Research Papers

No. 22

PALAEOECOLOGICAL EVALUATION OF THE RECENT ACIDIFICATION OF WELSH LAKES

6. Llyn Dulyn, Gwynedd

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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 of 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 Dulyn, a small corrie lake located on the Rhinnog plateau, Gwynedd, was the third site (Fig. 1) to be chosen in Wales. While no site details of acid deposition are available, records from nearby recording stations (Barrett _et al_. 1983) show that the Aber ystwyth region has a mean pH of precipitation of ca. 4.5 and an annual wet sulphate loading of 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.

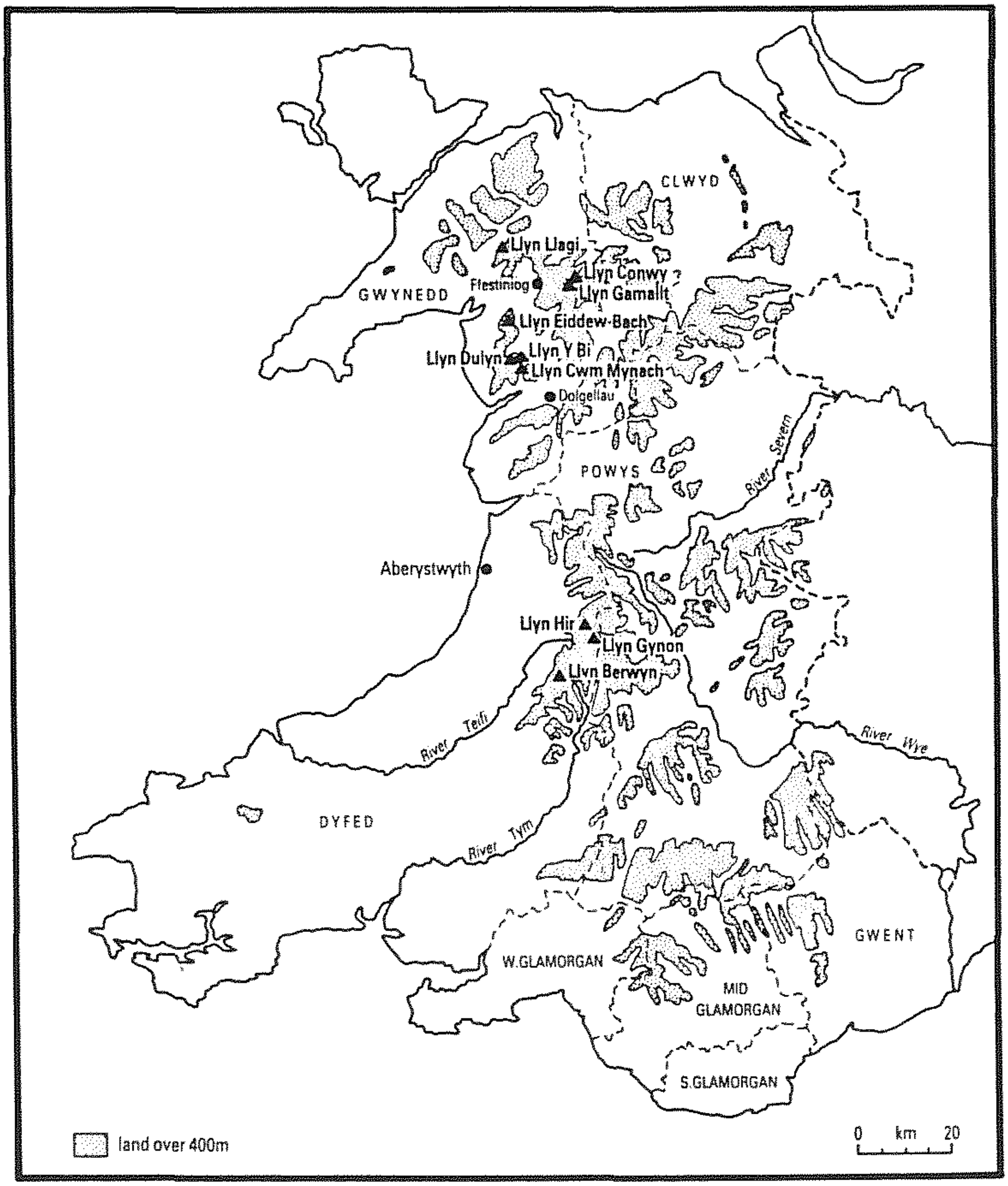

Fig. 1. Llyn Dulyn location map.

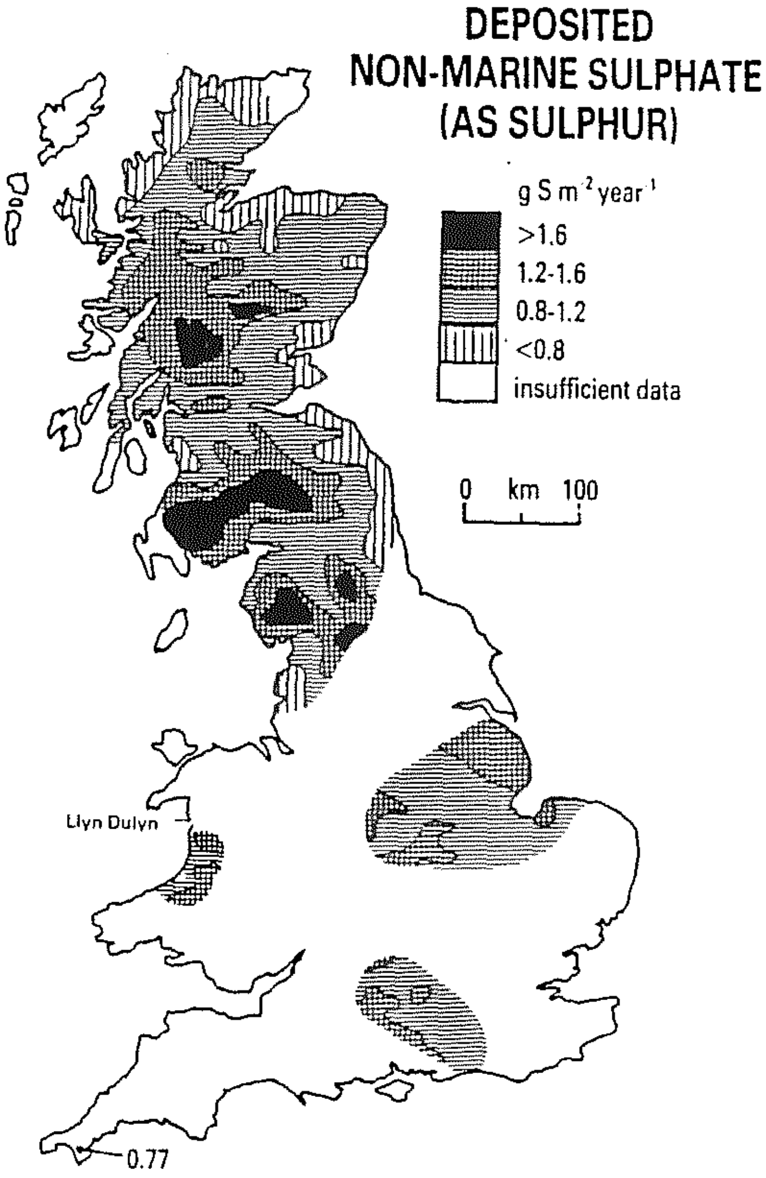

Fig. 3. Average annual deposition of non marine Sulphate for the U.K. (Redrawn from Barret et al.1983).

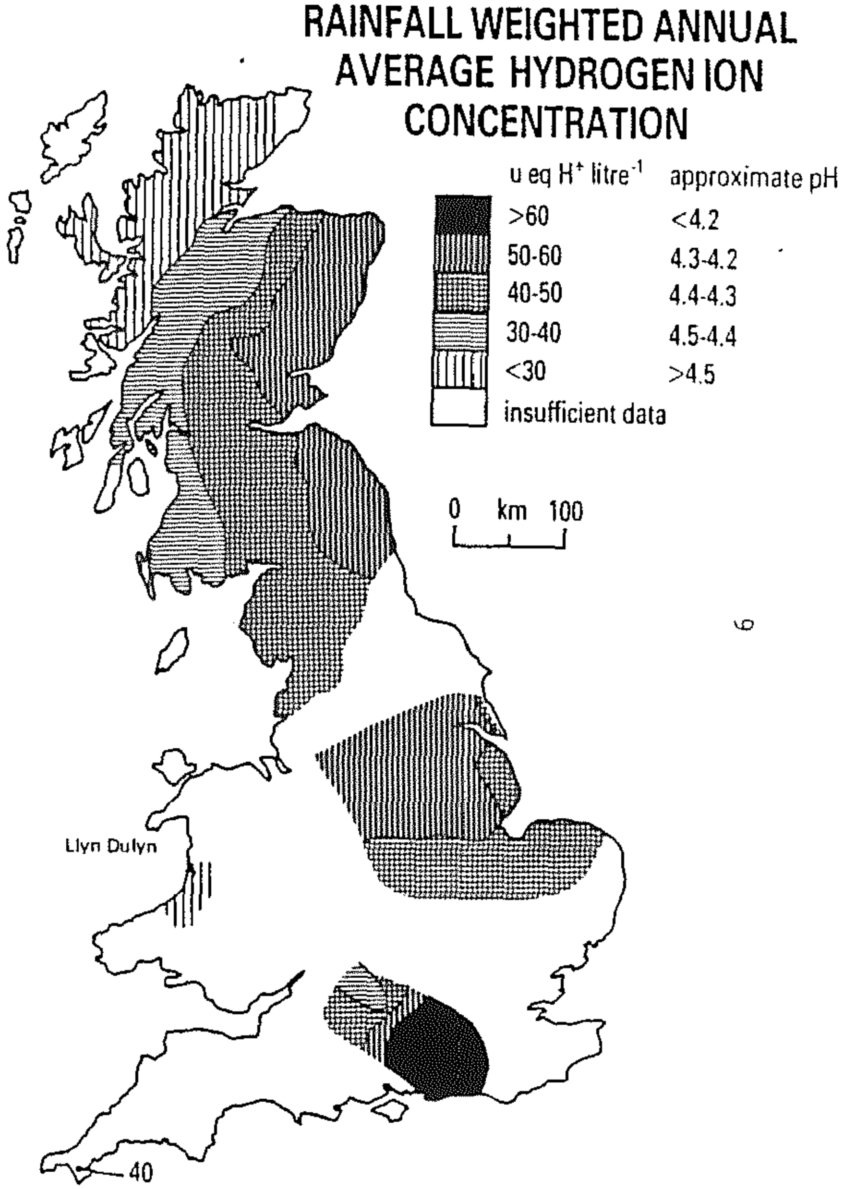

Fig. 2. Average annual rainfall weighted Hydrogen ion concentration deposition for the U.K. (Redrawn from Barret et al. 1983).

2.0 Site details

2.1 Lake

Llyn Dulyn is a small upland corrie lake lying at an altitude of over 520 m in an area which receives a rainfall in excess of 2000 mm yr^{-1}. The lake occupies some 19,782 m^2 and has a volume of 37,787 m^3. The detailed bathymetry (Fig. 4) reveals that the lake is an irregularly shaped asymmetrical basin with a 6.8 m deep hollow located in the northwest corner. The hollow is surrounded by extensive macrophyte dominated shallows. The lake is fed by two small inflows and by ground and surface water, and is drained to the west by a small stream leading to the reservoir of Llyn Bodlyn.

Table 1 Lake Characteristics

Area	19782 m^2
Volume	37787 m^3
Maximum depth	6.8 m
Mean depth	1.9 m

2.1.1 Lake chemistry

Lake water chemistry is characteristic of many of the acid water lakes examined in this present study (Fritz et al. 1986, Kreiser et al. 1986, Stevenson et al. 1987). Water chemistry results obtained by the WWA reveal a mean pH of 4.6 with corresponding low alkalinities of approximately 1.78 mg l^{-1} $CaCO_3$ (Table 2).

2.1.2 Lake vegetation

Fringing and littoral vegetation of Llyn Dulyn were mapped from the shoreline on the 30th May 1985. Sublittoral samples were obtained by Ekman grab on 22nd August of the same year (Fig. 5).

Rushes, *Juncus* spp., surround the lake (Table 3). Viewed through the exceptionally clear water (secchi disk depth > 5.0 m), aquatic vegetation apparently covers most of the lake floor. Inshore, *Lobelia dortmanna* is abundant, but *Juncus bulbosus* var. *fluitans* and *Equisetum fluviatile* are co-dominant in some embayments (Fig. 5). Filamentous algae and leafy liverworts are also locally abundant. *Isoetes lacustris* dominates deeper parts extending to 4.7 m depth in places (Table 4). *Sphagnum auriculatum* is locally abundant at 2-5 m depth approximately 50 m from the northern embayment. Similar sublittoral growth of this moss has been reported from several Galloway lakes (Raven 1986).

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*Nomenclature follows Tutin et al. 1964-1980.

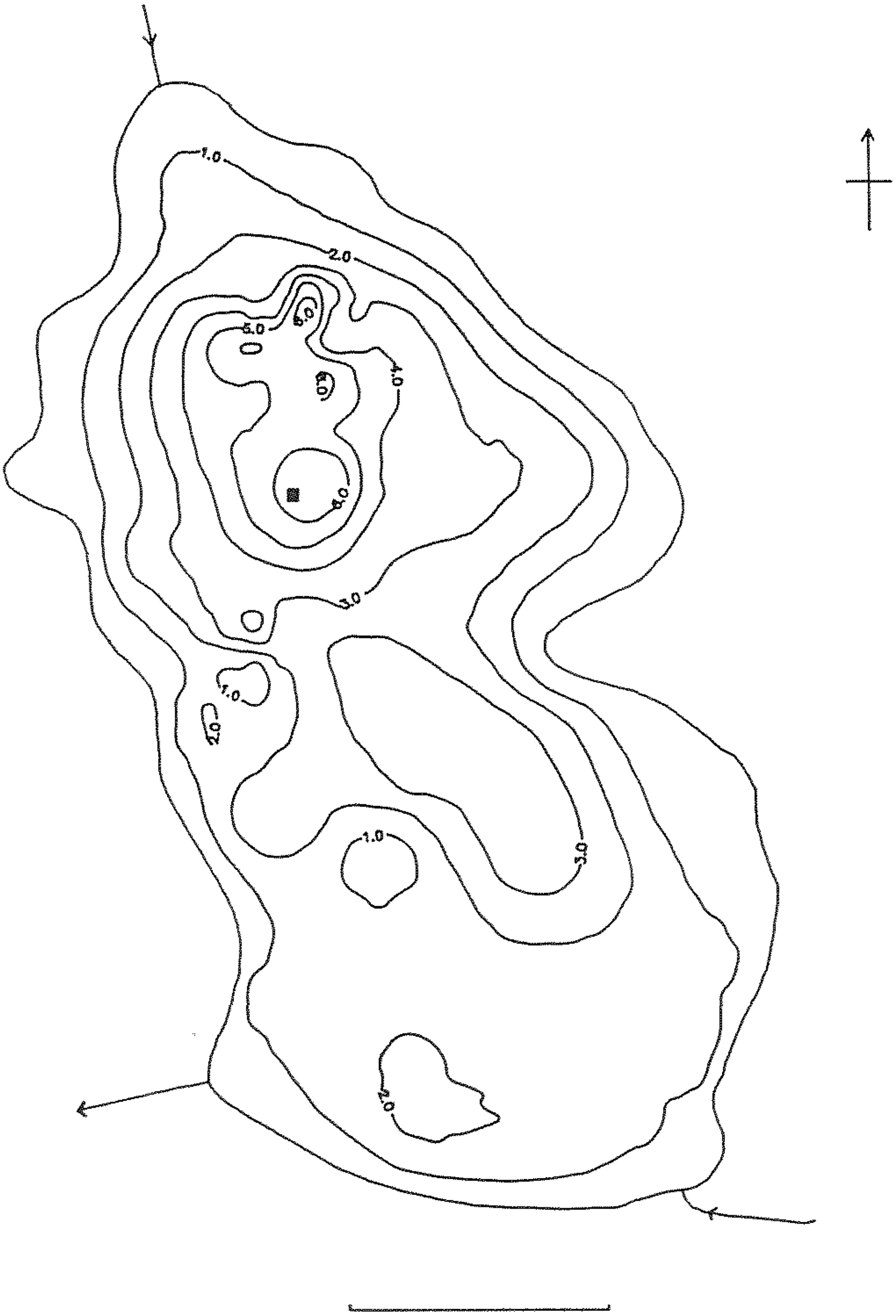
Table 2 Chemistry data for Llyn Dulyn (supplied by WWA)

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}
11/06/84	4.3	0.09	1.0	13.0	0.492	5.0	6.1
07/08/84	4.9	0.02	1.0	9.0	0.685	5.0	5.4
11/10/84	4.8	0.04	4.0	7.0	1.198	6.0	4.6
11/12/84	5.4	0.20	1.0	8.3	1.497	5.0	4.1
06/02/85	4.4	0.10	1.9	6.9	0.100	4.54	-
23/04/86	5.0	0.62	1.7	10.8	0.580	-	5.1
02/12/86	5.0	0.10	1.1	7.0	0.500	2.92	3.62

Date	Dissolved Potassium	Dissolved Calcium	Dissolved Magnesium	Dissolved Zinc mg l^{-1}	Dissolved Copper	Dissolved Lead	Dissolved Manganese	Dissolved Iron
11/06/84	1.0	1.41	1.02	0.029	0.005	0.01	0.07	0.02
07/08/84	1.0	1.21	0.89	0.058	0.020	--	0.06	0.09
11/10/84	1.0	0.94	0.64	0.024	0.005	--	0.04	0.03
11/12/84	1.0	0.98	0.73	0.023	0.005	--	0.05	0.04
06/02/85	1.0	--	--	0.110	---	--	--	--
23/04/86	0.47	1.00	1.00	0.026	0.005	--	0.06	0.05
02/12/86	0.29	0.76	0.602	0.009	---	--	0.03	0.01

Date	Conductivity us cm^{-1}	Dissolved Aluminium mg l^{-1}
23/04/86	52.0	0.150
02/12/86	37.0	0.092

LLYN DULYN BATHYMETRY



Contours in metres

■ *CORE SITE*

Fig. 4. Bathymetry and coring location for Llyn Dulyn.

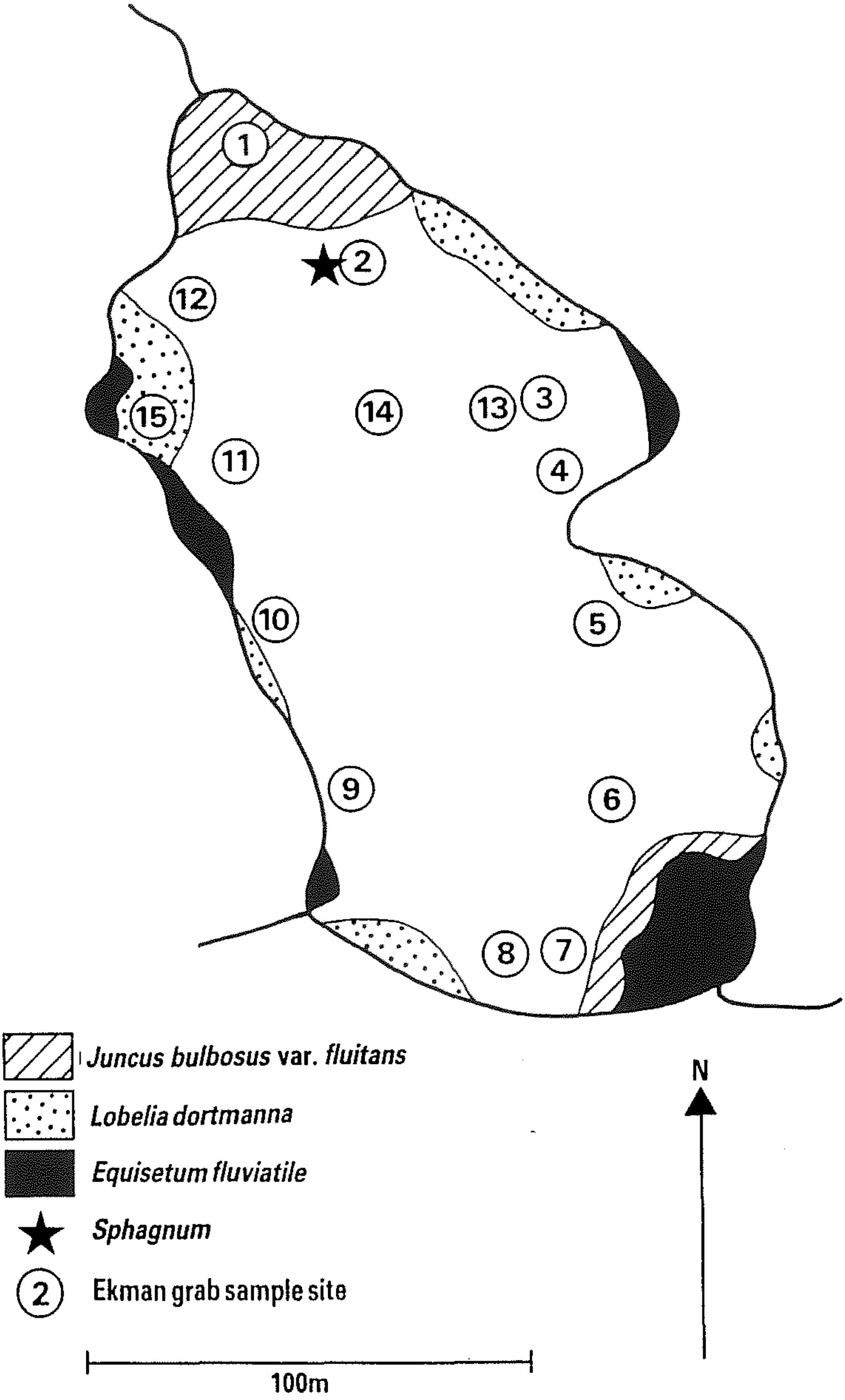


Fig. 5. Macrophyte vegetation of Llyn Dulyn.

Table 3: Fringing and aquatic vegetation of Llyn Dulyn, August 1985
(A= abundant; lf= locally frequent; r= rare).

i) Fringes
Juncus acutifloris (lf); *J.articulatus* (lf); *J.effusus* (A).

ii) Littoral zone
Filamentous algae including *Mougeotia* spp. (lf; leafy liverworts including *Jungermannia* spp. (lf); *Littorella uniflora*; *Lobelia dortmanna* (A); *Isoetes echinospora* (r); *Juncus bulbosus* var. *fluitans* (lf); *Equisetum fluviatile* (lf); *Glyceria fluitans* (r).

iii) Sublittoral zone
Isoetes lacustris (A); *Juncus bulbosus* var. *fluitans* (lf); *Sphagnum auriculatum* (lf).

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

1: 2.5m; mud; *Isoetes* (A), *Juncus fluitans* (A), *Sphagnum* (r)
2: 3.5m; mud; *Isoetes* (r), *Juncus fluitans* (r), *Sphagnum* (A)
3: 4.7m; mud; *Isoetes* (A), *Sphagnum* (r)
4: 3.0m; mud; *Isoetes* (A),
5: 2.5m; mud; *Isoetes* (A), *Juncus fluitans* (A).
6: 1.5m; mud; *Isoetes* (A),
7: 1.0m; mud; *Isoetes* (A),
8: 2.0m; mud; *Isoetes* (A),
9: 1.5m; mud; *Isoetes* (A),
10: 2.2m; mud; *Isoetes* (A),
11: 2.5m; mud; *Isoetes* (A),
12: 2.0m; mud; *Isoetes* (A),
13: 6.0m; mud; -----
14: 4.0m; mud; -----
15: 1.2m; mud; *Littorella* (A),

2.1.3 Fishing history

Llyn Dulyn is a small, remote lake which is only irregularly visited by anglers. Consequently little is known of its present fishery status.

Early in the 19th century Llyn Dulyn supported a char and trout population. In 1809 Fenton reported that the proprieter of the Corsygedol Estate had char potted and sent to London (Fisher 1917).

Cliffe (1860) described the trout in the lake as 'very handsome and of good size', being 'firm and of good quality'. However, the fishing was spoiled for the angler by poachers using nets and 'otter boards'.

Morris (1913) considered Llyn Dulyn to be the best lake for fishing in the Ardudwy region, so far as numbers were concerned. Ward (1931) reported the lake to be full of fine trout averaging nearly 0.5 lbs.

Char may have disappeared from Llyn Dulyn as Condry (1970) determined that the only char in Merioneth were found in the downstream lake - Llyn Bodlyn.

2.2 Catchment

The catchment occupies 53,6531 m^2, and has a large catchment : lake ratio of 26.12.

Table 5 Catchment characteristics

Total catchment area	536531 m^2
Area of land in catchment	516749 m^2
Area of lake	19782 m^2
Catchment/lake ratio	26.12
Maximum relief	80 m

2.2.1 Geology

The solid geology of the catchment is divided into two main sequences. The predominant geology to the east and northeast including the corrie back-wall are Cambrian coarse grained to pebbly greywackes of the Rhinog formation of the Harlech grits group. To the west, southeast and northwest are Cambrian siltstones and sandstones of the Hafotty formation of the Harlech grits group. The drift deposits in the catchment are restricted to the less steeply shelving slopes mainly on the Hafotty siltstones and mudstones which are covered by boulder clay and undifferentiated drift material (Allen & Jackson 1985).

2.2.2 Soils

Three principal catchment soil types dominate the site (Rudeforth *et al.* 1984). The steeply sloping corrie back-walls are dominated by acid humic rankers belonging to the Revidge soil formation (311a). These soils are very thin and in many locations extensive areas of the underlying Rhinog greywackes are exposed. In areas where the slope angles are less acid stagnohumic gleys of the Hafren formation (654a) have developed. Amorphous blanket peats belonging to the Crowdy II peat series (1013b) occur in areas of drainage impedance.

2.2.3 Present Vegetation

The catchment vegetation is dominated by acid moorland plants (Fig. 6). On the steeper corrie back-walls the vegetation is sparse and much bare rock is exposed. Vegetated areas here are dominated by *Vaccinium* / *Festuca* / *Agrostis*. The remainder of the catchment, in the drier areas, is dominated by *Vaccinium*/*Festuca* communities, especially in the northeast, and *Nardus*/*Festuca* communities, to the south of the outflow. In small areas of drainage impedance there are blanket peats dominated by *Eriophorum vaginatum*/*Juncus squarrosus* and *Sphagnum* communities. On a visit to the site in April 1986 the *Nardus* / *Festuca* grassland was apparently ungrazed suggesting that very little grazing now takes place within the catchment.

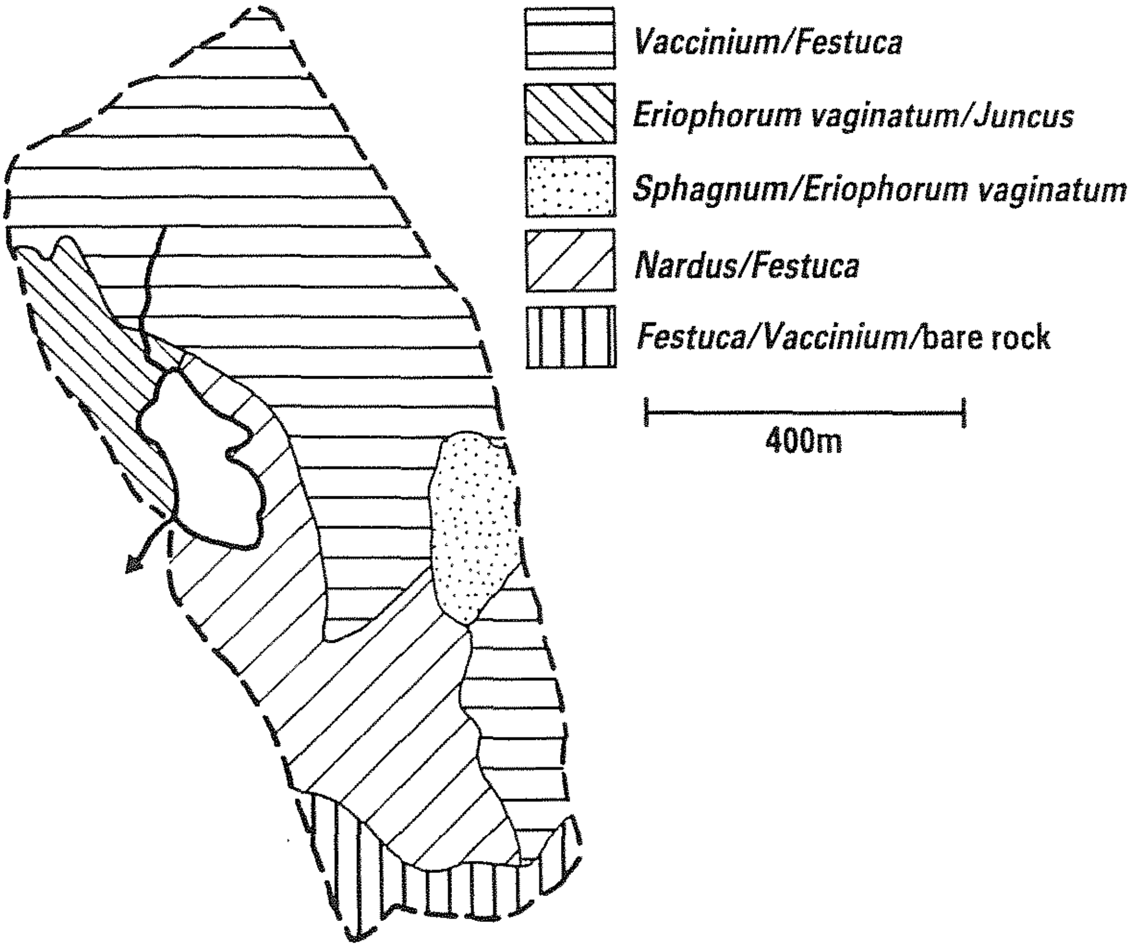


Fig. 6. The catchment vegetation of Llyn Dulyn.

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 at the inflows.

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

Two cores were taken using a modified Livingstone corer operated from a mini-raft of two small inflatable boats strapped together. Sampling was carried out during August 1985. Two cores were obtained, Dulyn 1 was used for dating and analysis (Fig. 4).

Core DUL 1 (150 cm) was extruded in the laboratory and the top 20 cm of the core sliced into 1/2 cm portions, the remainder sliced into 1 cm slices. The core 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

A very dark brown organic sediment ($Ld^3 4$) constitutes the majority of the core (150 - 20 cm). The wet density and dry weight do not vary much but the loss on ignition begins to rise at 40 cm, increases more rapidly at 24 cm, and then begins to drop at 15 cm. It increases again in the top 8 cm. As the sediment accumulation rate is low (Table 9) the erosion rate of material from the catchment must also be low and so changes in the organic and mineral components in the sediment may be due to changes in lake productivity as well as erosion rates from the catchment. The section of the core from 2 - 3 cm depth shows the presence of algal detritus (Ld^1, Dg3) and the top 2 cm of the core consists of a green gelatinous alga.

4.1.2. ^{210}Pb dating

Sediments from Llyn Dulyn (DUL 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 Figs. 8 & 9. The ^{137}Cs results are given in Table 7 and Fig. 10. Table 8 gives values of a range of other radioisotopes determined from the gamma spectra. The ^{210}Pb inventory of the core is 4.41 pCi cm^{-2}, and represents a mean ^{210}Pb supply rate of 0.14 pCi cm^{-2} yr^{-1}. This is comparable with the value for the adjacent Llyn y Bi (Fritz et al. 1987).

Fig. 11 shows the ^{210}Pb chronologies for core DUL 1, given by the CRS and CIC ^{210}Pb dating models (Appleby and Oldfield 1978). Both models indicate a recent acceleration in sedimentation rates. A consequence of this is that in the older sediments the CIC dates are younger than the CRS model dates. In view of the comparability of the ^{210}Pb fluxes in Llyn Dulyn and Llyn y Bi it would seem appropriate to use the CRS model dates, and these are given in Table 9. This chronology indicates that up to ca. 1950 there was a uniform sediment accumulation rate of 0.0055 g cm^{-2} yr^{-1}. During the period 1950-1960 the accumulation rate appears to have accelerated to ca. 0.010 g cm^{-2} yr^{-1}. A similar acceleration was observed in Llyn y Bi.

The ^{137}Cs data (Fig. 10) in this core does not appear to have any chronological value. The ^{137}Cs activity declines monotonically from a maximum value at the surface, and there are significant concentrations down to 15.75 cm, well below the ^{210}Pb equilibrium depth. There was no detectable ^{241}Am in the core.

4.1.3. Diatoms and pH reconstruction

Diatoms were analysed from the uppermost 77 cm of core DUL 1. The top 14 cm includes the ^{210}Pb-dated portion of the core. Fig. 12 shows the relative abundance of major taxa and pH reconstruction of the Llyn Dulyn core. Appendix A includes diagrams showing the stratigraphy of all taxa.

The diatom flora below 18 cm in the Llyn Dulyn sediments is quite stable and includes a diversity of benthic and epiphytic species (Fig. 12). The dominant taxa are the circumneutral *Achnanthes minutissima*,

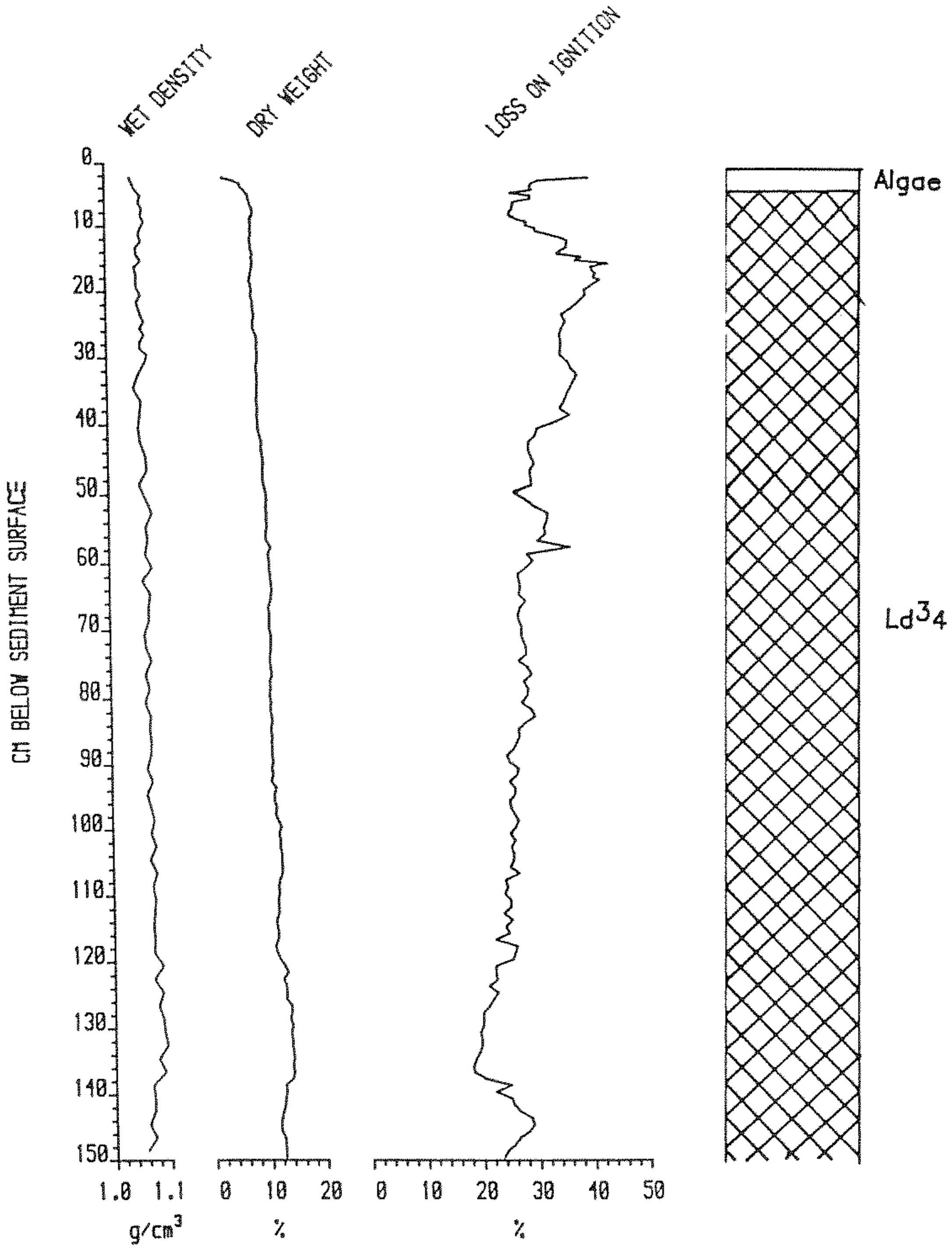


Fig. 7. Variations in dry weight, wet density and loss on ignition for the Llyn Dulyn I core.

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

Depth	Dry Mass	^{210}Pb Concentration		Standard Errors		^{226}Ra	
		Total	Unsupported	Concent.		concentration	
cm	g cm^{-2}	pCi g^{-1}	pCi g^{-1}	Total	Uns.	pCi g^{-1}	
							+/-
2.25	0.0212	14.75	14.14	1.07	1.11	0.61	0.30
3.75	0.1054	9.12	8.90	0.53	0.54	0.23	0.11
5.25	0.2180	6.94	6.83	0.38	0.39	0.11	0.08
7.25	0.3868	6.36	6.00	0.37	0.38	0.36	0.08
9.75	0.6063	2.42	1.93	0.19	0.20	0.49	0.06
12.75	0.8608	1.32	0.72	0.25	0.27	0.60	0.09
15.75	1.1197	0.31	-0.01	0.20	0.22	0.32	0.08
17.25	1.2485	0.59	0.00	0.29	0.31	0.59	0.12

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

Depth	Dry Mass	^{137}Cs concentration		Cumulative ^{137}Cs		Fract
cm	g cm^{-2}	pCi g^{-1}	+/-	pCi cm^{-2}	+/-	
2.25	0.0212	7.09	0.45	0.15	0.01	0.045
3.75	0.1054	6.97	0.24	0.74	0.04	0.224
5.25	0.2180	4.87	0.17	1.40	0.06	0.423
7.25	0.3868	4.08	0.15	2.16	0.07	0.650
9.75	0.6063	1.58	0.07	2.73	0.09	0.824
12.75	0.8608	1.10	0.09	3.07	0.09	0.926
15.75	1.1197	0.51	0.07	3.27	0.09	0.986
17.25	1.2485	0.24	0.10	3.32	0.09	1.000

Table 8. Other radioisotope data for Core DUL1.

Depth	^{226}Ra	^{238}U	^{235}U	^{228}Ac	^{228}Th	^{40}K
cm			pCi g^{-1}			
2.25	0.61	0.00	0.27	0.00	0.00	2.74
3.75	0.22	0.36	0.01	0.53	0.17	1.95
5.25	0.11	0.00	0.01	0.51	0.34	5.32
7.25	0.36	0.31	0.00	0.62	0.38	5.00
9.75	0.49	0.26	0.04	0.28	0.00	8.55
12.75	0.60	0.30	0.11	0.57	0.41	8.80
15.75	0.32	0.64	0.08	0.61	0.35	8.32
17.25	0.59	0.52	0.03	0.52	0.09	10.41

Table 9. CRS Model ^{210}Pb chronology

Depth	Dry Mass	Cumul. Unsupp. ^{210}Pb	Chronology Date	Age	Std. Error	Sedimentation Rate		Std. Error
cm	g cm^{-2}	pCi cm^{-2}	AD	Yr	Error	g cm^{-2}	cm yr^{-1}	%
0.00	0.0000	4.41	1985	0				
1.00	0.0094	4.29	1984	1	1	0.0091	0.329	8.0
2.00	0.0188	4.16	1983	2	1	0.0091	0.323	8.1
3.00	0.0633	3.62	1979	6	2	0.0100	0.245	7.8
4.00	0.1242	3.00	1973	12	2	0.0109	0.162	7.6
5.00	0.1992	2.41	1966	19	2	0.0105	0.136	8.1
6.00	0.2813	1.79	1956	29	2	0.0088	0.108	9.4
7.00	0.3657	1.30	1946	39	3	0.0067	0.079	10.9
8.00	0.4526	0.86	1932	53	5	0.0062	0.072	16.7
9.00	0.5404	0.55	1918	67	8	0.0063	0.073	23.9
10.00	0.6275	0.34	1903	82	10	0.0060	0.070	30.5
11.00	0.7123	0.19	1884	101	11)	ca.0.0050	0.058	30.5
12.00	0.7972	0.10	1865	120	13)			

^{210}Pb Flux = 0.14 +/- 0.01 pCi cm^{-2}
90% Equilibrium Depth = 9.6 cm. or 0.59 g cm^{-2}
99% Equilibrium Depth = 13.9 cm. or 0.96 g cm^{-2}

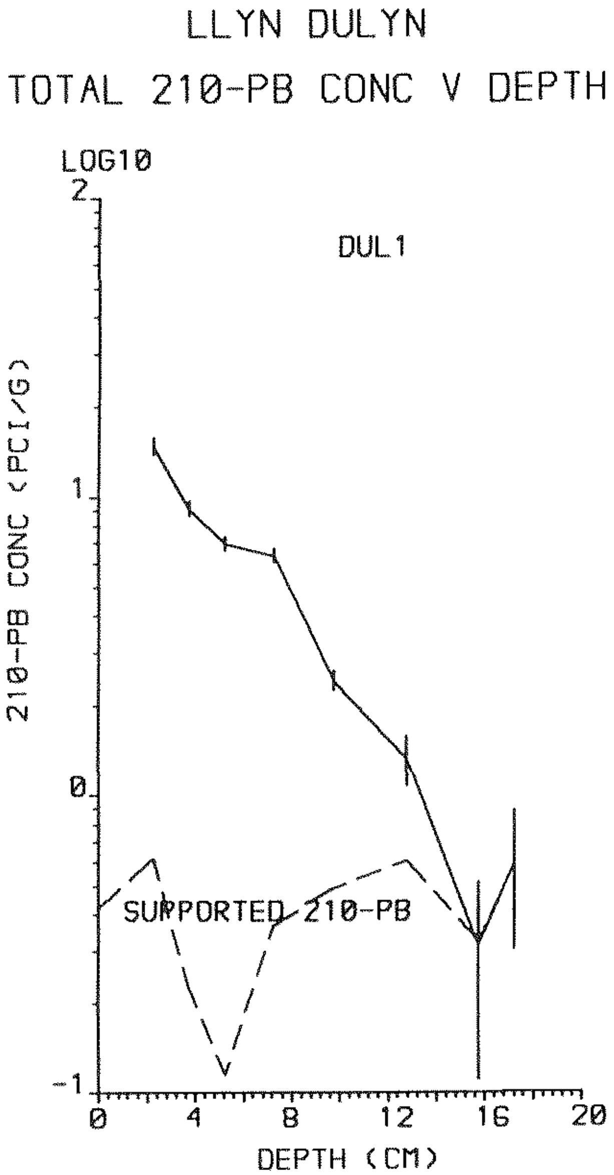


Fig. 8. Total ^{210}Pb profile for the Llyn Dulyn I core.

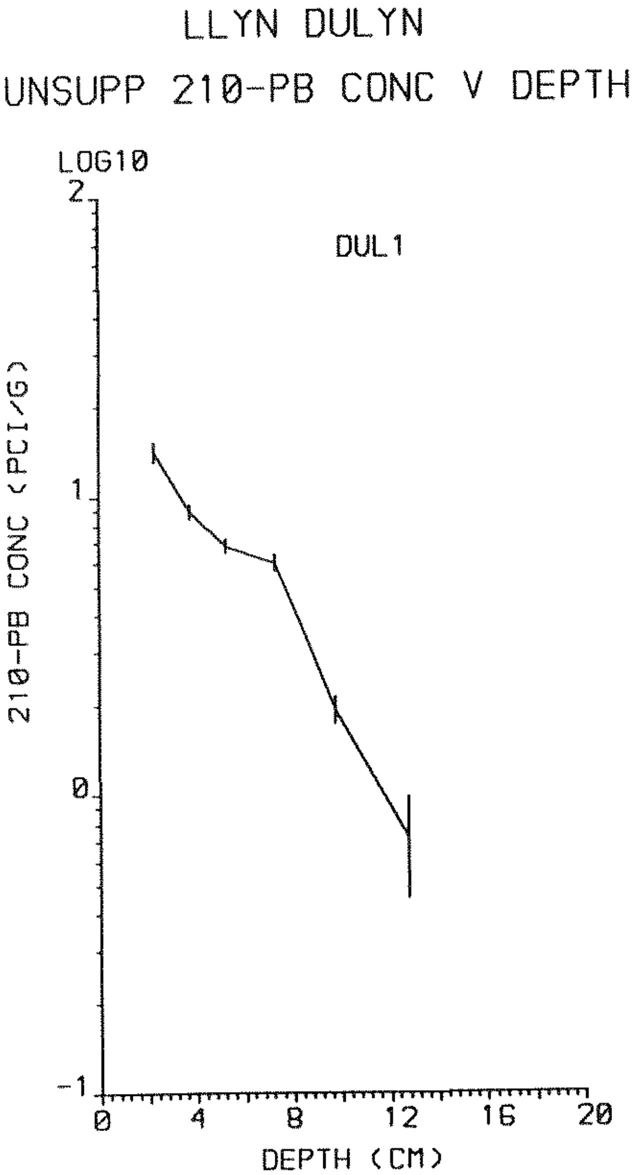


Fig. 9. Unsupported ^{210}Pb profile for the Llyn Dulyn I core.

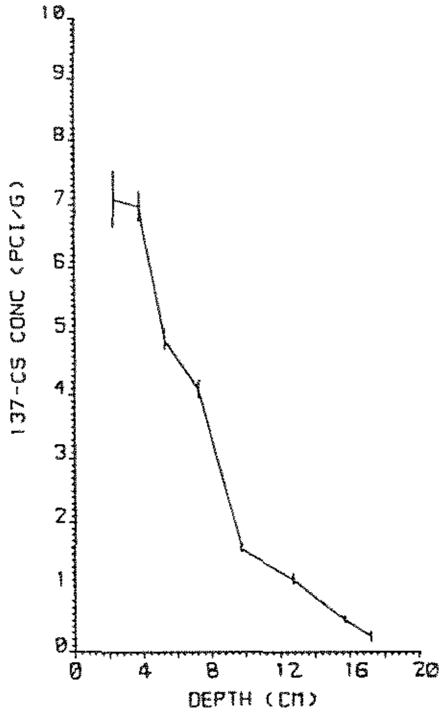


Fig. 10. ^{137}Cs profile for the Llyn Dulyn I core.

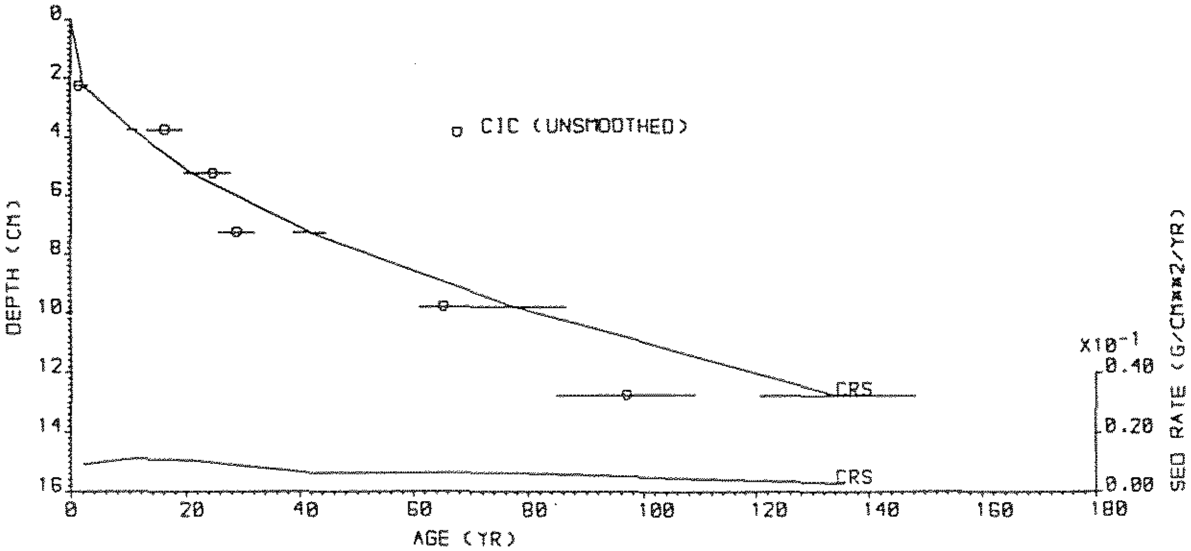


Fig. 11. CRS and CIC ^{210}Pb age/depth chronology for the Llyn Dulyn I core.

Anomoeoneis vitrea and *Fragilaria virescens*, as well as the acidophilous *Eunotia veneris*, *Melosira perglabra* var. *florineae* and *M. lirata* var. *lacustris*. Other common taxa include *Eunotia pectinalis* var. *minor*, *Fragilaria construens* var. *venter*, *Gomphonema gracile*, *Navicula seminulum*, *Melosira distans* and *Melosira perglabra* var. *perglabra*. The absence of euplanktonic taxa suggests that the lake has been moderately acidic throughout the period represented by these sediments. The diatom assemblage in these lower sediments is similar to the early flora of Llyn y Bi (Fritz *et al*. 1987) and Llyn Gynon (Stevenson *et al*. 1987), although Llyn Dulyn has higher percentages of acidophilous *Melosira* species.

Above 18 cm a number of acidophilous taxa increase in relative abundance, with a concomitant decrease in several circumneutral species. Between 18 and 6 cm is an expansion of *Achnanthes marginulata*, *Anomoeoneis serians* var. *brachysira* and *Navicula mediocris*, followed by *Frustulia rhomboides*, *Navicula hassiaca*, *N. heimansii*, *Melosira distans*, *M. distans* var. *nivalis* and *M. perglabra* var. *florineae*. *Gomphonema gracile* and *Achnanthes linearis* var. *pusilla* are the first taxa to decline in relative abundance, followed by *Anomoeoneis vitrea* and *Achnanthes minutissima*. An increase in *Melosira perglabra* and *Eunotia exigua* percentages and continued expansion of other acidophilous taxa occur from 6 cm to the sediment surface, with a concomitant decline in circumneutral taxa, including several aforementioned taxa and *Navicula seminulum*.

The modern flora of Llyn Dulyn is somewhat unusual in comparison with other non-afforested Welsh sites. The relatively high percentages of the epiphytic *Achnanthes marginulata* are not seen elsewhere and may reflect in part the extensive macrophyte beds in the southern end of the lake (see section 2.1.2). Of the British sites studied to date only Loch Dee and Loch Grannoch have moderate percentages of *Achnanthes marginulata* (Flower *et al*. 1987). The high proportions of *Melosira distans* and its varieties in surficial sediments of Llyn Dulyn are also somewhat unusual. Round Loch of Glenhead, Galloway (Flower & Battarbee 1983) contains these taxa in lower percentages and Llyn Hir has sizable proportions of other acidic *Melosira* species (Fritz *et al*. 1986). The low percentages of acidic *Tabellaria* species (*Tabellaria quadriseptata* & *T. binalis*) in the surface sediments of Llyn Dulyn are unusual among lakes with similar pH, excepting the nearby Llyn Eiddew Bach where these *Tabellaria* species are also absent (Patrick *et al* 1987).

pH reconstructions using index B-Scandanavia, index B-Galloway and multiple regression of preference groups (Flower 1986) all suggest a pH between 5.8 and 6.2 from 14 cm through the base of the analysed sediments (Fig. 12). Above 14 cm (mid-19th century), pH gradually declines to 5.1 - 5.2 at the core surface in the case of index-B and 4.7-4.9 in the case of multiple regression of prefernce groups. pH reconstructions suggest that pH decline was sharp from 14 - 5 cm (mid-19th century - ca. 1966) and more gradual after that. Measured lakewater pH in 1984 and 1985 ranged from 4.3 - 5.4 (mean = 4.8). The reconstructed pH at the sediment surface falls within this range.

The initial decline in lakewater pH in Llyn Dulyn is nearly synchronous with that at the nearby Llyn y Bi (Fritz *et al*. 1987) and with that at Llyn Hir in central Wales (Fritz *et al*. 1986). At other Welsh sites pH

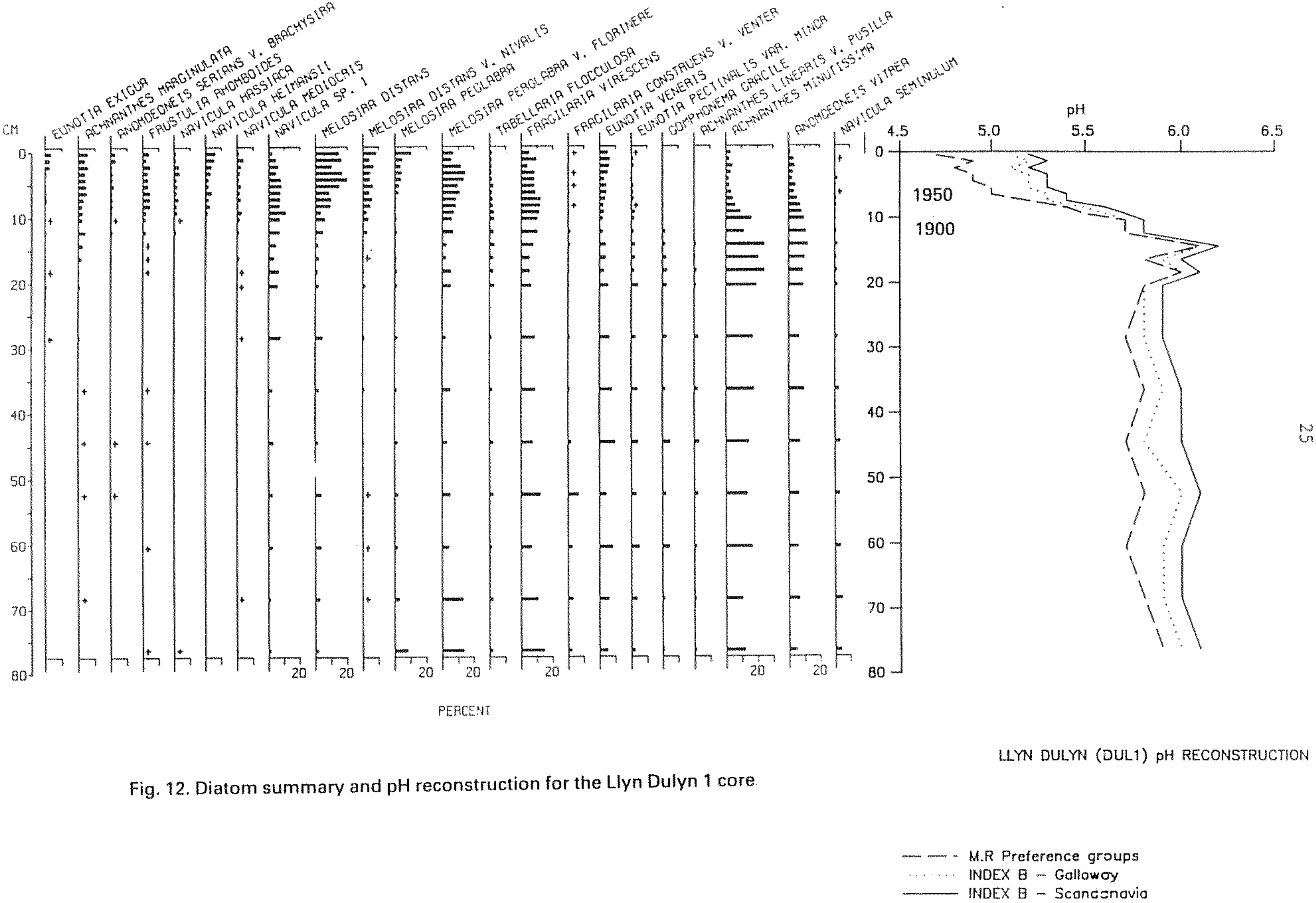


Fig. 12. Diatom summary and pH reconstruction for the Llyn Dulyn 1 core

declines occur considerably later (mid-20th century), suggesting sources of alkalinity in the lake catchments capable of neutralising acidic inputs. Llyn Dulyn is the only one of the non-afforested Welsh lakes where the post-1960 pH change is more gradual than earlier in the century.

4.1.4. Sediment chemistry

The sediment in Llyn Dulyn is different from the other Welsh cores examined so far (Fritz et al. 1986, Kreiser et al. 1986, Stevenson et al. 1987). It has a low dry weight (average 7.9%), low density (average 1.060 g cm^{-3}) and fairly high organic content (average 33.6%) over the whole length of the core (Fig. 7). However, the sediment is not peaty.

Major cations

The magnesium, sodium and potassium results indicate that there have been changes in the composition of inorganic material eroded from the catchment into the lake (Figs. 13 & 14). Potassium, sodium and magnesium behave similarily and the concentrations increase at 40 cm, reach a peak at 30 cm and then fall steadily towards the surface. There is a break in this steady decline of potassium and magnesium concentrations at 15 cm and there is also a break in the organic content profile at this depth. The organic content and density also increase a little at the 40 cm level where the major cation concentrations increase.

A comparison of the major ion and organic profiles indicates that there may have been changes in the erosion rate of material from the catchment (Engstrom & Wright 1984, Mackereth 1966). Normally when the erosion rate of material from the catchment increases the concentration of major cations in the sediment increase (especially when the concentrations are expressed per gramme minerals) while the loss on ignition drops. This is not so with Llyn Dulyn.

There are two main inconsistencies. At 40 cm both the major ion concentrations and loss on ignition increase whereas the loss on ignition should decrease as the major cations rise under the normal erosion-leaching hypothesis. Secondly, while the cation concentrations drop steadily above 30 cm the loss on ignition increases and then decreases. As just explained this is inconsistent with the erosion-leaching hypothesis.

This type of inconsistency was found in Loch Dee, Galloway, and it was suggested that the timescale of the changes was much shorter than that considered by the erosion-leaching hypothesis (unpublished results). The low sediment accumulation rate in Llyn Dulyn means that this cannot be the case here. It may be that the low influence of the catchment means that the normal erosion-leaching behaviour is not followed and that changes in the organic content are determined more by factors within the lake (see section 4.1.1).

The calcium-depth profile is similar to that of the loss on ignition (Figs. 13 & 14). This has been found in other Welsh lakes (Fritz et al. 1986, Kreiser et al 1986) and it may be that in these sediments with very low calcium concentrations calcium is not part of the mineral component but is complexed by the natural organic material. This is expected on theoretical grounds (Stumm & Morgan 1981, Sayles & Mangelsdorf 1977).

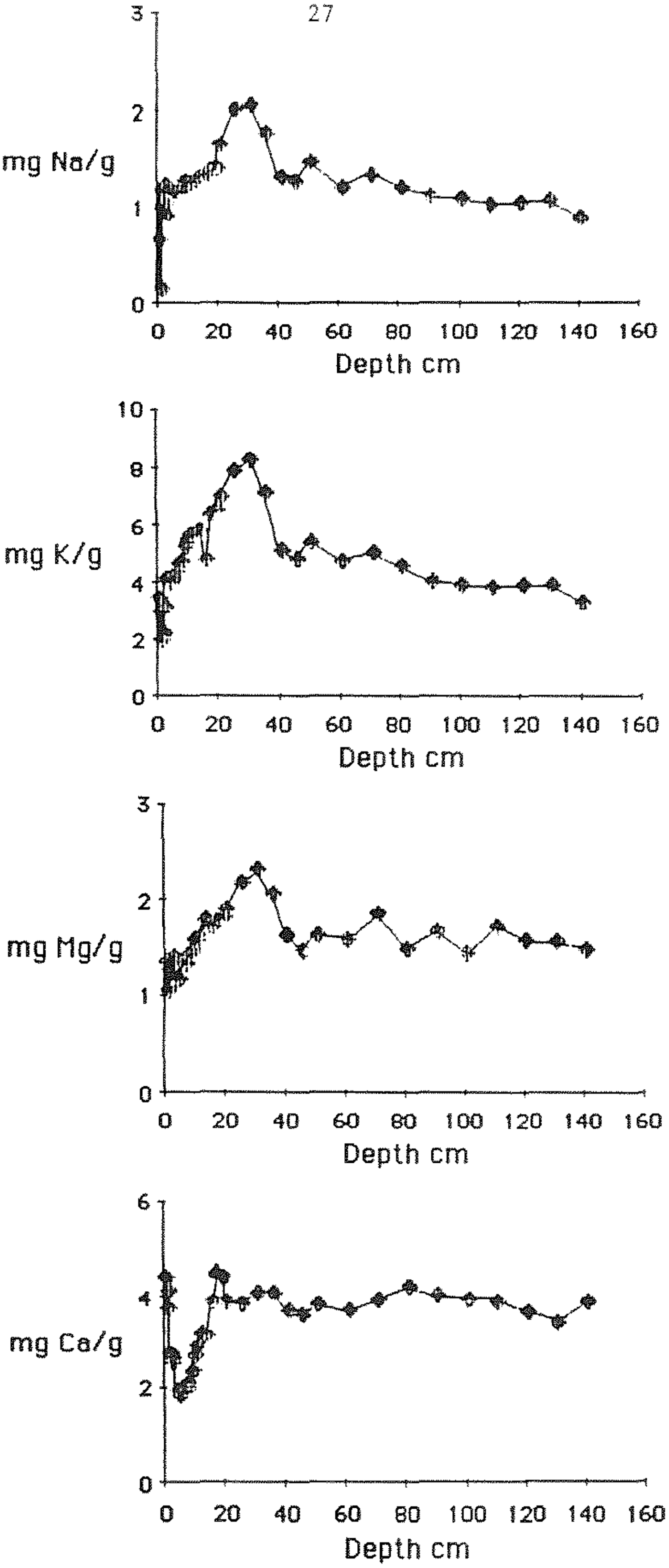


Fig. 13. Variations in Na, K, Mg & Ca gdw^{-1} for the Llyn Dulyn I core.

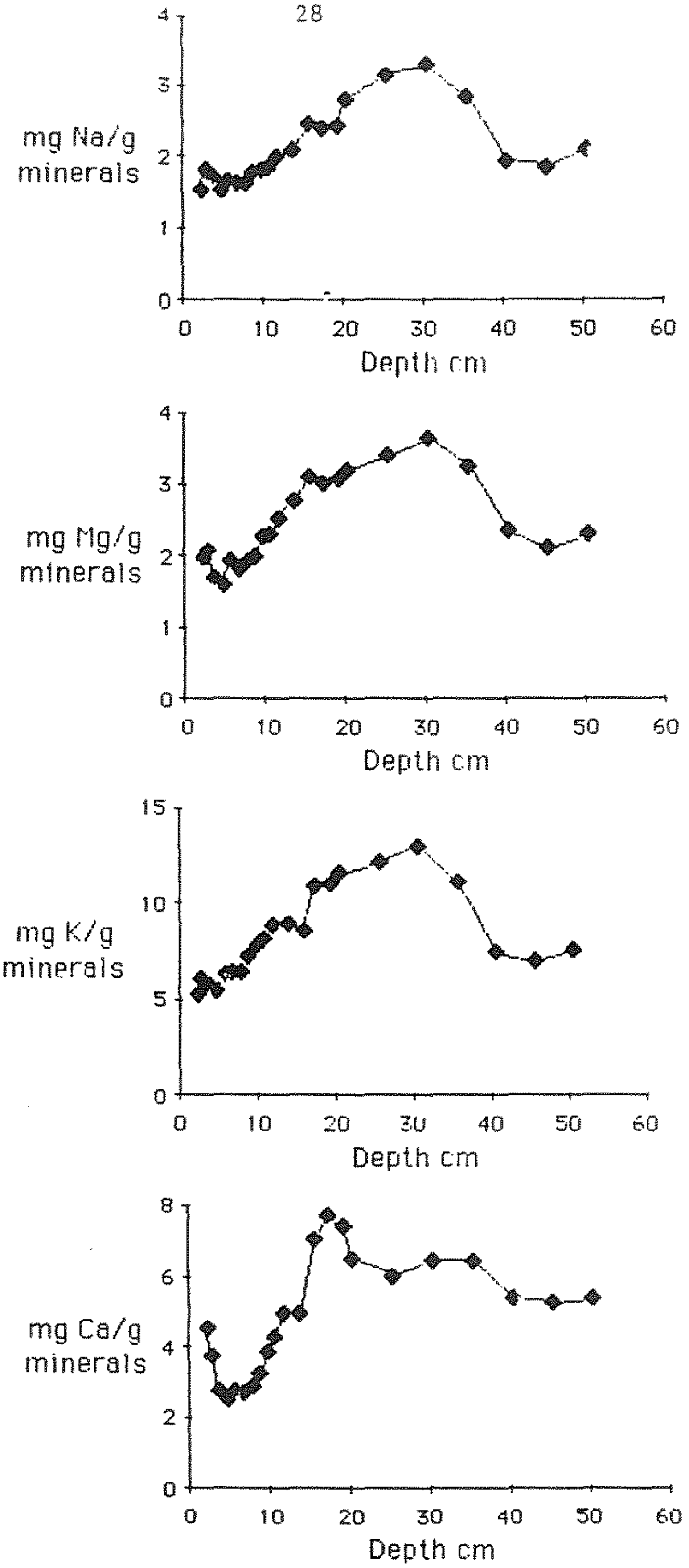


Fig. 14. Variations in Na, K, Mg & Ca per gram mineral dry weight for the Llyn Dulyn 1 core.

Trace Metals

Although the major cation concentrations drop from 30 cm to the sediment surface, zinc, lead, nickel and to a lesser extent copper, increase above 11 cm depth (Figs. 15-18). Because of changes in major ion concentrations above 40 cm the departure of the zinc/potassium and lead/potassium relationships have been used to choose the depth for the beginning of contamination (Figs. 19 & 20). This depth (11.5 cm) when trace metal contamination of the Llyn Dulyn sediment began corresponds to 1884 (Table 9).

The zinc and lead contamination rises to a maximum at 7.75 cm to 8.0 cm, fall to a trough at 3.75 to 4.0 cm and finally rises towards the surface (this rise is less clear with lead). The sediment accumulation rate also varies over this depth interval. It increases at 8 cm followed by a small drop at 4 cm (Table 9). These depths coincide with those where zinc and lead changes occur and suggest some link.

The increase in accumulation rate causes the two trace metal concentrations to drop while the drop allows them to recover. There appears to be a dilution effect by material eroded from the catchment. This is supported by the flux-depth behaviour where the accumulation rate and concentration changes combine to give a smooth flux-depth profile with little drop in flux when concentrations drop (Fig. 21).

In the other Welsh and Galloway cores the nickel and copper contamination was either small, zero or was so small that it was not detectable against the normal environmental variation of concentration. The low sediment accumulation rate in Llyn Dulyn means that conditions are suitable to detect low levels of contamination.

The background trace metal concentrations below 12 cm before contamination show that there is no mineralization in the Llyn Dulyn catchment. They are 95 ug Zn g^{-1}, 28 ug Pb g^{-1}, 21 ug Cu g^{-1} and 16 ug Ni g^{-1}.

The most likely source of trace metal contamination in Llyn Dulyn as in the other upland lakes in Wales and Galloway is deposition from the atmosphere. There is no mineralization in the catchment and trace metal containing effluents in this upland catchment are unlikely.

The mean fluxes in the 0 to 8 cm interval when there is contamination are lower than the other Welsh lakes examined so far (19.7 mg Zn m^{-2} yr^{-1}, 12.8 mg Pb m^{-2} yr^{-1}, 8.3 mg Cu m^{-2} yr^{-1} and 2.4 mg Ni m^{-2} yr^{-1}). The other lakes are in central Wales while Dulyn is in the north-west. Either there is less deposition of trace metals from the atmosphere in north-west Wales or more likely the sedimentation efficiency of these metals is low in Llyn Dulyn.

Table 10 presents the results a comparison of lead and zinc sedimentary fluxes compared to the dry mass accumulation rate for three other lakes in the same area of north-west Wales (Fritz et al 1987, Patrick et al. 1987a, Patrick et al. 1987b).

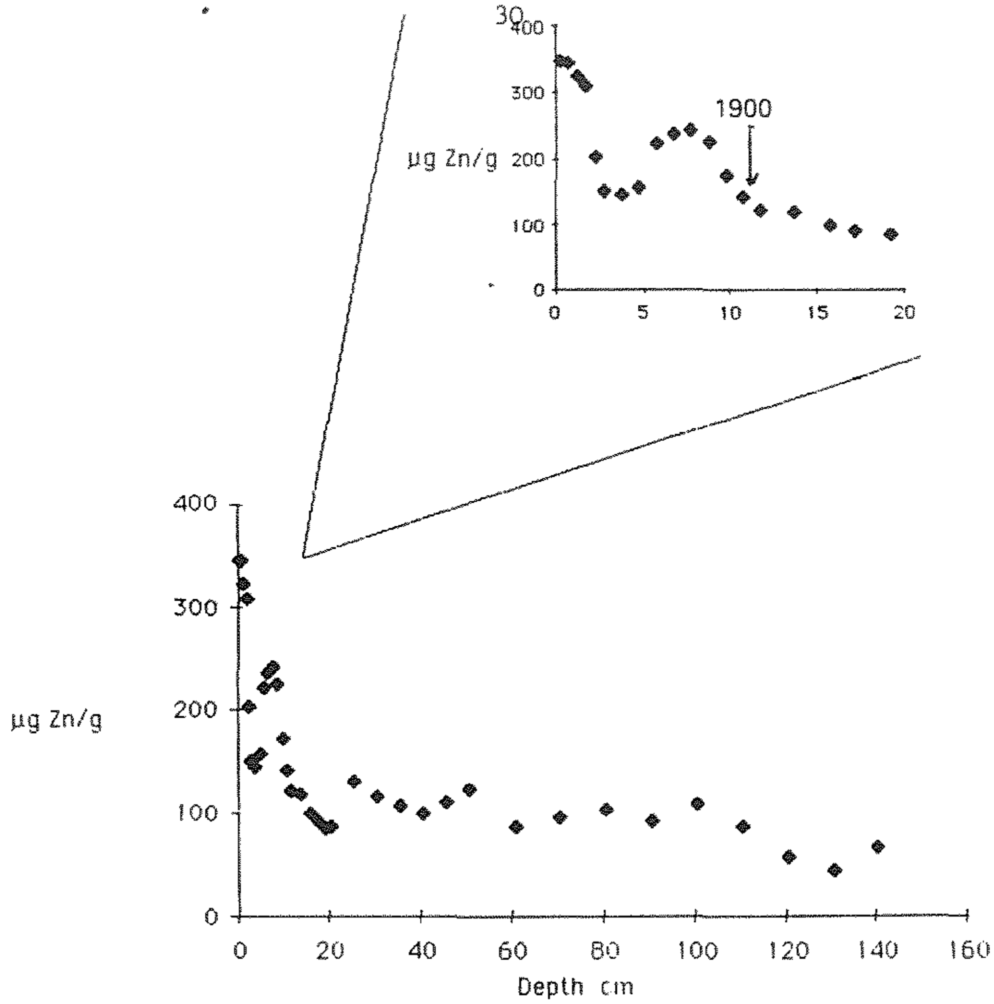


Fig. 15. Variations in Zn gdw^{-1} for the Llyn Dulyn I core.

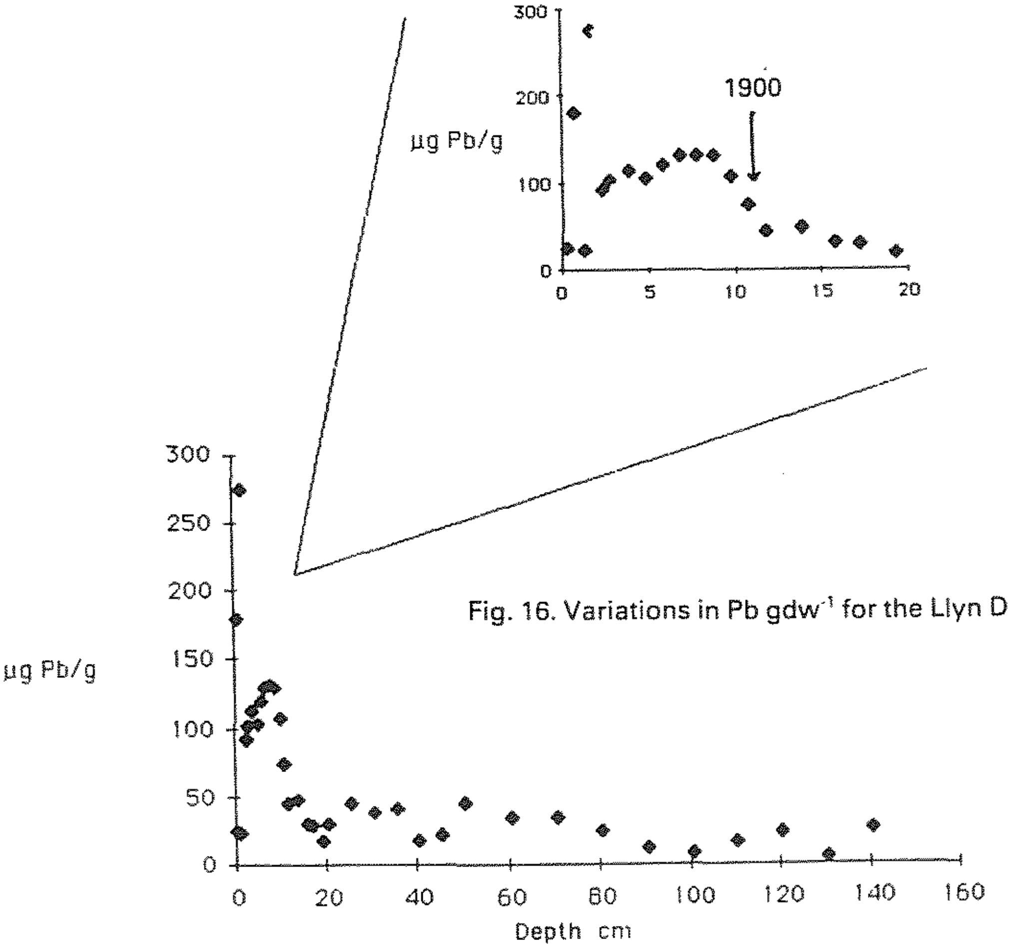
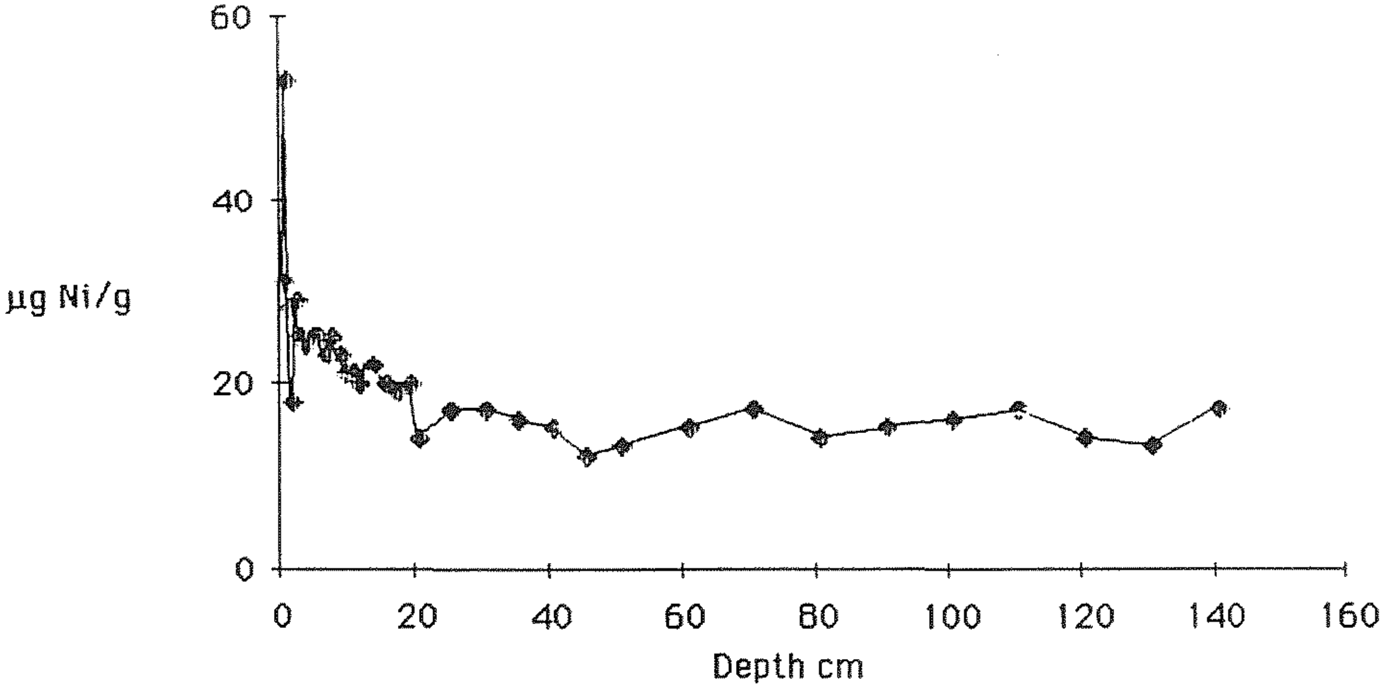


Fig. 16. Variations in Pb gdw^{-1} for the Llyn Dulyn I core.



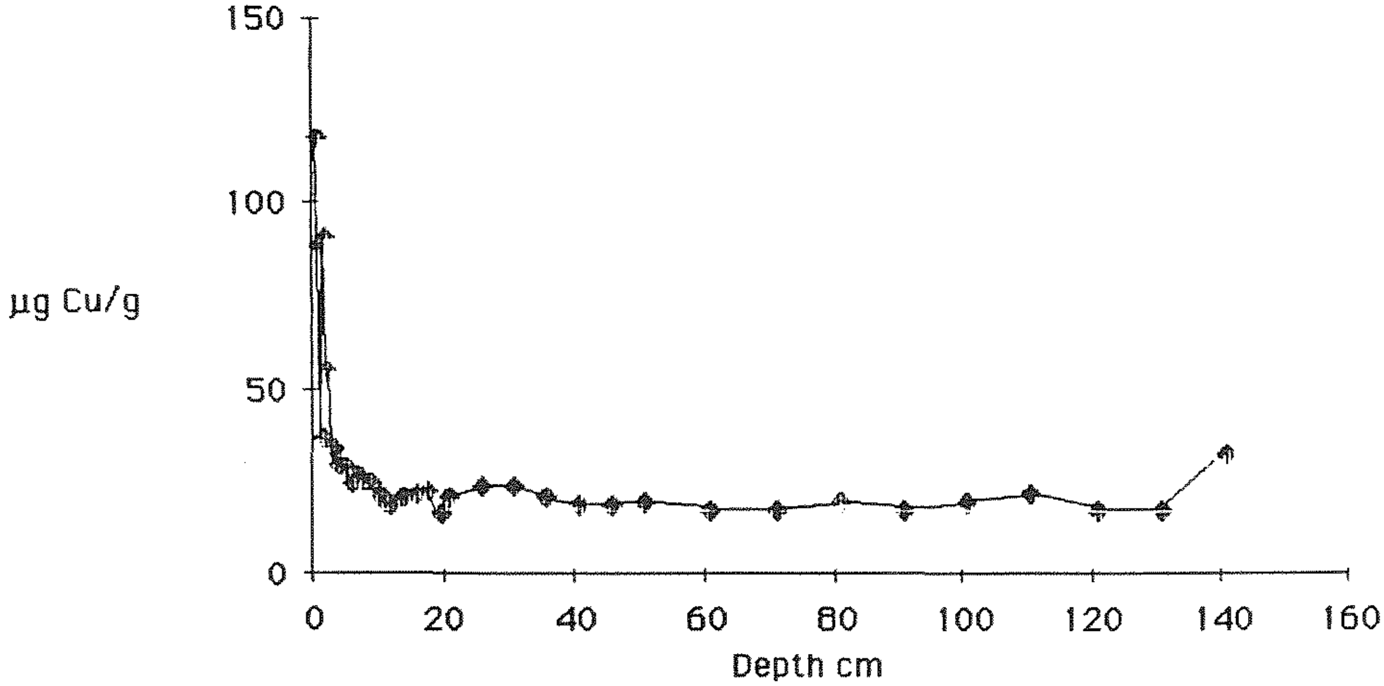


Fig. 17. Variations in Ni & Cu gdw^{-1} for the Llyn Dulyn I core.

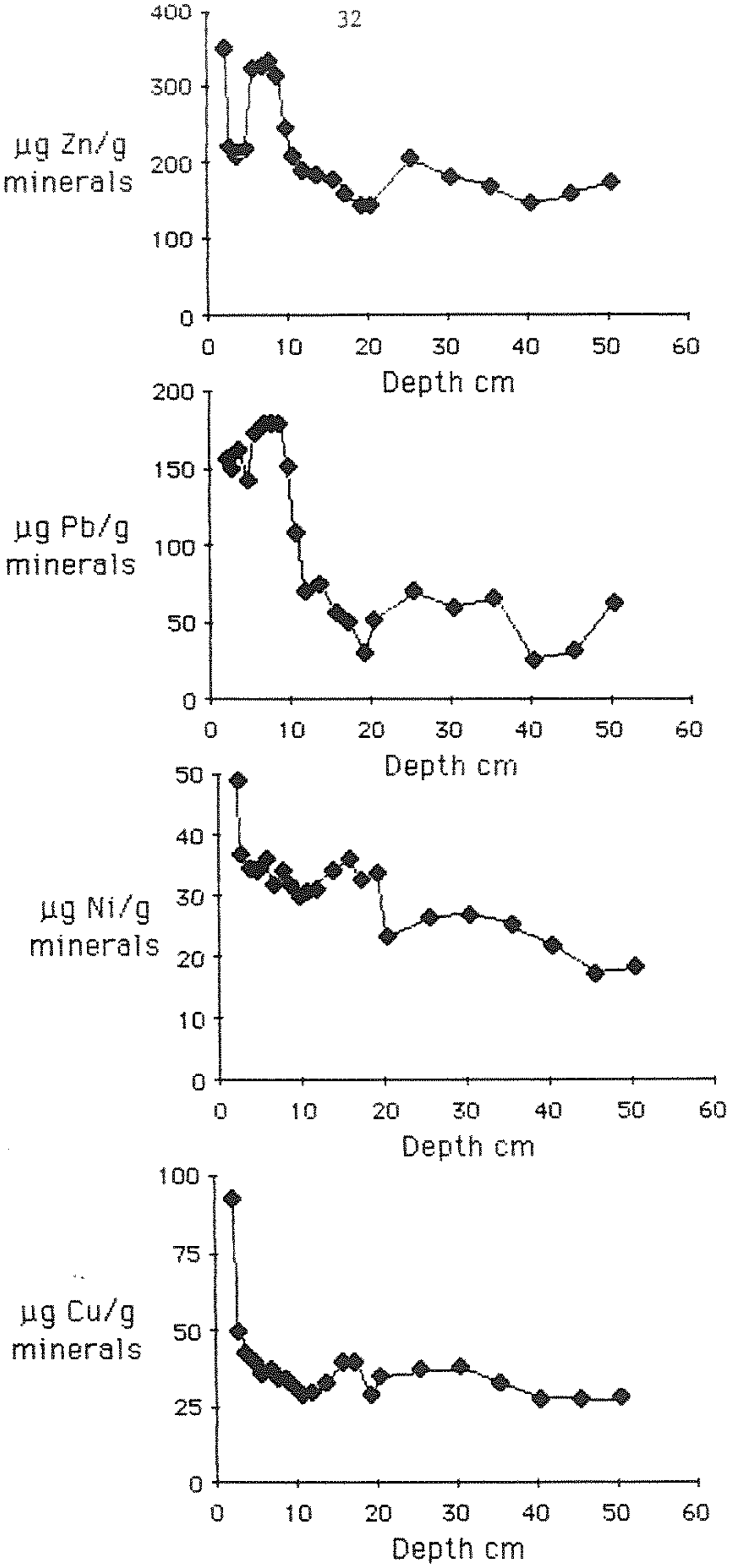


Fig. 18. Variation of trace metal concentrations with depth for Llyn Dulyn expressed as per gramme minerals.

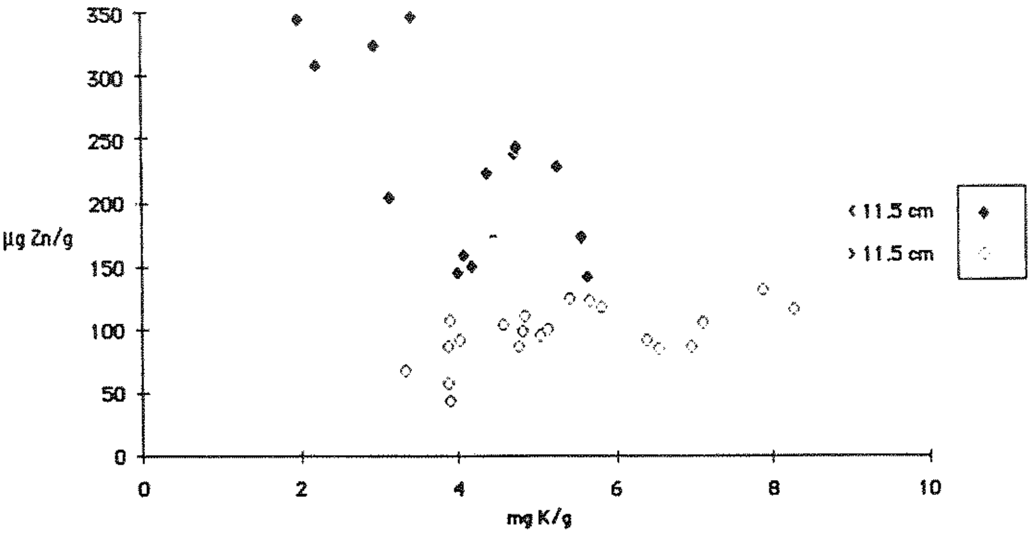


Fig. 19. Variations in Zn & K concentrations for the Llyn Dulyn I core.

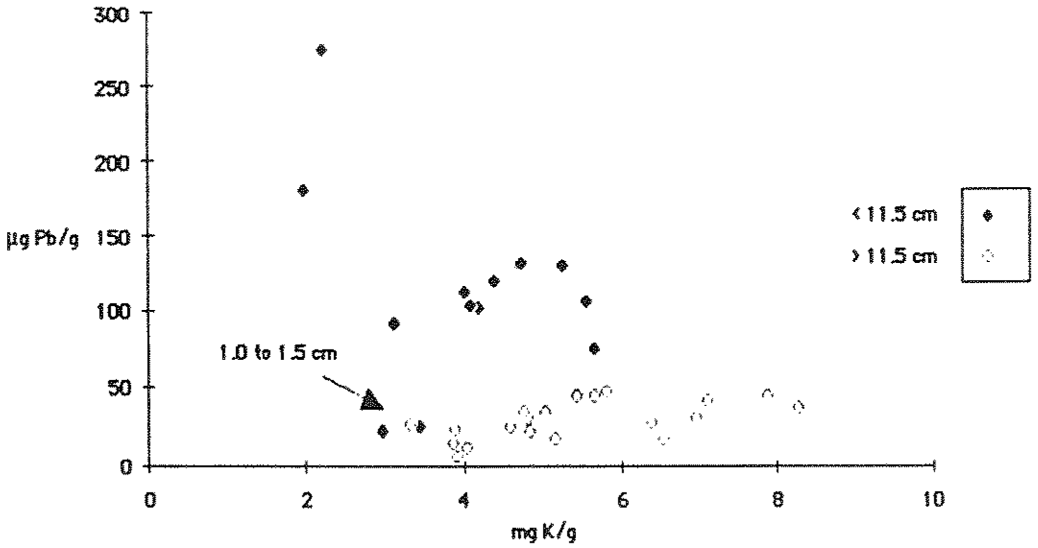


Fig. 20. Variations in Pb and K concentrations for the Llyn Dulyn I core.

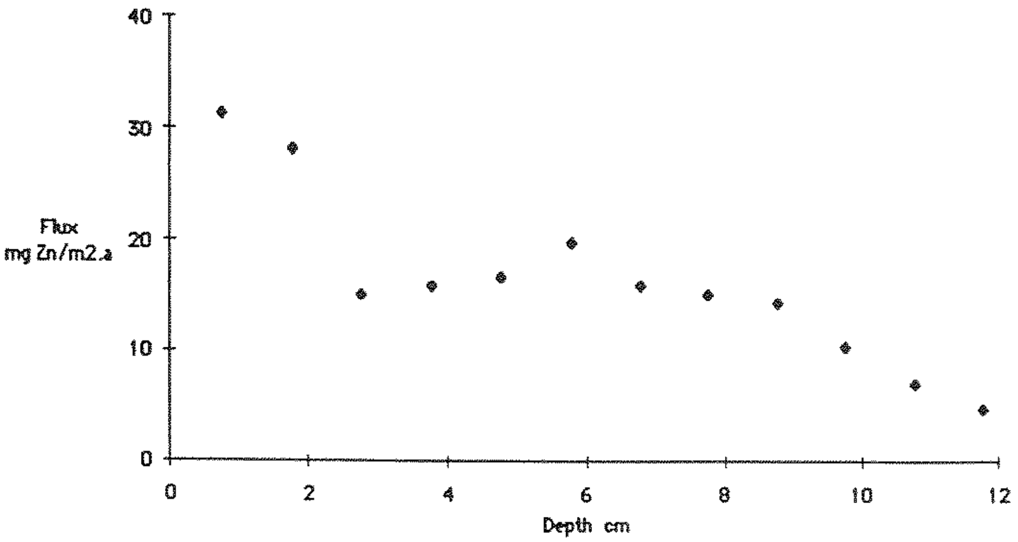


Fig. 21. Zinc flux for the Llyn Dulyn 1 core.

Table 10: Lead & zinc sedimentary fluxes & dry mass accumulation rates for Llyn Dulyn, Llyn y Bi, Eiddew Bach & Llyn Llagi.

Lake	Lead flux mg Pb m^{-2} yr^{-1}	Zinc flux mg Zn m^{-2} yr^{-1}	Dry mass accumulation mg cm^{-2} yr^{-1}
Dulyn	1.5 - 20	4 - 30	4 - 11
Llyn y Bi	2.9 - 8	1.5 - 18	4
Eiddew Bach	2.6 - 14	13 - 21	6
Llagi	43	56	15

As the sedimentary fluxes of lead and zinc in Llyn Llagi are similar to those in the lakes in central Wales and Galloway (up to over a hundred mg $^{-2}$ yr^{-1}). It is probable that the lower values in Llyn Dulyn, Llyn y Bi & Eiddew Bach are because of reduced sedimentation efficiencies due to lower dry mass accumulation rates. The contamination flux of trace metals from the atmosphere in north-west Wales then may be similar to that in central Wales and Galloway.

Sulphur

Since only a small amount of sediment was available in the top 10 cm of the core there are only a few data points in this important interval (Fig 21a). Although there is a suggestion that the sulphur concentration increases above 8 cm the evidence for this is not reliable.

4.1.5. Carbonaceous cenospheres "Soot"

The carbonaceous particle pattern for Llyn Dulyn, illustrating the number of particles per gram dry sediment is given in Fig. 22 & Table 11. It shows the presence of soot in small numbers at a depth of 13 cm (ca. 1860 A.D.) and a possible contamination peak at 21 cm (Table 11). Concentrations rise slowly to 10 cm (1903 A.D.) after which carbonaceous particle concentrations rise steeply toward the surface with a classic post 1940's steep rise at 7 cm.

The pattern for the soot count in terms of the organic content of dry sediment is given in Fig. 23. Soot 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 Dulyn. Values for the top 2 cm of the core cannot be calculated because of the presence of an highly organic algal mat (see section 4.1.1). Otherwise, the pattern is very similar to that in Fig. 22.

4.1.6. Magnetic Measurements

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

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.

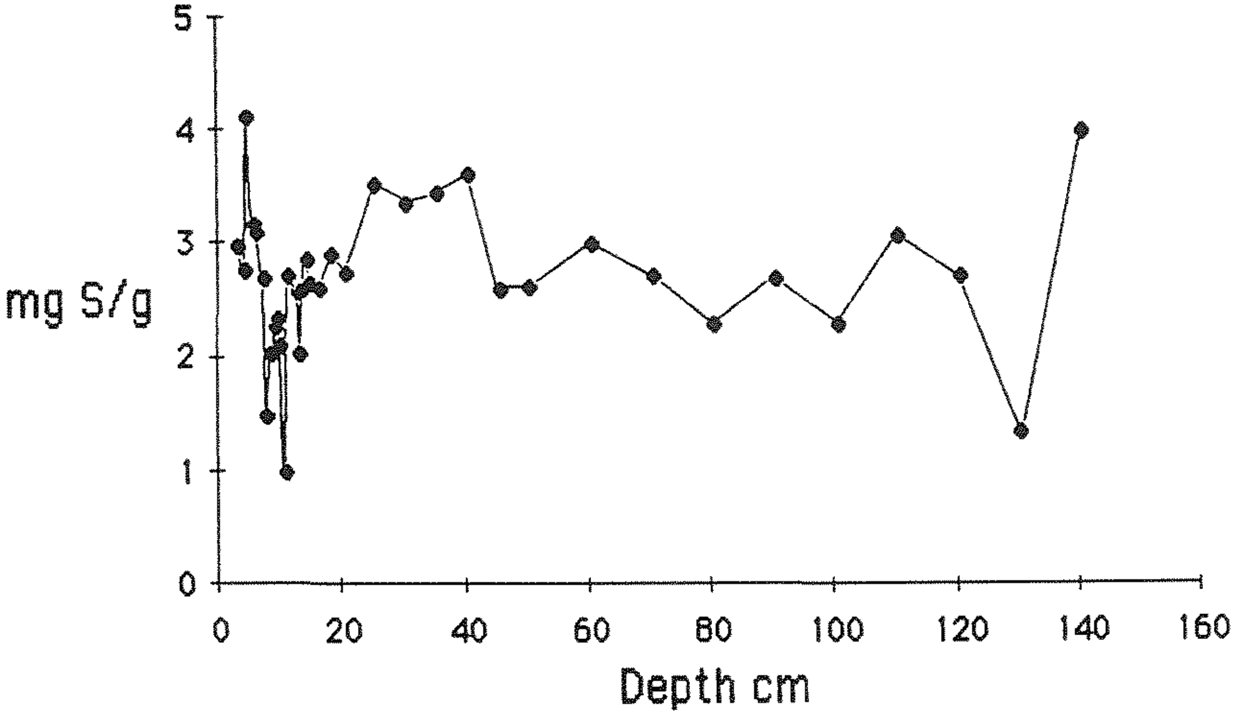


Fig. 21a Sulphur profile for the Llyn Dulyn 1 core

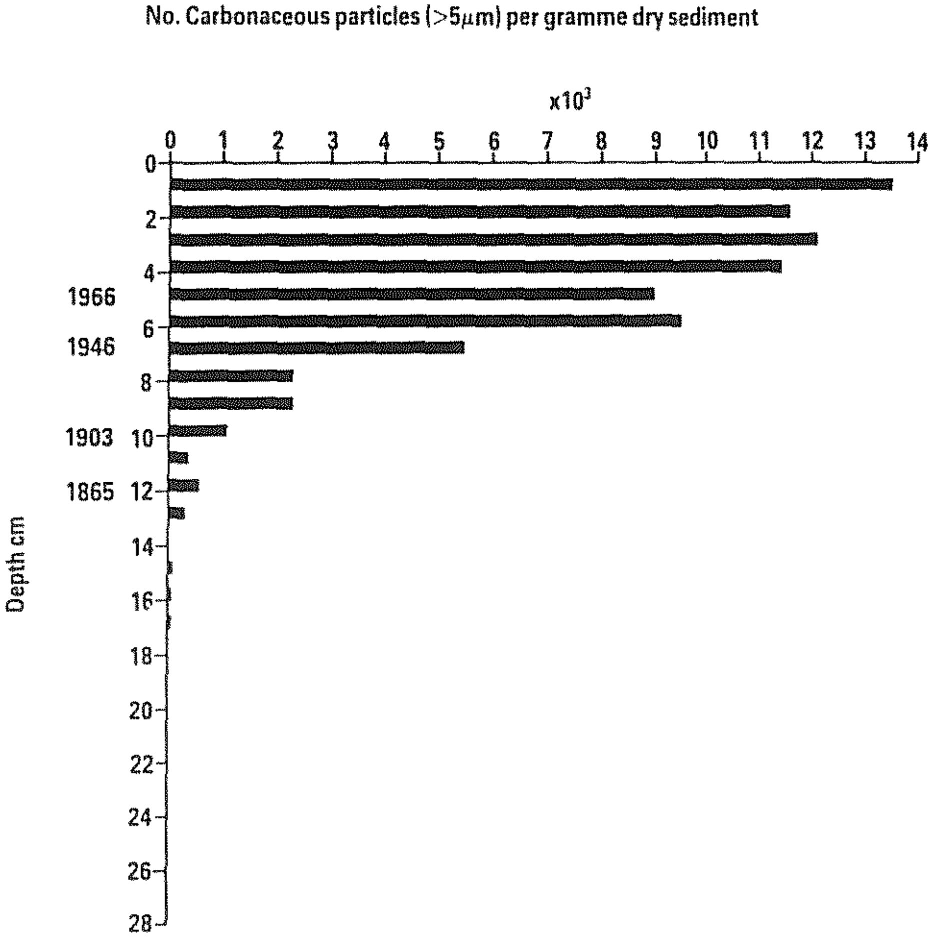


Fig. 22. Carbonaceous particle record gdw⁻¹ for the Llyn Dulyn I core.

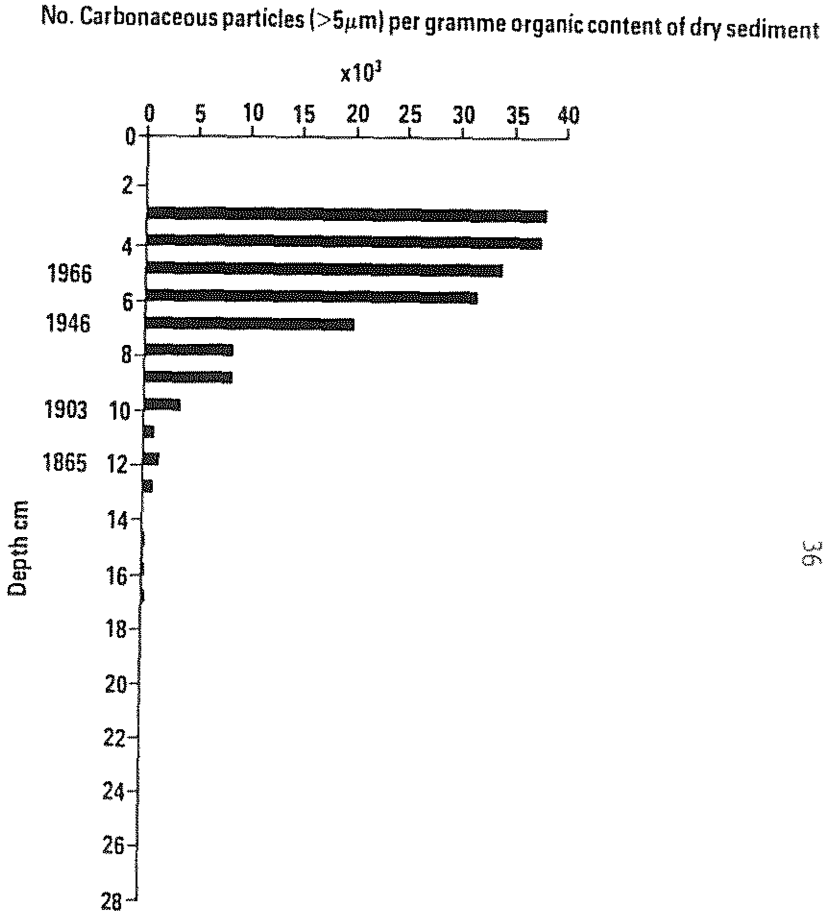


Fig. 23. Carbonaceous particle record per gram mineral dry weight for the Llyn Dulyn I core.

Table 10: Carbonaceous particle analysis for Dulyn 1

Depth (cm)	No. Carbonaceous Particles per g dry sed $\times 10^3$	No. Carbonaceous Particles per g organic content $\times 10^3$
0.5 - 1.0	13.48	--
1.5 - 2.0	11.58	--
2.5 - 3.0	12.06	38.0
3.5 - 4.0	11.35	37.6
4.5 - 5.0	9.04	33.8
5.5 - 6.0	9.55	31.4
6.5 - 7.0	5.49	20.2
7.5 - 8.0	2.34	8.8
8.5 - 9.0	2.35	8.5
9.5 - 10.0	1.10	3.7
10.5 - 11.0	0.39	1.2
11.5 - 12.0	0.62	1.7
12.5 - 13.0	0.28	0.8
13.5 - 14.0	0	0
14.5 - 15.0	0.07	0.2
15.5 - 16.0	0.10	0.2
16.5 - 17.0	0.08	0.2
17.5 - 18.0	0	0
18.5 - 19.0	0	0
19.5 - 20.0	0	0
21.0 - 22.0	1.08?	2.8?
23.0 - 24.0	0	0
25.0 - 26.0	0	0
27.0 - 28.0	0	0
29.0 - 30.0	0	0
31.0 - 32.0	0	0
33.0 - 35.0	0	0

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. 24 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. 25 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. 26 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.

SIRM values remain low and constant below 10 cm. At this depth they are only some 2 to 5 times those found in pre-industrial ombrotrophic peats. The steep increase above 9.5 cm continues to within 0.5 cm of the sediment surface despite possible dilution by unmineralized algal material in the top 2 cm. ARM values show a parallel though much less regular increase, and in several cases the readings on samples of low mass are close to instrumental noise levels. This contributes to the between sample variations in ARM, but more significantly it is almost entirely responsible for the extreme variations in SIRM/ARM between 7.5 cm and 10 cm. For this reason, SIRM/ARM variations have not been used for sample characterization at this site.

The increase in SIRM above 9.5 cm is reflected in both the magnetically soft ('magnetite') and hard ('haematite') components (Figs. 25 - 26). The final steep increase to peak values n the top 2 cm is reflected in the soft IRM only (Fig. 25) whereas the hard component actually declines. In Figs. 27 - 29 separate symbols are used for samples 0 - 2 cm, 2 - 9.5 cm & 9.5 cm - 20 cm. On the non-normalized plots (Figs. 26 & 27) the three groups tend to occupy discrete envelopes of values. In Fig. 29, which cross-plots 'soft' and 'hard' reverse field components normalized by SIRM, the envelopes are rather diffuse and overlapping suggesting that magnetic measurements alone cannot clearly distinguish different sample sets in the deposition sequence on a purely qualitative basis.

Fig. 30 shows the calculated SIRM and soft IRM ($SIRM - IRM_{-20mT}$) accumulation rates using the ^{210}Pb chronology. The first increases just predate the turn of the century. Rates increase more steeply after ca. 1910 A.D. and again after ca. 1940 A.D. Peak values in the 1980's are up to 20 times higher than those in the 19th century. The calculated accumulation rates parallel and are comparable in quantitative terms to those calculated for nearby Llyn-y-Bi (Fritz et al. 1987). Atmospheric deposition of magnetic particulates resulting from solid fuel combustion, power generation

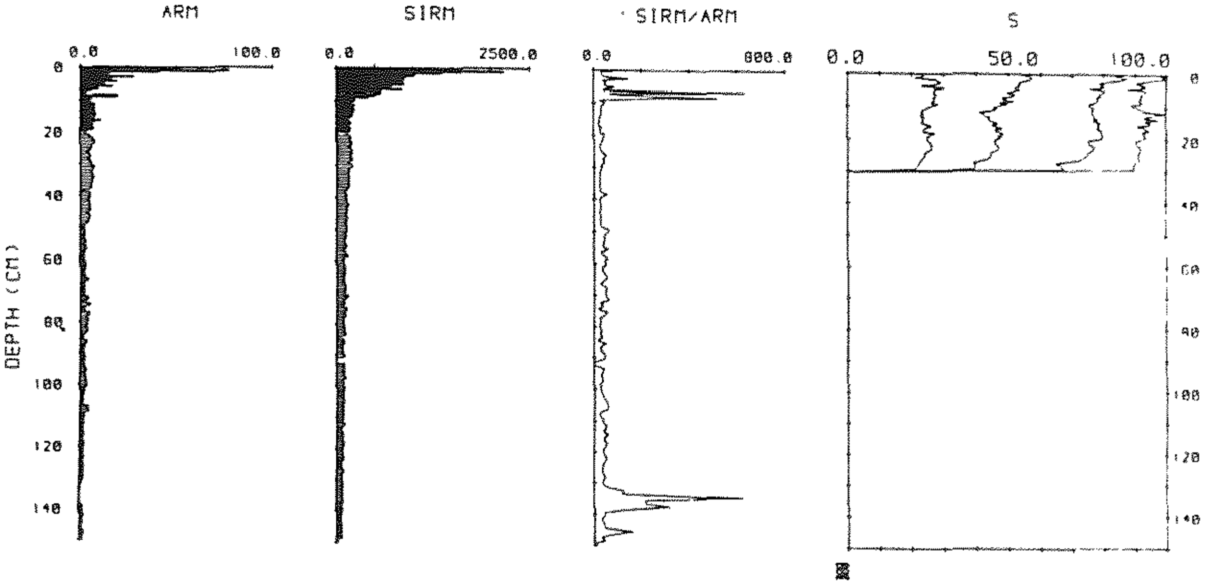


Fig. 24. ARM, SIRM and SIRM/ARM versus depth, 0 - 150cm. Reverse field ratios (see text) are plotted for the top 30cm only.

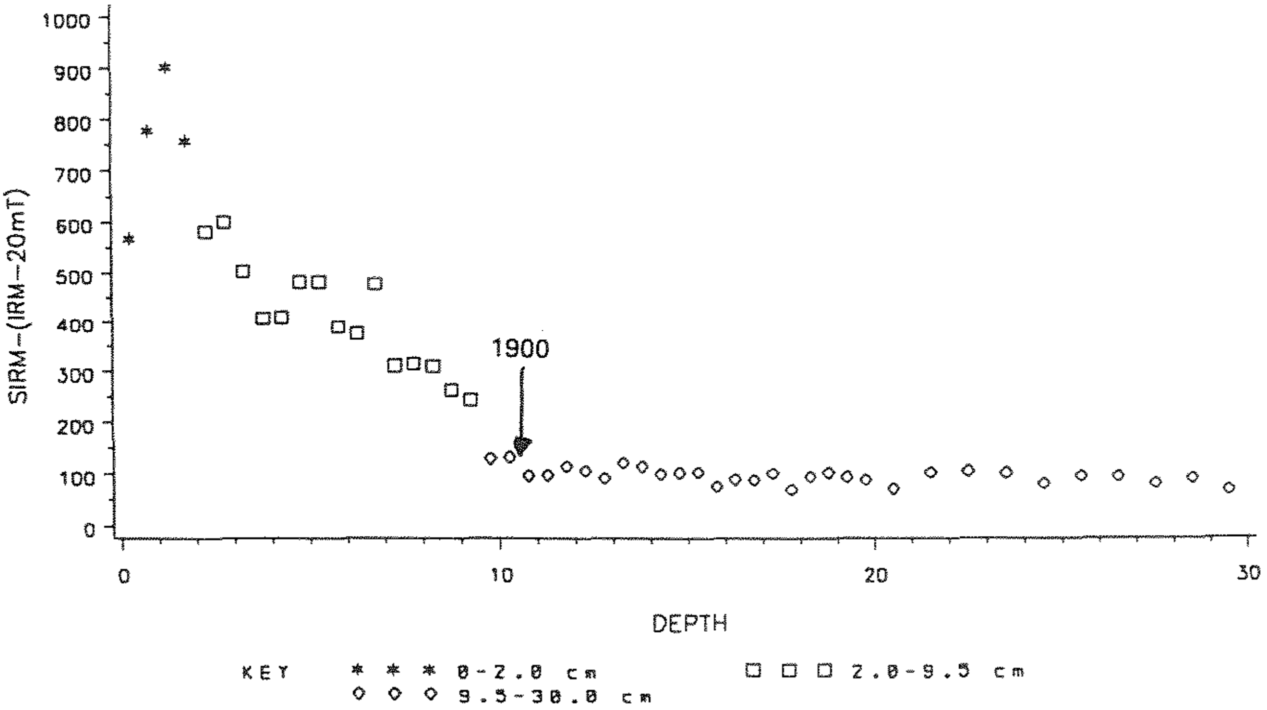


Fig. 25. SIRM-(IRM$_{-20mT}$) versus depth for the Llyn Dulyn I core.

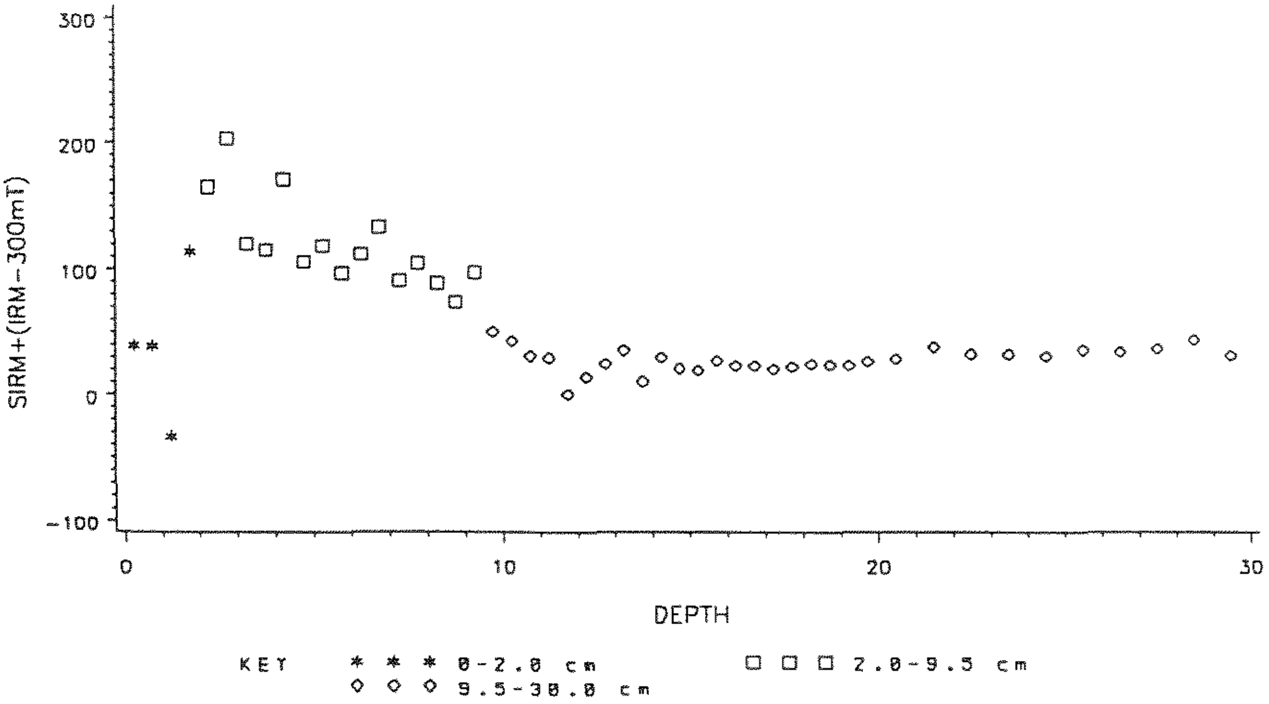


Fig. 26. SIRM+(IRM$_{-300mT}$) versus depth for the Llyn Dulyn I core.

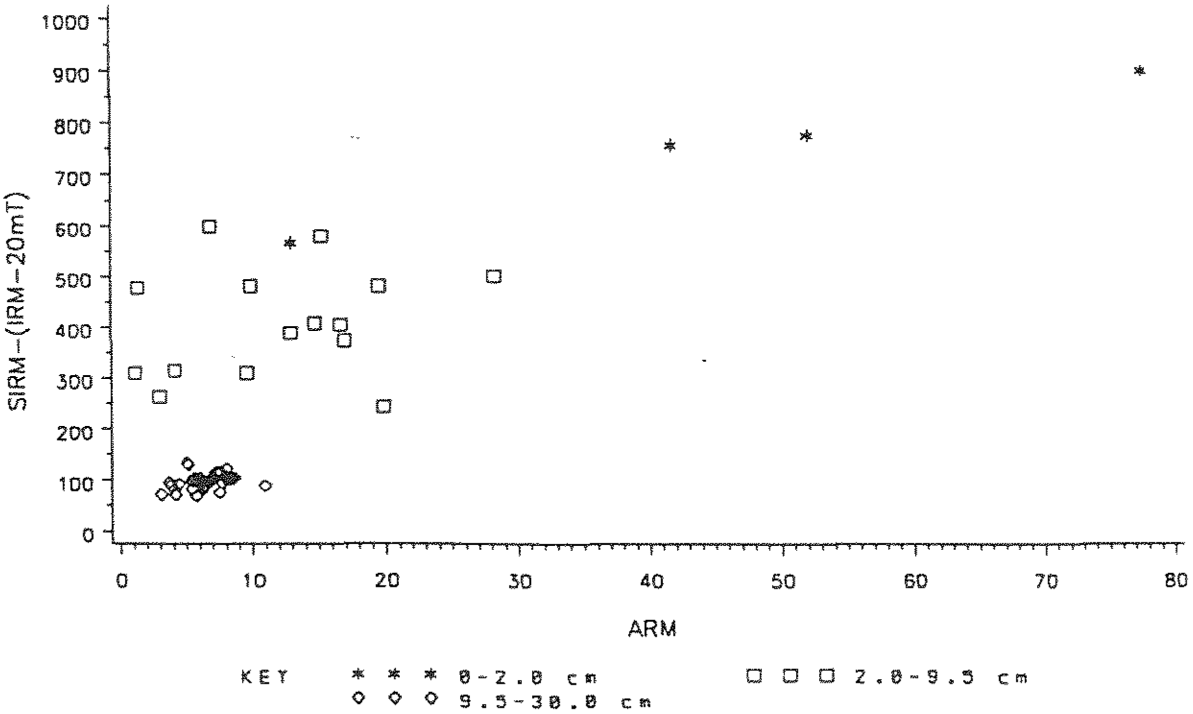


Fig. 27. SIRM-(IRM$_{-20mT}$) versus ARM for the Llyn Dulyn 1 core.

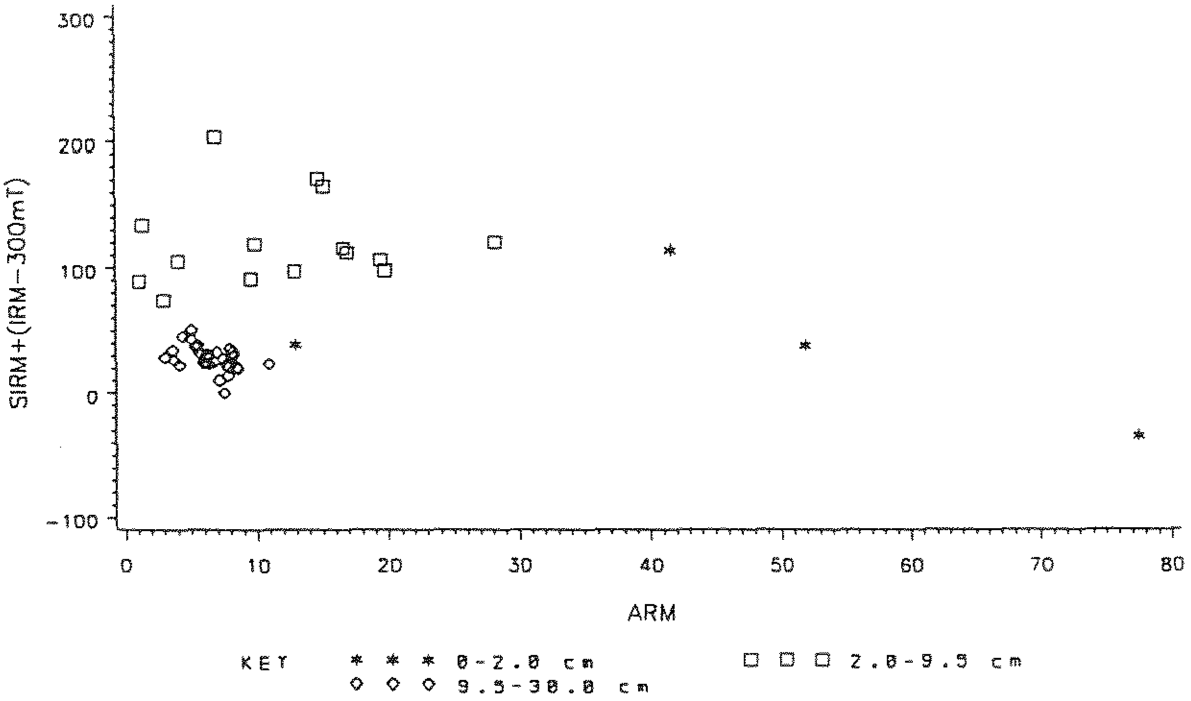


Fig. 28. SIRM+(IRM$_{-300mT}$) versus ARM for the Llyn Dulyn 1 core.

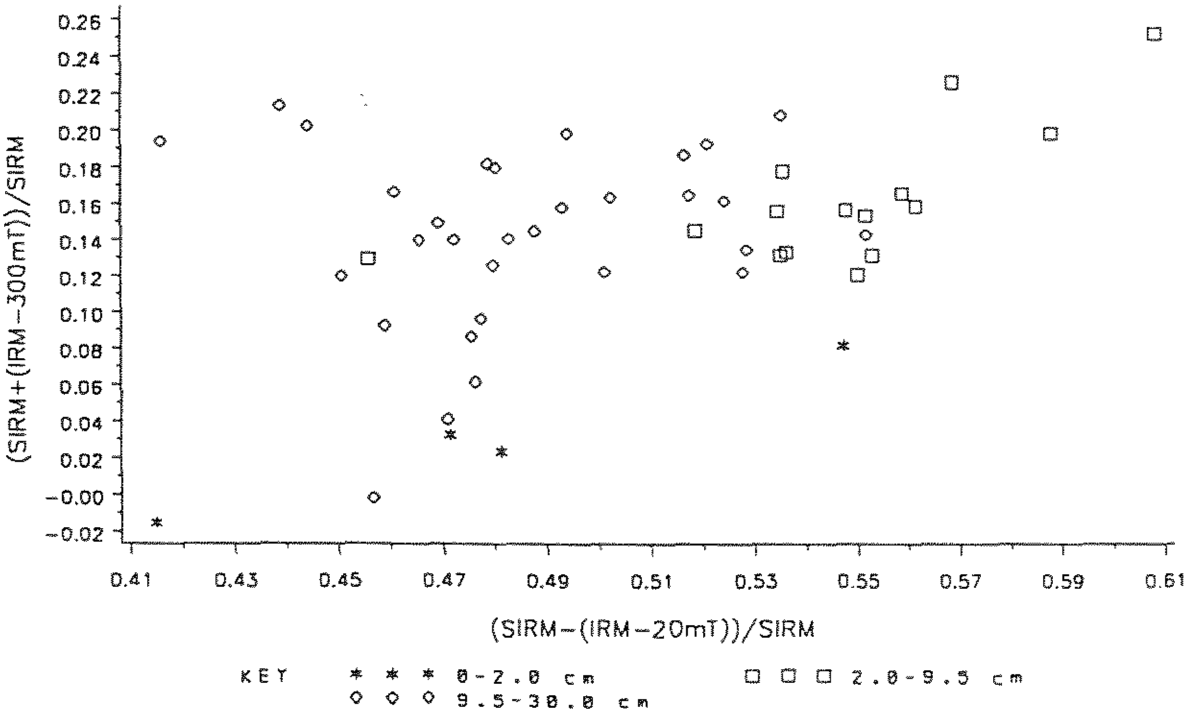


Fig. 29. (SIRM+(IRM$_{-300mT}$))/SIRM versus (SIRM-(IRM$_{-20mT}$)/SIRM for the Llyn Dulyn 1 core.

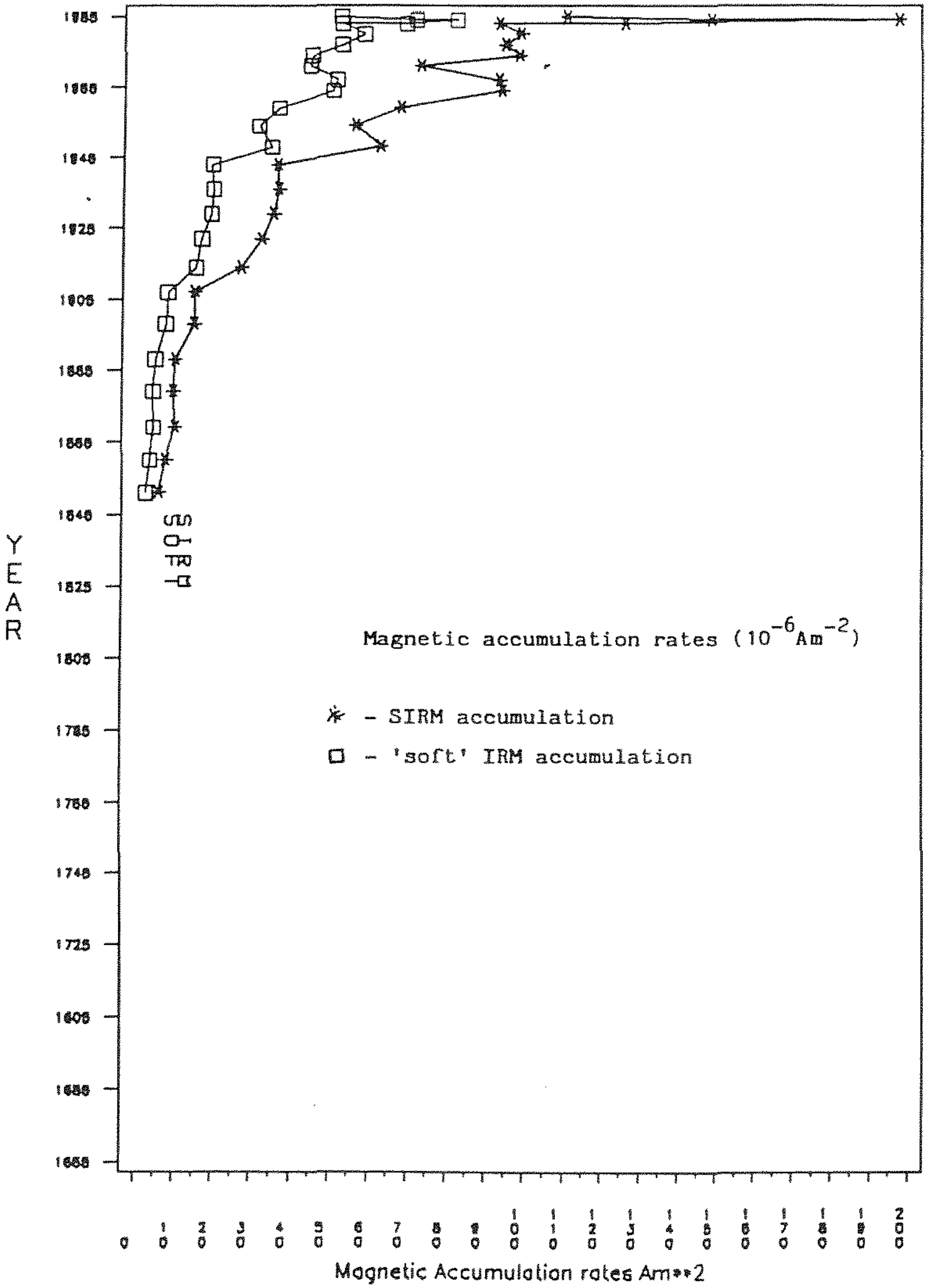


Fig. 30. Magnetic accumulation rate for Llyn Dulyn 1 core.

and other industrial processes is the most likely explanation, pending further studies.

4.1.7. Pollen

Figs. 31 & 32 present summary pollen diagrams of the Llyn Dulyn core and Fig. 33 presents a pollen concentration diagram. Appendix B contains the full pollen diagram. Three zones were defined using a departmental zonation package (ZONATION) (Birks & Gordon 1985).

DUL-1 *Quercus / Ulmus / Pinus* PAZ (150 cm - 95 cm)

The high values of *Quercus*, *Ulmus* & *Alnus* recorded throughout the zone indicate the presence of an early postglacial forest dating to around 7000 B.P. at the base. The indications are that this forest may have been local to the catchment, as in Eiddew Bach which is at a similar altitude (Patrick *et al.* 1987), since values of the major peatland indicators *Calluna* and *Gramineae* are very low until the end of the zone. The end of the zone is marked by a distinct elm decline, dating to around 5000 B.P., and is associated not only with anthropogenic forest disturbance as signified by peaks in the classic disturbance indicators *Fraxinus*, Liguliflorae & *Plantago lanceolata* but also with the first signs of peat initiation and spread within the catchment as tree pollen values fall and *Calluna* and Gramineae pollen values rise. Values of the aquatic macrophyte *Isoetes* are high throughout and are indicative of little or no catchment erosion.

The current rates of sedimentation are low (Table 9) and 19th century sedimentation rates are even lower (approx 0.05 cm yr^{-1}). Even if these historical sedimentation rates were extrapolated back to the base of the core this would still only give an age of some 3000 years at 150 cm. It is extremely likely, therefore, that a hiatus occurs in the core, probably directly after the elm decline (5000 B.P ca. 100 cm) and the beginnings of peat intiation. Such hiatuses appear to be frequent in these high altitude moorland lakes (Anderson *et al.* 1986, Stevenson *et al.* 1987). However, this hiatus appears not to be recorded in either the lithostratigraphy (Fig. 7), pollen concentration (Fig. 33) or the chemical and magnetic data.

DUL-2 *Calluna / Gramineae* PAZ (95 cm - 43 cm)

The transition to this zone is smooth despite the inferred presence of a hiatus and reflects the continuing expansion of peatland within the catchment as values of *Calluna* and Gramineae rise steadily and tree pollen values fall. Small remnants of these once widely spread oak and alder forests now occur in the lower reaches of the stream catchment. Anthropogenic disturbances of the extra-catchment forests are recorded by prominent peaks in the major disturbance indicators *Plantago lanceolata* and *Rumex crispus* type and increases in *Betula* and *Fraxinus* representation. Towards the end of the zone values of *Isoetes* fall probably as a result of a period of peat erosion as identified by an increase in the loss on ignition profile at this time (Fig. 7).

DUL-3 *Gramineae / Calluna* PAZ (43 cm - 0 cm)

This zone sees the final increase in peatland expansion. The most

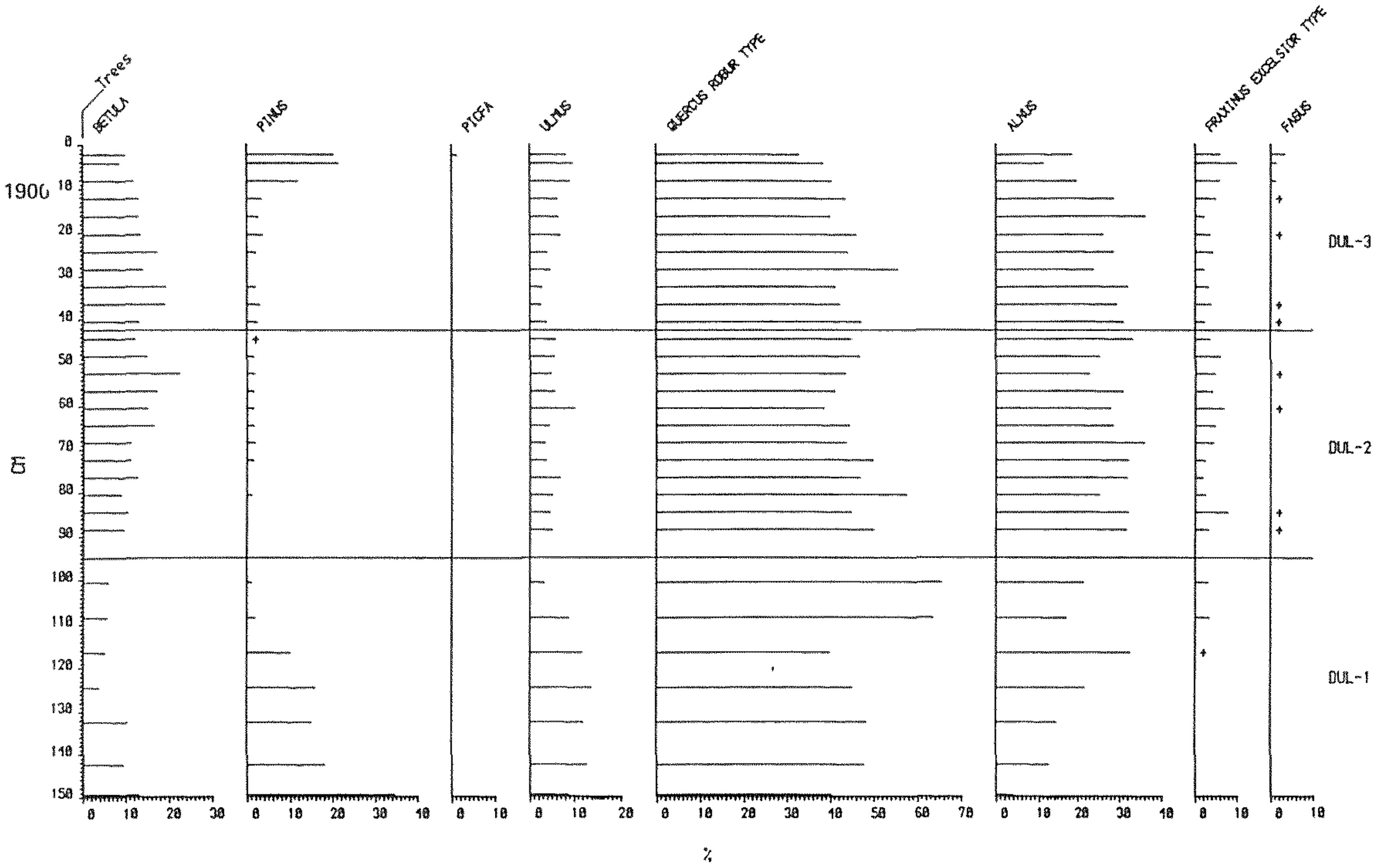


Fig. 31. Summary pollen diagram for the Llyn Dulyn 1 core. Trees expressed as a percentage of the Arboreal pollen. All other groupings as a percentage of the Arboreal pollen + the grouping.

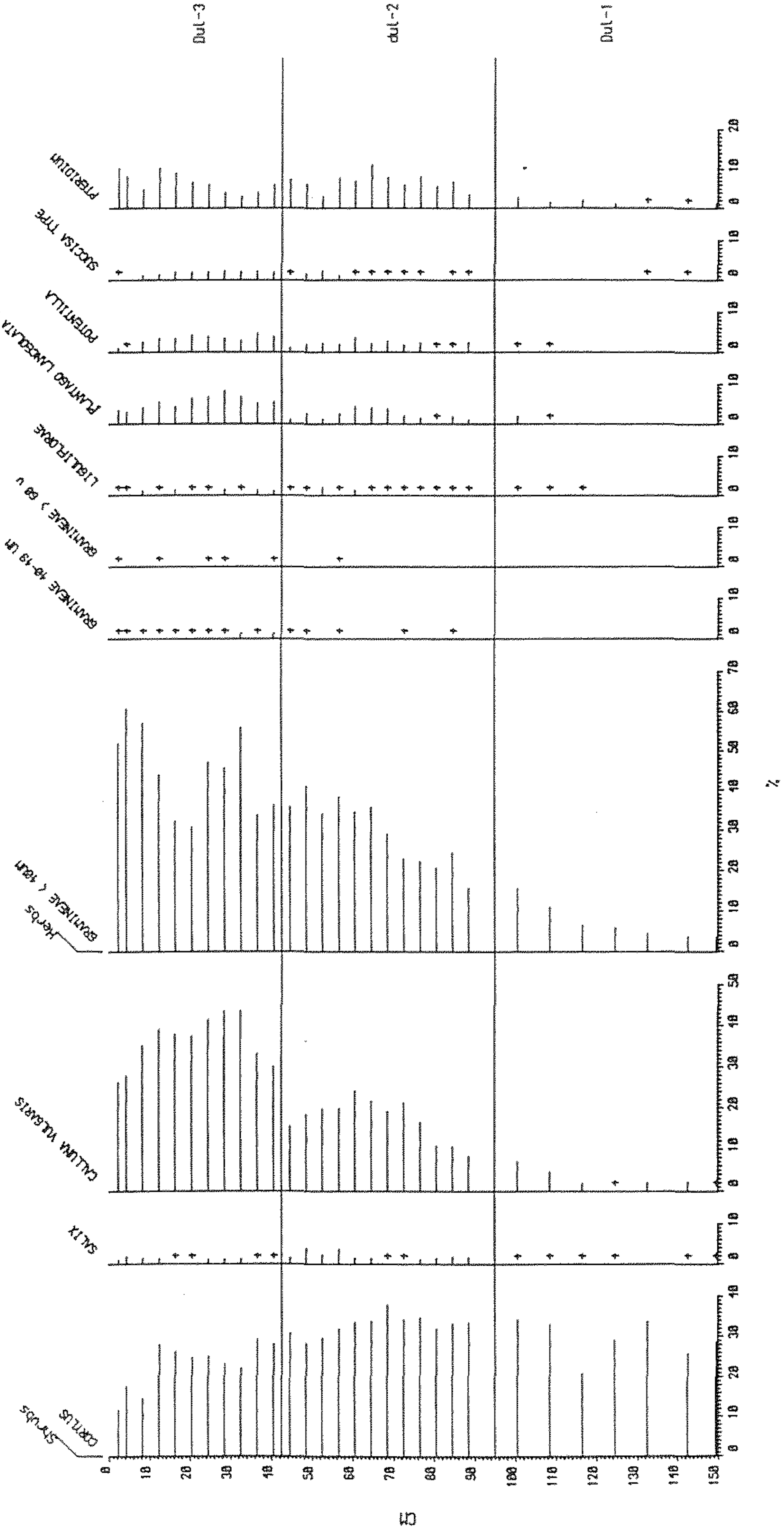
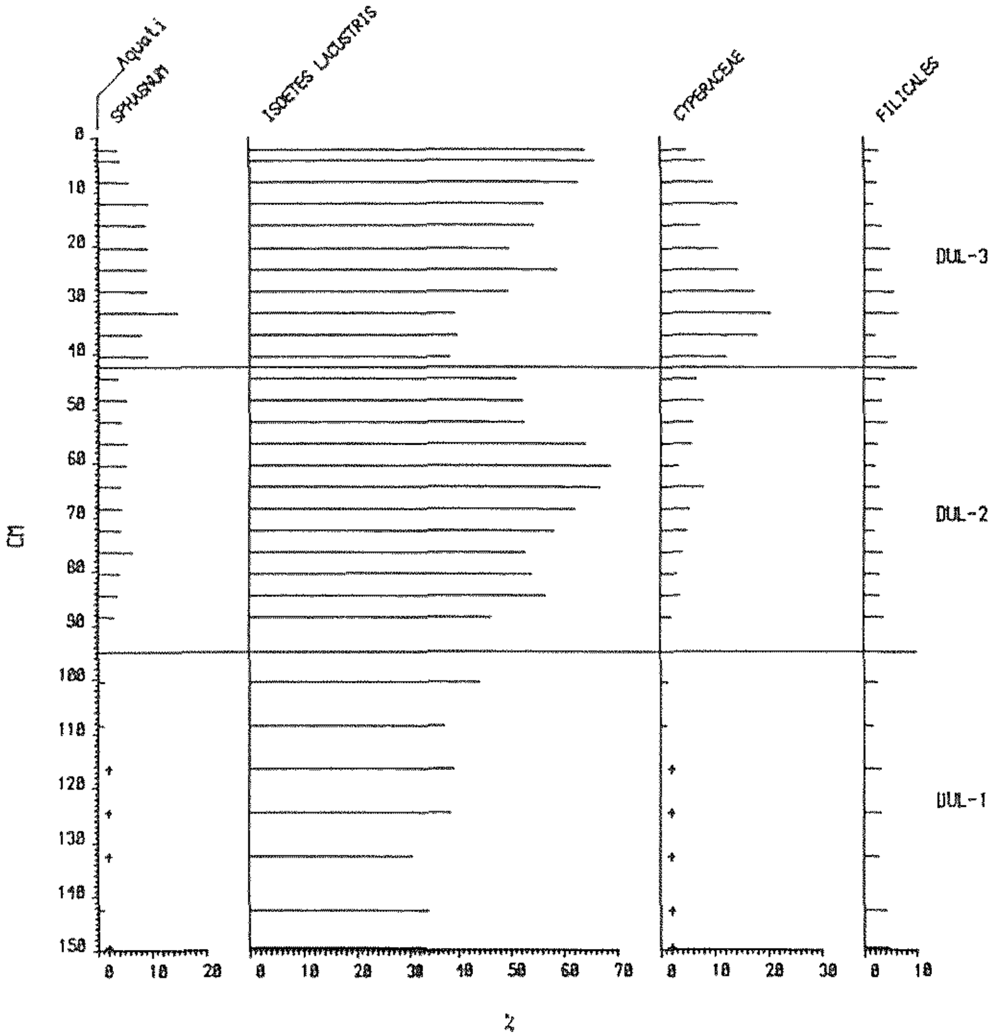

Dul-3
Dul-2
Dul-1
Shrubs
CORYLUS
SALIX
CALLUNA VULGARIS
Herbs
GRAMINEAE < 40um
GRAMINEAE 40-49 um
GRAMINEAE > 60 u
LIGULIFLORAE
PLANTAGO LANCEOLATA TYPE
POTENTILLA
SUCCISA TYPE
PTERIDIUM
%
cm
0
10
20
30
40
50
60
70
80
90
100
110
120
130
140
150

Fig. 31 ctd.


Aquati
SPHAGNUM
ISOETES LACUSTRIS
CYPERACEAE
FILICALES
CM
0
10
20
30
40
50
60
70
80
90
100
110
120
130
140
150
DUL-3
DUL-2
DUL-1
0
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30
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%

Fig. 31 ctd.

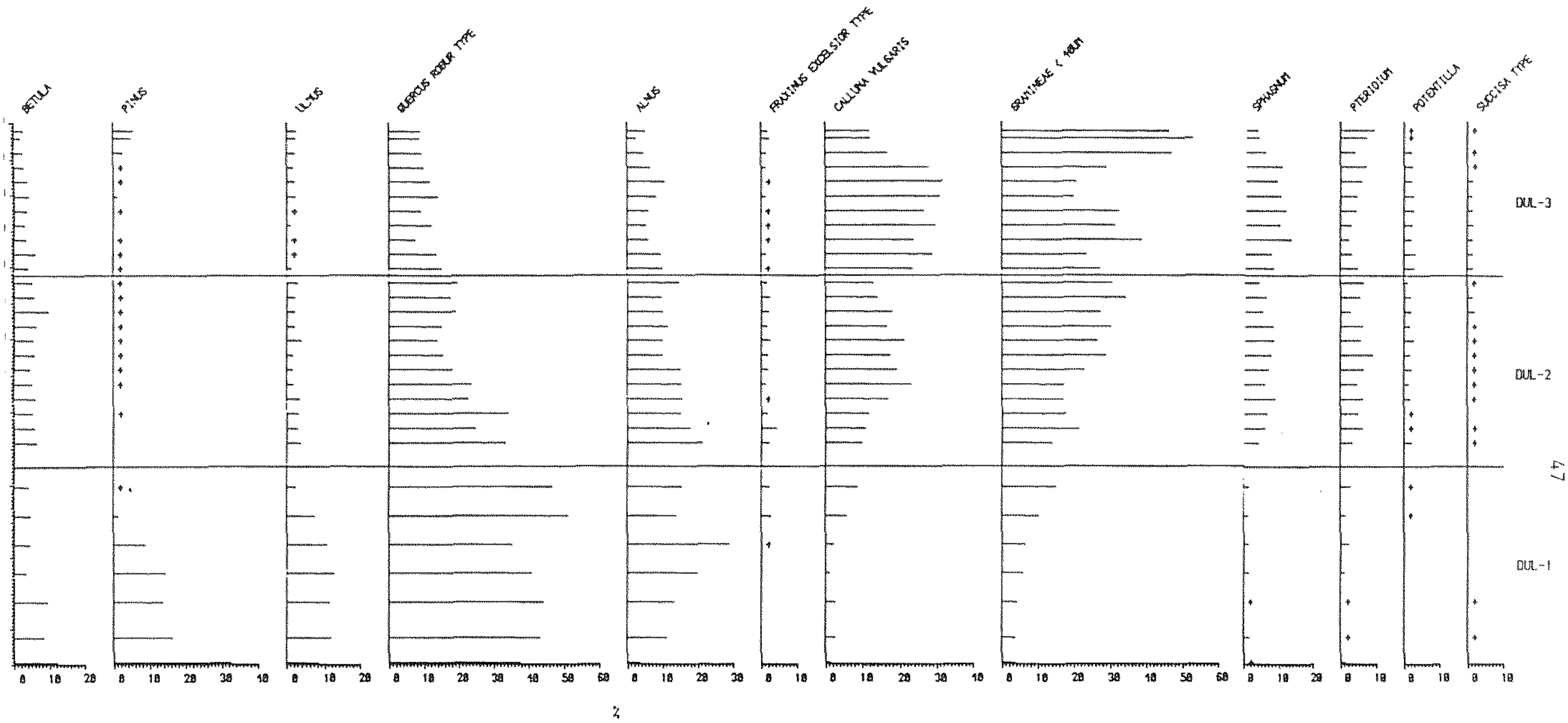

Fig. 32. Summary pollen diagram for the Llyn Dulyn 1 core. All taxa expressed as a percentage of the Arboreal pollen + peatland indicators.

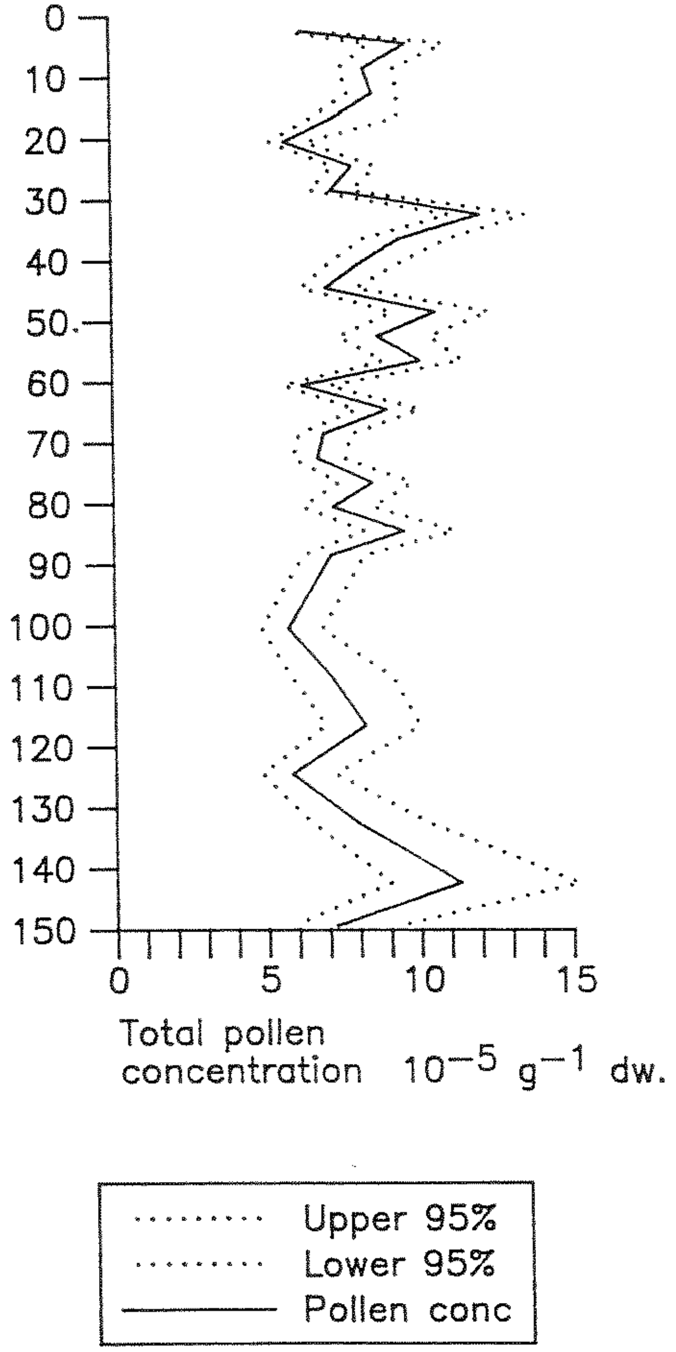

Fig. 33. Pollen concentration for the Llyn Dulyn 1 core.

noticeable feature of the zone is a change from Calluna domination by members of the Gramineae, presumably Molinia and Nardus and Festuca as a result of increased grazing and burning. This change is the reverse of what might be expected if the land-use change hypothesis as postulated by Rosenqvist et al. (1980) and Krug & Frink (1983) were in operation. The 1940's afforestation of the uplands of Wales is reflected in the pollen profile as seen by the increase in Pinus values from 8 cm (1932 A.D.) and the presence in the topmost sample of Picea pollen. Most of this tree pollen is probably derived from the Cwm Mynach catchment which lies some 2 km to the south (Kreiser et al. 1987). Fagus representation also increases presumably as a result of the planting of extensive beech hedges in the lowland valleys. The period of catchment erosion ends as values of Isoetes climb back to their previous high values from 40 cm.

4.2 Land use and Management (1)

4.2.1 Land use

At over 400 m on acidic soils the Llyn Dulyn catchment consists of unimproved moorland utilised for rough grazing. In terms of its vegetational composition (see Section 2.2.3) it contains species representative of both 'grassy' and 'shrubby 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).

The Llyn Dulyn catchment lies within an extensive block of moorland in excess of 700 ha, that is 'enclosed' by dry stone walls. Various estate papers at UCNW (3) and Dolgellau Record Office (4) indicate that this land was Crown Waste alloted to and enclosed by the Corsygedol Estate. The exact date of this 'enclosure' is unknown. Land in Llanddwywe (the catchment lies in Llanddwywe-is-y-Graig) was enclosed in 1810 (5) but precise details of the area(s) involved are not available (6). A map of 1806 (7) shows no indication of enclosure in the vicinity of the lake. A map and survey of 1815 (8) are the earliest documents to portray the enclosure. The land is described as 'exclusive sheepwalk belonging to Corsygedol called Cwm Bodlyn'. There are several entries in Corsygedol Estate accounts (9) between 1800-1816 relating to payments for the construction of new enclosures and mountain boundary walls. It is therefore probable that this land was 'enclosed' between 1800-1815, a period that coincides with the high point of moorland enclosure in Wales (Bowen 1914, Dodd 1927, Morgan 1959, Thomas 1965).

Enclosure at this altitude probably represented a 'land grab' by the estate and was not an attempt to actively improve the rough moorland grazing (cf. Morgan 1959, Thomas 1965, Dodd 1968). It appears that the walls acted as sheepwalk boundaries, the enclosure being too extensive to have encouraged intensified grazing in the area. Indeed, it is possible that grazing was less intensive after the 'enclosure' as stray beasts/flocks from neighboring sheepwalks were now fenced off the Corsygedol land.

Entries in the Corsygedol Estate accounts (1792-1816) (10) indicate that active improvement was occurring on the lower land and the ffridd above the demesne, but there is no evidence that the high mountain land was in any way considered suitable for improvement.

The altitude, soil acidity, exposure, wetness and steep margins determine that the catchment is 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. A lime kiln was constructed on the Corsygedol demesne in 1816 (11) but 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 (G. Bailley, J. Howell, pers. comms.) and authorities (D. Jarrett pers. comm.) confirm that agricultural lime has not been applied to the catchment in living memory.

Documentary evidence (12)

Descriptions of the vicinity of Llyn Dulyn from the 19th and 20th centuries suggest a landscape free from the improving effects of Man. Cliffe (1860) described the situation of the lake as "as wild and sequestered as it is possible to conceive" (p.54). Ward (1931) emphasised the 'wild surroundings' of the lake.

The tithe map and schedule of Llanddwywe (Llanddwywe-uwch-y-Graig and Llanddwywe-is-y-Graig) (13) provide very rough detail in the vicinity of Llyn Dulyn in the mid-19th century. The land is described as 'allotment' in the ownership of the Corsygedol Estate. The notation 'pasture' does not necessarily indicate improved grazing land (cf. Morgan 1959, Kain and Prince 1985).

The first and subsequent editions of the six inch ordnance survey map of the area (14) show the catchment to consist of 'rough or heathy pasture'.

The First Land utilisation Survey six inch manuscript map of 1937 (15) places the entire catchment in the 'moorland/rough grazing category. The Second Land Utilisation Survey six inch manuscript map of 1970 (16) indicates a vegetation cover and distribution very similar to the present situation. *Nardus* and *Festuca* dominate the drier areas, *Eriophorum vaginatum* the wetter areas, with *Vaccinium* characterising the steep rocky catchment walls (Fig. 6).

Non agricultural land use

Although it lies close to 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). Goats also ranged the hills in significant numbers (17) (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.

Particulars of the Dulyn area included in a sale brochure of the Corsygedol Estate in 1908 (18) describe the land surrounding the lake as 'sheepwalk - well supplied with water' considered 'one of the best sheepwalks in the district'. This suggests that the land was neither under nor over-grazed.

The only quantitative data relating to sheep numbers in the vicinity of Llyn Dulyn are those of the annual parish agricultural returns of Llanddwywe-is-y-Graig (19). These were analysed at quinquennial intervals and are presented in Fig. 34.

Although they represent the source of information most applicable to the Llyn Dulyn 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 risen in the parish between 1867-1983 (Fig. 34). The increasing significance of ewes and lambs at the expense of wether sheep over the last century, is also suggested from Fig. 34.

However, within the Llyn Dulyn catchment no significant change in sheep numbers has been recognised since ca. 1950 (G. Bailley, D. Jarrett 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). The Llyn Dulyn area represents the highest and most remote land in the parish, therefore it is unlikely that the catchment ever received much grazing pressure. Indeed, the current grazing of the catchment is minimal as exemplified by a recent visit in April 1986 which observed that the *Nardus* / *Agrostis* / *Festuca* grassland was totally ungrazed.

The Llyn Dulyn catchment lies in the Snowdonia National Park but this has no great effect on the management of the land.

Burning

Little is known of the history of burning in the catchment. The present grazier suggests that no burning has occurred in living memory (G. Bailley pers. comm.). Aerial photographs taken in 1946 indicate patterns that may represent evidence of burning. A later survey in 1962 shows no such evidence (20).

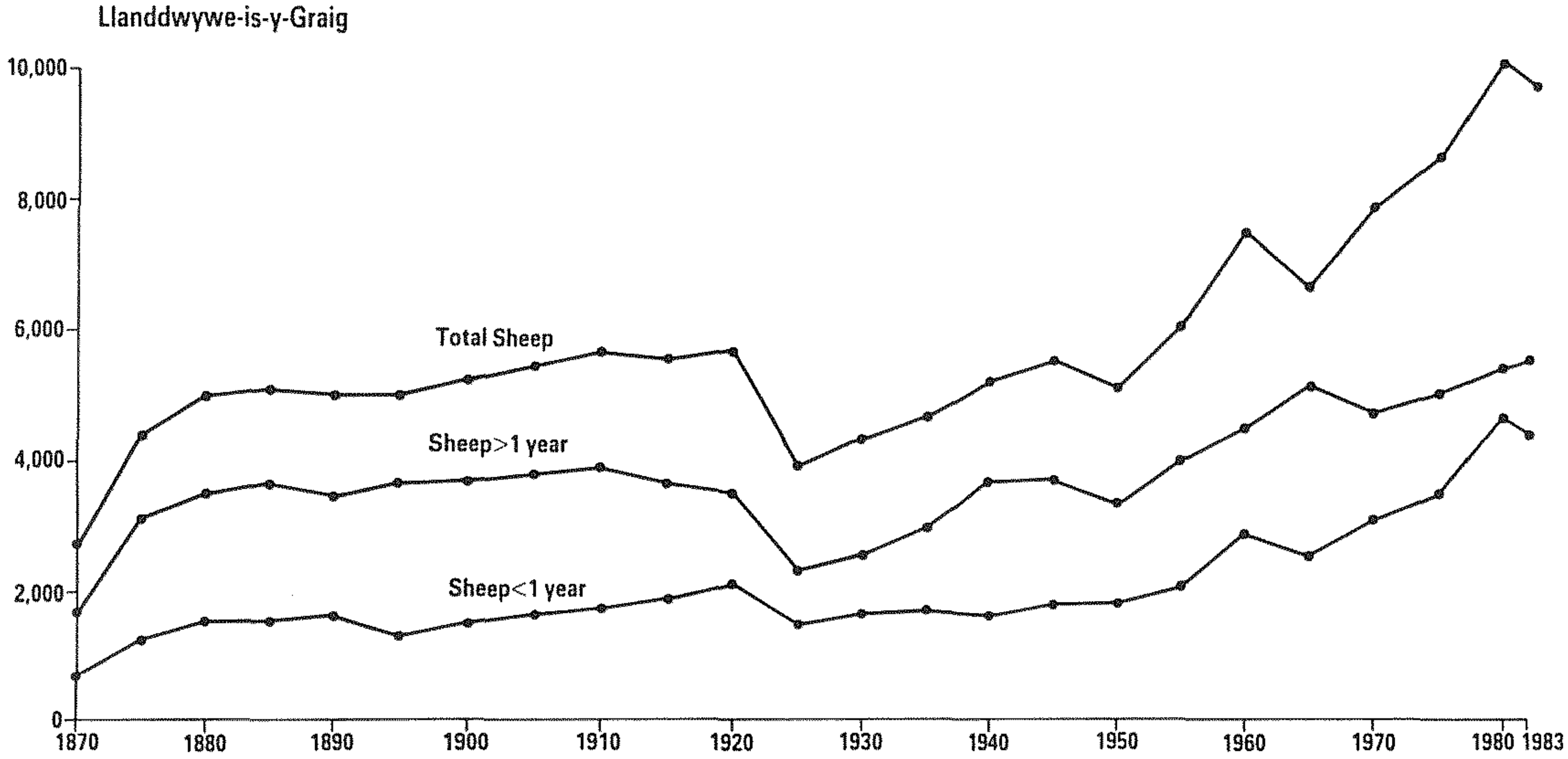

Fig. 34. Sheep numbers in Llanddwywe-is-y-Graig (1895-1983).

Subsidiary management practices

There is no evidence that this area was ever managed for game nor that game was actively pursued in the locality of the catchment.

5.0 Conclusions

i) Sediment accumulation rates at the core site were stable and low (0.0055 g cm^{-2} yr^{-1}) from the base of the core until 1950's and 1960's when the sediment accumulation rate accelerated to 0.010 g cm^{-2} yr^{-1}.

ii) The diatom based pH reconstructions suggest that the pH of Llyn Dulyn was 5.9 - 6.2 throughout most of the history recorded in the core. Planktonic diatoms were absent from the lake and the data suggest a fairly stable flora of attached circumneutral and acidophilous taxa. Acidification of Llyn Dulyn, marked by the expansion of Eunotia exigua , Achnanthes marginulata, Navicula heimansii and Navicula madumensis. 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 11.5 cm (1884). The low trace metal fluxes are thought to be the result of low dry mass accumulation rates and hence reduces sedimentation efficiencies.

iv) The contamination of the sediments by carbonaceous particles commences at 14 cm, earlier than the beginnings of trace metal contamination, but concurrent with lake acidification. The concentration of these particles increase rapidly from 7cm (1940's). 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 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. The pollen diagram also reveals a major hiatus in the core at 95 cm below which sediments dating to approximately the elm decline 'ca. 5000 B.P.' occur. A period of catchment erosion is identified by an Isoetes decline from 60 cm to 20 cm and matches a period of increased cation concentrations in the lake sediments.

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.

viii) This is the first evidence for lake acidificationin North-west Wales. The presence of many similar lakes in this area suggests that surface water acidification is widespread in this part of the U.K.

6.0 References

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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. UCNW Mostyn Collection:
   8610. 'Map and survey of Sir Thomas Mostyn's allotments of common in the parishes of Llanddwywe and Llandeddwyn', 1815.
   8622. 'Plan of lot 1 of Corsygedol Estate for sale', no date.
   8652. 'Map of allotments in the parishes of Llanddwywe and Trawsfynydd', no date.
   8673. 'Map of allotments in the parishes of Llanddwywe and Llaneddwyn', no date.

4. Dolgellau record office, Z/CD/27. 'Map and survey of allotments of common in the parishes of Llanddwywe and Llaneddwyn', 1891.

5. 50 Geo. 3, C.56.

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

7. UCNW Mostyn Collection 8603A. 'Map of Corsygedol Estate', 1806.

8. See note 1.

9. UCNW Mostyn Collection, 6774. 'Corsygedol account book', 1792-1816.

10. See note 9.

11. See note 9.

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

13. Tithe map and schedule for the parish of Llanddwywe, 1841. PRO (Kew) IR30 52/9.

14. 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.

15. Held at the London School of Economics archive.

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

17. A herd of feral goats roams the moorland of the Rhinog National Nature Reserve which lies some 2 km to the north of the Dulyn catchment.

18. Caernarvon Record Office, XSC 35. 'Particulars and plans and views for the sale of the Cors y Gedol (sic.) Estate', 1908.

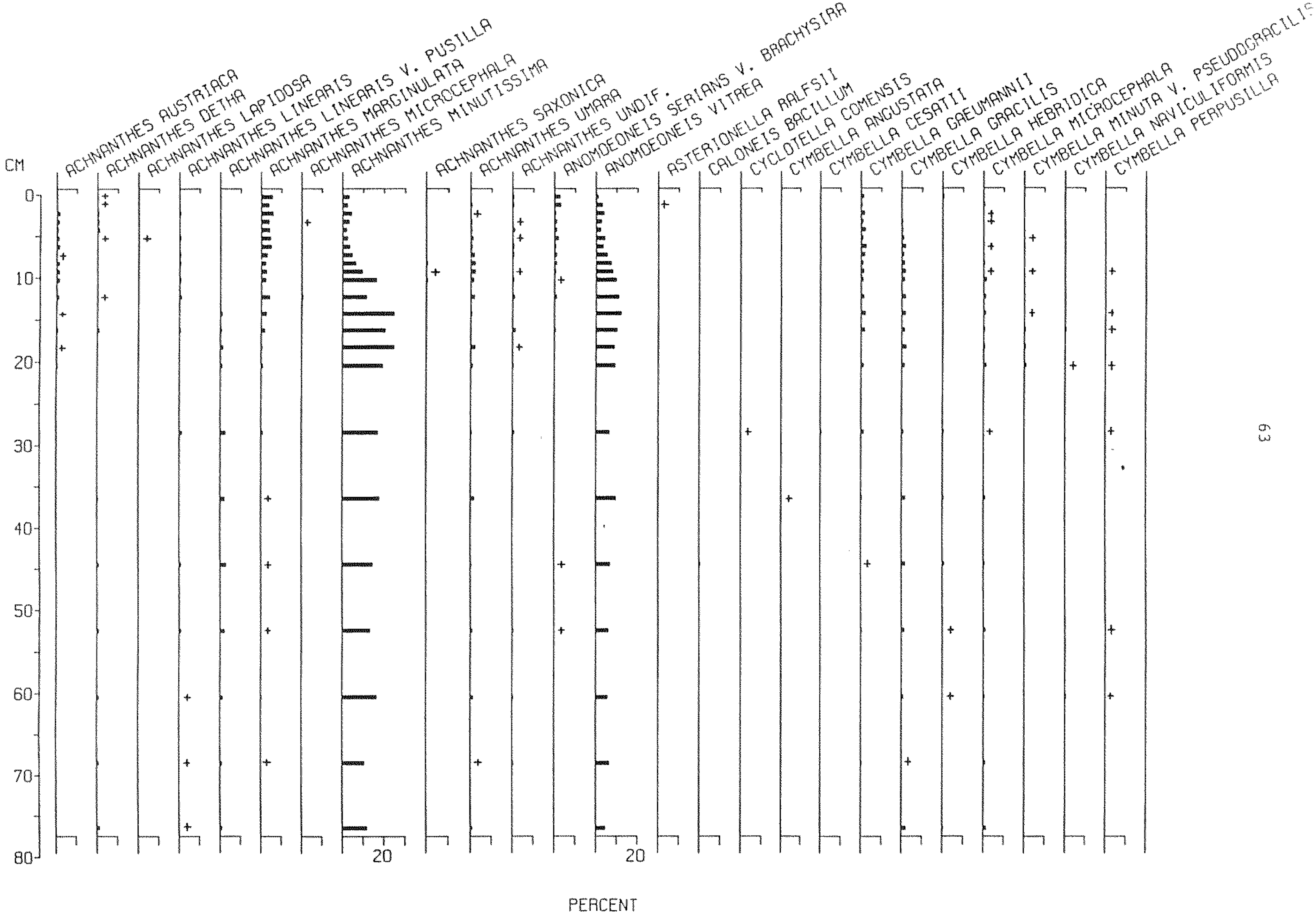
19. PRO (Kew) Class MAF 68.

20. Air Photograph Office, Welsh Office, Cardiff. 1:10,000.
369: 1223, 1224. May 4th 1946.
2074: 0087, 0088. June 6th 1962.

Appendix A

LLYN DULYN 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.
AC028A	ACHNANTHES SAXONICA	KRASSKE
AC034A	ACHNANTHES UMARA	CARTER
AC042A	ACHNANTHES DETHA	
AC9997	ACHNANTHES CF LAPIDOSA	
AC9999	ACHNANTHES SP	
AN003B	ANOMOEONEIS SERIANS V BRACHYSIRA	(BREB.) CLEVE
AN004A	ANOMOEONEIS VITREA	(GRUN.) ROSS
AS003A	ASTERIONELLA RALFSII	W. SMITH
CA002A	CALONEIS BACILLUM	(GRUN.) MERESCHKOWSKY
CM001A	CYMBELLA VENTRICOSA	KUTZ.
CM004A	CYMBELLA MICROCEPHALA	GRUN.
CM009A	CYMBELLA NAVICULIFORMIS	AUERSWALD
CM010A	CYMBELLA PERPUSILLA	A. CLEVE
CM015A	CYMBELLA CESATII	(RABH.) GRUN.
CM017A	CYMBELLA HEBRIDICA	(GREGORY) GRUN.
CM018A	CYMBELLA GRACILIS	(RABH.) CLEVE
CM020A	CYMBELLA GAEUMANNI	MEISTER
CM031A	CYMBELLA MINUTA	HILSE EX RABH.
CM031B	CYMBELLA MINUTA V PSEUDOGRACILIS	(CHOLNOKY) REIMER
CM035A	CYMBELLA ANGUSTATA	(W. SMITH) CLEVE
CM9993	CYMBELLA CF SCHUBARTII	PIRLA
CM9999	CYMBELLA SP.	
CY010A	CYCLOTELLA COMENSIS	GRUN.
DT002A	DIATOMA HIEMALE	(LYNGBYE) HEIBERG
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.
EU005A	EUNOTIA ALPINA	(NAEGELI) HUST.
EU006A	EUNOTIA LUNARIS	(EHR.) GRUN.
EU006B	EUNOTIA LUNARIS V SUBARCUATA	(NAEGELI) GRUN.
EU007A	EUNOTIA BIDENTULA	W.SMITH
EU008C	EUNOTIA MONODON V MAJOR	(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.
EU015A	EUNOTIA DENTICULATA	(BREB.) RABH.
EU019A	EUNOTIA FORMICA	EHR.
EU020A	EUNOTIA MEISTERI	HUST.
EU025A	EUNOTIA FALLAX	CLEVE
EU027A	EUNOTIA TRINACRIA	KRASSKE
EU029A	EUNOTIA VALIDA	HUST.
EU042A	EUNOTIA LAPPONICA	A.CLEVE
EU9983	EUNOTIA SP 1	L.HIR (SF)
EU9991	EUNOTIA SP 3	L.HIR (SF)
EU9999	EUNOTIA SP	
FR001A	FRAGILARIA PINNATA	EHR.
FR002A	FRAGILARIA CONSTRUENS	(EHR.) GRUN.
FR002C	FRAGIALRIA CONSTRUENS V VENTER	(EHR.) GRUN.
FR005A	FRAGILARIA VIRESCENS	RALFS
FR006A	FRAGILARIA BREVISTRIATA	GRUN.
FR007A	FRAGILARIA VAUCHERIAE	(KUTZ.) BOYE PETERSON
FR9995	FRAGILARIA CF PINNATA 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.
GO9999	GOMPHONEMA SP	
ME004C	MELOSIRA LIRATA V LACUSTRIS	GRUN.
ME005A	MELOSIRA DISTANS	(EHR.) KUTZ.
ME005D	MELOSIRA DISTANS V TENELLA	(NYGAARD) FLORIN
ME005E	MELOSIRA DISTANS V NIVALIS	(W.SM.) KIRCHNER
ME010A	MELOSIRA PERGLABRA	OSTRUP
ME010B	MELOSIRA PERGLABRA V FLORINIAE	CAMBURN
ME014A	MELOSIRA NYGAARDII	CAMBURN
ME9999	MELOSIRA SP	
NA002A	NAVICULA JAERNEFELTII	HUST.
NA003A	NAVICULA RADIOSA	KUTZ.
NA003B	NAVICULA RADIOSA V TENELLA	(BREB.) GRUN.
NA005A	NAVICULA SEMINULUM	GRUN.
NA006A	NAVICULA MEDIOCRIS	KRASSKE
NA013A	NAVICULA PSEUDOSCUTIFORMIS	HUST.
NA014A	NAVICULA PUPULA	KUTZ.
NA015A	NAVICULA HASSIACA	KRASSKE
NA016A	NAVICULA INDIFFERENS	HUST.
NA017A	NAVICULA VENTRALIS	KRASSKE
NA032A	NAVICULA COCCONEIFORMIS	GREGORY
NA033A	NAVICULA SUBTILISSIMA	CLEVE
NA036A	NAVICULA PERPUSILLA	GRUN.
NA037A	NAVICULA ANGUSTA	GRUN.
NA038A	NAVICULA ARVENSIS	HUST.
NA039A	NAVICULA FESTIVA	KRASSKE
NA041A	NAVICULA HEIMANSII	VAN DAM & KOOY.
NA042A	NAVICULA MINIMA	GRUN.
NA043A	NAVICULA SUBATOMOIDES	HUST.
NA044A	NAVICULA KRASSKEI	HUST.
NA045A	NAVICULA BRYOPHILA	PETERSEN
NA046A	NAVICULA CONTENTA	GRUN.
NA075A	NAVICULA SUBHAMULATA	GRUN.
NA082A	NAVICULA MURALIS	GRUN.
NA084A	NAVICULA ATOMUS	(KUTZ.) GRUN.
NA099A	NAVICULA BREMENSIS	HUST.
NA129A	NAVICULA SEMINULOIDES	HUST.
NA135A	NAVICULA TENUICEPHALA	HUST.
NA140A	NAVICULA MADUMENSIS	JORGENSEN
NA141A	NAVICULA DISJUNCTA	HUST.
NA144A	NAVICULA UTERMOHLII	HUST.
NA9943	NAVICULA SP 29	PIRLA
NA9944	NAVICULA SP 13	EIDDAW BACH (SF)
NA9952	NAVICULA DENTATA/SUBARVENSIS	L.HIR (SF)
NA9955	NAVICULA CF VITIOSA	L.HIR (SF)
NA9957	NAVICULA CF SCHASSMANNII	L.HIR (SF)
NA9958	NAVICULA SP 24	PIRLA
NA9960	NAVICULA SP 8	L.HIR (SF)
NA9961	NAVICULA SP 4	L.HIR (SF)
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
NA9967	NAVICULA IMPEXA/INVICTA	L.HIR (SF)
NA9999	NAVICULA SP	
NE003A	NEIDIUM AFFINE	(EHR.) CLEVE
NE003B	NEIDIUM AFFINE V LONGICEPS	(GREGORY) CLEVE
NE004A	NEIDIUM BISULCATUM	(LAGERSTEDT) CLEVE
NE9999	NEIDIUM SP	
NI005A	NITZSCHIA PERMINUTA	GRUN.
NI009A	NITZSCHIA PALEA	(KUTZ.) W. SMITH
NI025A	NITZSCHIA RECTA	HANTZSCH
NI9989	NITZSCHIA CF FONTICOLA	L.HIR (SF)
NI9999	NITZSCHIA SP	
PE002A	PERONIA FIBULA	(BREB. ex KUTZ.) +
PI002A	PINNULARIA ACUMINATA	SMITH SYN. PIO.
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.
PI022A	PINNULARIA SUBCAPITATA	GREGORY
PI033A	PINNULARIA BRAUNII	(GRUN.) CLEVE
PI033B	PINNULARIA BRAUNII V AMPHICEPHALA	(A. MAYER) HUST.
PI049A	PINNULARIA SUBSTOMATOPHORA	HUST.
PI9983	PINNULARIA SP 11	PIRLA
PI9992	PINNULARIA CF TERMITINA	L.HIR (SF)
PI9999	PINNULARIA SP	
RH003A	RHOPALODIA GIBBERULA	(EHR.) O. MULLER
SA001B	STAURONEIS ANCEPS F GRACILIS	(EHR.) CLEVE
SA004A	STAURONEIS ALPINA	HUST.
SA006A	STAURONEIS PHOENICENTERON	(NITZSCH) EHR.
SA9998	STAURONEIS ANCEPS V 1	L.HIR (SF)
SP001A	STENOPTEROBIA INTERMEDIA	LEWIS
SU9999	SURIRELLA SP	
SY011B	SYNEDRA DELICATISSIMA V ANGUSTISSIMA	GRUN.
SY9999	SYNEDRA SP	
TA001A	TABELLARIA FLOCCULOSA	(ROTH) KUTZ.
TA002A	TABELLARIA FENESTRATA	(LYNGBYE) KUTZ.
TA004A	TABELLARIA QUADRISEPTATA	KNUDSON
TA9999	TABELLARIA SP	
TE001A	TETRACYCLUS LACUSTRIS	RALFS
UN9996	PERIPHYTON	
UN9998	UNKNOWN NAVICULACEAE	


CM
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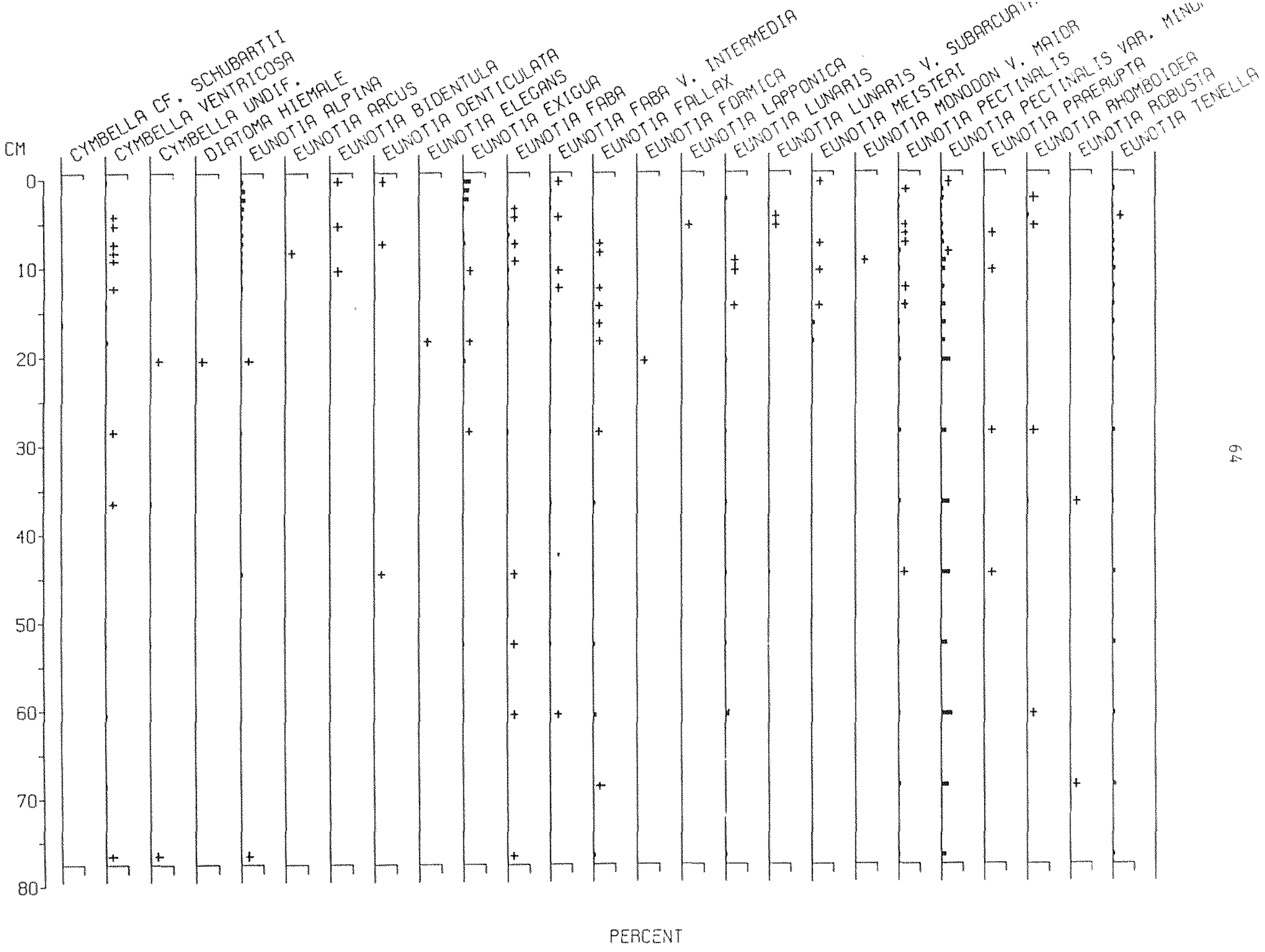
ACHNANTHES LAPIDOSA
ACHNANTHES LINEARIS
ACHNANTHES LINEARIS V. PUSILLA
ACHNANTHES MARGINULATA
ACHNANTHES MICROCEPHALA
ACHNANTHES MINUTISSIMA
ACHNANTHES SAXONICA
ACHNANTHES UMARA
ACHNANTHES UNDIF.
ANOMOEONEIS SERIANS V. BRACHYSIRA
ANOMOEONEIS VITREA
ASTERIONELLA RALFSII
CALONEIS BACILLUM
CYCLOTELLA COMENSIS
CYMBELLA ANGUSTATA
CYMBELLA CESATII
CYMBELLA GAEUMANNII
CYMBELLA GRACILIS
CYMBELLA HEBRIDICA
CYMBELLA MICROCEPHALA
CYMBELLA MINUTA V. PSEUDOGRACILIS
CYMBELLA NAVICULIFORMIS
CYMBELLA PERPUSILLA
0
10
20
30
40
50
60
70
80
20
20
PERCENT


CYMBELLA CF. SCHUBARTII
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CYMBELLA UNDIF.
DIATOMA HIEMALE
EUNOTIA ALPINA
EUNOTIA ARCUS
EUNOTIA BIDENTULA
EUNOTIA DENTICULATA
EUNOTIA ELEGANS
EUNOTIA EXIGUA
EUNOTIA FABA
EUNOTIA FABA V. INTERMEDIA
EUNOTIA FALLAX
EUNOTIA FORMICA
EUNOTIA LAPPONICA
EUNOTIA LUNARIS
EUNOTIA LUNARIS V. SUBARCUAT
EUNOTIA MEISTERI
EUNOTIA MONODON V. MAIOR
EUNOTIA PECTINALIS
EUNOTIA PECTINALIS VAR. MINU
EUNOTIA PRAERUPTA
EUNOTIA RHOMBOIDEA
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EUNOTIA TENELLA
CM
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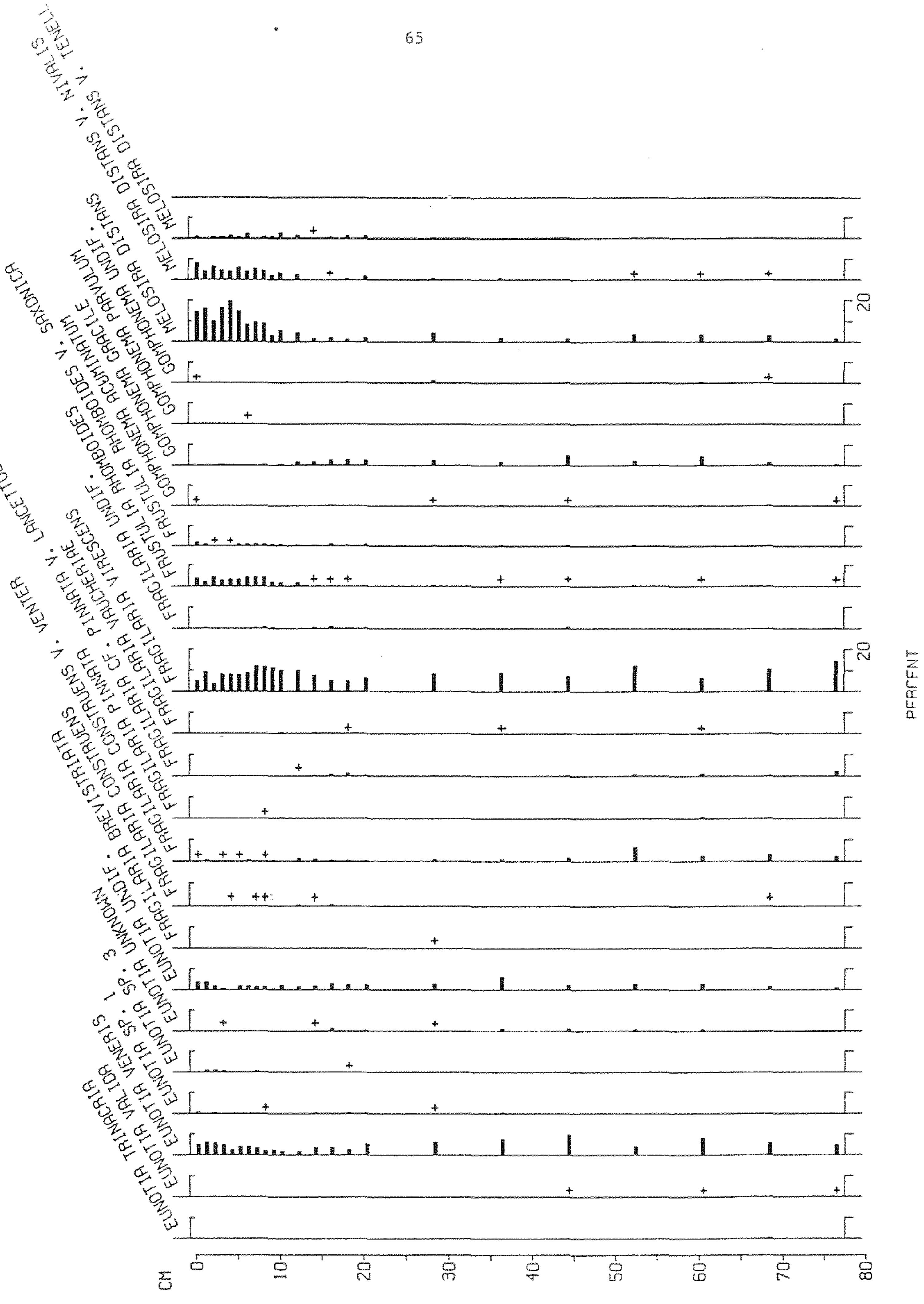
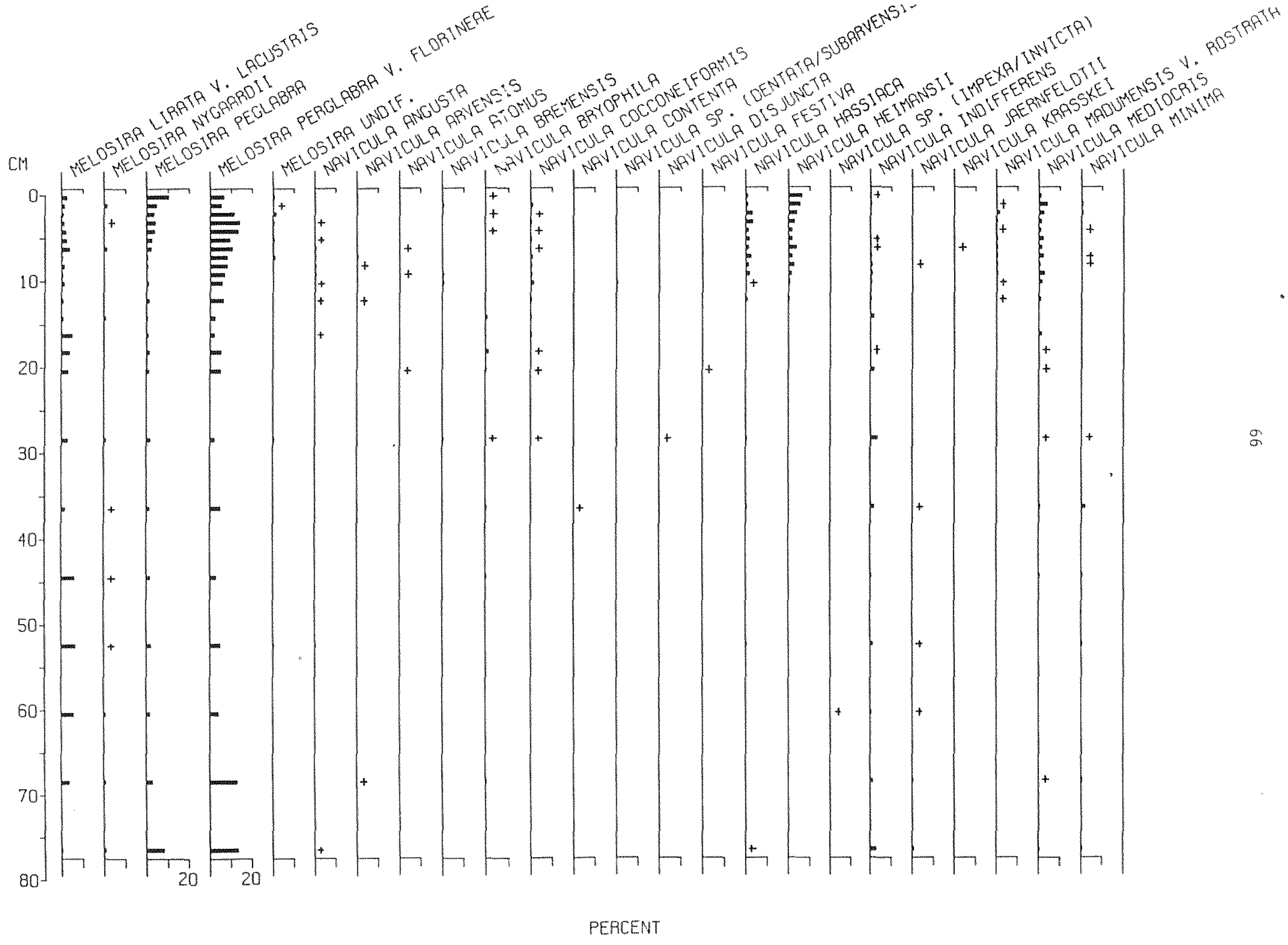
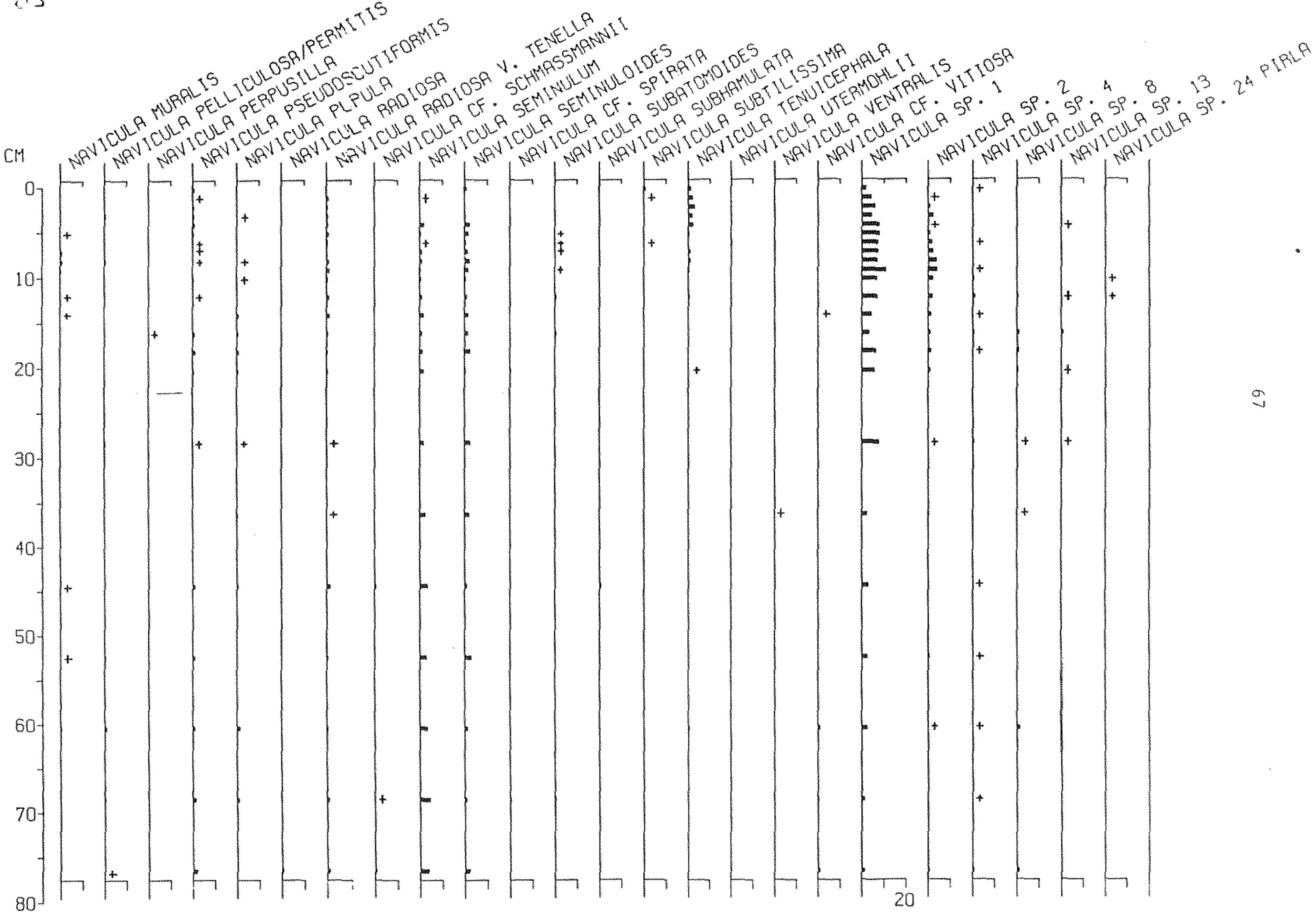
PERCENT


EUNOTIA TRINACRIA
EUNOTIA VALIDA
EUNOTIA VENERIS
EUNOTIA SP. 1
EUNOTIA SP. 3
EUNOTIA UNKNOWN
EUNOTIA UNDIF.
FRAGILARIA BREVISTRIATA
FRAGILARIA CONSTRUENS
FRAGILARIA CONSTRUENS V. VENTER
FRAGILARIA PINNATA
FRAGILARIA PINNATA V. LANCETTULA
FRAGILARIA CF. VAUCHERIAE
FRAGILARIA VIRESCENS
FRAGILARIA UNDIF.
FRUSTULIA RHOMBOIDES
FRUSTULIA RHOMBOIDES V. SAXONICA
FRUSTULIA UNDIF.
GOMPHONEMA ACUMINATUM
GOMPHONEMA GRACILE
GOMPHONEMA PARVULUM
GOMPHONEMA UNDIF.
MELOSIRA DISTANS
MELOSIRA DISTANS V. NIVALIS
MELOSIRA DISTANS V. TENELL
20
20
PERCENT
CM
0
10
20
30
40
50
60
70
80


CM
0
10
20
30
40
50
60
70
80
MELOSIRA LIRATA V. LACUSTRIS
MELOSIRA NYGAARDII
MELOSIRA PEGLABRA
MELOSIRA PERGLABRA V. FLORINEAE
MELOSIRA UNDIF.
NAVICULA ANGUSTA
NAVICULA ARVENSIS
NAVICULA ATOMUS
NAVICULA BREMENSIS
NAVICULA BRYOPHILA
NAVICULA COCCONEIFORMIS
NAVICULA CONTENTA
NAVICULA SP. (DENTATA/SUBARVENSIS
NAVICULA DISJUNCTA
NAVICULA FESTIVA
NAVICULA HASSIACA
NAVICULA HEIMANSII
NAVICULA SP. (IMPEXA/INVICTA)
NAVICULA INDIFFERENS
NAVICULA JAERNFELDTII
NAVICULA KRASSKEI
NAVICULA MADUMENSIS V. ROSTRATA
NAVICULA MEDIOCRIS
NAVICULA MINIMA
20
20
PERCENT

215


CM
0
10
20
30
40
50
60
70
80
NAVICULA MURALIS
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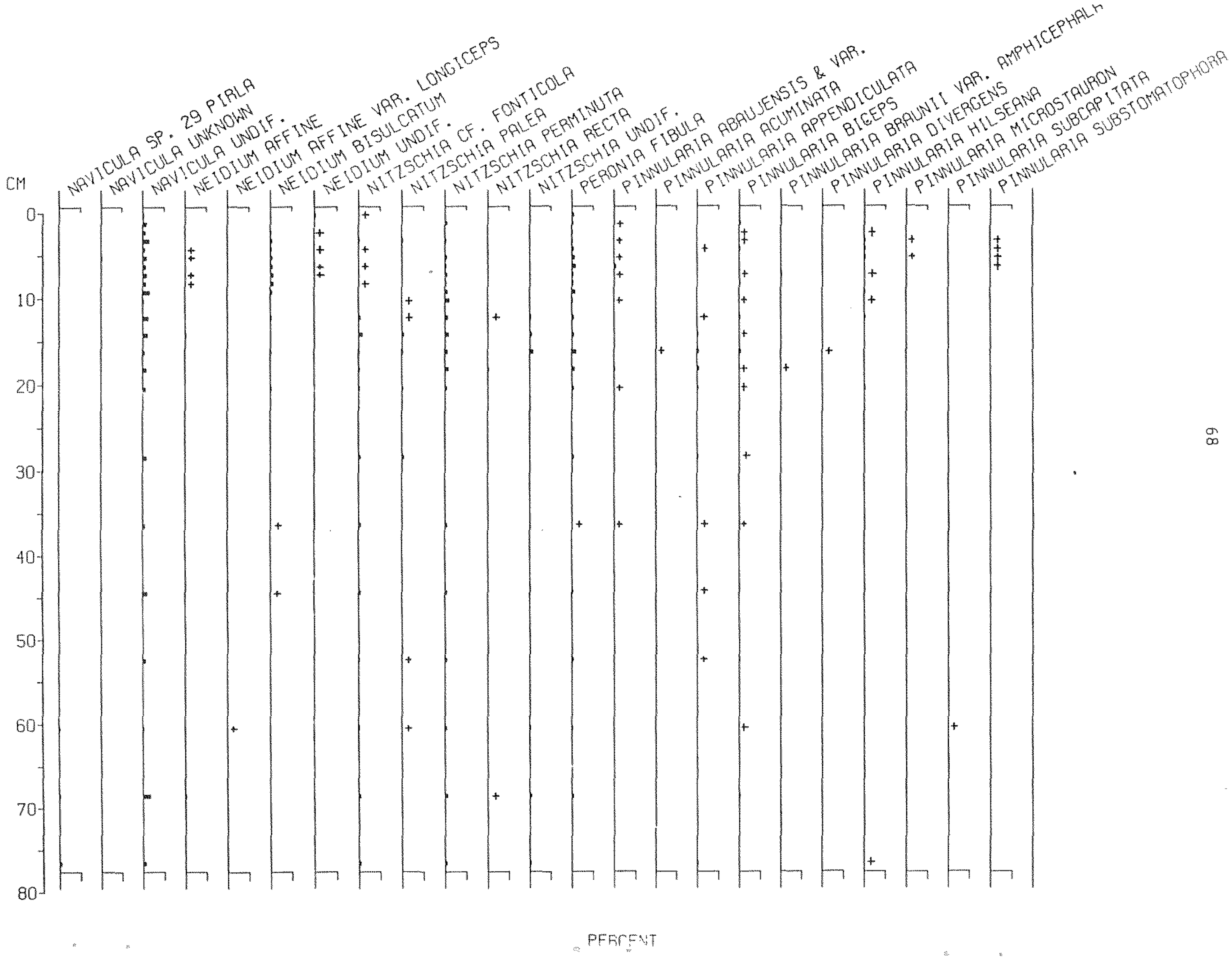
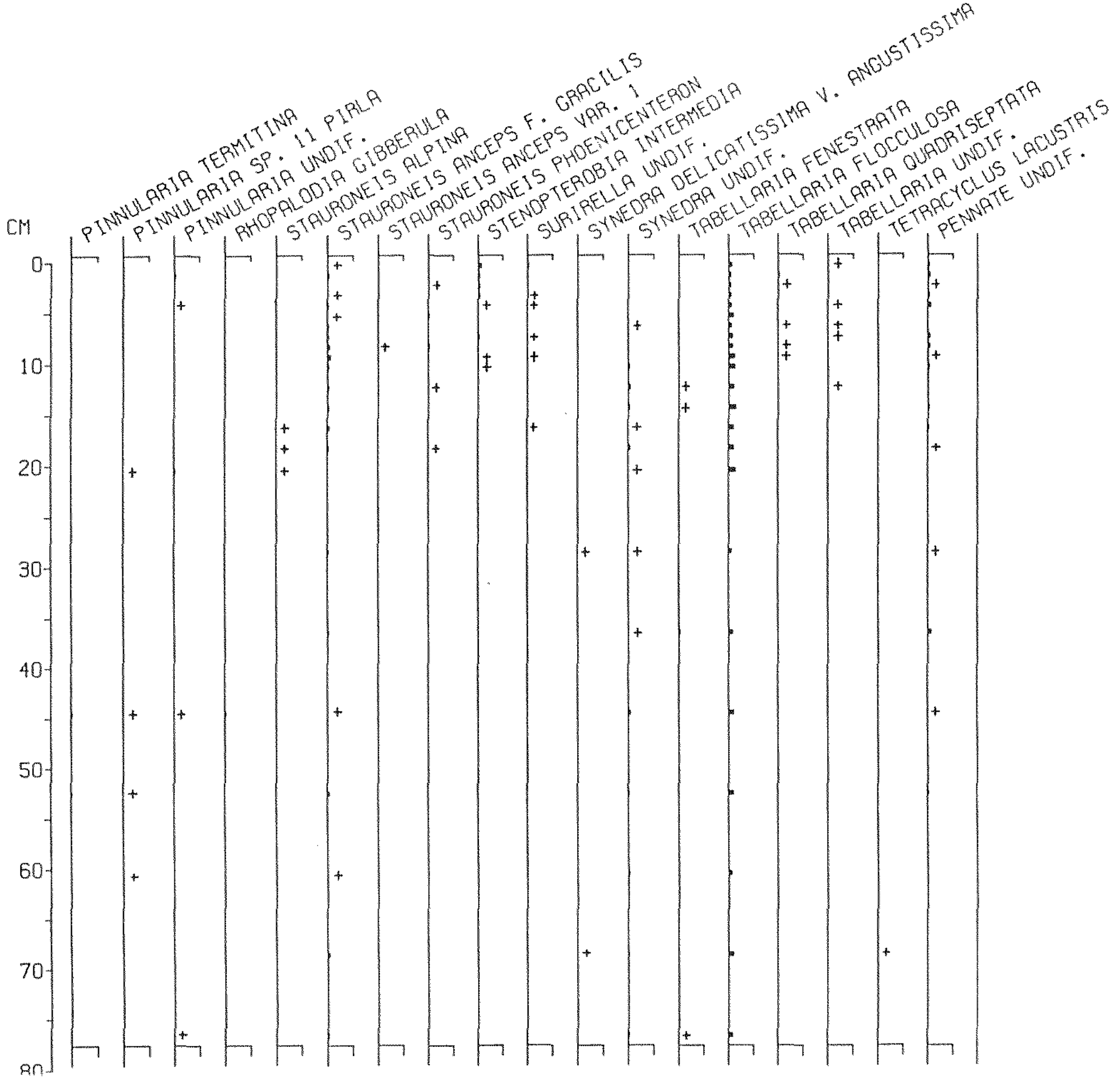
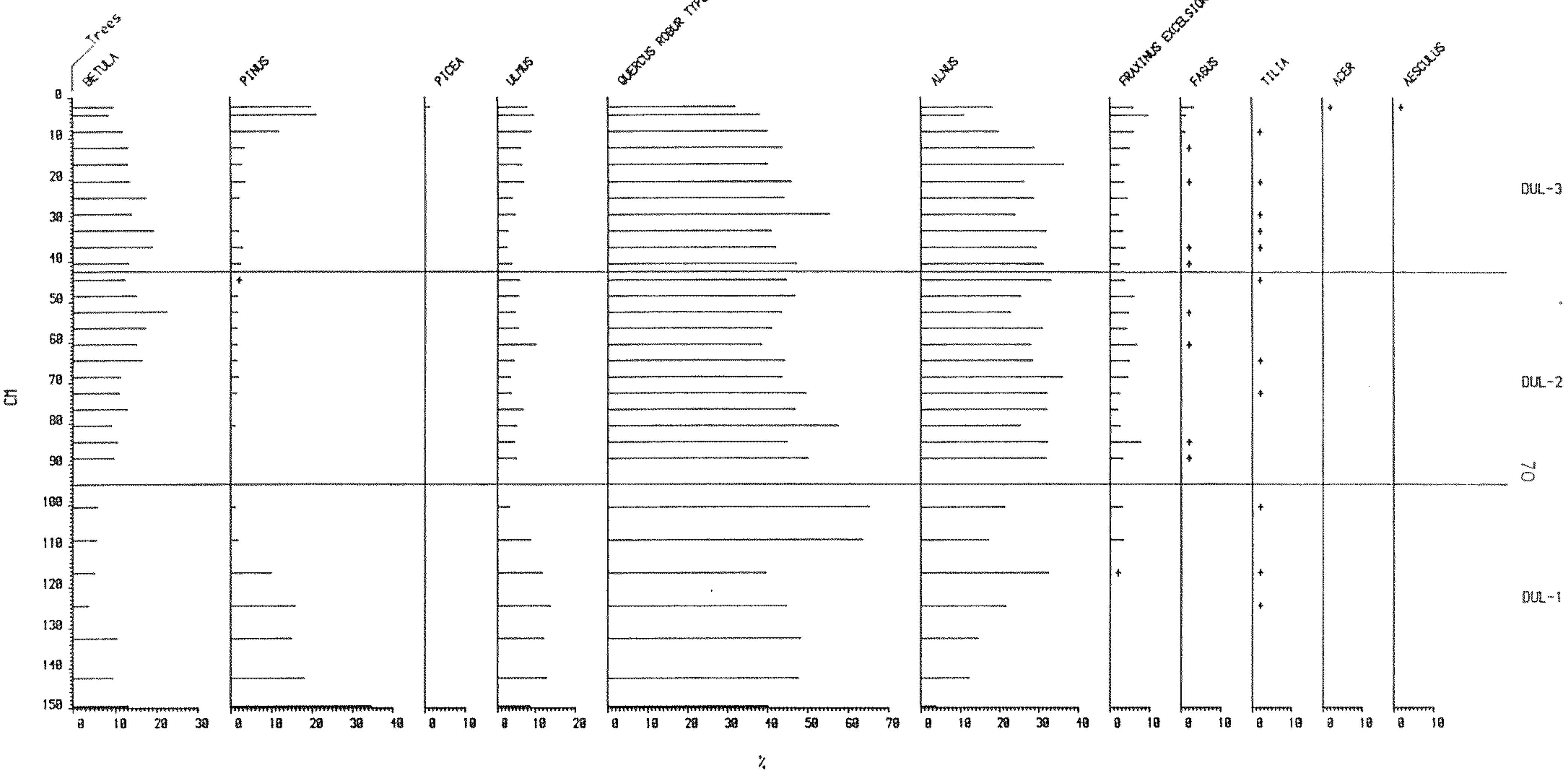
NAVICULA PERPUSILLA
NAVICULA PSEUDOSCUTIFORMIS
NAVICULA PLPULA
NAVICULA RADIOSA
NAVICULA RADIOSA V. TENELLA
NAVICULA CF. SCHMASSMANNII
NAVICULA SEMINULUM
NAVICULA SEMINULOIDES
NAVICULA CF. SPIRATA
NAVICULA SUBATOMOIDES
NAVICULA SUBHAMULATA
NAVICULA SUBTILISSIMA
NAVICULA TENUICEPHALA
NAVICULA UTERMOHLII
NAVICULA VENTRALIS
NAVICULA CF. VITIOSA
NAVICULA SP. 1
NAVICULA SP. 2
NAVICULA SP. 4
NAVICULA SP. 8
NAVICULA SP. 13
NAVICULA SP. 24 PIRLA
20


NAVICULA SP. 29 PIRLA
NAVICULA UNKNOWN
NAVICULA UNDIF.
NEIDIUM AFFINE
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 ACUMINATA
PINNULARIA APPENDICULATA
PINNULARIA BICEPS
PINNULARIA BRAUNII VAR. AMPHICEPHALA
PINNULARIA DIVERGENS
PINNULARIA HILSEANA
PINNULARIA MICROSTAURON
PINNULARIA SUBCAPITATA
PINNULARIA SUBSTOMATOPHORA
CM
0
10
20
30
40
50
60
70
80
PERCENT


PINNULARIA TERMITINA
PINNULARIA SP. 11 PIRLA
PINNULARIA UNDIF.
RHOPALODIA GIBBERULA
STAURONEIS ALPINA
STAURONEIS ANCEPS F. GRACILIS
STAURONEIS ANCEPS VAR. 1
STAURONEIS PHOENICENTERON
STENOPTEROBIA INTERMEDIA
SURIRELLA UNDIF.
SYNEDRA DELICATISSIMA V. ANGUSTISSIMA
SYNEDRA UNDIF.
TABELLARIA FENESTRATA
TABELLARIA FLOCCULOSA
TABELLARIA QUADRISEPTATA
TABELLARIA UNDIF.
TETRACYCLUS LACUSTRIS
PENNATE UNDIF.
CM
0
10
20
30
40
50
60
70
80

Appendix B



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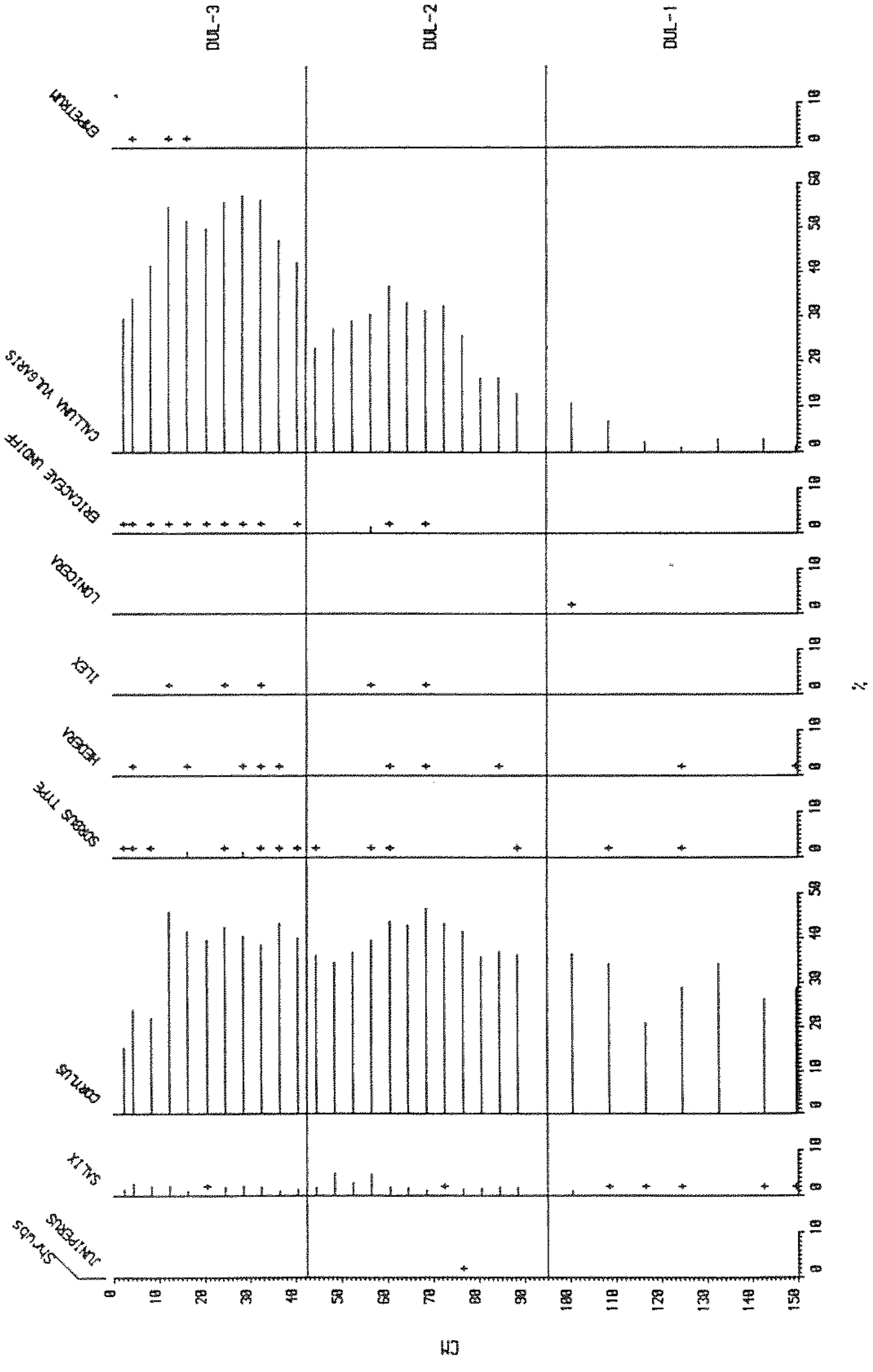
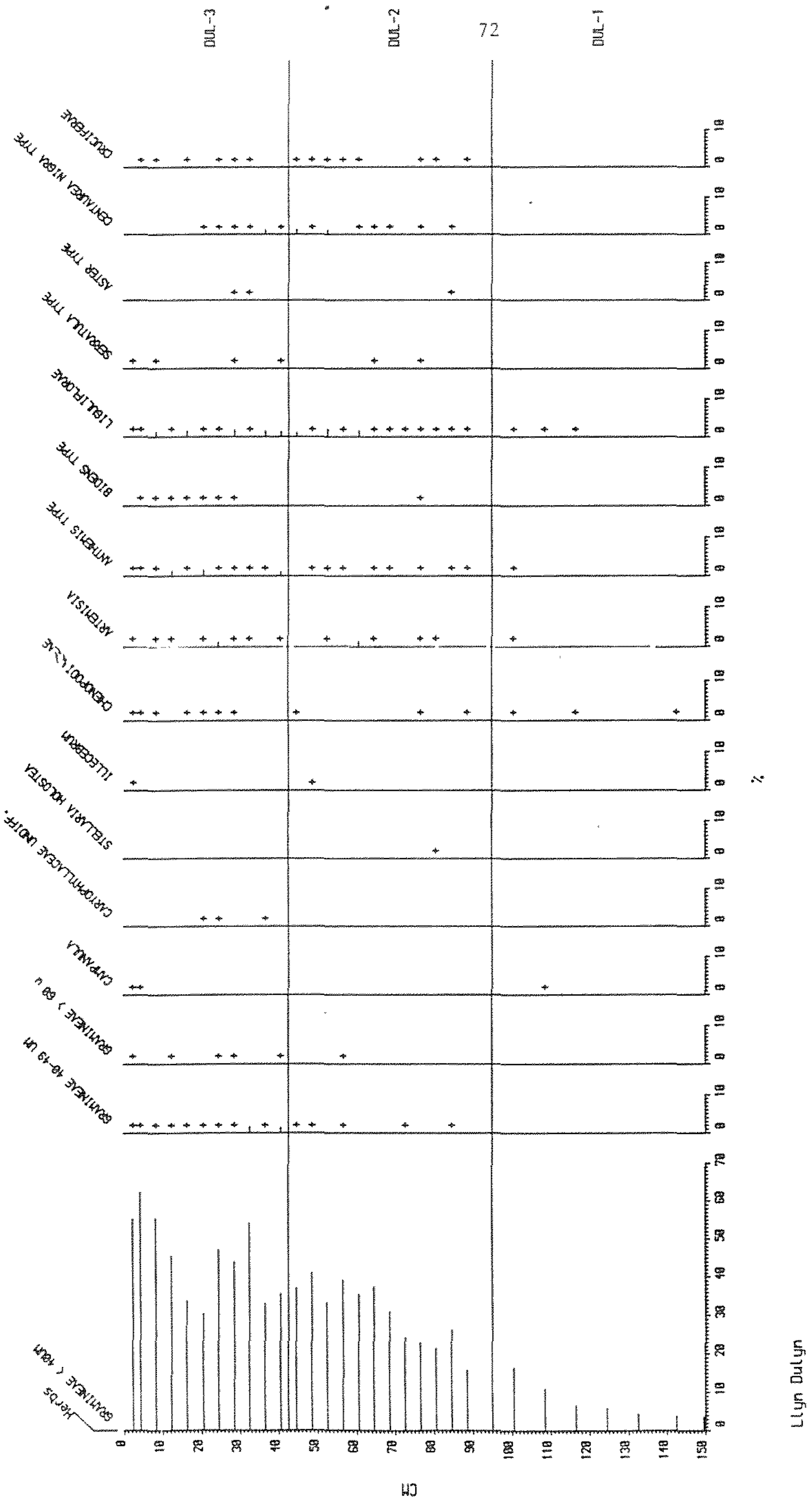
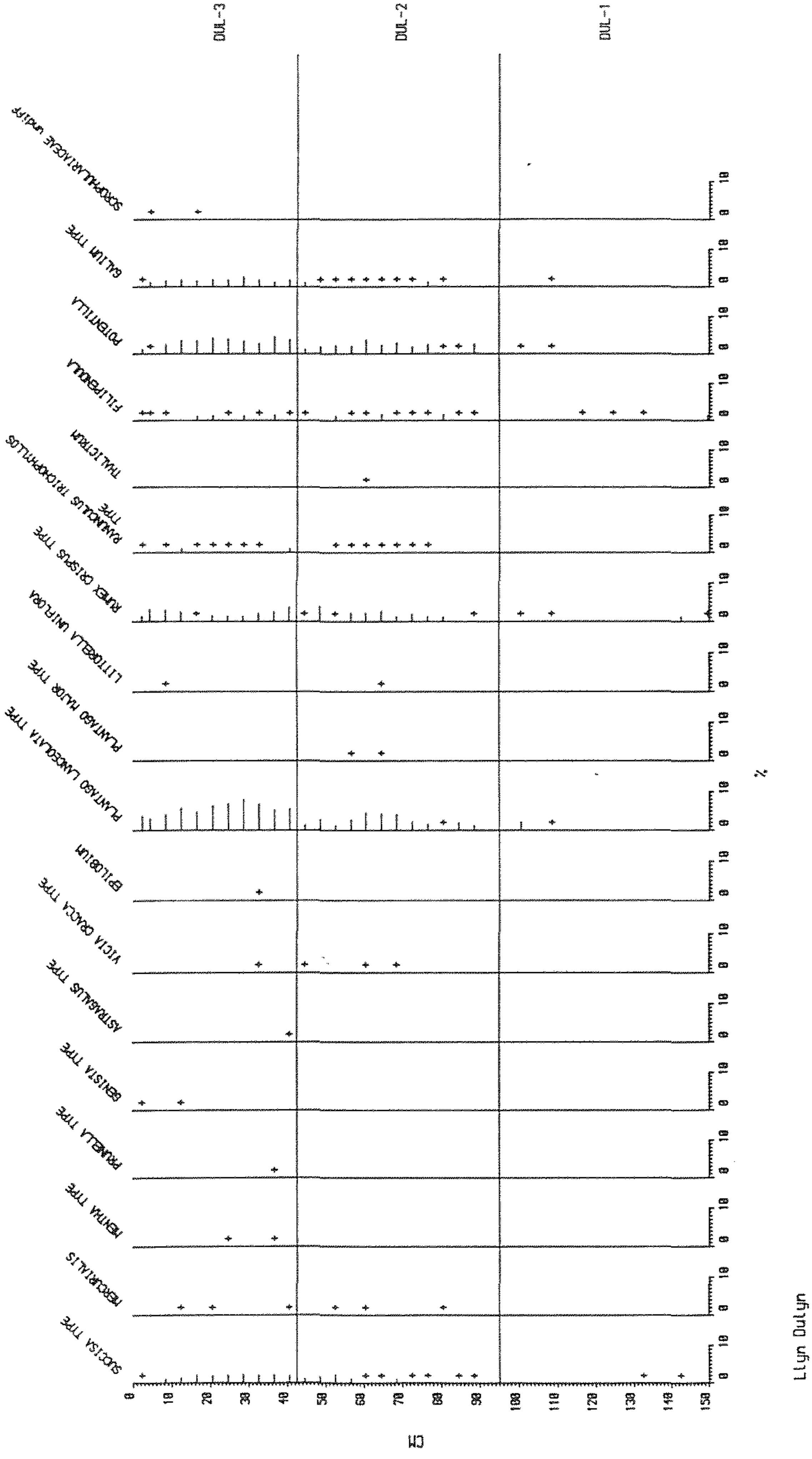
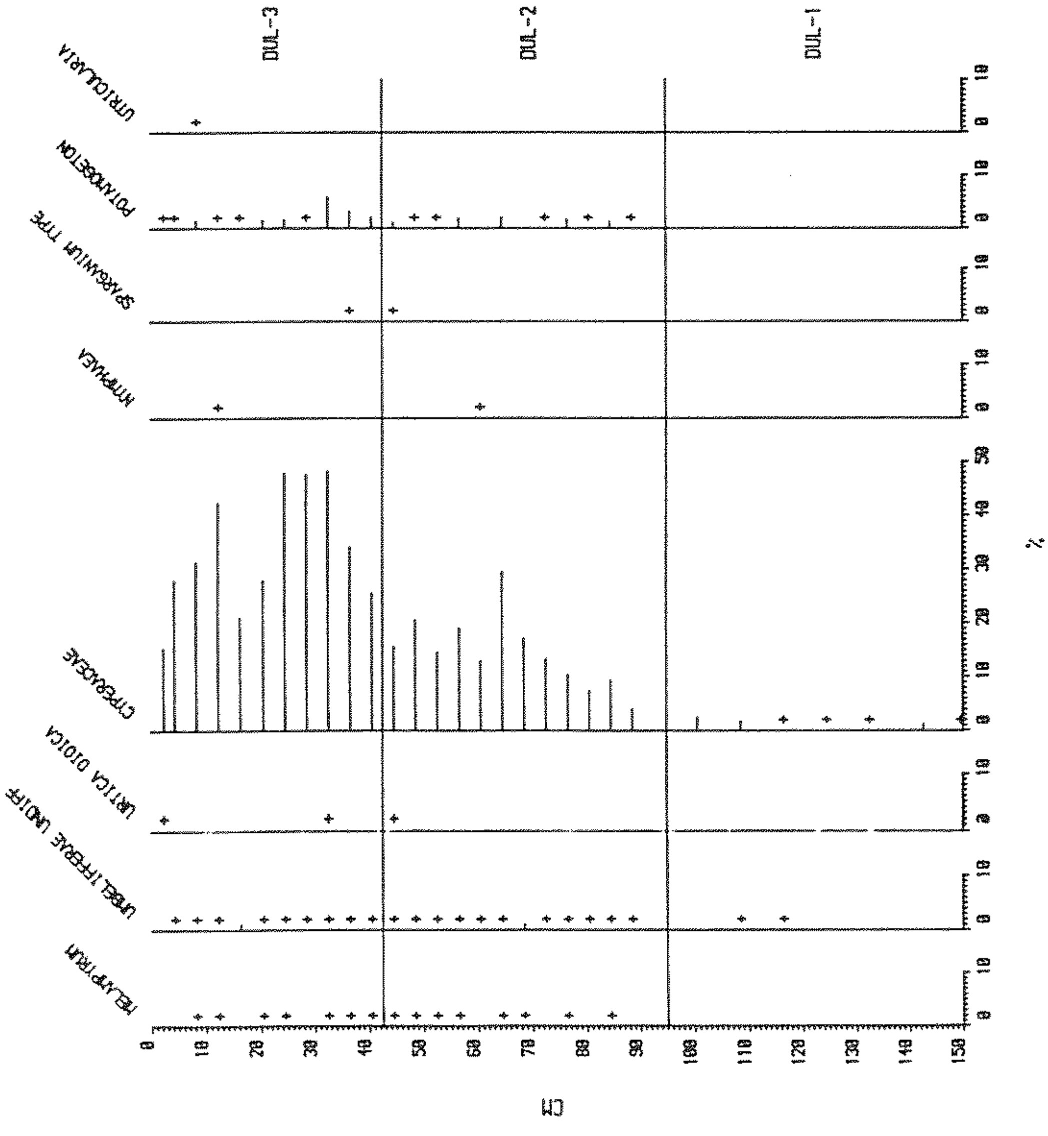

Shrubs
JUNIPERUS
SALIX
CORYLUS
SORBUS TYPE
HEDERA
ILEX
LONICERA
ERICACEAE UNDIFF
CALLUNA VULGARIS
EMPETRUM
DUL-3
DUL-2
DUL-1
0
10
20
30
40
50
60
70
80
90
100
110
120
130
140
150
cm
%

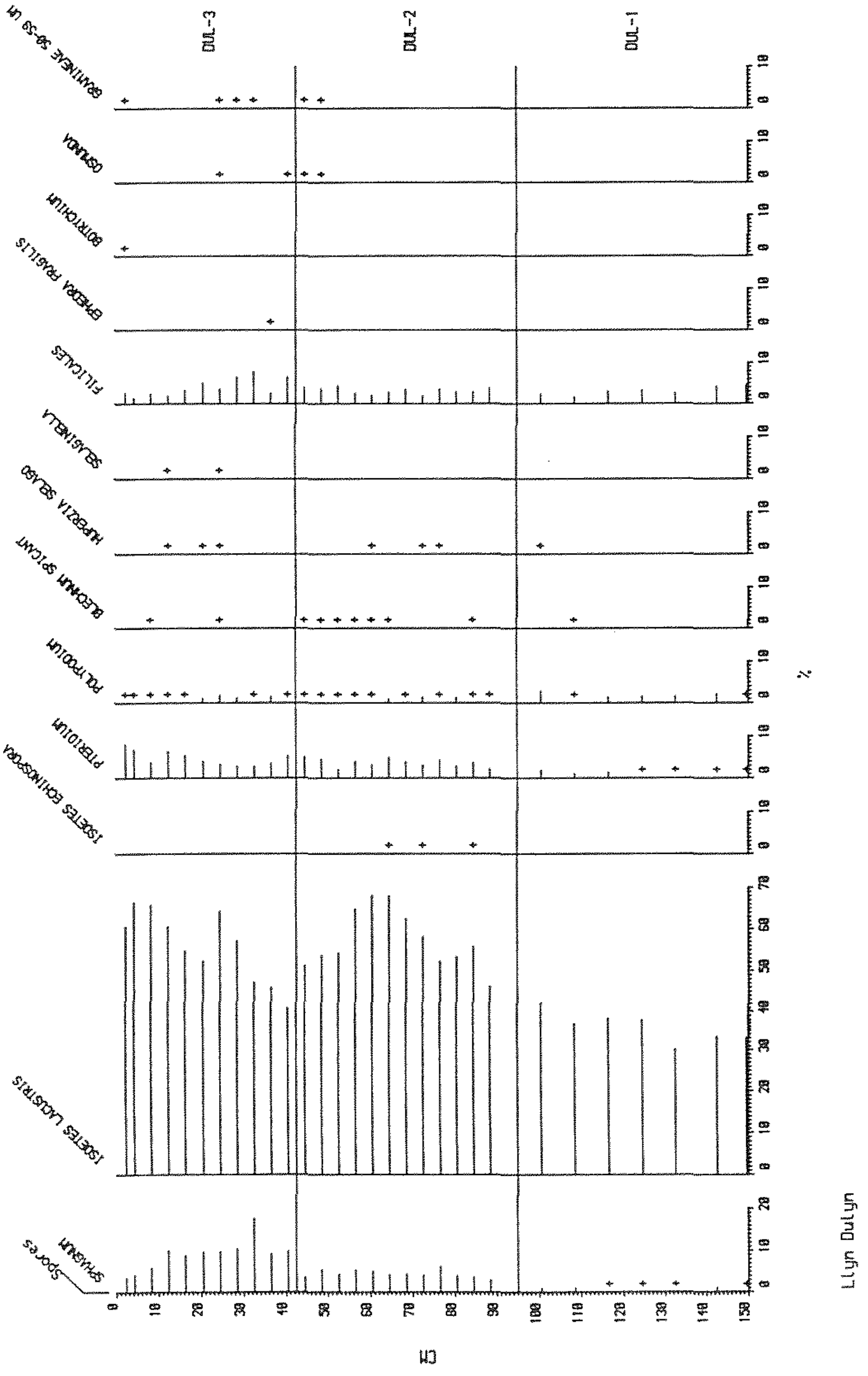
Llyn Dulyn


Llyn Dulyn
Herbs
GRAMINEAE < 40um
GRAMINEAE 40-49 UM
GRAMINEAE > 60 u
CAMPANULA
CARYOPHYLLACEAE UNDIFF.
STELLARIA HOLOSTEA
ILLECEBRUM
CHENOPODIACEAE
ARTEMISIA
ANTHEMIS TYPE
BIDENS TYPE
LIGULIFLORAE
SERRATULA TYPE
ASTER TYPE
CENTAUREA NIGRA TYPE
CRUCIFERAE
DUL-3
DUL-2
DUL-1
CM
0
10
20
30
40
50
60
70
80
90
100
110
120
130
140
150
%
0
10
20
30
40
50
60
70


DUL-3
DUL-2
DUL-1
SCROPHULARIACEAE undiff
GALIUM TYPE
POTENTILLA
FILIPENDULA
THALICTRUM
RANUNCULUS TRICHOPHYLLUS TYPE
RUMEX CRISPUS TYPE
LITTORELLA UNIFLORA
PLANTAGO MAJOR TYPE
PLANTAGO LANCEOLATA TYPE
EPILOBIUM
VICIA CRACCA TYPE
ASTRAGALUS TYPE
GENISTA TYPE
PRUNELLA TYPE
MENTHA TYPE
MERCURIALIS
SUCCISA TYPE
0
10
%
0
10
20
30
40
50
60
70
80
90
100
110
120
130
140
150
CM
Llyn Dulyn


HELIANTHEMUM
UMBELLIFERAE UNDIFF
URTICA DIOICA
CYPERACEAE
NYMPHAEA
SPARGANIUM TYPE
POTAMOGETON
UTRICULARIA
DUL-3
DUL-2
DUL-1
CM
%
0
10
20
30
40
50
60
70
80
90
100
110
120
130
140
150

Llyn Dulyn


Spores
SPHAGNUM
ISOETES LACUSTRIS
ISOETES ECHINOSPORA
PTERIDIUM
POLYPODIUM
BLECHNUM SPICANT
HUPERZIA SELAGO
SELAGINELLA
FILICALES
EPHEDRA FRAGILIS
BOTRYCHIUM
OSMUNDA
GRAMINEAE 50-59 UM
DUL-3
DUL-2
DUL-1
CM
0
10
20
30
40
50
60
70
80
90
100
110
120
130
140
150
%
Llyn Dulyn

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