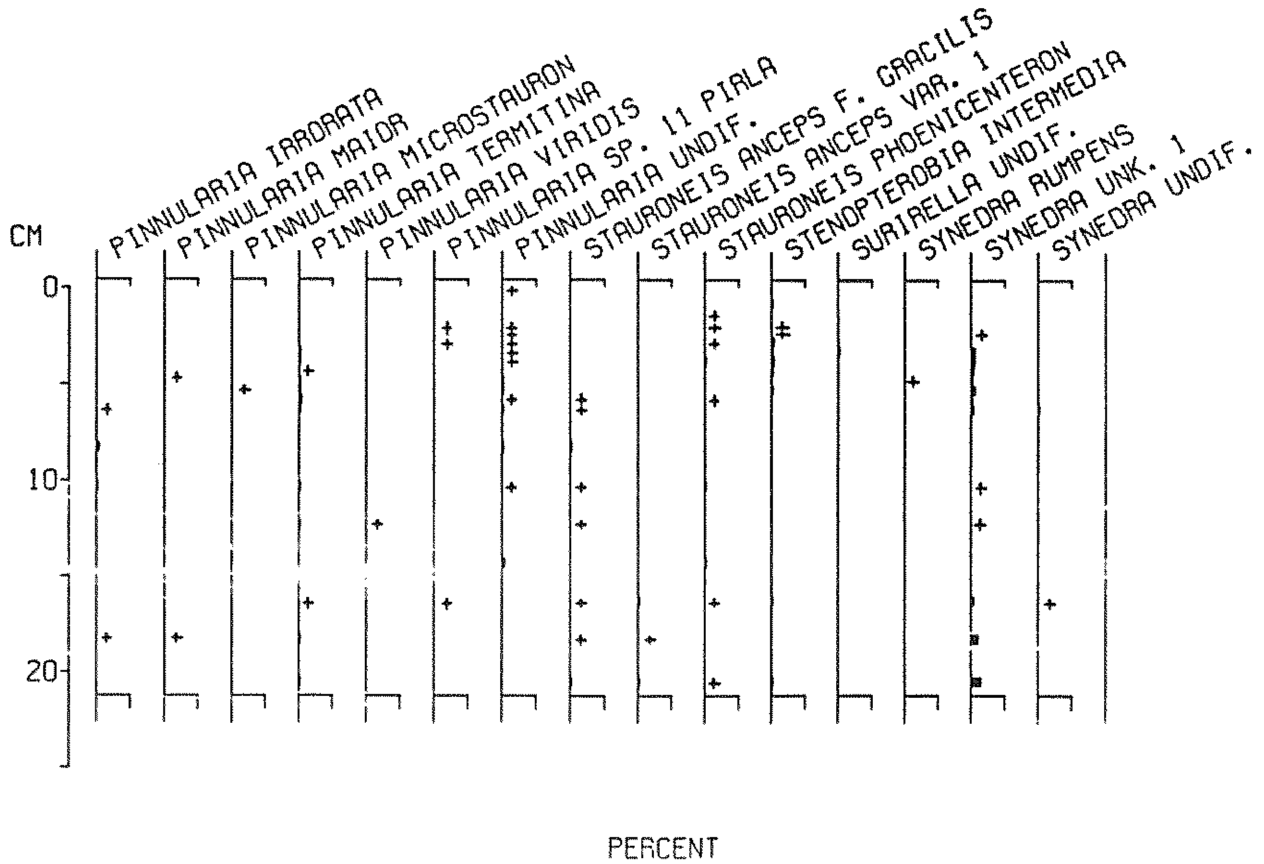
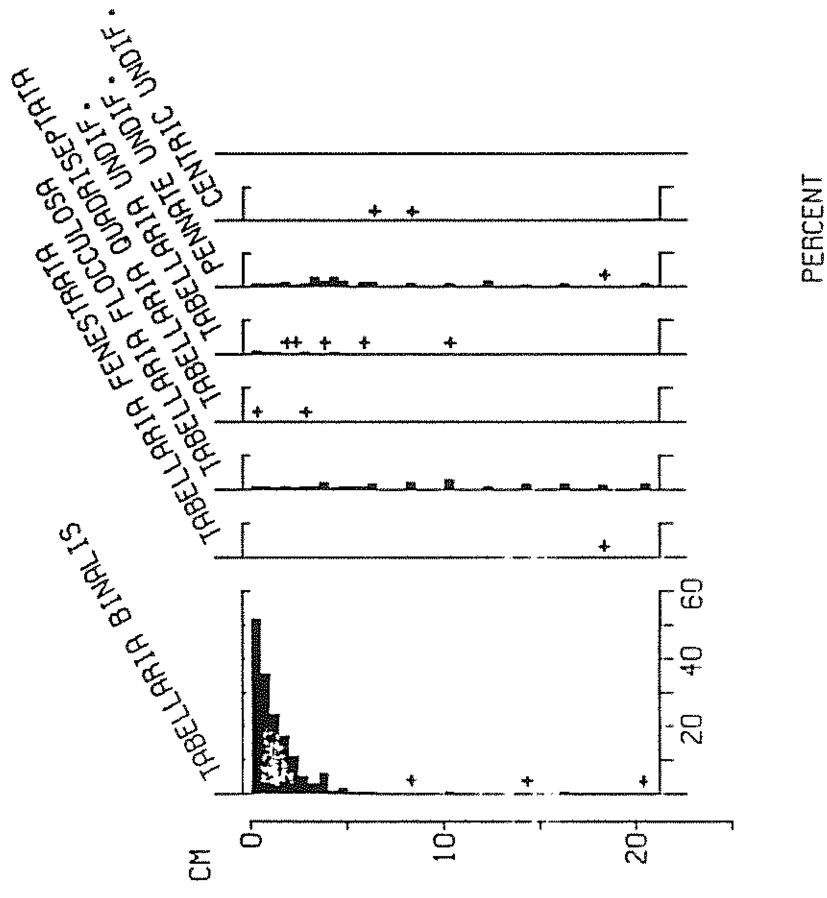
20
PERCENT

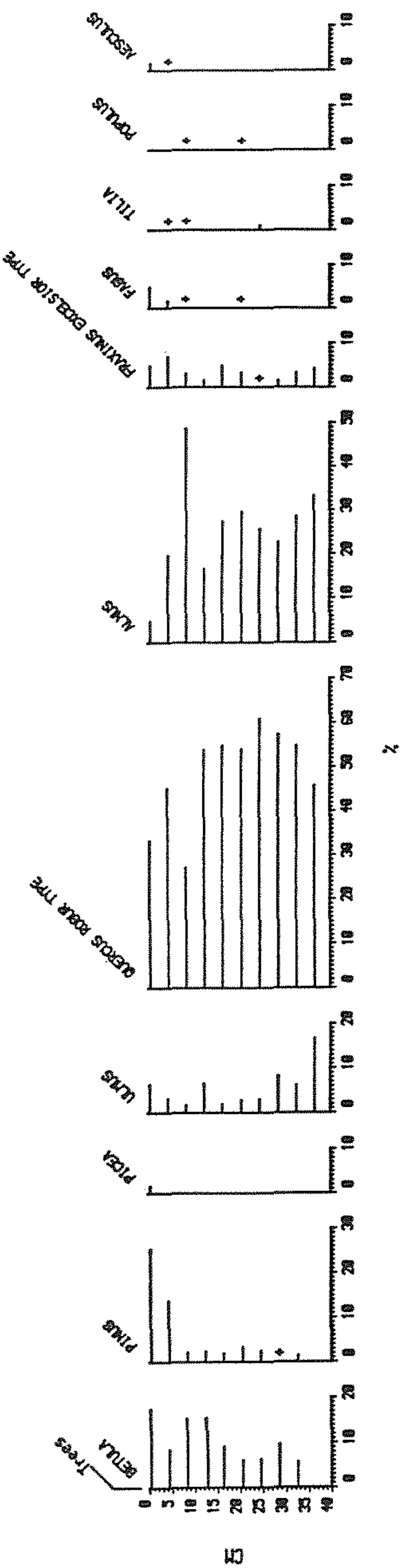

GOMPHONEMA ANGUSTATUM
GOMPHONEMA GRACILE (MONTANUM)
GOMPHONEMA SP. PARVULUM
GOMPHONEMA UNDIF.
HANTZSCHIA AMPHIOXYS
MELOSIRA DISTANS
MELOSIRA DISTANS V. NIVALIS
MELOSIRA PERGLABRA
MELOSIRA PERGLABRA V. FLORINEAE
MELOSIRA UNDIF.
NAVICULA ANGUSTATA
NAVICULA ARVENSIS
NAVICULA BREMENSIS
NAVICULA BRYOPHILA
NAVICULA COCCONEIFORMIS
NAVICULA CONTENTA
CM
0
10
20

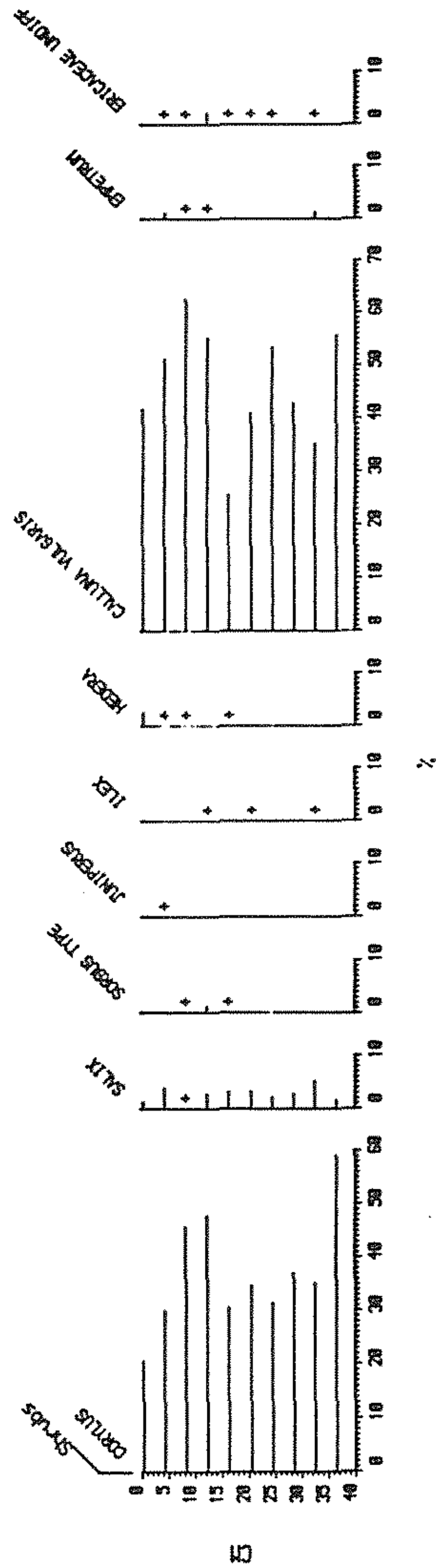

NAVICULA HEIMANSII
NAVICULA JAERNEFELDTII
NAVICULA MADUMENSIS
NAVICULA MADUMENSIS V. ROSTRATA
NAVICULA MEDIOCONVEXA
NAVICULA MEDIOCRIS
NAVICULA PUPULA
NAVICULA RADIOSA
NAVICULA RADIOSA V. TENELLA
NAVICULA SEMINULUM
NAVICULA SEMINULOIDES
NAVICULA SUBTILISSIMA
NAVICULA TENUICEPHALA
NAVICULA VENTRALIS
CM
0
10
20
20
40
PERCENT

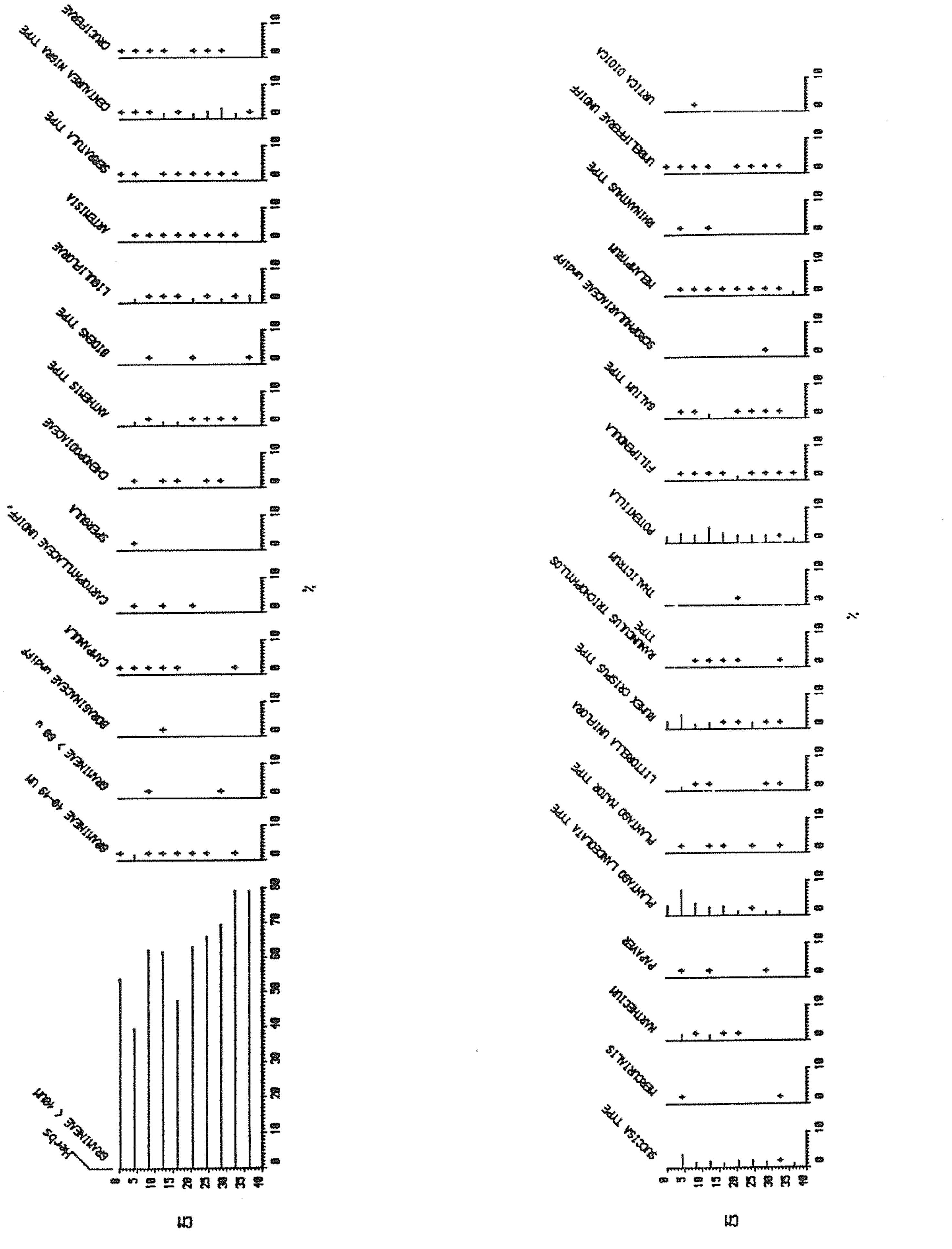

CM
0
10
20
PERCENT

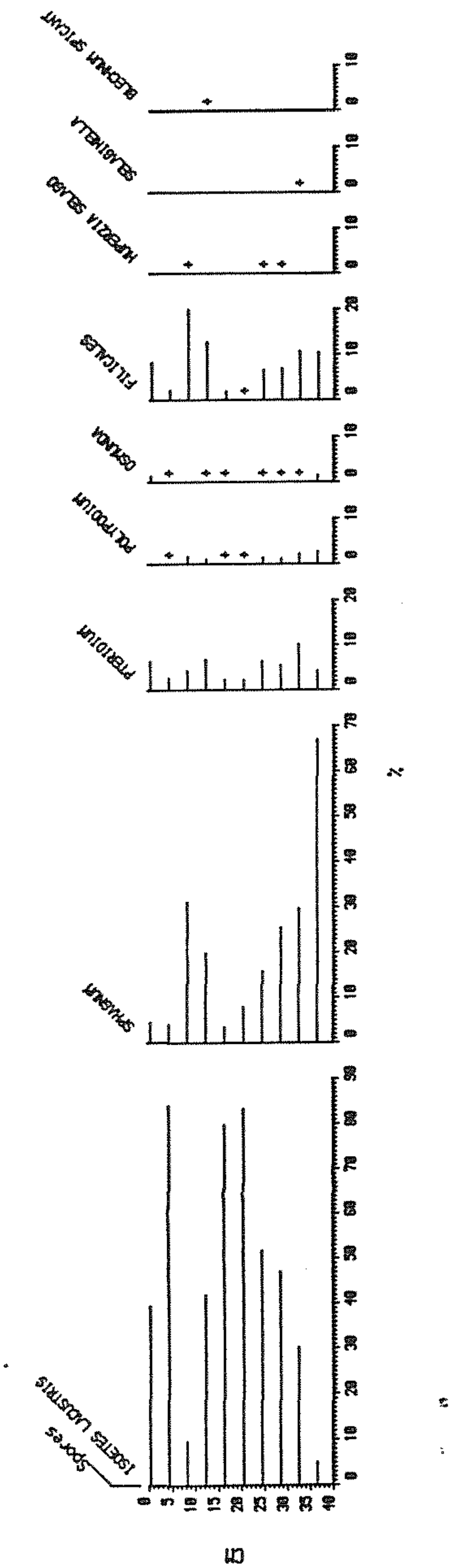

PINNULARIA IRRORATA
PINNULARIA MAIOR
PINNULARIA MICROSTAURON
PINNULARIA TERMITINA
PINNULARIA VIRIDIS
PINNULARIA SP. 11 PIRLA
PINNULARIA UNDIF.
STAURONEIS ANCEPS F. GRACILIS
STAURONEIS ANCEPS VAR. 1
STAURONEIS PHOENICENTERON
STENOPTEROBIA INTERMEDIA
SURIRELLA UNDIF.
SYNEDRA RUMPENS
SYNEDRA UNK. 1
SYNEDRA UNDIF.
CM
0
10
20
PERCENT

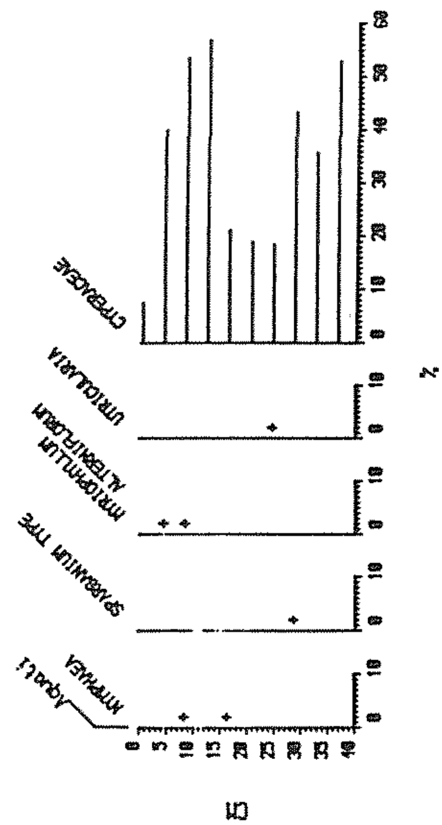

TABELLARIA BINALIS
PENNATE
CENTRIC
CM
0
10
20
20
40
60
PERCENT


Trees
BETULA
PINUS
PICEA
ULMUS
QUERCUS ROBUR TYPE
ALNUS
FRAXINUS EXCELSIOR TYPE
FAGUS
TILIA
POPULUS
AESCULUS
%
cm


Shrubs
CORYLUS
SALIX
SORBUS TYPE
JUNIPERUS
ILEX
HEDERA
CALLUNA VULGARIS
EMPETRUM
ERICACEAE UNDIFF.
%
cm


CRUCIFERAE
CENTAUREA NIGRA TYPE
SERRATULA TYPE
ARTEMISIA
LIGULIFLORAE
BIDENS TYPE
ANTHEMIS TYPE
CHENOPODIACEAE
SPERGULA
CARYOPHYLLACEAE UNDIFF.
CAMPANULA
BORAGINACEAE undiff
Herbs
URTICA DIOICA
UMBELLIFERAE UNDIFF
RHINANTHUS TYPE
SCROPHULARIACEAE undiff
GALIUM TYPE
FILIPENDULA
POTENTILLA
THALICTRUM
RANUNCULUS TRICHOPHYLLUS TYPE
RUMEX CRISPUS TYPE
LITTORELLA UNIFLORA
PLANTAGO MAJOR TYPE
PLANTAGO LANCEOLATA TYPE
PAPAVER
NARTHECIUM
MERCURIALIS
SUCCISA TYPE
%
CM


Spores
ISOETES LACUSTRIS
SPHAGNUM
PTERIDIUM
POLYPODIUM
OSMUNDA
FILICALES
HUPERZIA SELAGO
SELAGINELLA
BLECHNUM SPICANT
cm
%


Aquatics
NYMPHAEA
SPARGANIUM TYPE
MYRIOPHYLLUM ALTERNIFLORUM
UTRICULARIA
CYPERACEAE
cm
%

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