Research Papers

No. 18

PALAEOECOLOGICAL EVALUATION OF THE RECENT ACIDIFICATION OF WELSH LAKES

2. Llyn Berwyn, Dyfed

A. Kreiser[1], A.C. Stevenson[1], S.T. Patrick[1], P.G. Appleby[3]
F. Oldfield[2], B. Rippey[4], J. Darley[1] & R.W. Battarbee[1]
(With appendices supplied by the WWA)

Editors: A.C. Stevenson & S.T. Patrick

Palaeoecology Research Unit
Department of Geography
University College London

Report to the DOE under Contract PECD 7/7/139

Palaeoecological Evaluation of the Recent Acidification of Welsh Lakes. II. Llyn Berwyn, Dyfed

A. Kreiser[1], A.C. Stevenson[1], S.T. Patrick[1], P.G. Appleby[3], F. Oldfield[2], B. Rippey[4], J. Darley[1] & R.W. Battarbee[1]

[1] Palaeoecology Research Unit
Dept. Geography
University College London
26 Bedford Way
London W.C.1H 0AP

[2] Dept. Geography
University of Liverpool
P.O. Box 147
Liverpool L69 3BX

[3] Dept. Applied Mathematics & Theoretical Physics
University of Liverpool
P.O. Box 147
Liverpool L69 3BX

[4] Freshwater Laboratory
University of Ulster
Traad Point
Drumenagh
Magherafelt
N. Ireland.

Contents

Page		
3		Summary
4		Figures
5		Tables & Appendices
6		Explanation of Abbreviations
7	1.0	Introduction
10	2.0	Site details
10	2.1	Lake
10	2.1.1	Lake chemistry
10	2.1.2	Lake fauna and flora
10	2.1.3	Fishing history
13	2.2	Catchment
13	2.2.1	Geology
14	2.2.2	Soils
14	2.2.3	Present vegetation
16	3.0	Methods
16	3.1.1	Surveying
16	3.1.2	Core collection
17	4.0	Results
17	4.1	Lake history
17	4.1.1	Sediment description
17	4.1.2	^{210}Pb dating
25	4.1.3	Diatoms
25	4.1.4	Core chemistry
34	4.1.5	Carbonaceous cenospheres
37	4.1.6	Pollen
41	4.2	Catchment history
41	4.2.1	Land use
42	4.2.2	Land management
46	5.0	Discussion
46	5.1	Inwash & hiatus
46	5.2	pH reconstruction
49	6.0	Notes
50	7.0	Bibliography
53	8.0	Acknowledgements
54	9.0	Appendices
55		Appendix A
59		Appendix B
60		Appendix C
67		Appendix D
69		Appendix E

Summary

i) The LOI and dry weight profiles demonstrate a period of soil inwash probably associated with catchment drainage in 1974.

ii) The ^{210}Pb inventory of the core is incomplete and indicates strong dilution and missing sediment below 20 cm. The data suggest a hiatus in the core occurs at about 30 cm representing a time gap of at least 150 years.

iii) The diatom flora shows distinct changes in the upper 30 cm of the core. The pre-hiatus part of the core contains a mainly acidophilous diatom flora indicating pH values between 5.4 and 6.0. The pH decrease from 30-20 cm is thought to be an artefact of the reworking of older sediments caused by the post-1974 inwash event. The more recent pH decrease starts 8-13 cm above the hiatus. This is characterised by a large expansion of A.ralfsii and Cymbella perpusilla and indicates a water pH of 4.5-4.7 and conditions similar to those observed for the lake immediately before liming in 1984.

iv) Although the problems of a hiatus in Llyn Berwyn core prevent a full and detailed interpretation of the last 150 years history of the lake, the trace metal, sulphur and "CP" results do provide firm evidence that the lake has been contaminated by material deposited from the atmosphere. This started sometime before 1974, probably some tens of years, but trends of atmospheric contamination cannot be assessed.

v) While the post-hiatus pollen record is obscured by the secondary reworking of pollen from eroding blanket peats, the pre-hiatus pollen profile shows an already open moorland landscape with a few relict woodland populations of oak and birch.

vi) The documentary land use study has shown no appreciable change in land use or management apart from the recent afforestation.

vii) A comparison of the pre and post-hiatus diatom assemblages show that the lake has been acidified by approximately 1 pH unit (prior to liming). However, because of the uncertain dating the timing of this acidification is unkown.

viii) A further, post-hiatus, acidification can also be identified that may be related to the effects of deep drainage of the catchment in 1974.

ix) The analysis of a core containing a complete sedimentary record of the 19th and 20th centuries would enable the impact of both episodes of catchment drainage to be assessed independently of both forest growth and atmospheric input, and new cores from more favourable areas of the lake (if such exist) are required.

Figures

1. Llyn Berwyn location map
2. Average annual deposition of non-marine sulphate for the U.K. (Redrawn from Barret et al. 1983).
3. Average annual rainfall weighted hydrogen ion concentration deposition for the U.K. (Redrawn from Barret et al. 1983).
4. Bathymetry and coring locations for Llyn Berwyn
5. Bi-weekly lake chemistry results before and after liming (Data supplied by WWA)
6. Catchment diagram showing forestry planting map, trackways & contours
7. Stratigraphic profile of the Llyn Berwyn I core
8. Profiles of core variation in dry weight, wet density and loss on ignition for the Llyn Berwyn I core.
9 Total ^{210}Pb profile for the Llyn Berwyn I core
10 Unsupported ^{210}Pb profile for the Llyn Berwyn I core
11 ^{137}Cs profile for the Llyn Berwyn I core
12 CRS and CIC ^{210}Pb age/ depth chronology for the Llyn Berwyn I core
13 Diatom concentration diagram for the Llyn Berwyn I core
14 Diatom percentage summary diagram for the Llyn Berwyn I core
15a Variations in Na gdw^{-1} for the Llyn Berwyn I core.
15b Variations in Na per gram mineral dry weight for the Llyn Berwyn I core .
16a Variations in Mg gdw^{-1} for the Llyn Berwyn I core
16b Variations in Mg per gram mineral dry weight for the Llyn Berwyn I core.
17a Variations in K gdw^{-1} for the Llyn Berwyn I core
17b Variations in K per gram mineral dry weight for the Llyn Berwyn I core.
18a Variations in Ca gdw^{-1} for the Llyn Berwyn I core
18b Variations in Ca per gram mineral dry weight for the Llyn Berwyn I core.
19a Variations in Ni gdw^{-1} for the Llyn Berwyn I core
19b Variations in Ni per gram mineral dry weight for the Llyn Berwyn I core.
20a Variations in Zn gdw^{-1} for the Llyn Berwyn I core
20b Variations in Zn per gram mineral dry weight for the Llyn Berwyn I core.
21a Variations in Pb gdw^{-1} for the Llyn Berwyn I core
21b Variations in Pb per gram mineral dry weight for the Llyn Berwyn I core.
22a Variations in Cu gdw^{-1} for the Llyn Berwyn I core
22b Variations in Cu per gram mineral dry weight for the Llyn Berwyn I core.
23 Variations in S gdw^{-1} for the Llyn Berwyn I core
24 Carbonaceous particle record gdw^{-1} for the Llyn Berwyn I core
25 Carbonaceous particle record per gram mineral dry weight for the Llyn Berwyn I core.
26 Total pollen concentration diagram for the Llyn Berwyn I core.
27 Summary percentage pollen diagram for the Llyn Berwyn I core. Trees expressed as a percentage of the Arboreal pollen. All other groupings expressed as percentage of the Arboreal pollen + the grouping.
28 Summary percentage pollen diagram for the Llyn Berwyn I core. Taxa expressed as a percentage of those shown.
29 Sheep numbers in Caron and Caron-is-Clawdd Parishes - 1867-1983.
30 Crude sheep/rough grazing stocking densities in Caron and Caron-is-Clawdd Parishes - 1895-1983.
31 pH reconstruction of the Llyn Berwyn core according to three different methods:- Index B, Index B (Galloway) and Multiple Regression of pH preference groups.

Tables and Appendices

Tables

1. Lake characteristics
2. Catchment characteristics
3. ^{210}Pb & ^{226}Ra data for the Llyn Berwyn I core
4. ^{137}Cs data for the Llyn Berwyn I core
5. Other radioisotope data from the Llyn Berwyn I core
6. Comparison of ^{210}Pb & ^{137}Cs parameters for Llyn Berwyn with corresponding parameters for Llyn Hir & Llyn Gynon
7. CRS dating model chronology of the Llyn Berwyn I core
8. CIC dating model chronology of the Llyn Berwyn I core
9. Flux data for selected elements for Llyn Berwyn (BER 1) and Loch Dee (DEE 1) sediment cores.
10. Carbonaceous cenosphere record for the Llyn Berwyn 1 core

Appendices

A. Bi-weekly chemistry data for Llyn Berwyn from November 1983-March 1986 (courtesy of WWA)
B. Invertebrate list from Llyn Berwyn (courtesy of WWA)
C. Full diatom diagrams for the Llyn Berwyn I core
D. Full physical and chemical characteristics of the Llyn Berwyn 1 core
E. Full pollen diagrams for the Llyn Berwyn I core

Explanation of Abbreviations

ADAS	Agricultural and Development Advisory Service.
AERE	Atomic Energy Research Establishment
BGS	British Geological Survey
ITE	Institute of Terrestrial Ecology
LSE	London School of Economics
MAFF	Ministry of Agriculture, Fisheries and Food.
NCC	Nature Conservancy Council
NLW	National Library of Wales
PAH	Polyaromatic Hydrocarbons
PRO	Public Record Office
SSSI	Site of Special Scientific Interest
UCL	University College London
WWA	Welsh Water Authority

1.0 Introduction

Surface water acidification is recognised as one of the most important environmental problems in Europe and North America, yet despite the pioneering work of Gorham on precipitation chemistry in Cumbria (Gorham 1958) the extent of acidification in the UK is still not known. In earlier papers Flower and Battarbee 1983, Battarbee et al. 1985 & Jones et al. 1986) we established that both non-afforested and afforested lakes on granitic rocks in Galloway, South West Scotland, were strongly acidified, and that the most likely cause of the acidification in the non-afforested lakes was acid deposition. We have now extended our enquiry to other non-afforested acid lakes in Wales and other parts of Scotland to test the general hypothesis that non-afforested 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. To date we have established that Llyn Hir in west Wales, a lake with a non-afforested catchment, has been strongly acidified in the same way and over a similar time period to the Galloway lakes (Fritz et al. 1986)

However, it has also been shown that in the case of Loch Fleet (Anderson et al. 1986) afforestation has played an important role in the acidification of the lake, supporting the observations of Harriman and Morrison (1982) and Stoner and Gee (1985) that afforested stream catchments are more acidic, have higher concentrations of SO_4 and Al, and poorer fisheries than moorland control streams.

Llyn Berwyn (Fig. 1) is one of two afforested sites selected to investigate the relationship between afforestation and lake water acidity in Wales. At present the catchment is 80% afforested and a marked fishery decline occurred shortly after the afforestation in 1963. The lake has been recently limed (Underwood et al. 1986) but the pre-liming pH was 4.5. The mean pH of precipitation is > 4.5 and the annual wet sulphate loading is 1.2 - 1.6 g m^{-2} yr^{-1} (Figs. 2 & 3).

Our approach involves the use of diatom analysis to reconstruct past pH values; ^{210}Pb analysis to establish a lake sediment chronology; geochemical 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.

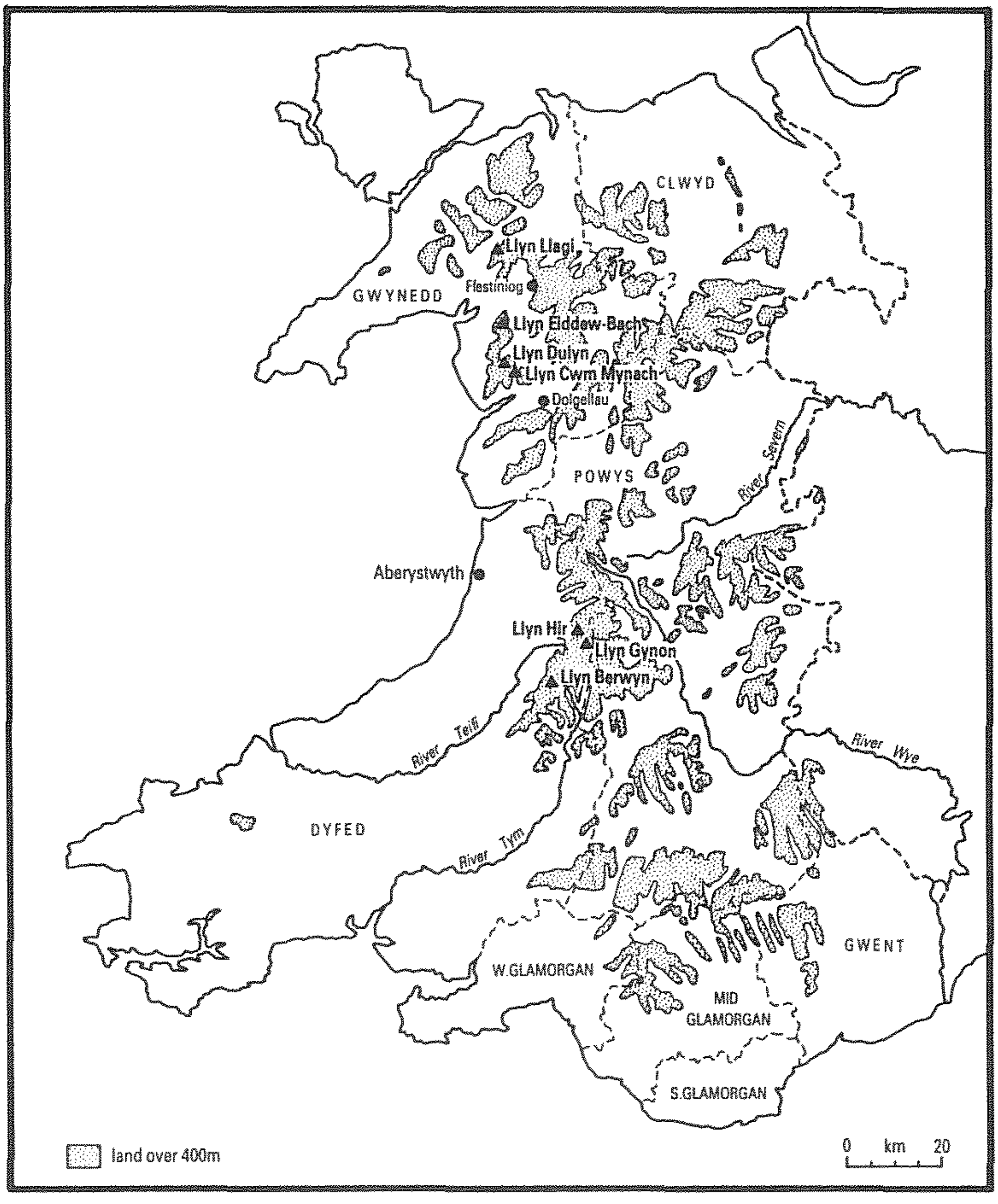


Fig. 1. Llyn Berwyn location map.

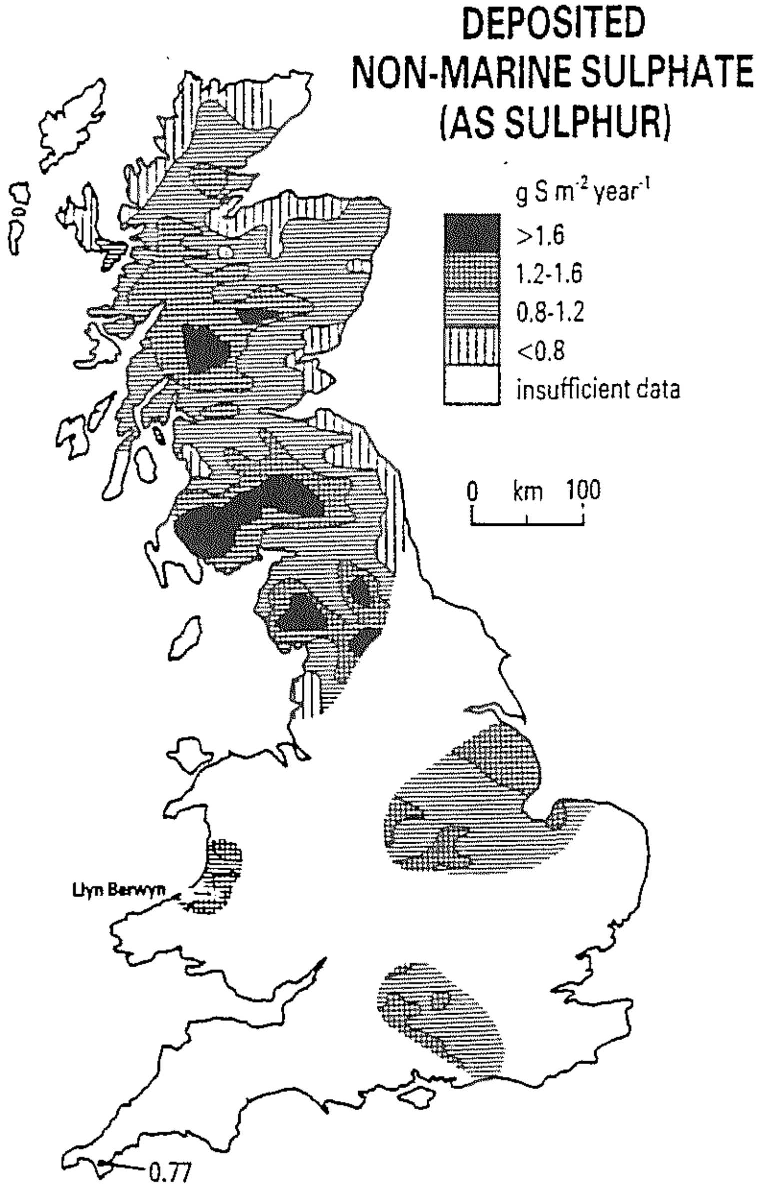


Fig. 2. Average annual deposition of non marine Sulphate for the U.K. (Redrawn from Barret et al.1983).

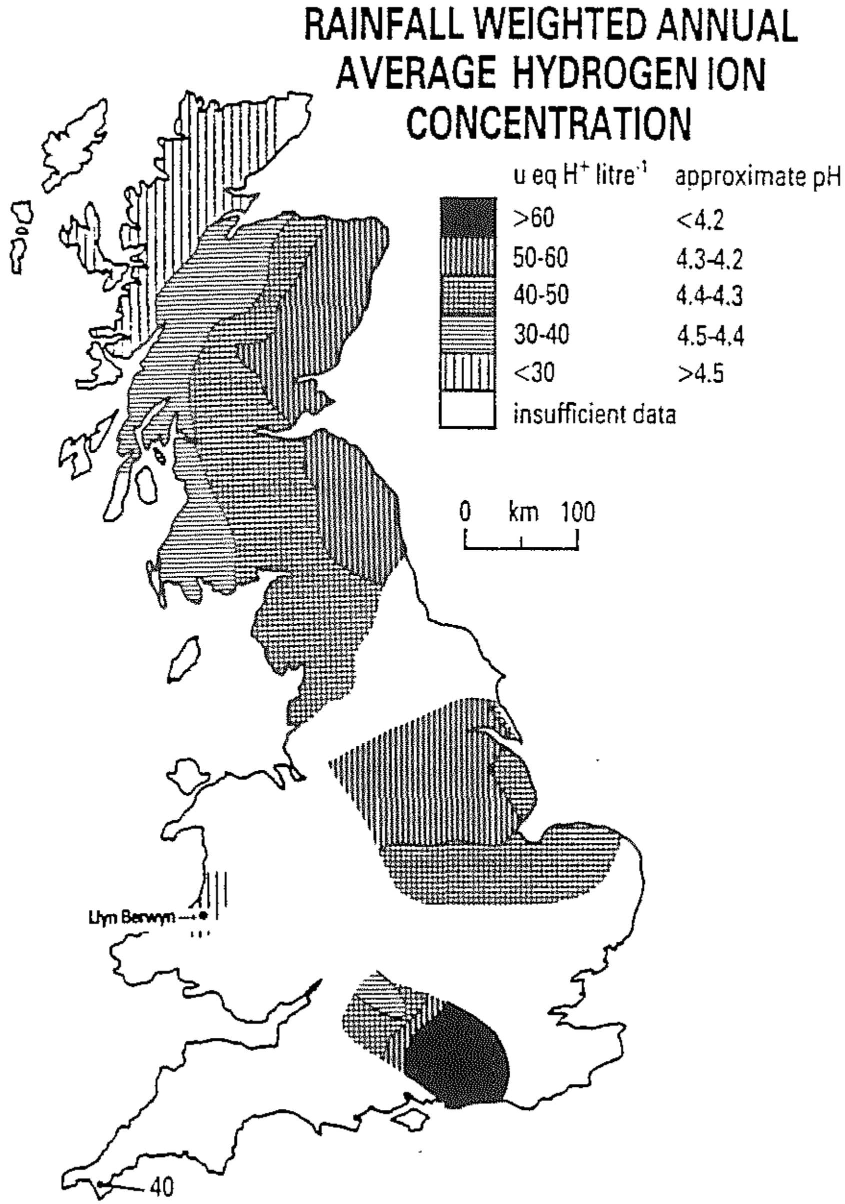


Fig. 3. Average annual rainfall weighted Hydrogen ion concentration deposition for the U.K. (Redrawn from Barret et al. 1983).

2.0 Site details

2.1 Lake

The lake lies at an altitude of 438 m in an area which receives rainfall of 2000 mm yr^{-1}. Llyn Berwyn is an oligotrophic lake draining a catchment of 0.96 km^2. The detailed bathymetry (Fig. 2) reveals that the lake is composed of a single basin, 14 m deep, surrounded by an extensive shallow rim. The lake has a mean depth of 3.25 m and a volume of 417,655 m^3 and displays minimal variation in water level (Table 1 & Underwood et al. 1986). The former drainage network was poorly formed until deep forest drains were cut in 1974 (see section 4.2.2). The lake has two very small inflows and the outflow, Nant y Llyn, drains to the south east (mean flow 0.039 m^3 s^{-1}, Underwood et al. 1986) (Fig. 6).

Table 1 Lake Characteristics

Area	130,350	m^2
Volume	417,655	m^3
Maximum depth	14	m
Mean depth	3.25	m

2.1.1 Water chemistry, pre & post-liming

Llyn Berwyn, together with Llyn Hir (see Fritz et al. 1986), were the subject of a detailed liming experiment by the WWA designed to ameliorate the acidity of the lake and provide conditions suitable for fish populations. Detailed results may be found in Underwood et al. (1986). Before liming, pH at Llyn Berwyn varied between 4.1 & 4.5 with very low levels of dissolved calcium (0.4 - 1.0 mg l^{-1}). After liming on the 1 & 2 April 1985 pH, alkalinity and dissolved calcium all increased significantly, while dissolved metal concentrations, especially aluminium, decreased (Fig. 3, Appendix A). Subsequently, pH, alkalinity and dissolved calcium all decreased again as calcium rich lake water was replaced by acid surface and ground waters. The lake was re-limed on 29/10/85 to bring the pH back to 7.0 (Underwood et al. 1986) some two months earlier than predicted.

2.1.2 Lake flora and fauna

A survey before liming by the WWA showed that the leafy liverwort, *Nardia compressa*, was the dominant macrophyte in the littoral zone together with *Drepanocladus fluitans*, *Isoetes lacustris** and *Fontinalis squamosa*. The only macrophyte recorded at depth was *Sphagnum acutifolium* a common plant of highly acidic, oligotrophic waters in Galloway (Raven 1986). Compared to Llyn Hir, Llyn Berwyn supported a more diverse macro-invertebrate population before liming with up to 63 species, but all characteristic of oligotrophic waters (Appendix B, WWA 1986, B. Morrison pers. comm.).

2.1.3 Fishing history

A rapid deterioration of the fishery was recognised in Llyn Berwyn from ca. 1974 (R. Hughes, G. Jones, M. Morgan pers. comm.). By the early 1980s the lake only supported a population of eels (Underwood et al. 1986).

(Nomenclature follows Tutin et al 1964-1980)

LLYN BERWYN BATHYMETRY

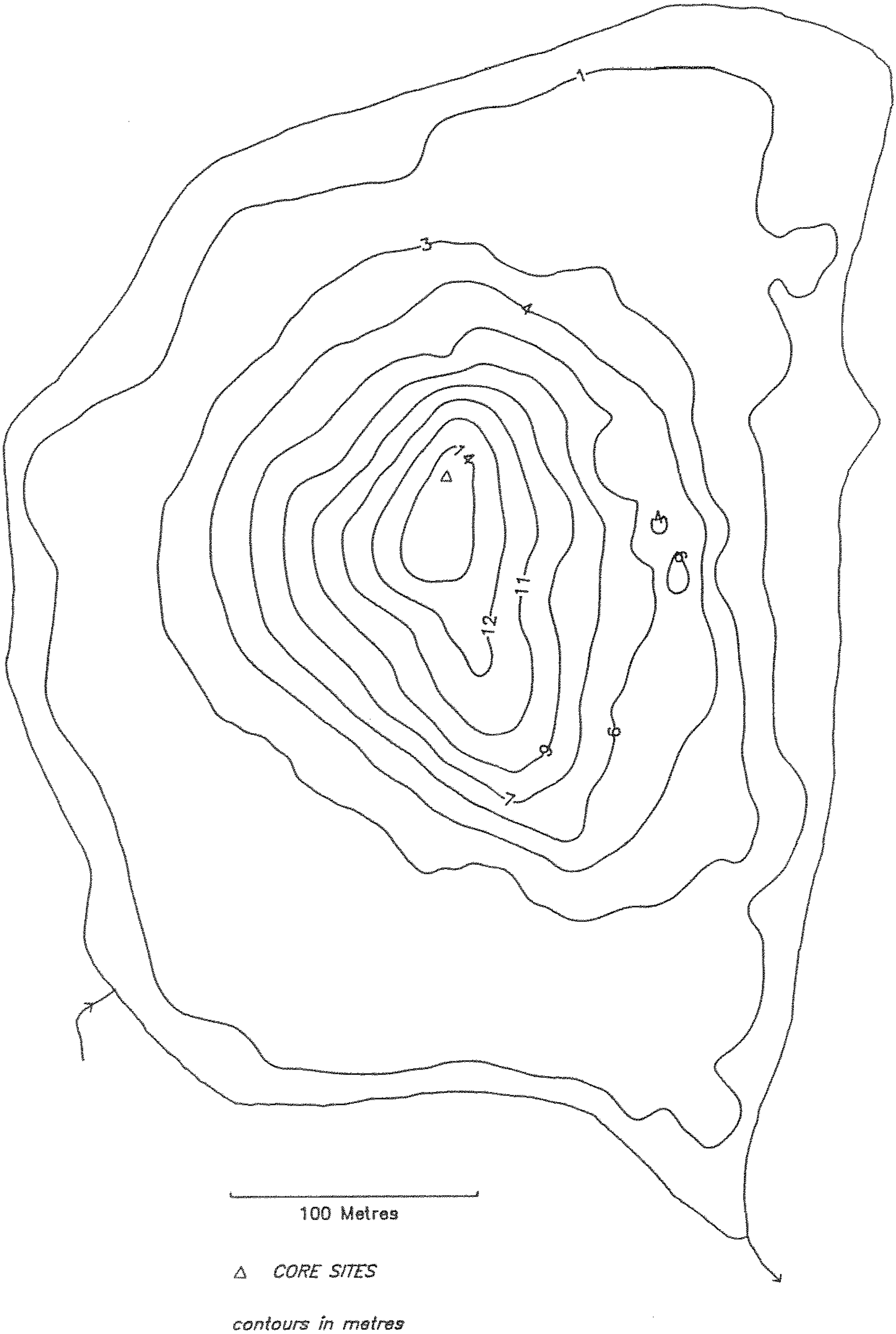


Fig. 4. Bathymetry and coring locations for Llyn Berwyn.

LLYN BERWYN WATER CHEMISTRY, OCT. 1983 – MAR. 1986

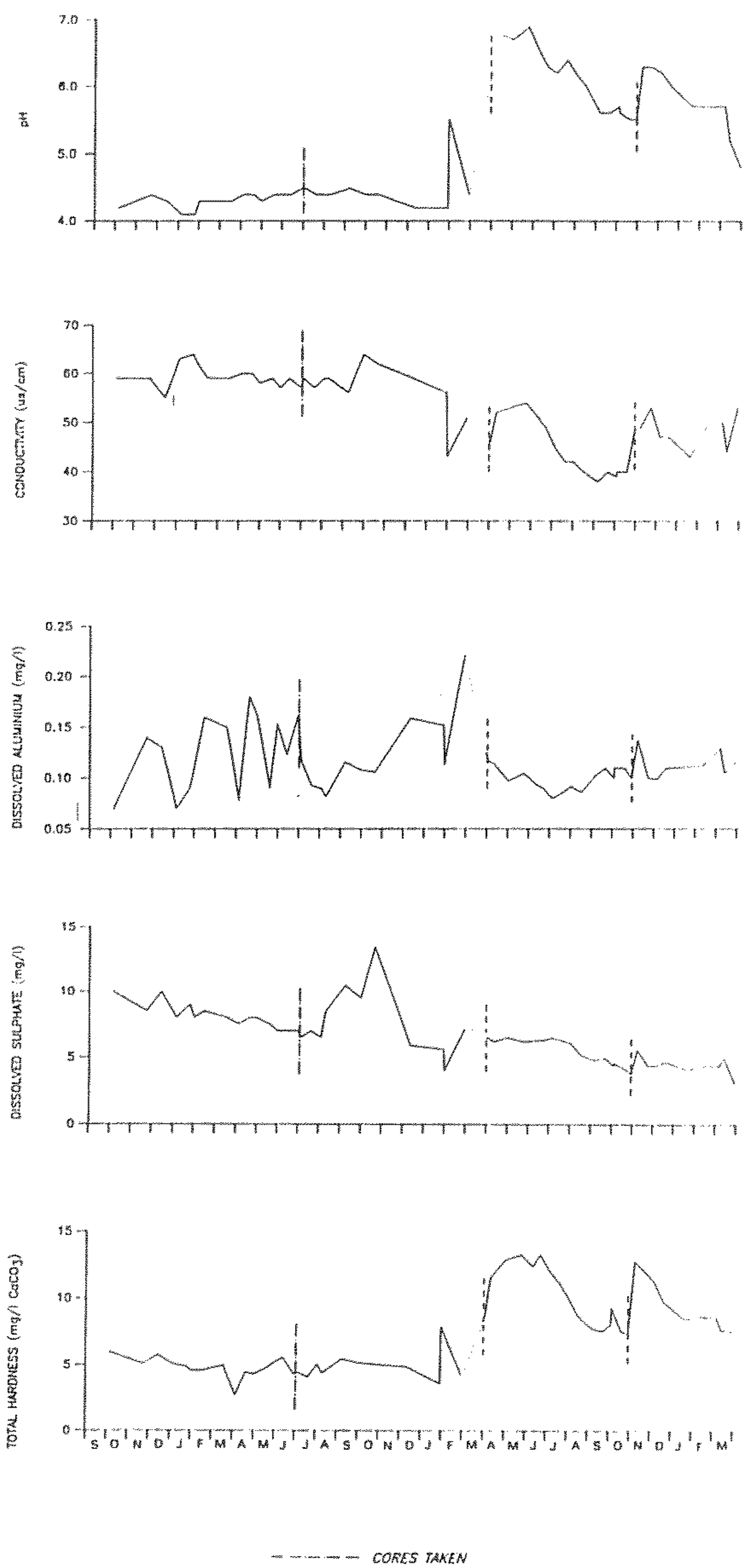


Fig. 5. Bi weekly lake chemistry results before and after liming (Data supplied by WWA).

Before this decline Llyn Berwyn was noted as an excellent trout fishery. Cliffe (1860) described two fishing days during which 44 trout weighing upwards of six ounces were landed. Subsequent authors confirmed the health and viability of the fish stock (Morgan 1874, Bradley 1903, Ward 1931, Rees 1936). Ward (1931) noted that the fish averaged eight ounces in weight, many being much larger, and that their quality was 'excellent'.

Sea trout migrated up the outflow stream to the lake until that stream was diverted, sometime in the early 20th century, by a farmer wishing to encourage the fish to follow an adjacent watercourse (R. Hughes, M. Morgan pers. comm.). The diversion did not seem to affect the indigenous fish stock. Anglers recall good fishing with catches of brown trout weighing up to 1.5 pounds and sea trout up to three pounds through the 1950s (Underwood et al. 1986, R. Hughes, G. Jones, M. Morgan pers. comm.).

The Forestry Commission acquired the fishing rights in the late 1950's prior to the plantation of the catchment. Tregaron Angling Society leased the fishing from the Forestry Commission in the early 1960s. It is from this period that a gradual decline in fish catches was first noticed (M. Morgan pers. comm.).

Fish from the River Teifi were introduced to the lake in the mid 1960s (1), but they did not establish themselves. An attempt to stock with fish from a neutral water hatchery in the late 1960s failed totally, with 100% mortality inside a week (M. Morgan pers. comm.).

Underwood et al. (1986) note that the demise in fishery status of Llyn Berwyn coincides with the period of increasing acidification, and ascribe the decline to low pH conditions. However, it should also be noted that the original decline from the early 1960s coincides with the preparation and planting of the catchment with conifers, and with easier access for anglers by the new forestry road. The major decline after ca. 1974 is coincidental with the deep drainage of the maturing forest (Section 4.2.2).

Following liming by the WWA in April 1985 the lake was successfully stocked with 600 brown trout (Underwood et al. 1986).

2.2 Catchment

Llyn Berwyn occupies an acidic, blanket peat covered, upland site of some 967,371 m² of which the lake occupies 130,351 m² (Table 2).

Table 2 Catchment Characteristics

Total catchment area	967,371 m²
Area of land in catchment	837,020 m²
Area of lake	130,351 m²
Catchment/lake ratio	6.42
Maximum relief	467 m

2.2.1 Geology

Base poor, lower Palaeozoic, Silurian mudstones and shales dominate the geology (Rudeforth 1970). These largely impermeable rocks are resistant to chemical weathering and the drainage waters are of low hardness (Underwood et al. 1986). Detailed geological mapping is not yet available but a survey by the BGS is in progress nearby (R. Bazley pers. comm.)

2.2.2 Soils

The dominant soil type of the catchment belongs to the Crowdy peat series (1013a). Typically, these are amorphous blanket peats often up to 2 m thick. Other soil types within the catchment are those belonging to the Hiraethog series of the Hafren association (654a) and are chiefly stagnopodzols and stagnohumic gleys (Rudeforth et al. 1984). Typically these soils are thin (30-40 cm) with a wet peaty surface horizon and bleached subsurface horizons, often with a thin ironpan.

2.2.3 Present Vegetation

Before afforestation in 1962-1963 Llyn Berwyn had a blanket peat catchment covered by extensive Molinia caerulea and Eriophorum vaginatum interspersed with small areas of Nardus grassland. Sphagnum (eg. S.cuspidatum, S.papillosum & S.compactum), Polytrichum commune, Aulocomnium palustre and Tricophorum caespitosus were also common. The catchment was afforested with sitka spruce (Picea sitchensis) and lodgepole pine (Pinus contorta) in 1962-1963 and these dominate the present catchment vegetation. A small area of Japanese larch (Larix kaempferi) was planted on the better drained hillsides to the west in 1960. Fig. 6 illustrates the planting regime of the forest. Remains of the former vegetation cover are restricted to areas around the edge of the present forest and to the south and northeast of the catchment (Fig. 6).

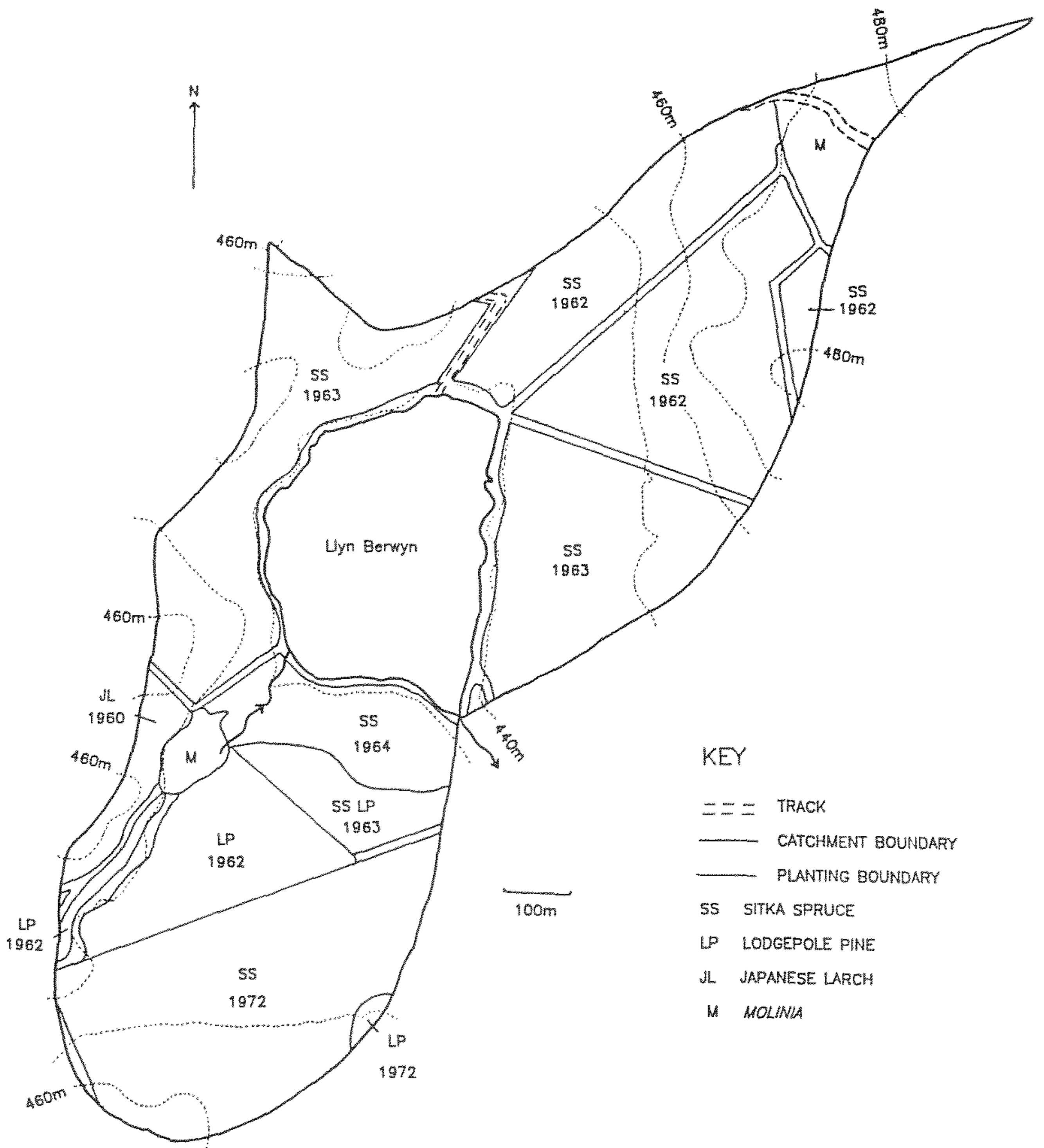


Fig. 6. Catchment diagram showing forestry planting map,trackways & contours.

3.0 Methods

3.1.1 Surveying

The lake bathymetry was surveyed using the techniques described in Stevenson *et al.* 1987. Shore surveying stations were located adjacent to the inflow and outflow.

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

Cores were taken using a Mackereth mini-corer (Mackereth 1969) operated from an inflatable boat. Sampling was carried out during July 1984 (Fig. 2). Core BER I was used for dating and analysis.

Core BER I (83 cm) was extruded in the laboratory and sliced into 1 cm slices. The top 50 cm of sediment was sub-sampled at 1 cm intervals for dry weight, loss on ignition (at 550°C), wet density measurements. The lithostratigraphy of the core was recorded using the Troels-Smith method of sediment description (Troels-Smith 1955). The remaining core was sampled at 2 cm intervals.

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

4.0 Results

4.1 Lake history

4.1.1 Sediment Description

The core contains three stratigraphic units (Fig. 7); a black organic sediment containing fibrous bryophyte remains down to 20 cm, a gritty, grey-brown mottled band composed of mineral and organic material from 20-28 cm where there is a gradual change to a dark brown organic unit from 30 cm down to the base of the core at 81 cm. These changes are reflected in the percentage dry weight, loss on ignition and wet density profiles (Fig. 8). The dry weight and wet density graphs show increases in the 20-30 cm section, all indicative of rapid inwash of catchment materials. Loss on ignition decreases in this section but increases rapidly from 32% at 22 cm to a peak of 73% at 15 cm, followed by a decline to values around 50% at the surface.

4.1.2 ^{210}Pb dating

Sediments from BER 1 were analysed for ^{210}Pb, ^{226}Ra at Harwell A.E.R.E. Additional measurements for ^{210}Pb, ^{226}Ra and ^{137}Cs were carried out by gamma spectrometry at Liverpool University (Appleby et al. 1986). The ^{210}Pb and ^{226}Ra results are given in Table 3, and shown graphically in Figs. 9 & 10. The ^{137}Cs results are given in Table 4 and Fig. 11. Table 5 gives values of a range of other radioisotopes determined from the gamma spectra. The tables also give results of the analysis of a single sample from a second core (BER 2).

Fig. 12, Tables 7 & 8 show the ^{210}Pb chronologies for BER I given by the CRS and CIC dating models (Appleby and Oldfield 1978), assuming that the ^{210}Pb inventory of the core is complete. The two models give results which differ in detail, but both indicate 19th century dates for sediments below ca. 13-14.5 cm. These results are incompatible with the sedimentary data, which indicate that sediments down to ca. 30 cm are mainly post-1970 inwash material. Sediments between 23 cm and 28 cm have a low organic matter content and high bulk density typical of minerogenic inwash. They also have high ^{226}Ra concentrations, and high ^{238}U and ^{40}K values (Table 5). Sediments above 21 cm have a high organic matter content, low bulk density, and low ^{226}Ra, ^{238}U and ^{40}K concentrations, and are assumed to derive largely from peat inwash. This can only be explained by supposing that the ^{210}Pb inventory is incomplete and that there is a hiatus in sediment accumulation.

Table 6 compares ^{210}Pb and ^{137}Cs parameters for Llyn Berwyn (BER I) with corresponding parameters from Llyn Hir (HIR I) (Fritz et al. 1986) and Llyn Gynon (GYN 3) (Stevenson et al. 1986). The measured ^{210}Pb inventory of 9.7 pCi cm^{-2} in Llyn Berwyn (BER I) is lower than at the other two sites and so is not inconsistent with the supposition of a hiatus

The single measurement on material from 55.5-56 cm in core BER2 gives values typical of the inorganic sediments in BER1 below 20 cm.

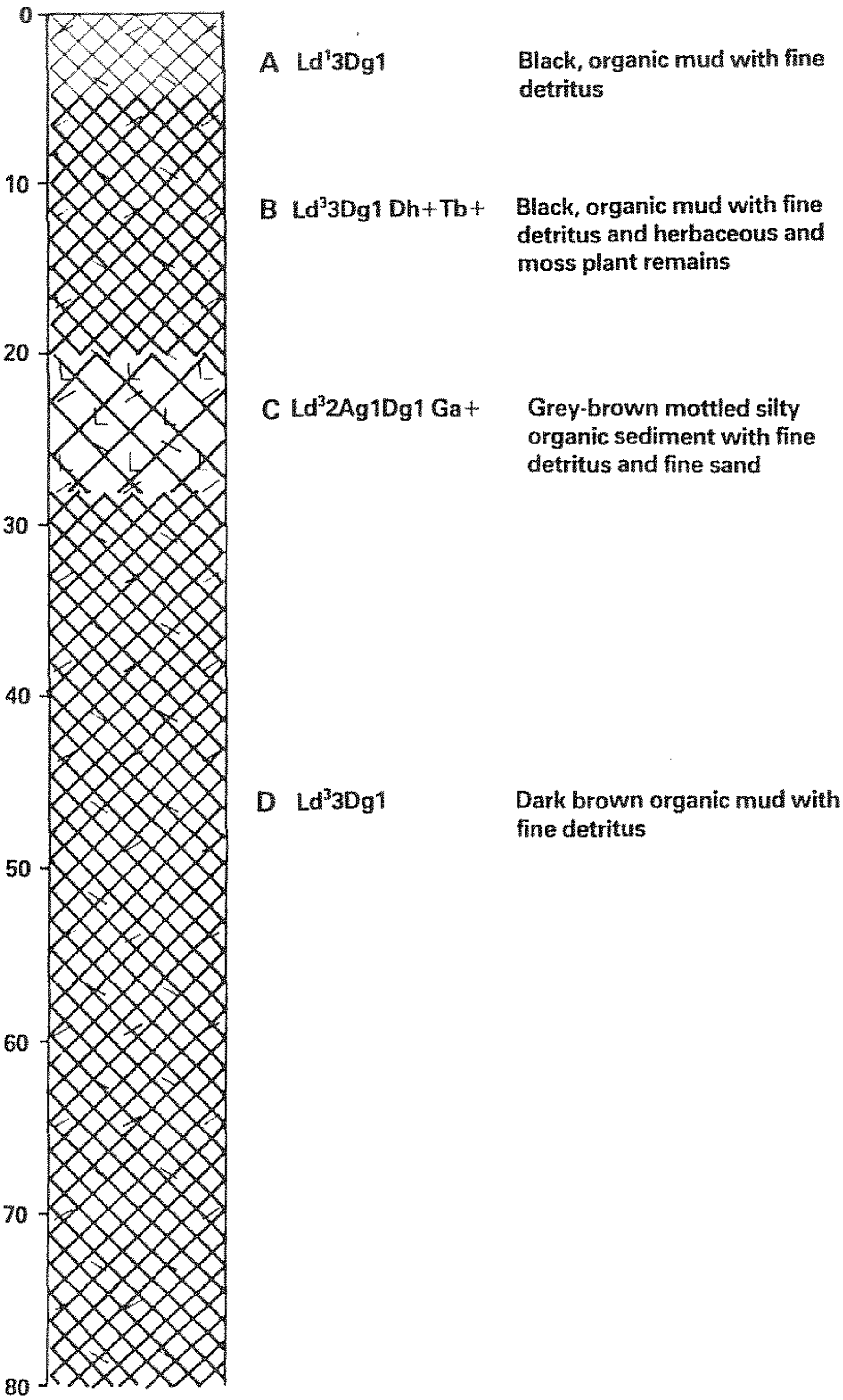


Fig. 7. Stratigraphic profile of the Llyn Berwyn I core.

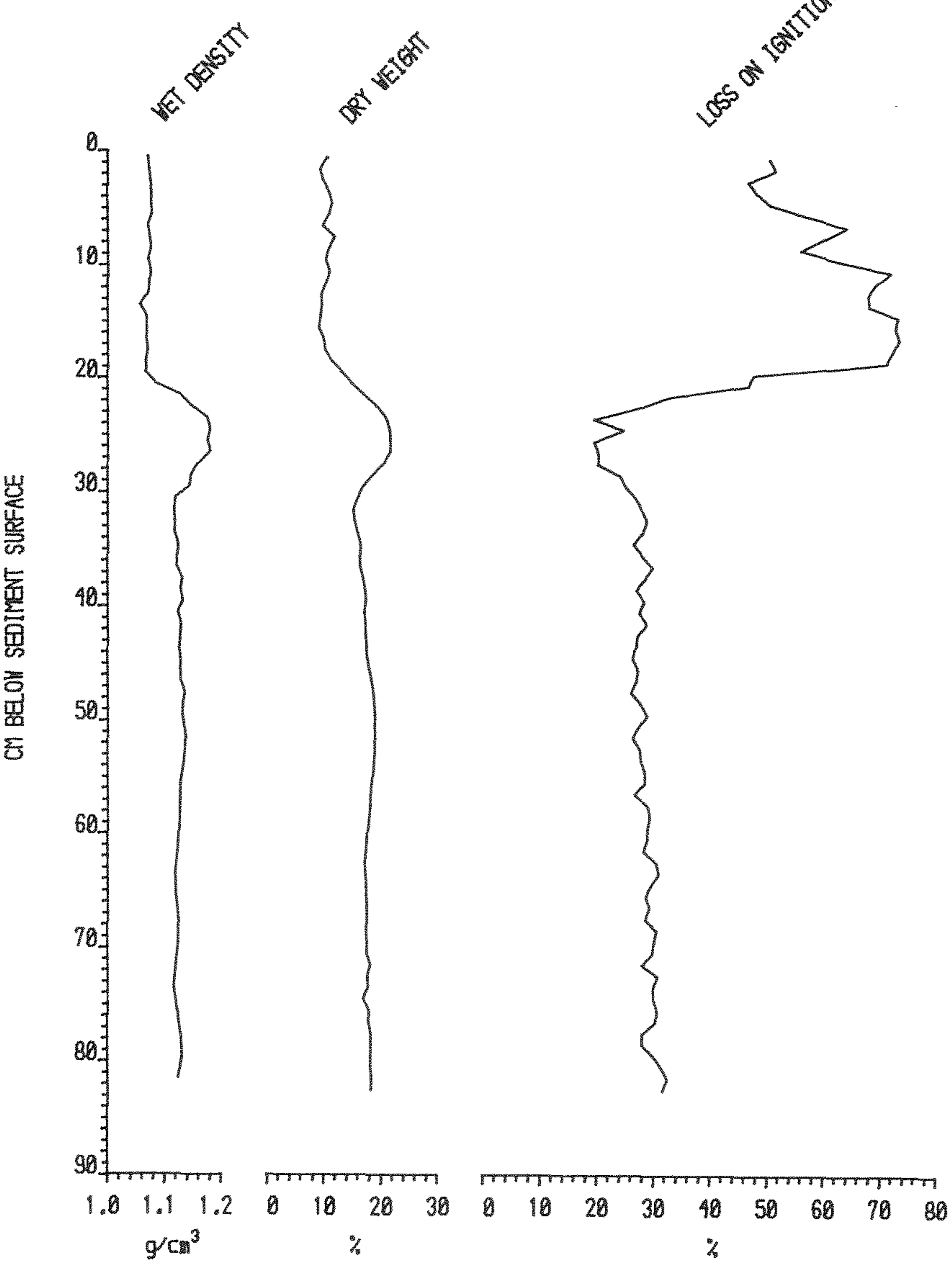


Fig. 8. Profiles of down core variation in dry weight, wet density and loss on ignition for the Llyn Berwyn I core.

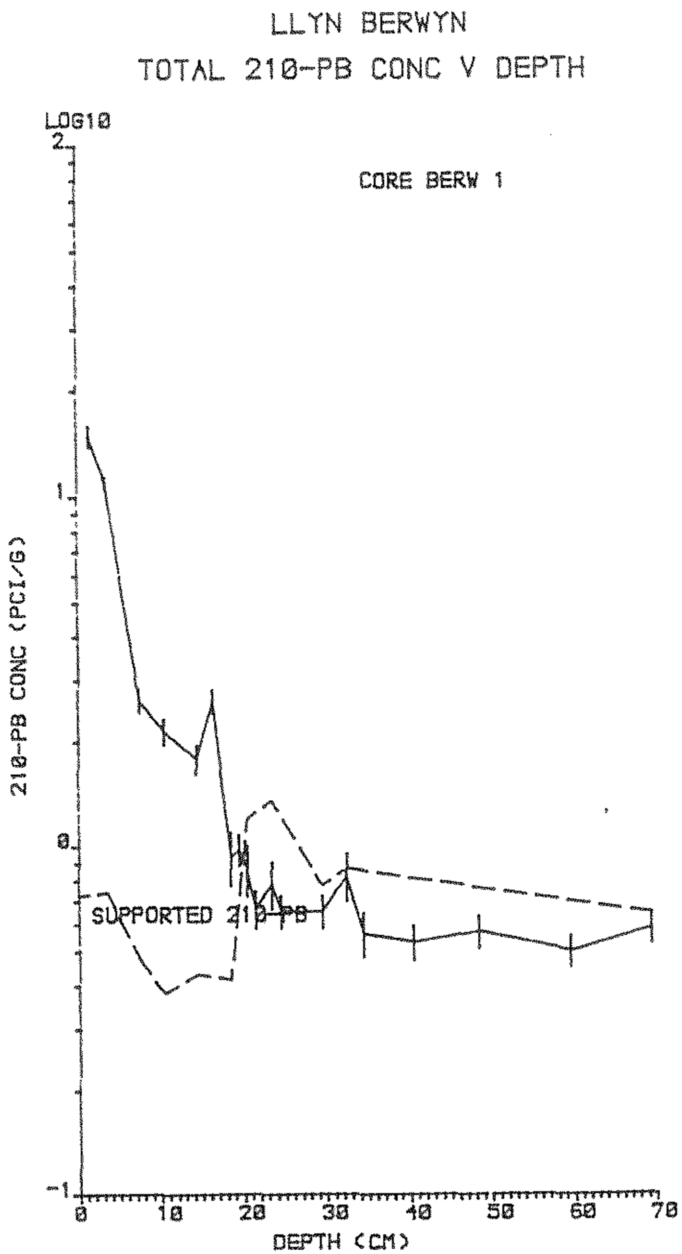


Fig. 9. Total ^{210}Pb profile for the Llyn Berwyn I core.

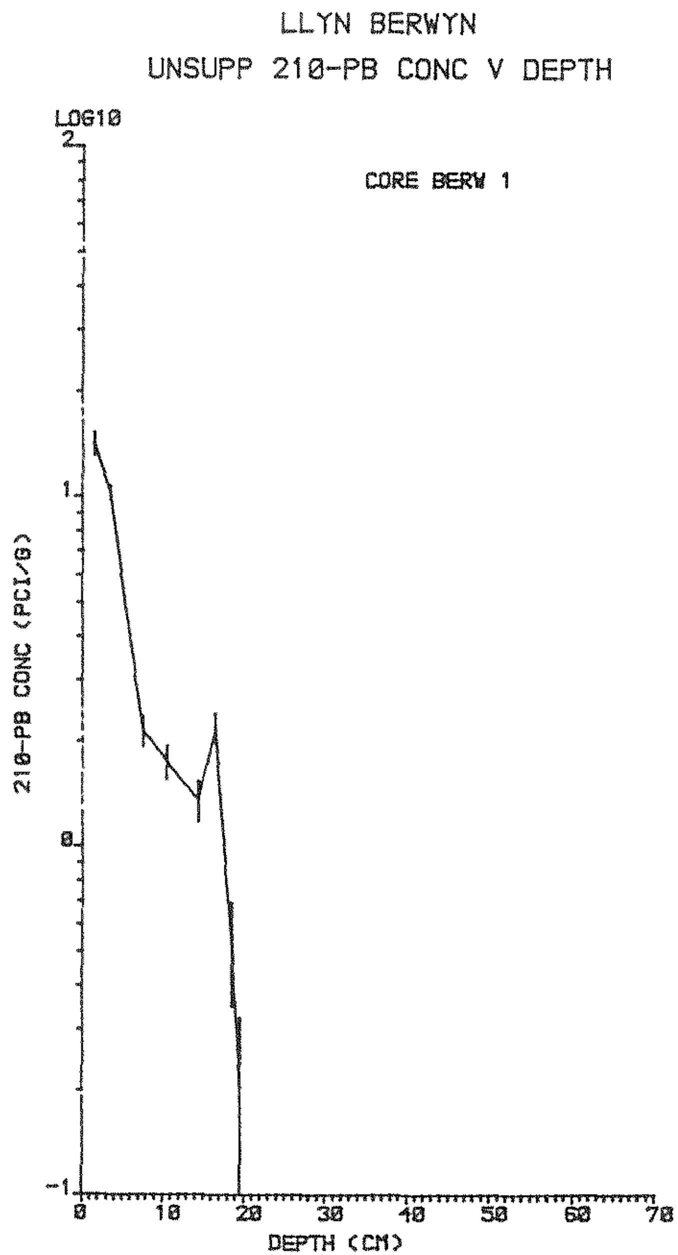


Fig. 10. Unsupported ^{210}Pb profile for the Llyn Berwyn I core.

Table 3. Llyn Berwyn (BER I) ^{210}Pb Data

Depth	Dry Mass	^{210}Pb Conc.		Cumulative Unsupported	Std. Errors			^{226}Ra Conc.	Std. Error
		Total	unsupported	^{210}Pb	Conc.		Cum.		
cm	g cm^{-2}	pCi g^{-1}	pCi g^{-1}	pCi cm^{-2}	Total	Uns.	Uns.	pCi g^{-1}	Total
1.50	0.1615	14.900	14.168	2.732	1.10	1.10	0.22		
3.50	0.3762	10.940	10.200	5.326	0.44	0.45	0.36	0.740	0.09
7.50	0.8477	2.610	2.140	7.781	0.20	0.21	0.41	0.470	0.05
10.50	1.1993	2.120	1.740	8.461	0.18	0.19	0.42	0.380	0.07
14.50	1.6270	1.780	1.350	9.119	0.17	0.18	0.43	0.430	0.07
16.50	1.8282	2.600	2.178	9.470	0.20	0.21	0.43		
18.50	2.0532	0.930	0.516	9.740	0.16	0.17	0.44	0.414	0.06
19.50	2.1855	0.980	0.203	9.760	0.10	0.12	0.44		
20.50	2.3382	0.860	-0.335	9.778	0.14	0.15	0.44	1.195	0.06
21.50	2.5170	0.660	-0.581	9.685	0.08	0.10	0.44		
23.50	2.9613	0.780	-0.576	9.437	0.12	0.13	0.44	1.356	0.05
24.50	3.2126	0.650	-0.604	9.349	0.07	0.09	0.44		
29.50	4.4008	0.650	-0.120	8.858	0.07	0.11	0.45	0.770	0.08
32.50	4.9341	0.820	-0.046	8.812	0.13	0.14	0.46	0.866	0.05
34.50	5.2921	0.560	-0.295	8.787	0.08	0.09	0.46		
40.50	6.4386	0.530	-0.290	8.548	0.08	0.08	0.47		
48.50	8.0609	0.570	-0.201	8.219	0.08	0.08	0.48		
59.50	10.3826	0.500	-0.200	7.711	0.08	0.08	0.51		
69.50	12.3489	0.580	-0.080	7.290	0.08	0.08	0.54	0.640	0.06
70.00	12.4479			7.284					

BER 2 results

55.50	6.5320	0.760	-0.167		0.15	0.16		0.927	0.06
56.00	6.5912								

Table 4. Llyn Berwyn (BER I) ^{137}Cs data.

Depth	Dry Mass	^{137}Cs Conc		Cumulative ^{137}Cs		Fract
cm	g cm^{-2}	pCi g^{-1}	+/-	pCi g^{-1}	+/-	
3.50	0.3762	46.93	0.50	17.66	0.90	0.580
10.50	1.1993	1.60	0.11	28.70	1.39	0.943
14.50	1.6270	2.29	0.08	29.52	1.39	0.970
18.50	2.0532	0.72	0.06	30.10	1.39	0.989
20.50	2.3382	0.18	0.04	30.21	1.39	0.992
23.50	2.9613	0.19	0.03	30.33	1.39	0.996
32.50	4.9341	0.01	0.03	30.45	1.39	1.000

BER 2 results

55.50	6.5320	0.00	0.00	0.00	0.00	0.000

Table 5. Llyn Berwyn (BER I) Radioisotope Data.

Depth cm	^{226}Ra	^{238}U	^{235}U pCi g^{-1}	^{228}Ac	^{228}TH	^{40}K
3.50	0.74	0.19	0.00	0.90	1.02	22.03
10.50	0.38	0.00	0.00	0.35	0.37	11.27
14.50	0.43	0.00	0.13	0.33	0.99	11.70
18.50	0.41	0.18	0.04	0.66	0.54	11.13
20.50	1.20	0.43	0.12	1.29	2.02	26.38
23.50	1.36	0.84	0.15	1.42	2.36	30.61
32.50	0.87	0.27	0.11	0.87	1.45	19.16
BER 2 results						
55.75	0.93	0.74	0.09	1.09	1.54	24.34

Table 6. Llyn Berwyn (BER I), Gynon (GYN 3) and Hir (HIR 1) ^{210}Pb and ^{137}Cs Parameters.

	Surface unsupported ^{210}Pb concentration pCi g^{-1}	Unsupported ^{210}Pb inventory pCi cm^{-2}	Mean ^{210}Pb flux pCi cm^{-2} yr^{-1}	^{226}Ra Conc pCi g^{-1}	99% Equ. depth g cm^{-2}	Surface ^{137}Cs concentration pCi g^{-1}	^{137}Cs Inventory pCi cm^{-2}
Llyn Berwyn	14.2	9.7	0.30	0.77	1.51	46.9	30.5
Llyn Gynon	22.1	29.7	0.93	1.16	2.58	34.0	40.5
Llyn Hir	45.9	12.2	0.38	0.88	0.46	22.0	10.9

Table 7: CRS model dating chronology for the BER I core assuming no hiatus

Depth	Dry Mass	Cumulative Unsupported ^{210}Pb	Date	Age	Sediment accumulation rate		Standard
cm	g cm^{-2}	p Ci cm^{-2}	AD	yr	g cm^{-2} yr^{-1}	cm yr^{-1}	%
0.00	0.0000	9.70	1984	0			
0.50	0.0538	8.34	1979	5	0.0142	0.133	6.8
1.50	0.1615	6.97	1973	11	0.0153	0.143	7.5
2.50	0.2689	5.52	1966	18	0.0143	0.130	6.6
3.50	0.3762	4.38	1958	26	0.0134	0.117	5.7
4.50	0.4941	3.56	1952	32	0.0170	0.147	7.2
5.50	0.6119	2.90	1945	39	0.0207	0.177	8.6
6.50	0.7298	2.36	1939	45	0.0243	0.208	10.1
7.50	0.8477	1.92	1932	52	0.0280	0.238	11.5
8.50	0.9649	1.66	1927	57	0.0261	0.225	12.2
9.50	1.0821	1.44	1923	61	0.0242	0.213	12.9
10.50	1.1993	1.24	1918	66	0.0222	0.200	13.6
11.50	1.3062	1.03	1912	72	0.0201	0.182	16.1
12.50	1.4131	0.85	1906	78	0.0179	0.164	18.6
13.50	1.5201	0.71	1900	84	0.0157	0.147	21.0
14.50	4.6270	0.58	1894	90	0.0135	0.129	23.5
15.50	1.7276	0.37	1879	105	0.0084	0.080	25.1
16.50	1.8282	0.23	1864	120	0.0033	0.031	26.7

^{210}Pb flux = 0.30 +/- 0.01 pCi cm^{-2} yr^{-1}
90% Equilibrium Depth = 12.2 cm or 1.38 g cm^{-2} yr^{-1}
99% Equilibrium Depth = 17.5 cm or 1.94 g cm^{-2} yr^{-1}

Table 8: CIC dating model for the BER I core assuming no hiatus

Depth	Dry Mass	Cumulative Unsupported ^{210}Pb	Date	Age	Sediment accumulation rate	
cm	g cm^{-2}	p Ci cm^{-2}	AD	yr	g cm^{-2} yr^{-1}	cm yr^{-1}
0.00	0.0000	20.95	1984	0		
1.50	0.1615	14.17	1972	12	0.0140	0.131
3.50	0.3762	10.20	1962	22	0.0140	0.123
7.50	0.8477	2.14	1912	72	0.0181	0.154
10.50	1.1993	1.74	1905	79	0.0296	0.266
14.50	1.6270	1.35	1897	87	0.0390	0.372
16.50	1.8282	2.18	1912	72	0.0162	0.152
18.50	2.0532	0.52	1866	118	0.0162	0.136
19.50	2.1855	0.20	1836	148	0.0162	0.114

90% Equilibrium Depth = 14.6 cm or 1.64 g cm^{-2}
99% Equilibrium Depth = 19.4 cm or 2.18 g cm^{-2}

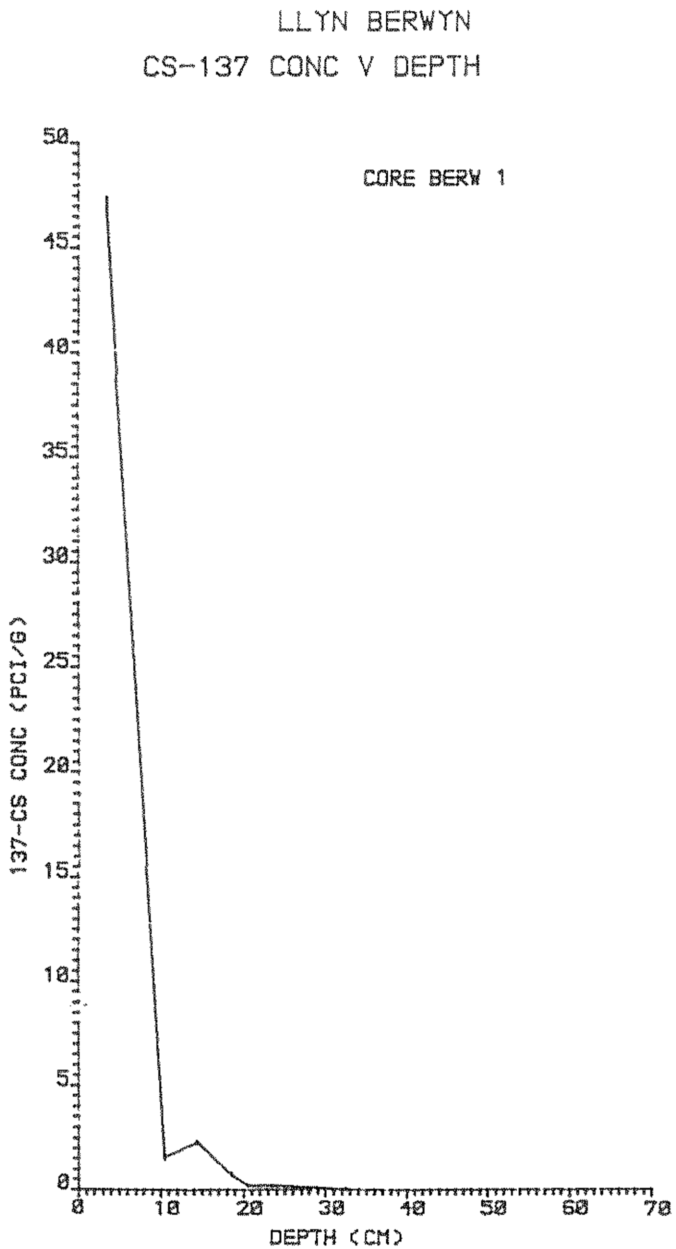


Fig. 11. ^{137}Cs profile for the Llyn Berwyn I core.

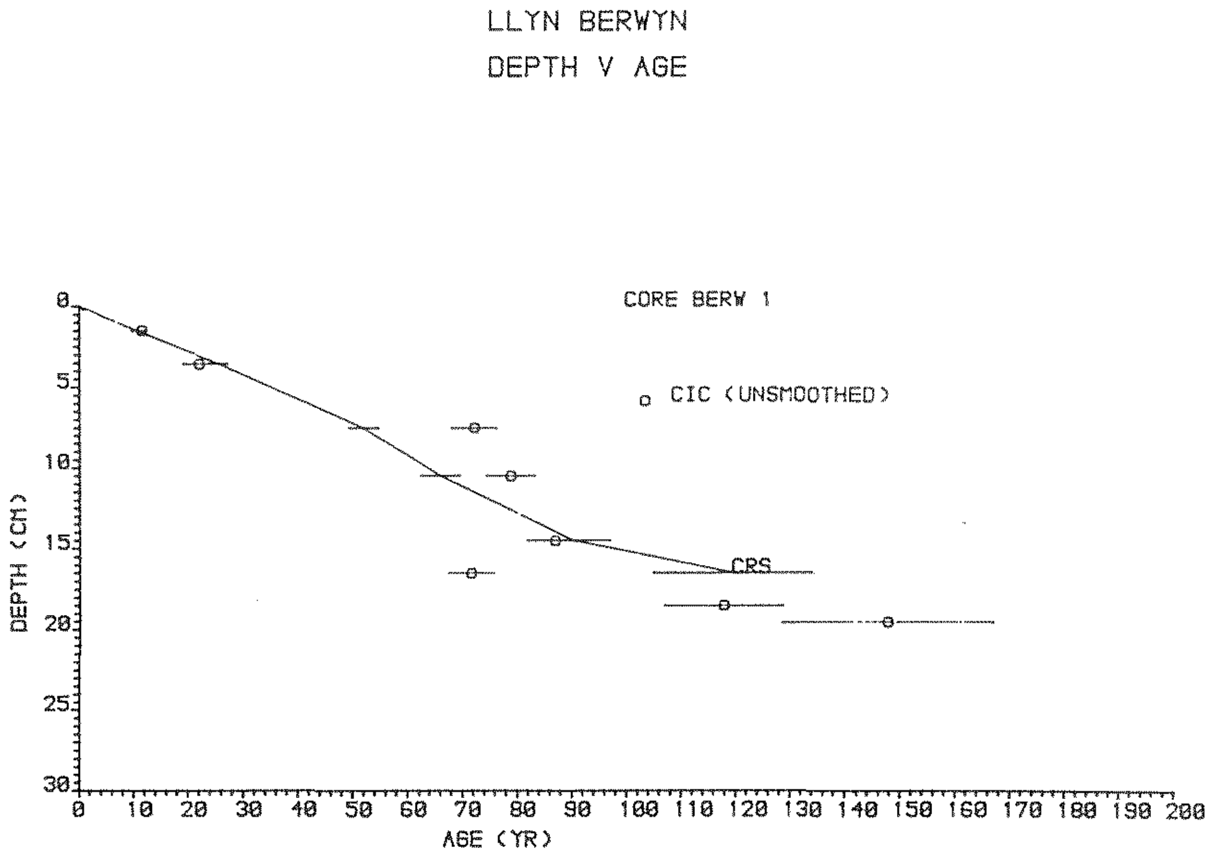


Fig. 12. CRS and CIC ^{210}Pb age/depth chronology for the Llyn Berwyn I core.

4.1.3 Diatom analysis

The concentration of total diatom cells per gram dry sediment is shown in Fig. 13. There is no major change in diatom concentration until 20 cm when there is a general decrease due to dilution by the inwash of organic material. However, from 30 - 20 cm the concentrations fluctuate, possibly due to dilution both by inwashed mineral material, and the large proportion of broken diatom frustules in some samples in this unit leading to inaccuracies in the total counts. At 5 cm the concentration increases to values higher than those found below 20 cm due to the decreasing sediment accumulation rate.

The major floristic changes can be seen in the summary diagram (Fig. 14). A full diagram of relative percentage abundance is given in Appendix C. The diatom flora throughout the core is dominated by periphytic acidophilous forms, increasing from 50%-60% from below 30 cm to 80%-90% in the upper organic unit. Conversely, circumneutral species decrease from 20%-30% below the mineral inwash to 5% in the upper organic unit.

A marked change in the diatom flora occurs at 25 cm when the percentages and concentrations of the circumneutral *Fragilaria virescens* and *Cymbella gracilis* and the alkaliphilous *Fragilaria construens* v. *venter* begin to decline as the acidophilous *Eunotia veneris* and *Frustulia rhomboides* become dominant in the percentage data but with unaltered concentrations in the sediment. At 20 cm the circumneutral species have almost disappeared and other acidophilous taxa, such as *Tabellaria flocculosa*, *Cymbella perpusilla*, *Eunotia exigua* and *Pinnularia hilseana* appear at this point. However, a major increase in the acidophilous species occurs at 15 cm including the rapid increase of *Asterionella ralfsii* which has the effect of depressing the percentage abundance of the previously dominant *Eunotia veneris*.

4.1.4 Sediment chemistry

Major Cations

The loss on ignition, dry weight and density profiles show that there is a major change in sediment constitution between 18 and 30 cm (Fig. 8). From the base of the core to 30 cm the sediment constitution is fairly constant but above this is a denser more inorganic layer from 30 to 23 cm, with a much more organic layer above this. This change is a result of catchment ploughing and afforestation (Section 4.2.2).

The sodium, potassium and magnesium profiles respond to this catchment disturbance (Figs. 15a, 16a, 17a). The concentrations increase in the more inorganic layer and decrease strongly in the organic layer. The strong negative correlation between these cation concentrations and LOI indicates that dilution of the sediment by the additional organic material delivered to the lake as a result of the disturbance is the main cause of the decrease in sedimentary concentrations in the upper 18 cm of sediment.

This is confirmed by the cation profiles when the concentrations are expressed per gramme of minerals in the sediment (Fig. 15b, 16b, 17b). In these profiles the concentration drop above 23 cm, which is striking in

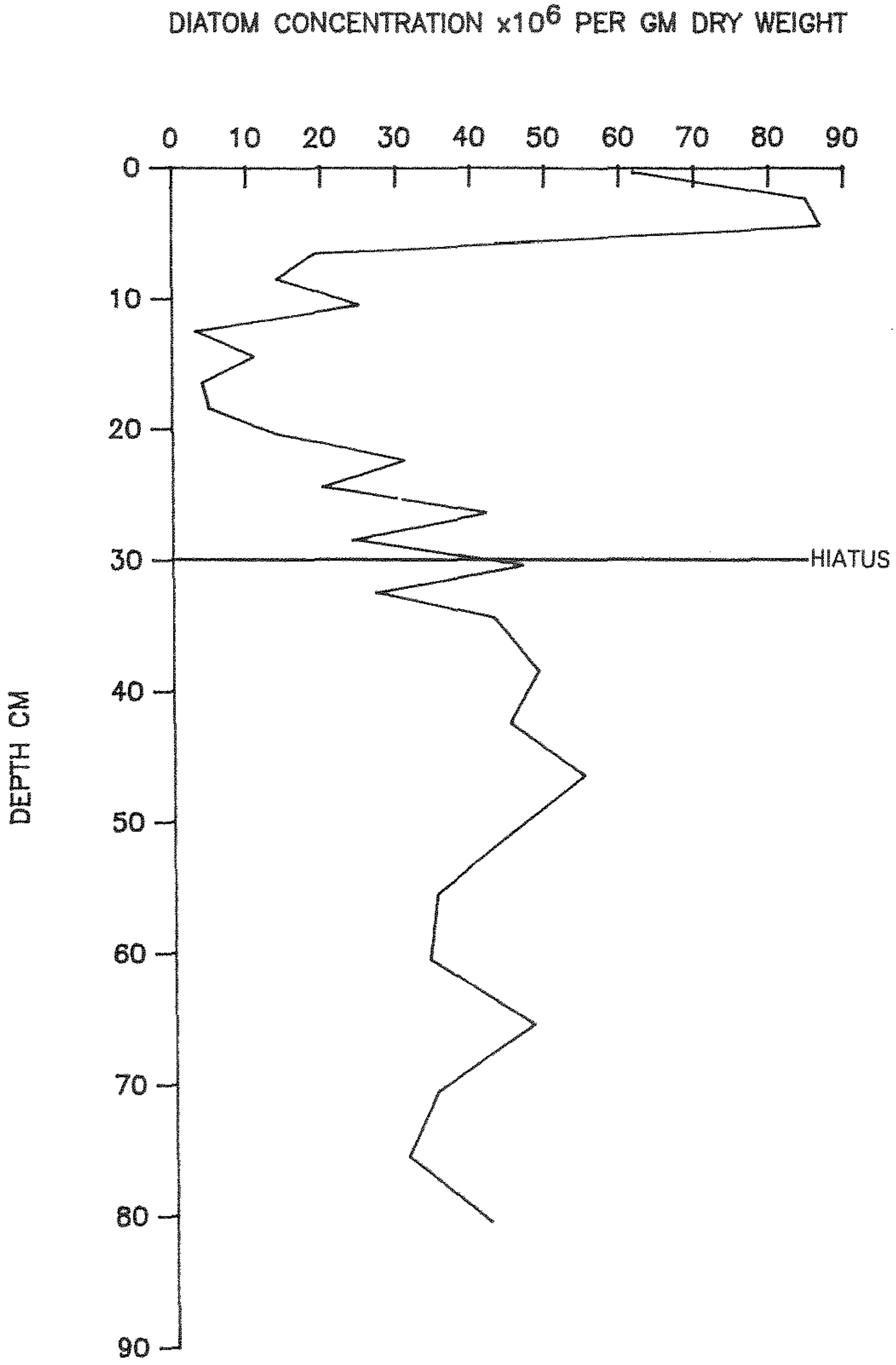


Fig. 13. Diatom concentration diagram for the Llyn Berwyn I core.

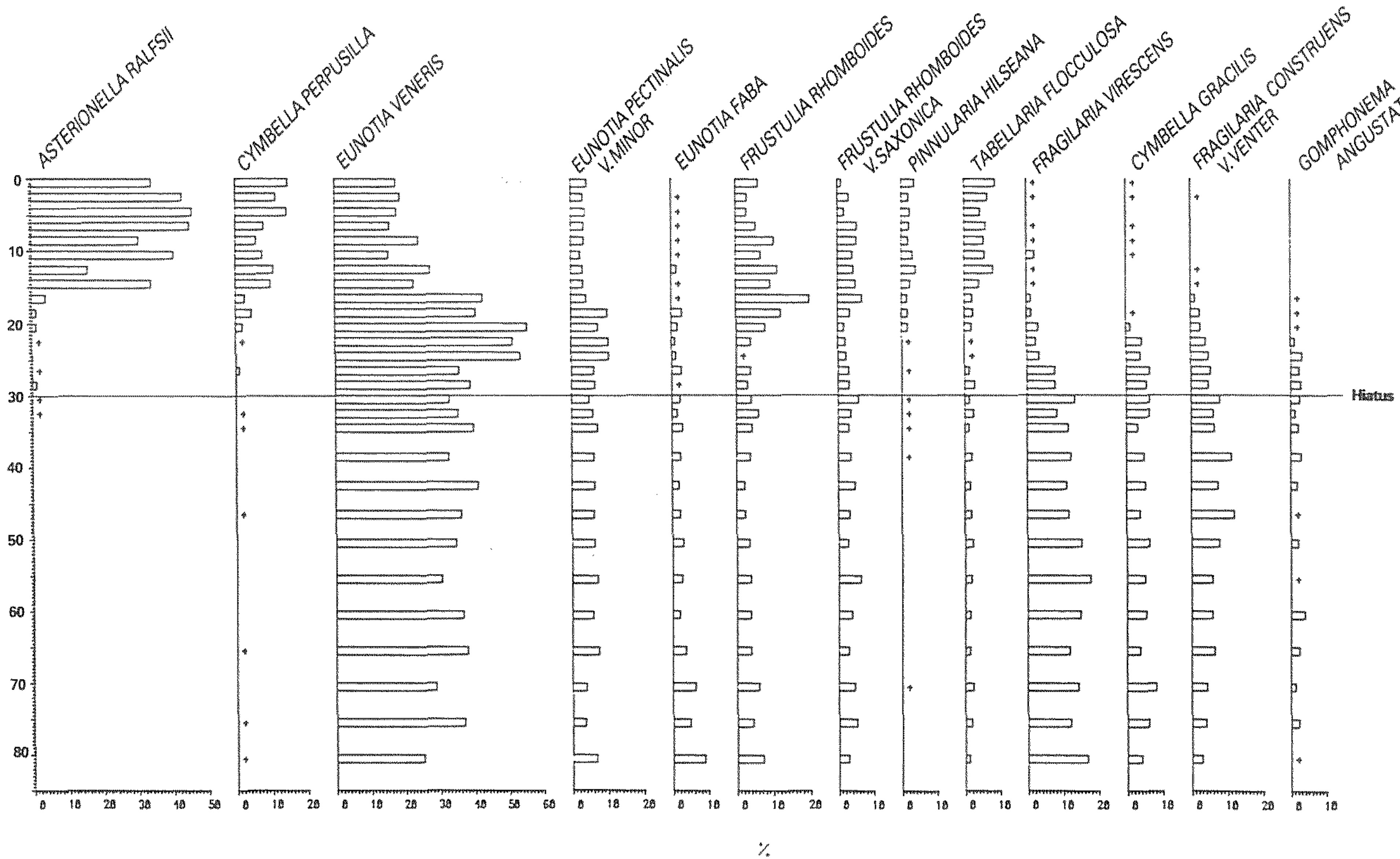


Fig. 14. Diatom percentage summary diagram for the Llyn Berwyn I core.

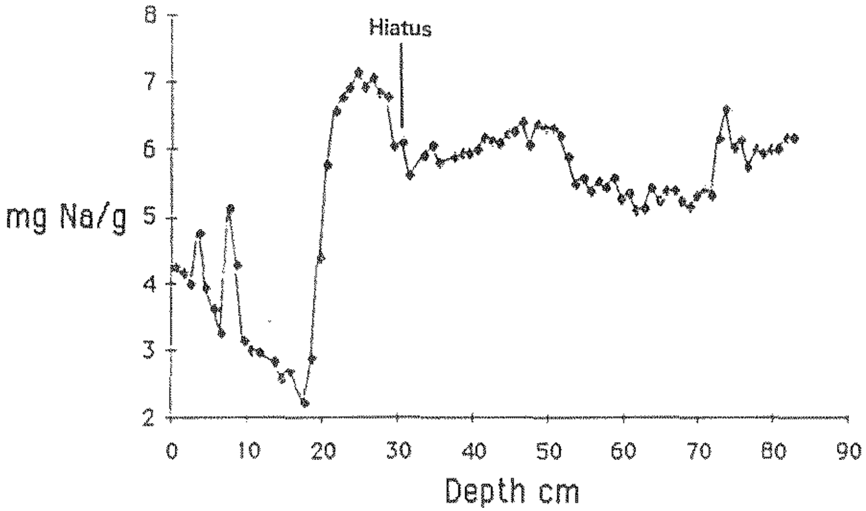


Fig. 15a. Variations in Na gdw^{-1} for the Llyn Berwyn I core.

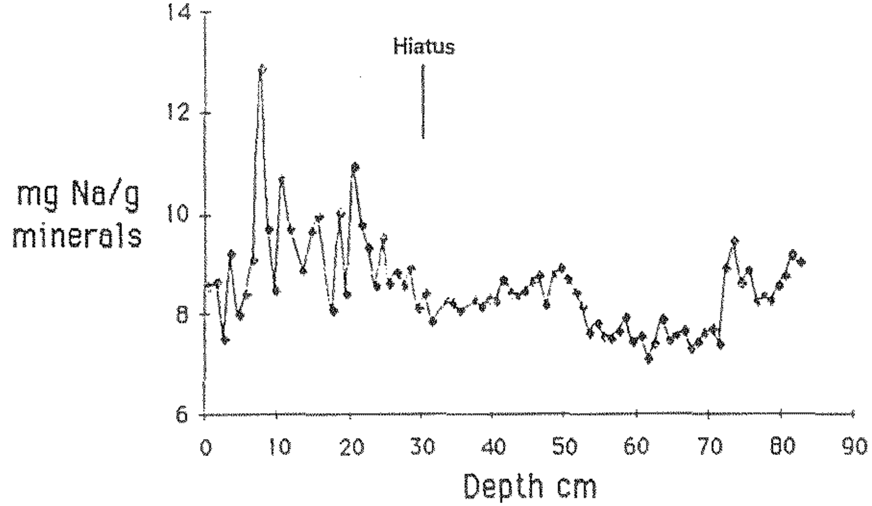


Fig. 15b. Variations in Na per gram mineral dry weight for the Llyn Berwyn I core.

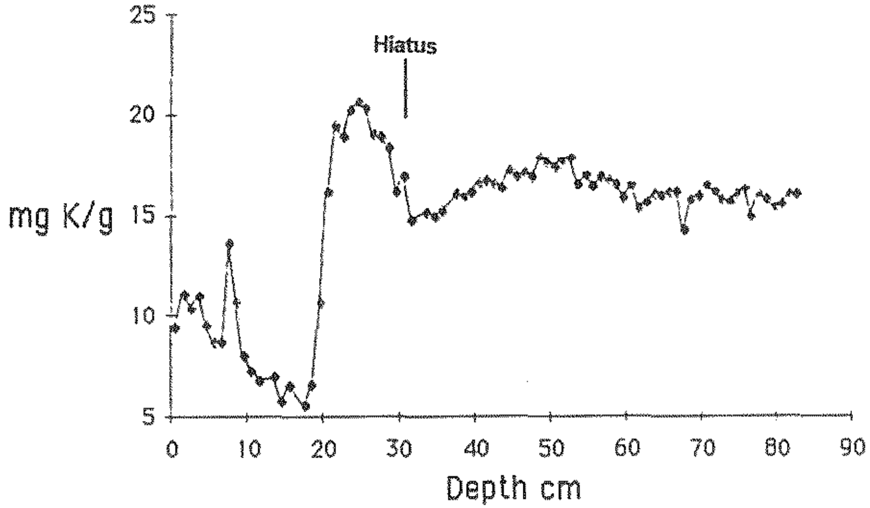


Fig. 16a. Variations in K gdw^{-1} for the Llyn Berwyn I core.

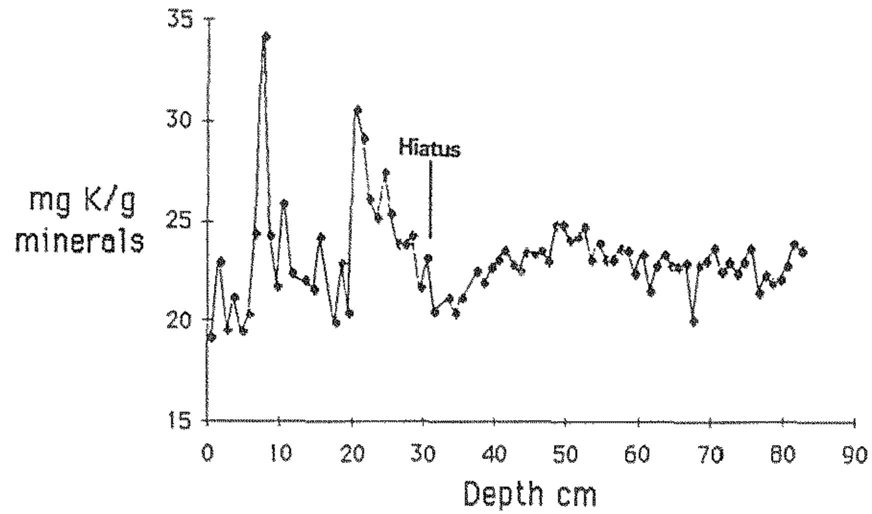


Fig. 16b. Variations in K per gram mineral dry weight for the Llyn Berwyn I core.

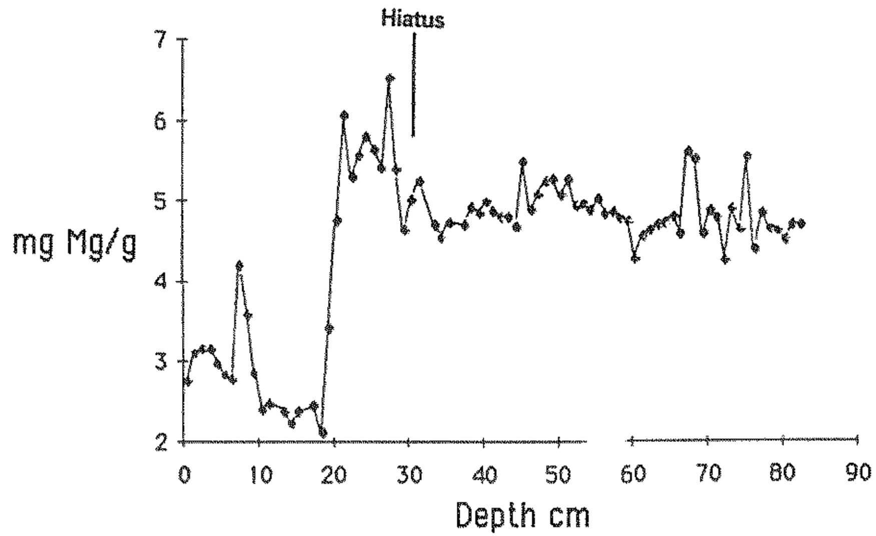


Fig. 17a. Variations in Mg gdw^{-1} for the Llyn Berwyn I core.

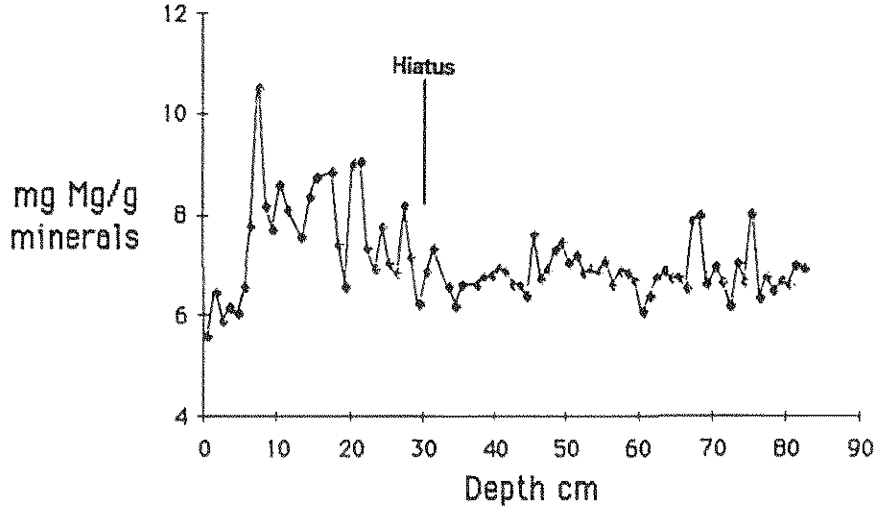


Fig. 17b. Variations in Mg per gram mineral dry weight for the Llyn Berwyn I core.

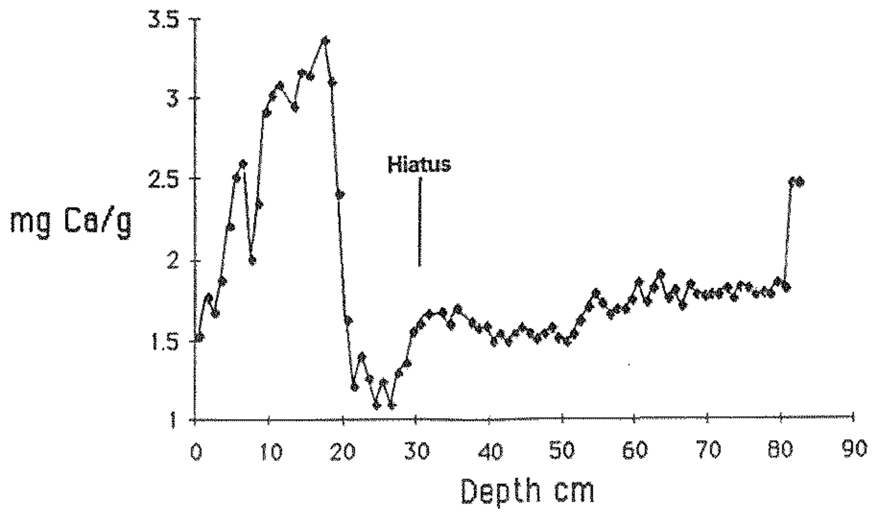


Fig. 18a. Variations in Ca gdw^{-1} for the Llyn Berwyn I core.

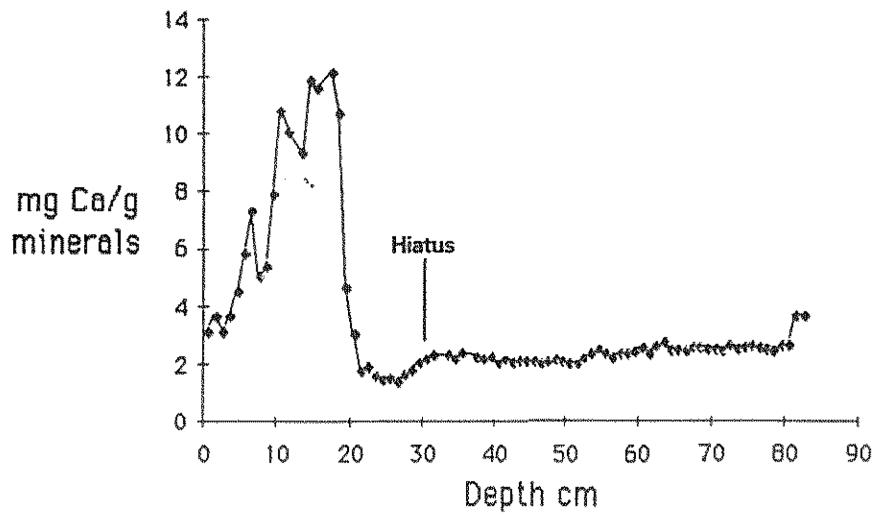


Fig. 18b. Variations in Ca per gram mineral dry weight for the Llyn Berwyn I core.

Figs. 15a-17a, is not noticeable with magnesium and sodium and is much subdued with potassium. When soil erosion rates increase in a catchment, the tendency is for the major cation concentration of the mineral material to be higher than when erosion rates are lower (Mackereth 1966, Engstrom & Wright 1984). Although the timescale is short in the upper part of this core, the concentrations of potassium and magnesium are higher than above 30 cm during the period of catchment disturbance. Magnesium is maintained at a higher concentration through the inorganic layer while potassium drops back to concentrations typical of the lower part of the core.

Calcium behaves very differently to the other three major cations (Fig. 18) and correlates strongly with LOI (Fig. 8) This was also found in Llyn Hir and the reasons are probably the same. Bivalent calcium ions are selectively complexed by dissolved humic material in the lake water and sediment (Stumm & Morgan 1981 pp. 640-647, Sayles and Mangelsdorf 1977) and so variations in the rate of incorporation of organic material into the sediment controls the sedimentary calcium concentration.

Trace metals

The nickel behaviour (Fig. 19) is similar to the major cations, sodium, magnesium and potassium (Figs. 15-17). As the nickel concentration in the mineral component of the sediment is fairly constant (Fig. 19b), the drop in nickel concentration in the whole sediment between 11 and 20 cm is due to dilution of the sediment by the addition of organic matter (Fig. 8). There is little if any atmospheric contamination of the sediment by nickel.

In the upper 20 cm of sediment, however, the zinc (Fig. 20), lead (Fig. 21) and copper (Fig. 22) concentrations increase. This increase is in spite of the sediment dilution by organic matter which causes the sodium, magnesium and potassium and nickel concentrations to fall. The sediment contamination is made clearer when the changes in organic content of the sediment are eliminated by expressing the results as per gramme minerals (Figs. 20b-22b).

Because of the hiatus in this core (Section 4.1.2) it is not possible to determine the date when trace metal contamination of the sediment started. As the sediments above 20 cm are post-1974, the contamination started sometime before this. Other lakes which have also received trace metals deposited from the atmosphere show a steady increase in sedimentary trace metal concentration from the depth when contaminated. As the zinc and lead concentrations rise very quickly above 20 cm (1974) in Llyn Berwyn, it is likely that the contamination started some tens of years before 1974. It is also not possible to determine reliably the size of this contamination flux. We can, however, use the trace metal results to check on the proposed sediment chronology above 20 cm.

We can use the proposed sediment chronology to calculate the sedimentary fluxes of the trace metals and other elements. If this gives values which are environmentally reasonable then there is indirect support for the dating. The mean sedimentary fluxes for the eight elements in the interval 0 - 20 cm are shown in Table 9. As this interval in the Llyn Berwyn core is during a period of catchment disturbance, we feel it is realistic to compare the results with those measured under catchment disturbance conditions elsewhere. In Loch Dee, in Galloway, the interval from 31 - 66 cm corresponds to a period of catchment disturbance (1859 - 1901). These

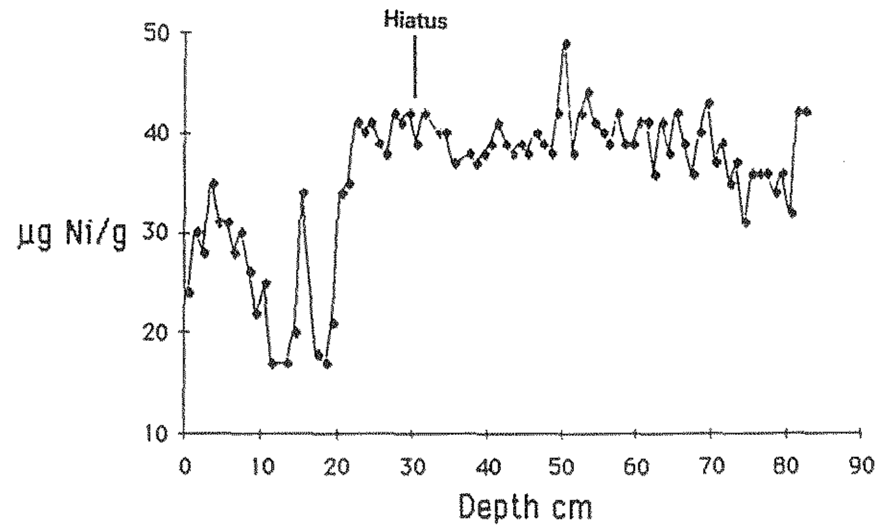


Fig. 19a. Variations in Ni gdw^{-1} for the Llyn Berwyn I core.

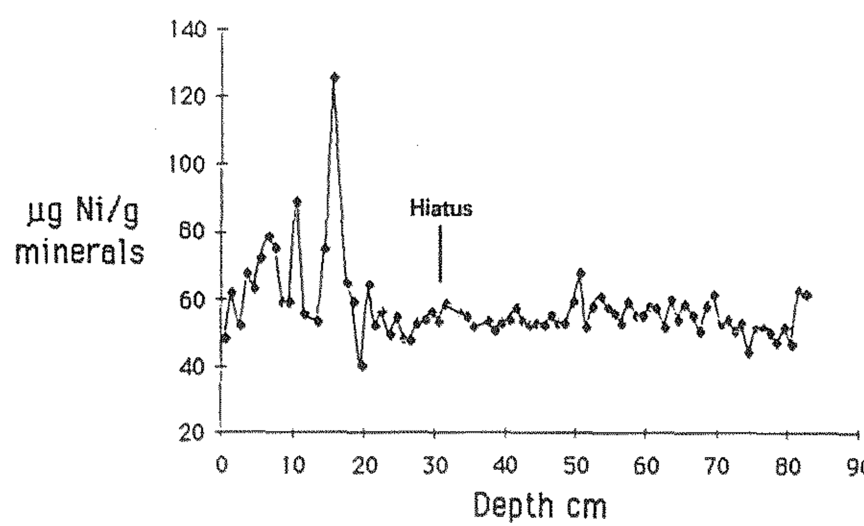


Fig. 19b. Variations in Ni per gram mineral dry weight for the Llyn Berwyn I core.

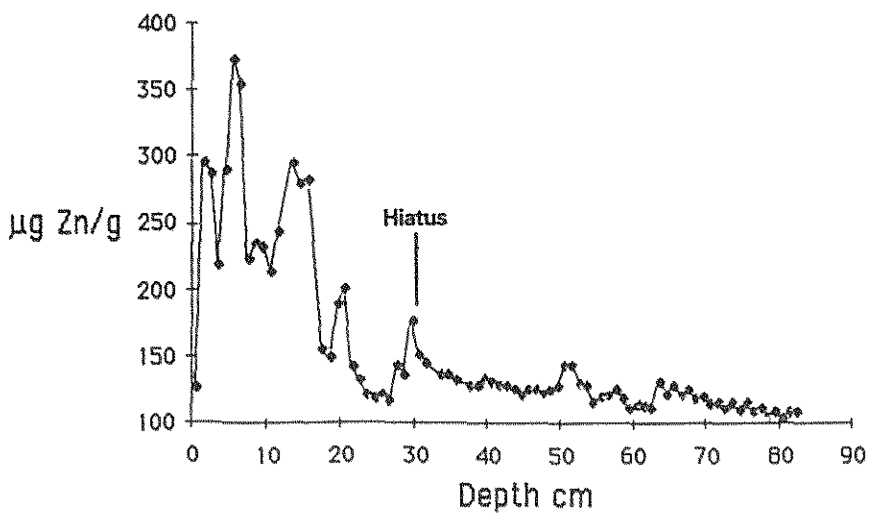


Fig. 20a. Variations in Zn gdw^{-1} for the Llyn Berwyn I core.

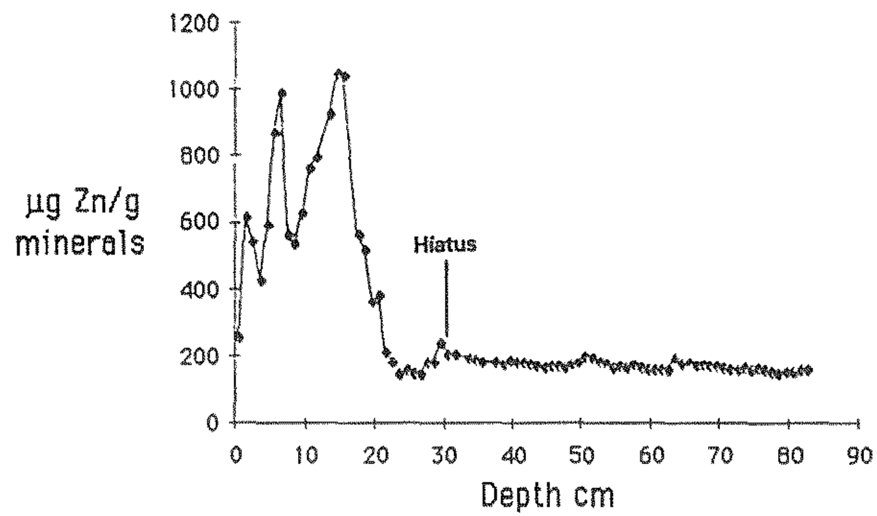


Fig. 20b. Variations in Zn per gram mineral dry weight for the Llyn Berwyn I core.

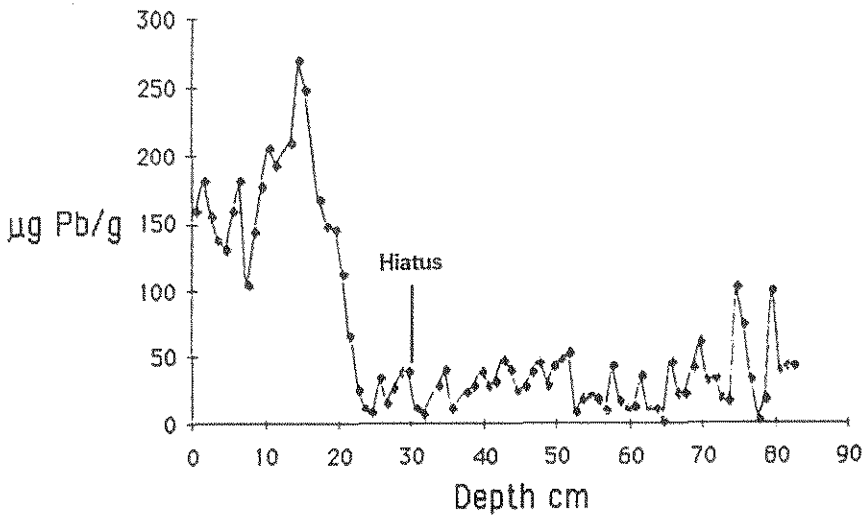


Fig. 21a. Variations in Pb gdw^{-1} for the Llyn Berwyn I core.

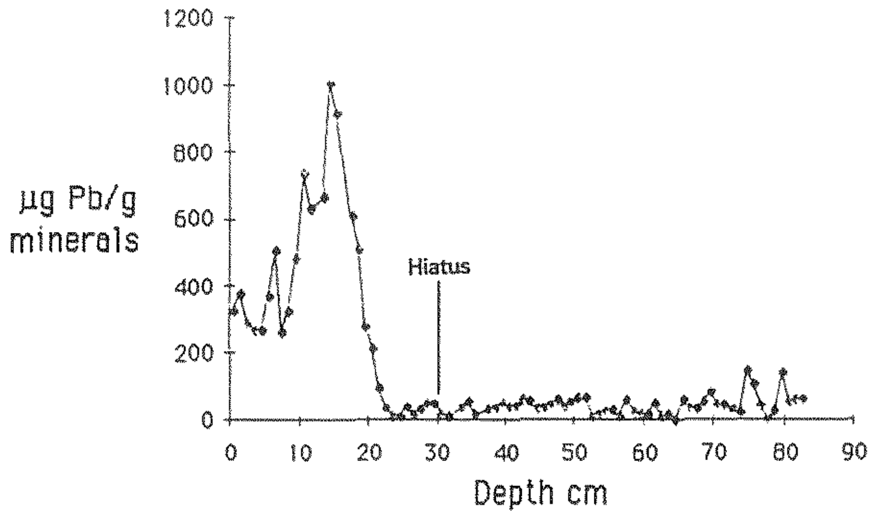


Fig. 21b. Variations in Pb per gram mineral dry weight for the LLyn Berwyn I core.

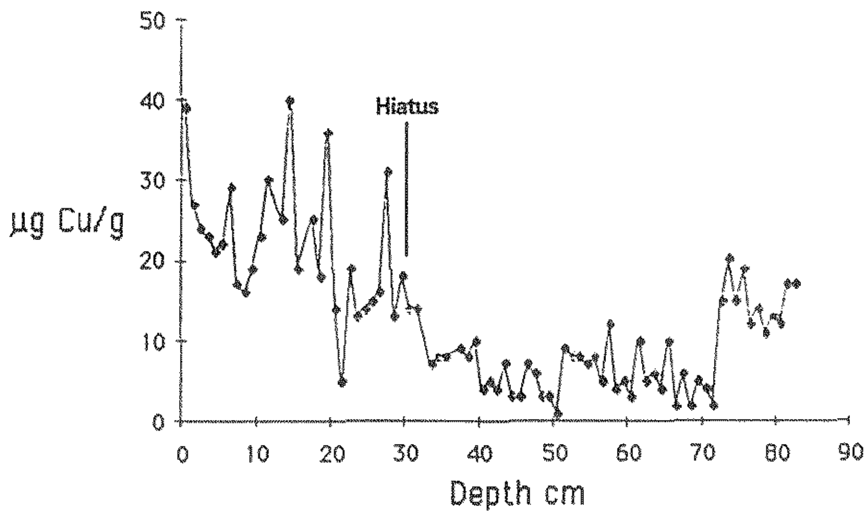


Fig. 22a. Variations in Cu gdw^{-1} for the Llyn Berwyn I core.

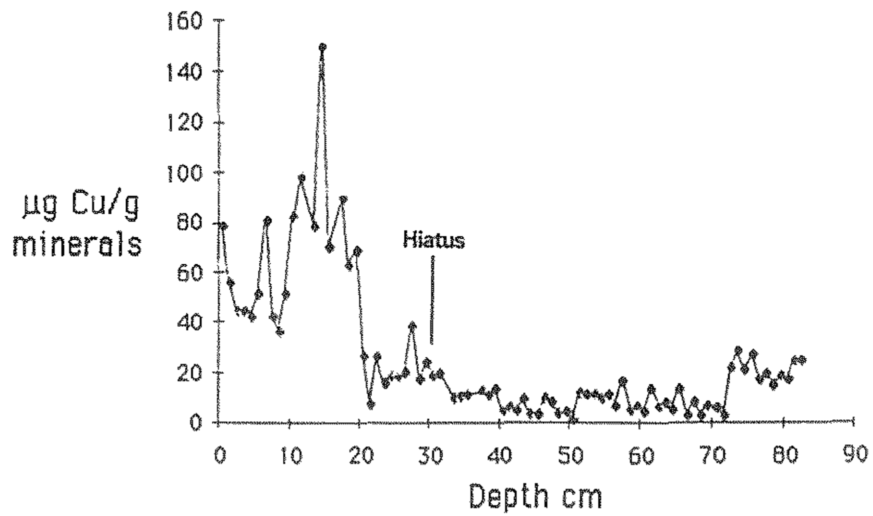


Fig. 22b. Variations in Cu per gram mineral dry weight for the Llyn Berwyn I core.

mean values are averaged over their respective time intervals.

Table 9 indicates that the major element and trace metal fluxes in the upper 20 cm of the Llyn Berwyn core vary from roughly similar to three times those measured during the catchment erosion period in Loch Dee. As the dry mass accumulation rate in Llyn Berwyn is roughly three times that in Loch Dee, the sedimentary fluxes of metals in Berwyn, then, are environmentally realistic. As they are derived from the proposed sediment dating, this must also be reasonable.

We are not able to extract from the total sedimentary trace metal fluxes reliable values for the contamination component. Cumulative concentration-depth profiles, a comparison of the zinc flux behaviour with that of sodium and a flux calculated from the 'anthropogenic pollution term' as defined by Hilton et al. (1985) all suggest a zinc contamination flux of around 100 mg m^{-2} yr^{-1}. This is a reasonable figure but it must be considered unreliable.

Table 9: Comparison of the element fluxes during erosive periods in Llyn Berwyn & Loch Dee

Element	Llyn Berwyn, 0 - 20 cm Mean (n=18)	Loch Dee 31 - 66 cm Mean (n=24)
Na g m^{-2} yr^{-1}	7.4	5.3
K g m^{-2} yr^{-1}	18.1	6.0
Ca g m^{-2} yr^{-1}	5.2	6.2
Mg g m^{-2} yr^{-1}	5.9	8.6
Zn mg m^{-2} yr^{-1}	501	209
Pb mg m^{-2} yr^{-1}	349	191
Cu mg m^{-2} yr^{-1}	52	22
Ni mg m^{-2} yr^{-1}	52	50
Dry mass accumulation rate mg m^{-2} yr^{-1}	210	70

Sulphur

The sulphur behaviour (Fig. 23) is similar to that of lead (Fig. 21). The same limitations of interpretation apply as with lead and all we can say is that post-1974 sediments are contaminated by sulphur compounds deposited from the atmosphere.

PAH

Analyses are in progress but are not yet available.

4.1.5 Carbonaceous particles "CP"

The "CP" pattern for Llyn Berwyn, illustrating the number of particles per gramme dry sediment, is given in Fig. 24 and Table 10. It shows the presence of soot in small numbers at a depth of 28 cm. There is a slight peak at 10-12 cm and the onset of a trend of rapidly increasing counts commences at 6 cm, continuing to the surface.

The carbonaceous particle count in terms of the organic content of dry

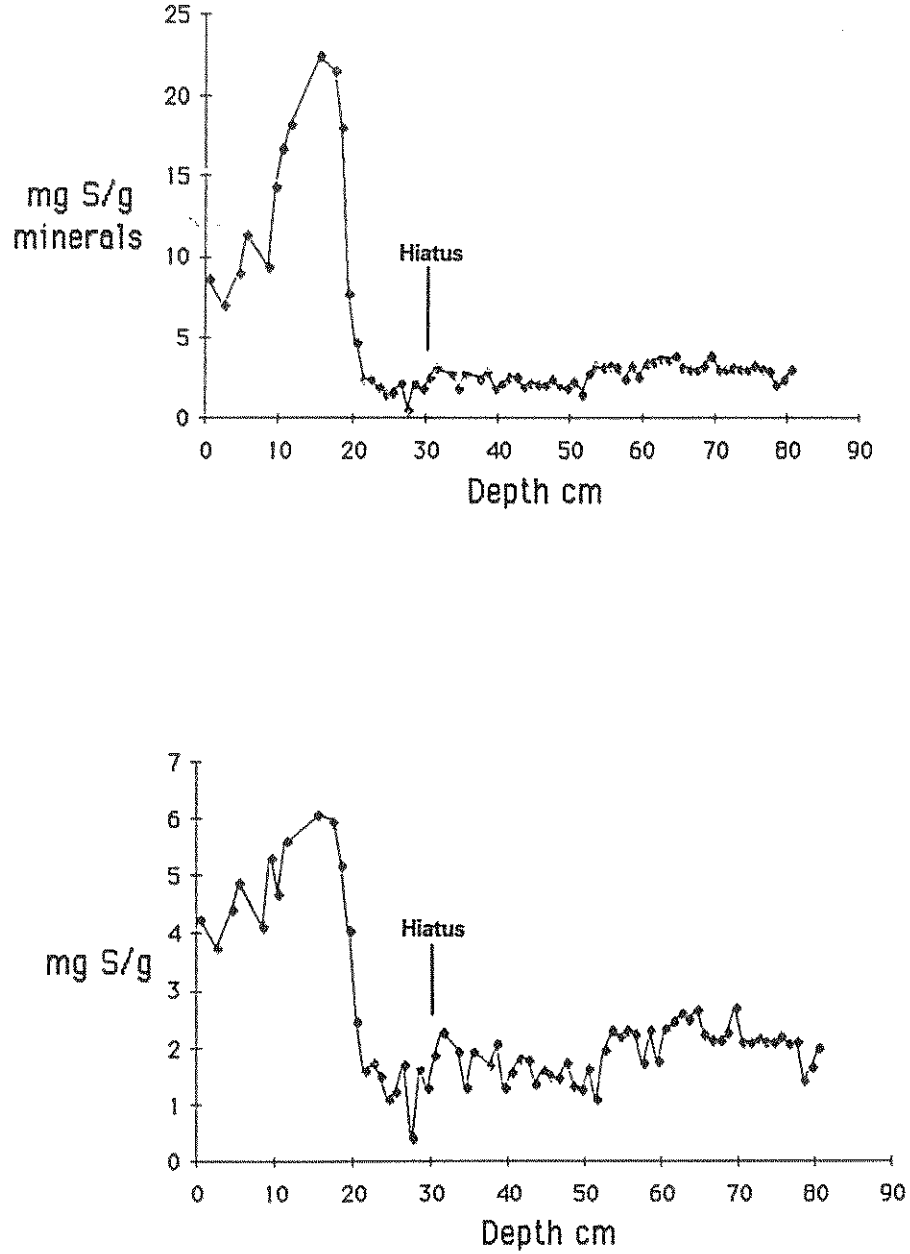


Fig. 23. Variations in S gdw^{-1} for the LLyn Berwyn I core.

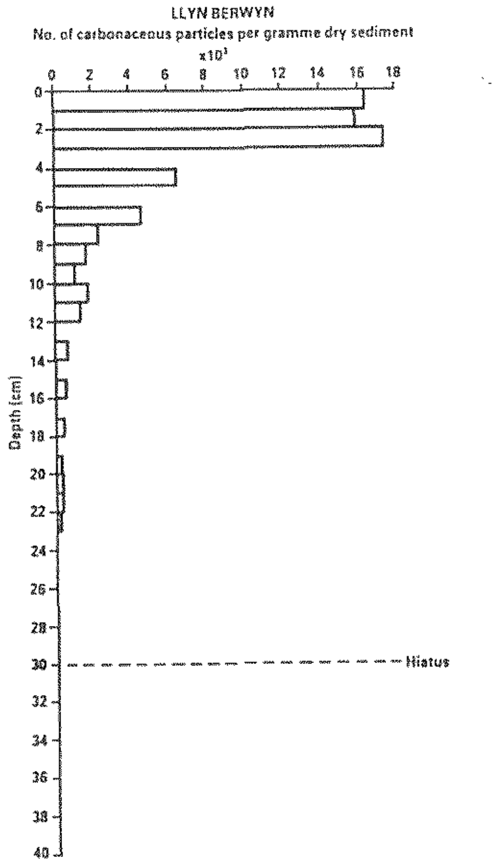


Fig. 24. Carbonaceous particle record gdw^{-1} for the Llyn Berwyn I core.

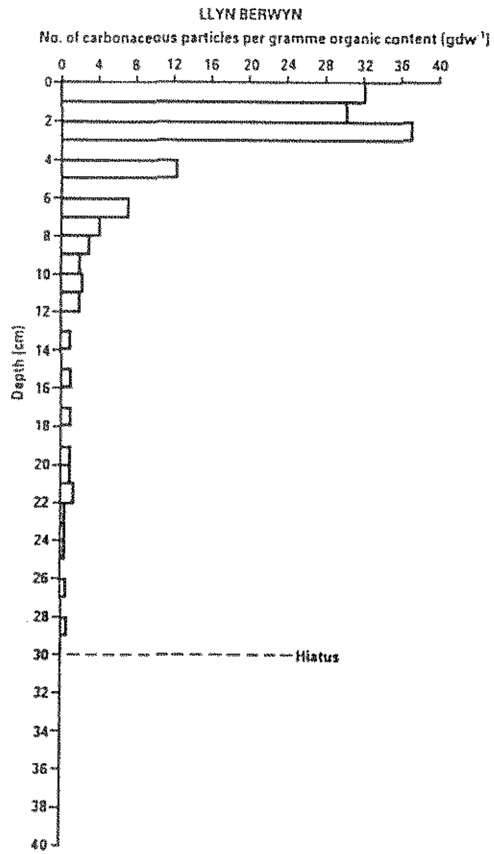


Fig. 25. Carbonaceous particle record per gram mineral dry weight for the Llyn Berwyn I core.

Table 10: "Soot" Analysis for Berwyn 1

Depth (cm)	No. Carbonaceous Particles per g dry sed x 10^3	No. Carbonaceous Particles per g organic content x 10^3
0-1	16.38	32.34
1-2	15.84	30.64
2-3	17.38	37.20
4-5	6.40	12.61
6-7	4.58	7.13
7-8	2.26	3.76
8-9	1.72	3.07
9-10	1.07	1.70
10-11	1.77	2.46
11-12	1.37	1.98
13-14	0.68	1.00
15-16	0.58	0.80
17-18	0.51	0.71
19-20	0.34	0.71
20-21	0.37	0.79
21-22	0.41	1.25
22-23	0.10	0.36
23-24	0.04	0.20
24-25	0.05	0.20
25-26	-	-
26-27	0.06	0.30
28-29	0.06	0.25
29-30	-	-
31-32	-	-
35-36	-	-
39-40	-	-

sediment is given in Fig. 25. Normally, CP patterns in terms of the organic fraction of sediment (using LOI) are 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. However, since both organic and inorganic fluxes to the lake vary widely only an expression of CP in terms of flux will enable an accurate assessment of CP influx into the lake basin. However, there are no reliable dates on which to make the calculation.

4.1.6 Pollen

Figs. 26, 27 & 28 present the total pollen concentration & summary percentage diagrams for the Llyn Berwyn core. Full details of the pollen record may be found in Appendix E.

Inspection of the concentration diagram (Fig. 26) reveals that the diagram can be divided into two major sections viz: the pre-inwash, undated, portion and the post-inwash, dated portion of the core. This division is shown by a halving of the pollen concentration from 28 cm to 24 cm and is firstly associated with a mineral inwash and then by a subsequent peat inwash.

The pre-inwash part of the percentage diagrams (Figs. 27 & 28) shows a relatively stable pollen sequence with few major changes occurring throughout. The only local change that appears to have occurred is the early peak in *Pteridium*, suggesting that the catchment may have been better drained at some period in the past. Within the regional pollen record most of the tree pollen is probably derived from small remnants of relict deciduous forest, dominated by *Betula* and *Quercus*, left over from the various clearance phases of upland Wales recorded in the many pollen diagrams of this area (Moore and Chater 1969a, Moore and Chater 1969b, Moore 1973). Small disturbance phases in these forests are recorded by the two peaks in *Plantago lanceolata* and *Filipendula* and associated regeneration peaks in *Fraxinus*.

The sediment post-inwash (28 cm - 0 cm) provides clear evidence for changes in the catchment vegetation. However, most of the changes can be misleading since most are directly related to the inwash of peats and the inevitable reworking of their older pollen component into the lake. The initial mineral inwash only appears to have had an effect on the pollen concentration diagram. It is only with the marked increase in LOI, resulting from catchment peat erosion, that changes can be identified in the pollen record. The most notable of these is the large reduction in values of the aquatic fern, *Isoetes*, from 20 cm onwards. As in previous studies, *Isoetes* appears to be very sensitive to turbidity changes associated with phases of peat inwash and general catchment disturbance (Anderson *et al.* 1986). The *Calluna* rise recorded at the same time is not the result of an increase in *Calluna* in the catchment but is merely a reflection of the inwash of large amounts of *Calluna* pollen-rich peats into the lake. The present afforestation of the lake does not appear to be reflected in the pollen diagram but may also be linked to the masking effect of the inwashed pollen-rich catchment peats.

The regional pollen flora suggests that *Quercus* expands during this zone but this rise is only caused because the dilution of the *Quercus* pollen rain by the peat inwash is relatively lower than that of *Pinus* and hence the

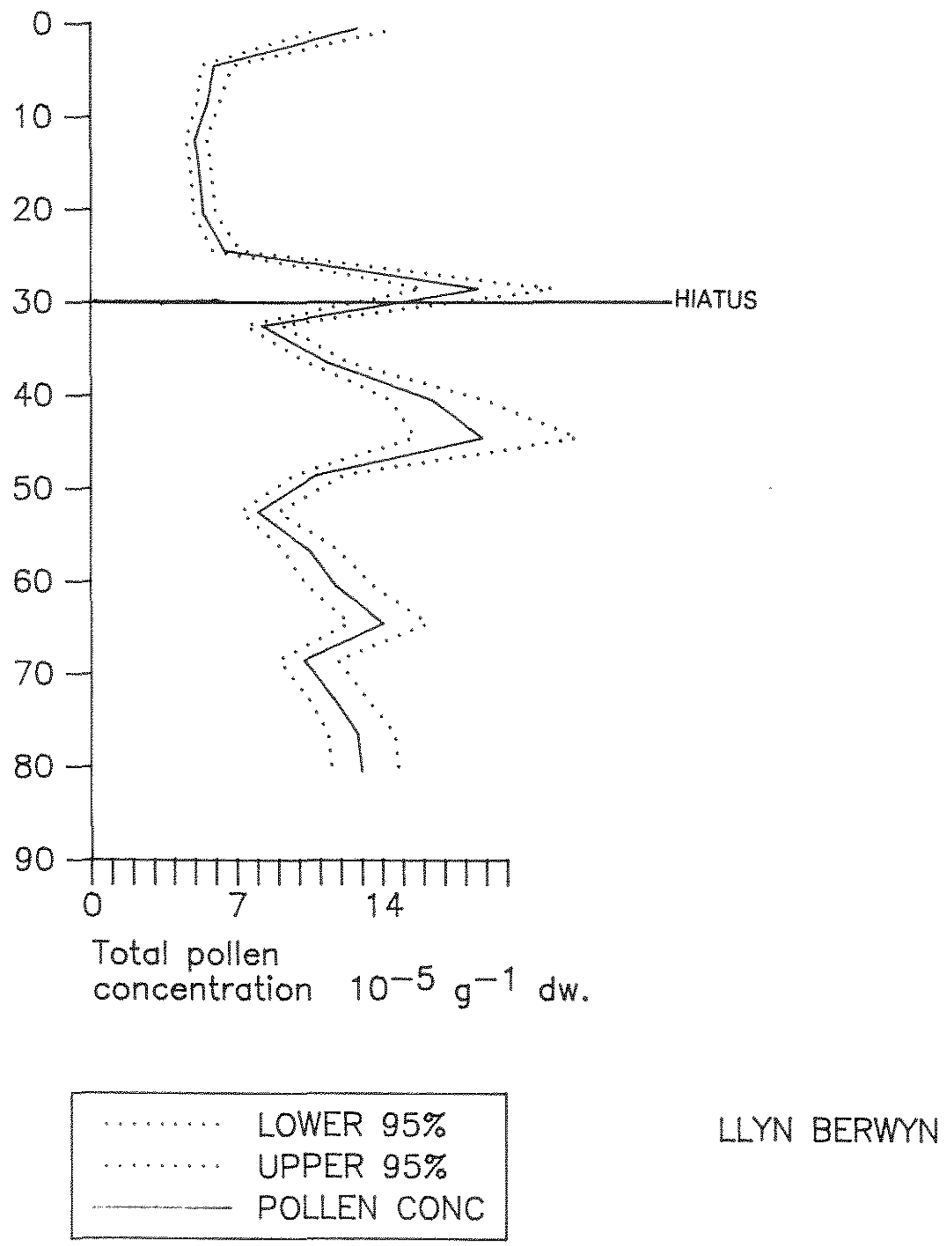


Fig. 26. Total pollen concentration diagram for the Llyn Berwyn I core

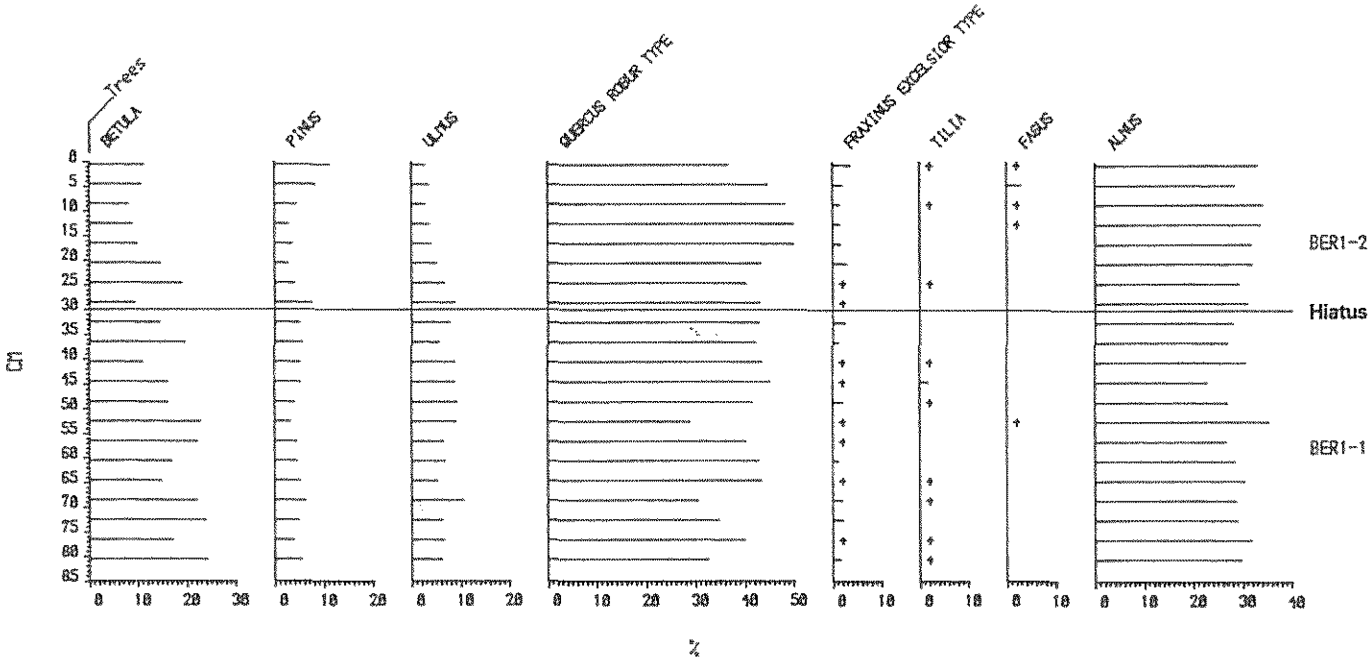
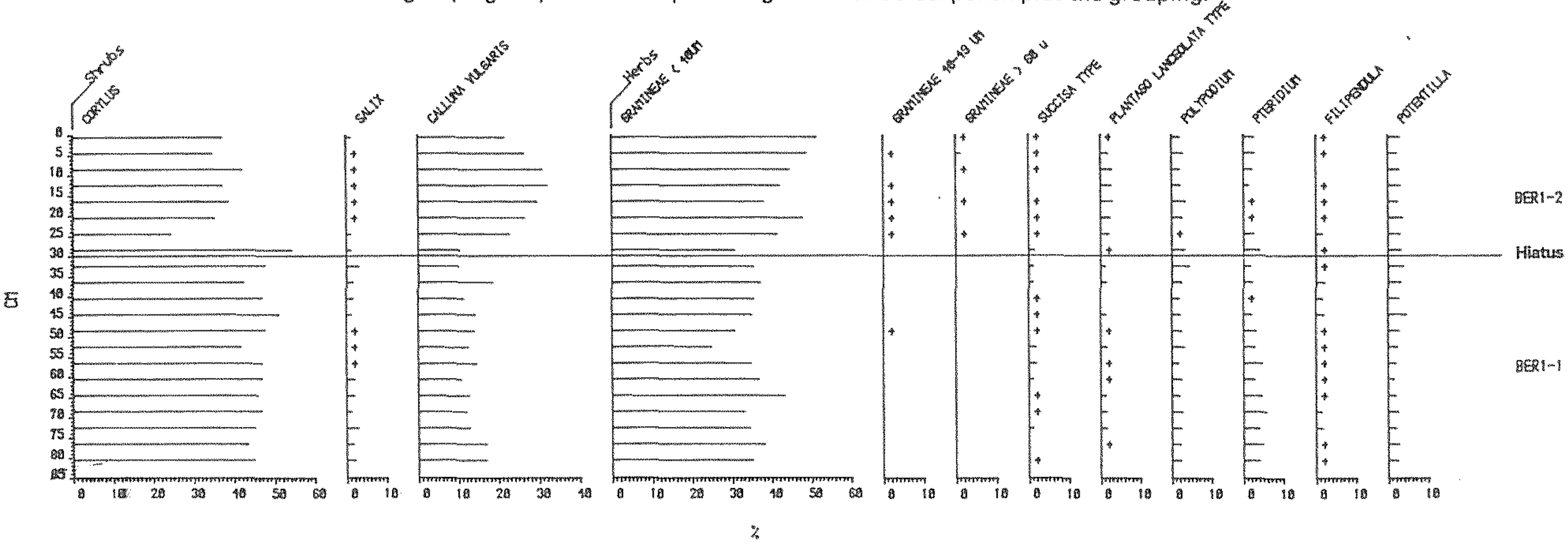
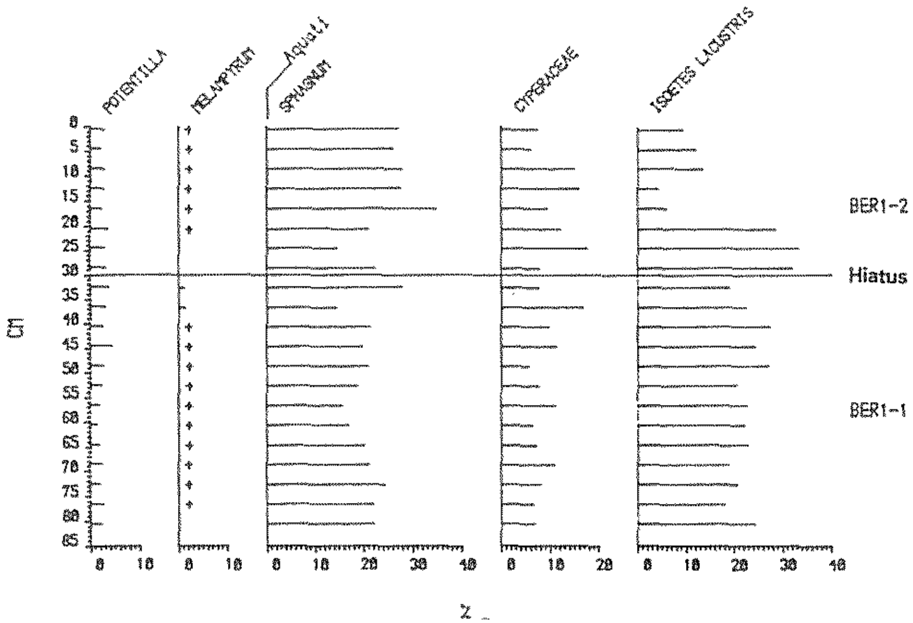


Fig. 27. Summary percentage pollen diagram for the Llyn Berwyn I core. Trees expressed as a percentage of the Arboreal pollen. All other groupings expressed as a percentage of the Arboreal pollen plus the grouping.





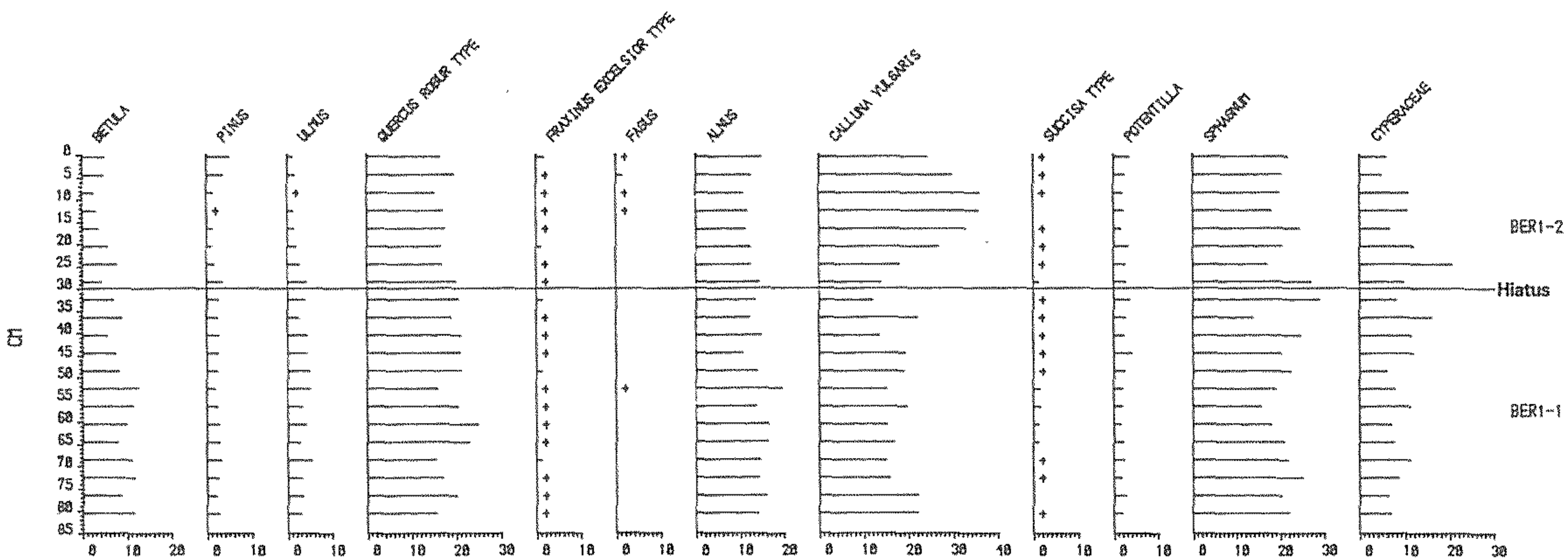


Fig. 28. Summary percentage pollen diagram for the Llyn Berwyn I core. Taxa expressed as a percentage of those shown

proportional construction of the diagram presents a misleading picture of events. The inwash, is also probably the reason why Pinus values take off relatively late since the concentration diagram reveals that Pinus concentrations were as high before the onset of the inwash as they were at the end of the period.

Regional changes in the amount of pastoral and arable land appear to be reflected in the pollen record as a peak of the pastoral indicator Plantago lanceolata is replaced by a cereal peak. Indicating a change from pastoral to arable in the vicinity of the lake.

4.2 Land use and management (2)

4.2.1 Land use

With the exception of small areas of Molinia dominated rough grazing to the north-east and south, the catchment is planted with Sitka spruce (Picea sitchensis), Lodgepole pine (Pinus contorta) and Japanese larch (Larix kaempferi) (Fig. 6).

The catchment was afforested between 1960-1963 (Fig. 6). Before that date documentary sources (Patrick 1986) indicate that the catchment comprised rough grazing land of the 'moorland core'. There is no evidence from air photographs or on the ground (of relict enclosures, drainage or cultivation features) to suggest that any improvement was ever attempted. There is no evidence for, nor rational expectation of, any attempt to improve the acid upland soils of the catchment with agricultural lime (cf Fritz et al. 1986).

The tithe map of the combined parish of Caron (3) (the lake and catchment lie predominantly within the parish of Caron-is-Clawdd, with a small section at the extreme south lying in Llanddewi Brefi -) indicates that in 1842 the catchment comprised the sheepwalk land belonging to three individual farms.

Successive editions of the Ordnance Survey six inch topographic coverage (4) from 1887 show the land adjacent to the lake to be 'marshy'. Further back marsh gives way to 'rough or heathy pasture'.

The first Land Utilisation Survey of 1933 (5) provides no specific information on vegetation distribution within the catchment. The area is described as 'typical sheepwalk' composed largely of Molinia, Agrostis/Festuca and Nardus.

The catchment lies in the area which Davies (1936) described as some of the most dense Molinia tussock land in Wales. The second Land Utilisation Survey of 1970 (6) shows Molinia dominating the unafforested part of the catchment as it does today.

Analysis of air photographs (7) and primary data of the 'Mid Wales uplands Survey' (Parry and Sinclair 1985) (8), confirms the unimproved state of the catchment in 1946 and 1948 respectively.

Several contemporary descriptions attest to the unimproved nature and in particular the wetness of the catchment prior to afforestation (eg. Bradley 1903, Ward 1931). Cliffe (1860) described it as "a shelterless waste", "a more wild, dreary scene than that which surrounds the Llyn would be difficult to conceive" (p.204).

The forest planted in the early 1960s is still maturing and no deforestation has taken place.

There is no evidence of the exploration for, or the exploitation of, any mineral within or in the vicinity of the catchment.

4.2.2 Land management

Pastoralism

At an altitude of over 400m and comprising wet and exposed land, it is unlikely that the Llyn Berwyn catchment ever supported a significant livestock population. Although a few cattle were grazed on the hills in the locality in summer up to ca. 1930 (R. Hughes pers. comm.), the grazing history of the catchment is dominated by sheep.

Annotated information on the First Land Utilisation Survey map (1933) indicates that sheep grazed the catchment in summer only. Davies (1936) reported that the tussocky *Molinia* of this region received virtually no grazing.

Evidence for the presence of sheep is indicated by a sheep wash, depicted on six inch Ordnance Survey maps, to the west of the lake.

Some areas of *Molinia* were cut for hay which until recently represented the only winter fodder in the region (R. Hughes pers. comm.). Other areas were frequently burnt to provide an early bite for the sheep (R. Hughes pers. comm.).

Apart from a boundary fence separating Cwm Berwyn and Diffwys sheepwalks there was no enclosure in the catchment.

The only evidence concerning sheep numbers comes from the annual parish agricultural returns (9). The interpretation of these data are subject to several constraints (Patrick 1986). In particular they cannot be catchment specific and take only limited account of changes in sheep type and no account of changes in grazing regime.

Parish returns are available for Caron-is-Clawdd from 1910 (Fig. 29). There was a gradual rise in sheep numbers up to the plantation of the catchment in 1960. From that period sheep numbers rose rapidly but the potential significance of that trend is limited to a small proportion of the catchment. By combining sheep numbers with the area of rough grazing (also drawn from the parish returns), a crude indication of stocking density on unimproved land may be obtained (Fig. 30). Again the increase in stocking density is most marked after the date of afforestation.

A major drovers road leading to the fattening pastures of England passed up Cwm Berwyn and to the north of the Llyn Berwyn catchment (Davies 1934). The passage of store cattle and wether sheep along this road reached a peak in 1860 before disappearing in the face of competition from the railway (Davies 1934, 1936). It is conceivable that the north-east of the catchment experienced an enhanced grazing pressure in summer months as the transient

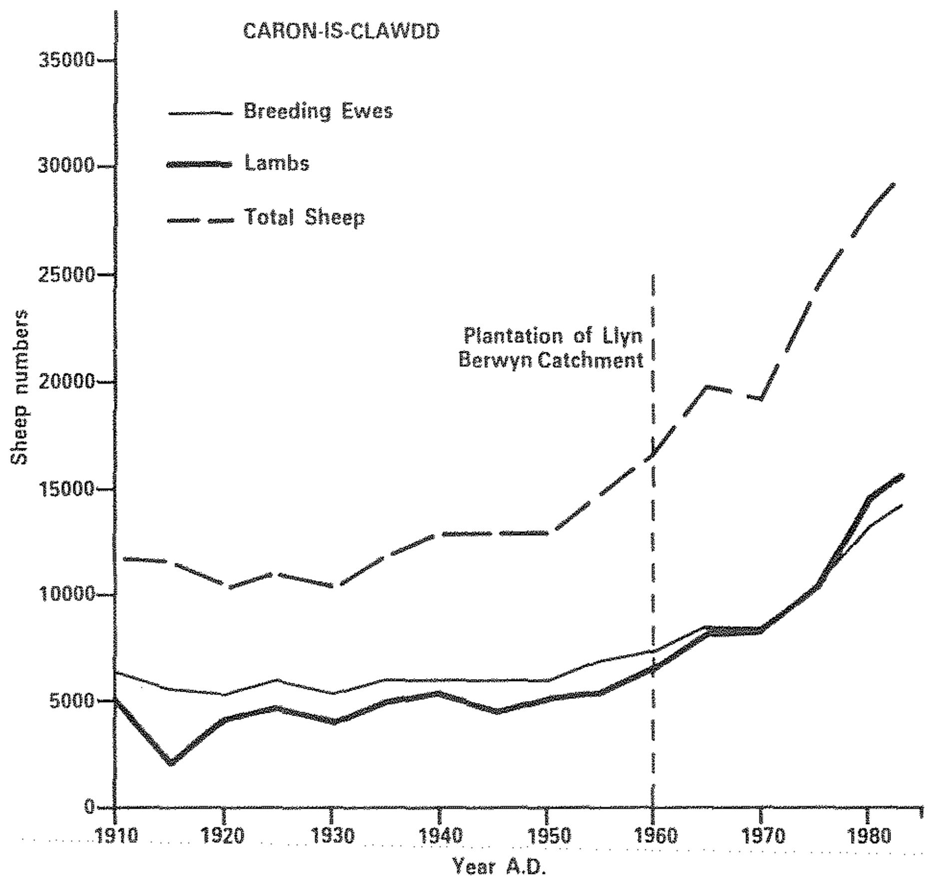


Fig. 29. Sheep numbers in Caron-is-Clawdd Parish 1867-1983.

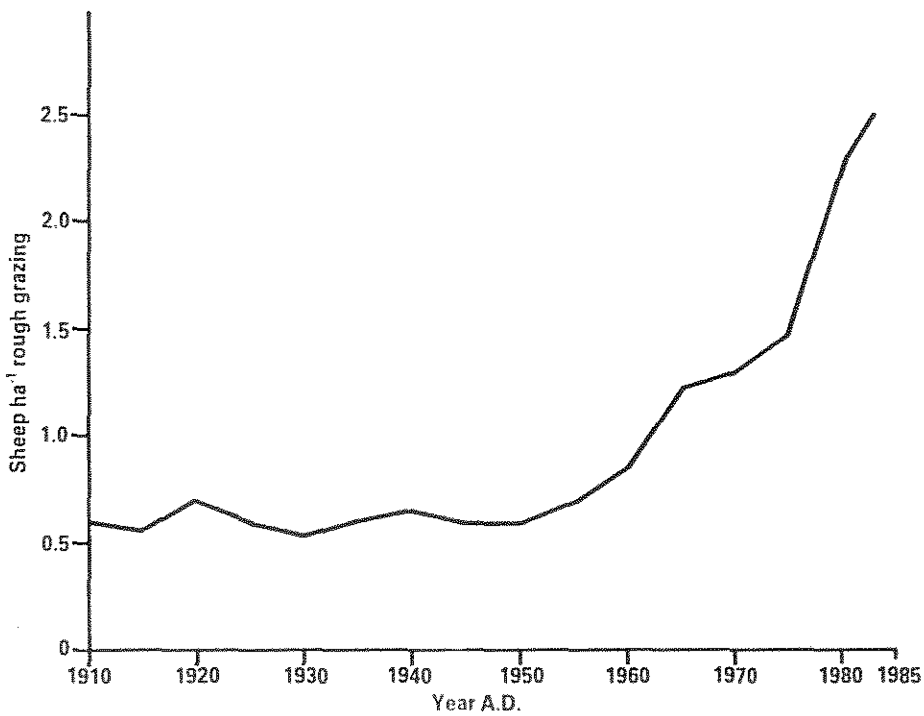


Fig. 30. Crude sheep/rough grazing stocking densities in Caron-is-Clawdd Parish 1895-1983.

herds and flocks passed along the drove road (cf. Fritz et al. 1986).

In the early 20th century the Cwm Berwyn drove road was utilised by shepherds from the eastern central Welsh mountains and the Brecon Beacons to drive their summer flocks to the wintering pastures of the Cardiganshire coastal plateau (Davies 1935).

Forestry

Fig. 6 illustrates the planting of the catchment by Forestry Commission compartment number, date and species. Planting was conducted down to the lake edge. Prior to planting the site was ploughed/drained. 2.5 ha of compartment 263 was hand spread with GMP prior to planting. Compartment 270 was similarly treated soon after planting at about 250 kg ha^{-1}. In 1964 and 1968 phosphate fertiliser was applied by hand to compartment 267. The catchment was spread with phosphate/potassium fertiliser from the air in 1973 at a loading of approximately 250 kg ha^{-1} (R. Gattis pers. comm.).

By the early 1970s the shallow drains and furrows that had provided rooting and drainage for the young trees were proving inadequate for the needs of maturing trees. Consequently ca. 1974 deep drains, approximately 20 m apart were driven through the entire forested area (R. Hughes, M. Morgan pers. comm.).

Subsidiary management practices

There is no evidence that any part of the catchment has ever been managed for game.

Air photographs (10) show features in the north of the catchment (now under forest) which may represent old peat excavations. The proximity of the road at this point (Fig. 6) suggests that this would not be infeasible but there is no documentary evidence for the presence of a turbary.

5.0 Discussion

5.1 Inwash and hiatus

It is clear from the LOI, dry weight, diatom & pollen evidence that the BER 1 core is characterised by a distinct inwash phase. The most likely cause of this inwash is the result of ploughing and afforestation activities within the catchment. The presence of a mineral-rich sediment from 30-20 cm followed by an overlying black organic sediment suggests a significant amount of sub soil erosion followed by continued peat erosion. This inwash cannot be expected to have come from the rather superficial ploughing of the catchment that took place in 1962-63 (Section 4.2.2) but must derive from the extensive deep drains emplaced in 1974. Furthermore, the lack of any indication of the initial catchment ploughing in the sediment below 30 cm the lack of unsupported ^{210}Pb below 20 cm suggests that a hiatus must exist at 30 cm. This hiatus could have been caused by removal of sediment by the inwashed material or the absence of sedimentation in the cored area of the lake until the arrival of inwash material at that site.

Therefore, it is assumed that the sediments above 30 cm are post-1974. Those below the hiatus contain no unsupported ^{210}Pb and consequently pre-date ca. 1800.

5.2 pH RECONSTRUCTION

The lake pH can be reconstructed from the core by including the diatom pH preference group percentage data into the three pH reconstruction models; Index B (Scandanavia), Index B (Galloway) and Multiple Regression of pH preference groups against pH (Galloway) (Flower 1986). All three models clearly show a decline in pH through time (Fig. 31) with values in the range pH 5.4-5.9 below 30 cm. Values decrease across the inwash band to pH 5.0 and below in the upper organic unit. Of the three pH models the multiple regression equation comes closest to predicting pH in the top sediments where water quality data are available for comparison. The Index B models show the same trend but with an extended range of values.

The pH history of Llyn Berwyn given by the sediment core can be divided into two units separated by the mineral inwash or hiatus boundary at 30 cm.

The diatom assemblages of the pre-hiatus sediment are dominated by acidophilous forms with circumneutral and alkaliphilous taxa contributing up to 40% of the total count. In this respect Llyn Berwyn is unusual. Pre-1800 sediments in other recently acidified lakes in Galloway (Flower & Battarbee 1983, Jones et al. 1986, Flower et al. 1987) and in nearby Llyn Hir (Fritz et al. 1986) have a more diverse circumneutral and alkaliphilous flora, with species such as Achnanthes minutissima, Anomoeoneis vitrea and planktonic Cyclotella in abundance. The Berwyn flora at this time is more acidophilous and the reconstructed pH gives a maximum value of pH 5.9 using Index B (Galloway) and pH 5.8 with the multiple regression model. Although we do not know how far back in time this core extends, it would seem unlikely that Llyn Berwyn had a mean pH greater than pH 6 in the recent past.

The interpretation of the upper 30 cm of sediment is more problematic. There can be little doubt that the mineral-rich band from 20-30 cm is inwash from the catchment drainage but the absence of unsupported ^{210}Pb in this

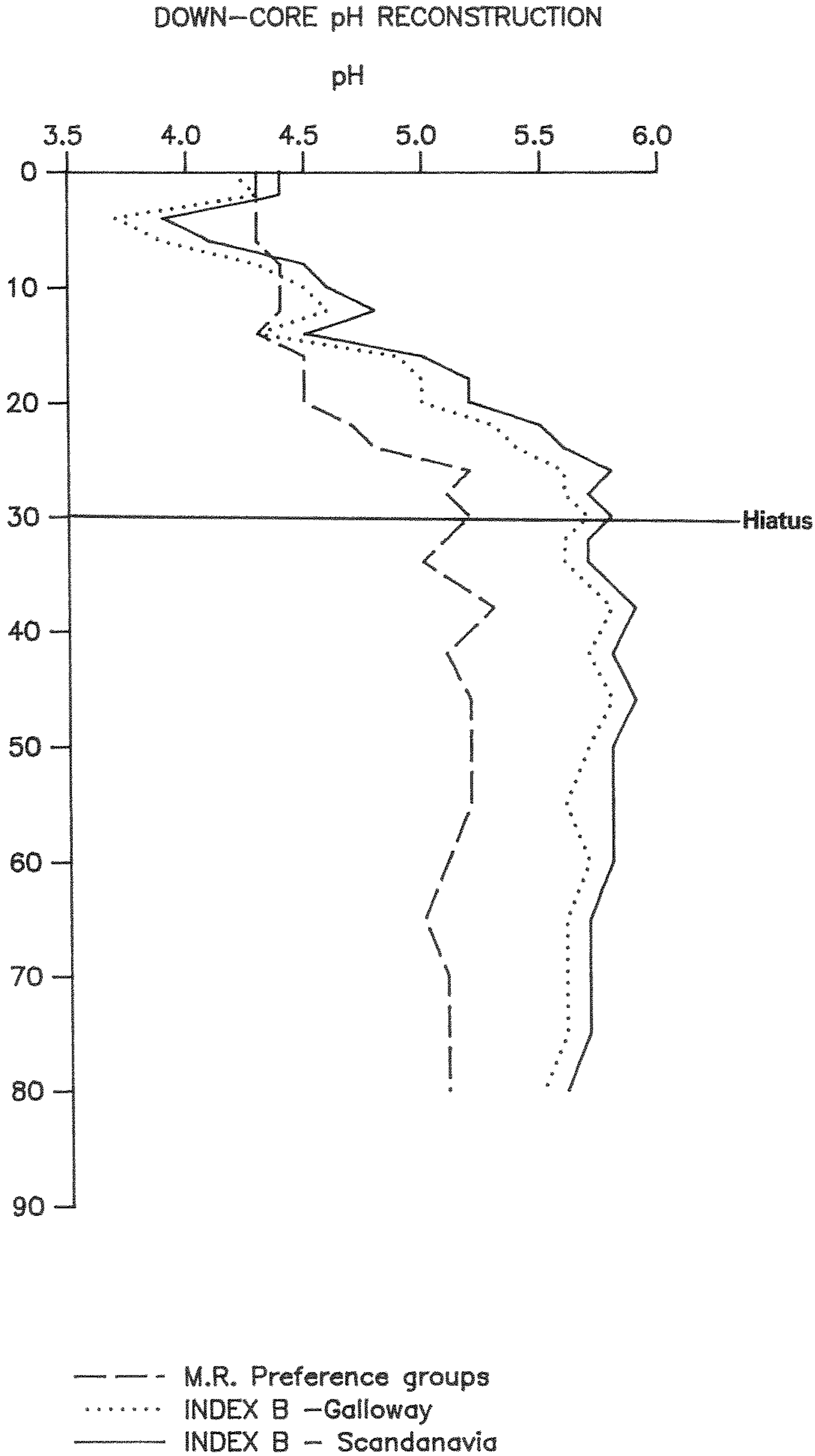


Fig. 31. pH reconstruction of the Llyn Berwyn core according to three different methods:- Index B (Galloway) an
Multiple Regression of ph preference groups.

section cannot be the result of dilution by inwashed sediment alone since the diatom concentrations are not markedly reduced A possible explanation is that the sediment contains re-suspended older material rich in diatoms but lacking unsupported ^{210}Pb. In this case the diatom assemblages do not necessarily reflect a decline in lake pH during the period represented by the 20-30 cm inwash.

The 20 cm level is the lowest level with unsupported ^{210}Pb but for reasons outlined above is thought to date from shortly after 1974. The reconstructed pH of this level is 4.7 and this declines to 4.5 with the increase in acidophiles at 15 cm including A.ralfsii, a species associated with the high humic acid concentrations resulting from catchment peat drainage (Liehu et al. in press). In general, the data show a clear post-afforestation acidification but it is not clear whether an earlier acidification prior to planting has occurred.

6.0 NOTES

1. The purpose of this exercise was to save riverine fish whose habitat was being destroyed by a drainage scheme.

2. For a definition of these terms see Patrick (1986).

3. Tithe map and schedule of Caron. PRO Kew, IR 30 46/10 (part 1) map A.

4. First edition surveyed 1887, published 1891.
   Second edition surveyed 1904, published 1906
   Provisional edition ammended 1948, published 1953.

5. Manuscript held at the LSE archive.

6. Manuscript six inch sheet no. 364, King's College London, Geography Department.

7. Air Photograph Office, Welsh Office, Cardiff. Plates 372 - 3188, 3189, 4192, 4193. Flown May 4th 1946, scale c.1:10,000.

8. 1:25,000 maps and computer files containing land use information held at the Countryside Commission, Newtown, Powys.

9. PRO (Kew) class list MAF 68.

10. See note 7.

7.0 References

Anderson, N.J.A., Battarbee, R.W., Appleby, P.G., Stevenson, A.C, Oldfield, F., Darley, J & Glover, G. (1986) Palaeolimnological evidence for the recent acidification of Loch Fleet, Galloway. Research Paper No 17. Palaeoecological Research Unit, Dept Geography, University College London.

Appleby, P.G. & Oldfield, F. (1978) The calculation of ^{210}Pb dates assuming a constant rate of supply of unsupported ^{210}Pb to the sediment. Catena, 5, 1-8.

Appleby, P.G., Nolan, P., Gifford, D.W., Godfrey, M.J., Oldfield, F., Anderson, N.J. & Battarbee, R.W. (In Press) ^{210}Pb dating by low background gamma counting.

Battarbee, R.W., Flower, R.J., Stevenson, A.C. & Rippey, B. (1985) Lake acidification in Galloway: A palaeoecological test of competing hypotheses. Nature 314 350-352.

Barret, C.F., Atkins, D.H.F., Cape, J.N., Fowler, D., Irwin, J.G., Kallend, A.S., Martin, A., Pitman, J.I., Scriven, R.A. & Tuck, A.F. (1983) Acid Deposition in the United Kingdom. Report of the United Kingdom Review Group on Acid Rain, Warren Spring Laboratory.

Bradley, A.C. (1903) Highways and byways in south Wales. Macmillan. London.

Cliffe, J.H. (1860) Notes and recollections of an angler. Hamilton, Adams & Co, London.

Davies, J.L. (1934) The livestock trade in West Wales in the nineteenth century. Aberwystwyth Studies. 8, 85-105.

Davies, J.L. (1936) The livestock trade in West Wales. Aberystwyth Studies 9, 93-113.

Davies, E. (1935) Seasonal movements of sheep in Wales. Journal of the Manchester Geographical Society. 45, 24-40.

Engstrom, D. & Wright, H.E. (1984) Chemical stratigraphy of lake sediments In: Lake Sediments and Environmental History (eds. E.Y. Haworth & J.W.G. Lund), Leicester University Press.

Flower, R.J. (1986) Relationships between surface sediment diatom assemblages and pH in 33 Galloway lakes: Some regression models for reconstructed pH & their application to sediment cores. Hydrobiologia in press.

Flower, R.J. & Battarbee, R.W. (1983). Diatom evidence for the recent acidification of two Scottish lochs. Nature 305, 130-133.

Flower, R.J., Battarbee, R.W. & Appleby, P.G. (1987) Palaeolimnological studies in Galloway: lake acidification & the role of afforestation. Journal of Ecology in press.

Fritz, S.C., Stevenson, A.C., Patrick, S.T., Appleby, P.G., Oldfield, F. Rippey, B. & Darley, J. (1986) Palaeoecological evaluation of the acidification of Welsh lakes. I: Llyn Hir, Dyfed. Research Paper No. 16, Palaeoecological Research Unit, Dept Geography, University College London.

Gorham, E. (1958) The influence and importance of daily weather conditions in the supply of chloride, sulphate and other ions to fresh waters from atmospheric precipitation. Phil. Trans. Royal Soc. London, B, 241 147

Harriman, R. & Morrison, B.R.S. (1982) Ecology of streams draining forested and non-forested catchments in an area of Central Scotland subject to acid precipitation. Hydrobiologia 88, 251-63

Hilton, J., Davison, W. & Ochsenbeim, U. (1985) A mathematical model for analysis of sediment core data: implications for enrichment factor calculations and trace-metal transport mechanisms. Chemical Geology. 48, 281-291.

Jones, V., Stevenson, A.C. & Battarbee, R.W. (1986) Lake acidification and the "land-use" hypothesis: a mid-postglacial analogue Nature 322 157-158.

Liehu, A., Sandman, O. & Simola, H. (In Press) Effects of peatbog ditching in lakes: Problems in palaeolimnological interpretation. Hydrobiologia.

Mackereth, F.J.H. (1966) Some chemical observations on post-glacial sediments. Phil. Trans. Royal Soc B. 250, 165-213.

Mackereth, F.J.H. (1969) A short core sampler for sub-aqueous deposits. Limnol. Oceanogr. 14, 145-151.

Moore, P.D. (1973) The influence of prehistoric cultures upon the initiation and spread of blanket bogs in Upland Wales. Nature. 241 350-354.

Moore, P.D. & Chater, E.H. (1969a) Studies in the vegetation history of mid-Wales. I. The postglacial period in Cardiganshire. New Phytol. 68, 183-196.

Moore, P.D. & Chater, E.H. (1969b) The changing vegetation of West-Central Wales in the light of human history. J. Ecol. 57, 361-379.

Morgan, J. (1874) New Guide to Aberwystwyth and Neighbourhood. Morgan, Aberwystwyth.

Parry, M & Sinclair, G. (1985) Mid Wales Upland Study. Countryside Commission Report ICP 177.

Patrick, S.T. (in press) Evaluation of the recent acidification of Welsh lakes: land use and land management change.

Raven, P.J. (1986) Occurance of Sphagnum moss in the sublittoral of several Galloway lochs with particular reference to Loch Fleet. Research Paper No. 13 (Palaeoecology Research Unit, University College London)

Rees, T. (1936) The beauties of England and Wales. Vol 18 South Wales London.

Rudeforth, C.C. (1970) Soils of North Cardiganshire. Memoirs of the Soil Survey of Great Britain. Agricultural Research Council, Harpenden.

Rudeforth, C.C., Hartnup, R., Lea, J.W., Thompson, T.R.E. & Wright, P.S. (1984) Soils and their use in Wales. Soil Survey of England and Wales, Bulletin No. 11. Harpenden

Sayles, F.L. & Mangelsdorf, P.C. (1977) The equilibration of clay minerals with seawater:exchange reactions. Geochemica et Cosmochimica Acta. 41, 951-960.

Stevenson, A.C., Patrick, S.J., Kreiser, A., Rippey, B., Darley, J. & Battarbee, R.W. (1987) Palaeoecological evaluation of the recent acidification of Welsh Lakes: Methods. Research Paper No. ** (Palaeoecology Research Unit, University College London.)

Stevenson, A.C., Patrick, S.J., Fritz, S.C., Rippey, B., Appleby, P.G., Oldfield, F., Darley, J. & Battarbee, R.W. (1986) Palaeoecological evaluation of the recent acidification of Welsh Lakes: IV. Llyn Gynon, Dyfed. Research Paper No. 20 (Palaeoecology Research Unit, University College London.)

Stoner, J.S. & Gee, A.S. (1985) Effects of forestry on water quality and fish in Welsh rivers and lakes. J. Water Engineers & Scientists 39, 27-45.

Stumm, W. & Morgan, J.J. (1981) Aquatic Chemistry, Wiley, London.

Troels-Smith, J (1955) Karakterisering af lose jordarter. Characterisation of unconsolidated sediments. Danm. geol. Unders. Ser. 3(10) 73pp

Tutin, T.G., Heywood, V.H., Burges, N.A., Moore, D.M., Valentine, D.H., Walters, S.M. & Webb, A.A. (1964,1968,1972,1976,1980). Flora Europaea volumes 1-5. Cambridge University Press, London.

Underwood, J., Donald, A.P. & Stoner, J.H. (In Press) Investigations into the use of limestone to combat acidification in two lakes in West Wales.

Ward, F. (1931) The lakes of Wales. Jenkins, London.

8.0 Acknowledgments

We would like to thank N.J. Anderson, R.J. Flower, S.J. Phethean, D.M. Monteith and A.J. Nicholson for their invaluable help in the field and in the laboratory; Mrs. K. Phethean for typing and A. Newman for diagram production; & in particular the staff of WWA: J. Underwood, N.Milner, R. Hemsworth, M.Mills, J.Stoner and A.Gee are thanked for allowing us access to unpublished data and their comments on an earlier draft of this manuscript. Furthermore, the following people are thanked for allowing us to discuss the local history of the area with them: G. Jones, M.Morgan (Tregaron Angling Society), Mr C. Evans and J.R. Davies of ADAS (Trawscoed and Lampeter), Mr R. Hughes (Cwm Berwyn Farm, Tregaron), Mr R. Gattis (Forestry Commision, Llandovery) Dr L. Sinclair (Environmental Information Services, Narbeth) and Dr. M.Parry (Dept Geography, University of Birmingham).

Appendices

Appendix A: Bi-weekly lake chemistry data for Llyn Berwyn (before and after liming)
(Courtesy of WWA)

Date	pH	Conductivity 20°C us cm⁻¹	Total Oxidised Nitrogen mg l⁻¹	Total Hardness mg l⁻¹	Free Carbon dioxide mg l⁻¹	Total Alkalinity mg l⁻¹	Chloride mg l⁻¹
05/10/83	4.2	59	0.1	6.0	3.4	-	9.0
21/11/83	4.4	59	0.1	5.1	3.7	-	8.0
13/12/83	4.3	55	0.1	5.8	4.2	-	9.0
04/01/84	4.1	63	0.2	5.1	5.0	-	8.0
23/01/84	4.1	64	0.1	-	4.8	-	10.0
02/02/84	4.3	62	0.1	4.6	6.3	-	9.0
14/02/84	4.3	59	0.1	4.6	4.8	-	10.0
06/03/84	4.3	59	0.1	5.0	6.1	-	9.0
06/04/84	4.4	60	0.1	2.7	5.2	-	10.0
18/04/84	4.4	60	0.1	4.5	-	-	10.0
30/04/84	4.3	58	0.1	4.3	-	-	10.0
18/05/84	4.4	59	0.1	4.8	5.4	-	10.0
31/05/84	4.4	57	0.1	5.2	-	-	10.0
12/06/84	4.4	59	0.1	5.6	5.9	-	10.0
28/06/84	4.5	57	0.1	4.3	-	-	10.0
04/07/84	4.5	59	0.1	4.5	6.9	-	10.0
18/07/84	4.4	57	0.1	4.1	7.8	-	10.0
03/08/84	4.4	59	0.1	5.1	-	-	10.0
10/08/84	4.4	59	0.1	4.4	-	-	10.0
07/09/84	4.5	56	0.1	5.5	6.2	0.2	10.0
01/10/84	4.4	64	0.1	5.2	6.3	-	10.0
19/10/84	4.4	62	0.1	5.1	7.5	-	10.0
10/12/84	4.2	59	0.1	4.9	5.8	-	8.0
28/01/85	4.2	56	0.1	3.6	4.9	-	8.0
29/01/85	5.5	43	0.1	7.9	2.8	1.7	7.0
27/02/85	4.4	51	0.1	4.3	4.9	-	8.0

02/04/85	6.3	46	0.1	8.8	2.3	3.9	8.0
10/04/85	6.8	52	0.1	11.6	2.1	6.9	8.0
01/05/85	6.7	53	0.1	12.9	2.3	9.1	8.0
22/05/85	6.9	54	0.1	13.3	2.1	7.6	8.0
11/06/85	6.5	51	0.1	12.4	2.3	5.9	8.0
20/06/85	6.3	49	0.1	13.3	2.9	5.5	8.0
04/07/85	6.2	45	0.2	12.1	2.5	5.1	7.0
18/07/85	6.4	42	0.1	--	4.0	-	7.0
01/08/85	-	42	0.1	10.1	-	-	6.0
15/08/85	6.0	40	0.1	8.7	-	-	6.0
05/09/85	5.6	38	0.1	7.8	4.1	2.5	7.0
19/09/85	5.6	40	0.1	7.6	3.4	2.4	6.0
19/09/85	5.7	39	0.1	7.8	2.8	2.7	6.0
03/10/85	5.7	39	0.1	8.1	3.0	2.4	6.0
04/10/85	5.6	40	0.1	9.3	2.8	2.1	6.0
17/10/85	5.5	40	0.1	7.6	3.7	1.7	7.0
29/10/85	5.5	48	0.2	7.4	6.4	3.7	7.0
07/11/85	6.3	49	0.1	12.8	4.1	6.6	7.0
21/11/85	6.3	53	0.2	--	4.2	7.1	7.0
05/12/85	6.2	47	0.1	11.3	3.1	5.6	6.0
18/12/85	6.0	47	0.1	9.8	3.6	3.6	7.0
18/01/86	5.7	43	0.2	8.5	2.9	2.8	7.0
12/02/86	5.7	49	0.2	8.7	3.1	2.0	7.0
27/02/86	5.7	50	0.2	8.6	3.9	2.5	9.0
12/03/86	5.2	44	0.1	7.7	3.4	1.5	8.0
26/03/86	4.8	53	0.1	7.6	6.9	1.1	7.0

Date	Orthophosphate	Dissolved Silica	Dissolved Sulphate (mg l⁻¹)	Dissolved Sodium	Dissolved Potassium	Dissolved Calcium	Dissolved Zinc
05/10/83	0.02	-	10.0	4.9	0.17	1.10	---
21/11/83	0.02	0.8	8.5	4.5	0.15	0.90	0.014
13/12/83	0.02	0.6	10.0	4.4	0.18	1.00	0.015
04/01/84	0.02	0.7	8.0	4.6	0.15	0.90	0.031
23/01/84	0.02	0.7	9.0	-	--	--	--
02/02/84	0.02	0.6	8.0	4.6	0.13	0.70	0.013
14/02/84	0.02	0.6	8.5	5.1	0.40	0.70	0.024
06/03/84	0.02	0.6	8.0	4.1	0.17	0.70	0.015
06/04/84	0.02	0.5	7.5	3.0	0.19	0.43	0.021
18/04/84	0.02	0.5	8.0	5.0	0.36	0.65	0.022
30/04/84	0.02	0.5	8.0	4.1	0.60	0.74	0.020
18/05/84	0.02	0.2	7.5	4.1	0.36	0.67	0.023
31/05/84	0.02	0.3	7.0	4.6	0.51	0.78	0.025
12/06/84	0.02	0.2	7.0	5.3	0.58	0.94	0.016
28/06/84	0.02	0.2	7.0	4.0	0.23	0.58	0.021
04/07/84	0.02	0.2	6.5	5.4	0.19	0.65	0.027
18/07/84	0.02	0.2	7.0	3.8	0.14	0.66	0.016
03/08/84	0.02	0.2	6.5	4.7	--	0.89	0.014
10/08/84	0.02	0.2	8.5	5.0	0.16	0.60	0.021
07/09/84	0.02	0.3	10.5	5.1	0.28	0.88	0.026
01/10/84	0.02	0.4	9.5	4.8	0.26	0.92	0.019
19/10/84	0.02	0.5	13.5	4.4	0.24	0.73	0.007
10/12/84	0.02	0.7	5.9	4.5	0.28	0.83	0.021
28/01/85	0.02	0.7	5.6	3.4	0.13	0.61	0.014
29/01/85	0.02	0.6	4.0	3.6	0.10	2.34	0.009
27/02/85	0.02	0.7	7.1	3.7	0.10	0.72	0.027
02/04/85	0.02	0.7	6.5	3.9	0.10	2.52	0.017
10/04/85	0.02	0.6	6.2	4.1	0.05	3.65	0.013
01/05/85	0.02	0.7	6.5	4.3	0.10	4.16	0.015
22/05/85	0.02	0.5	6.2	4.0	0.24	4.32	0.014
11/06/85	0.02	0.3	6.3	4.1	0.18	4.12	0.011
20/06/85	0.02	0.2	6.3	4.0	0.21	4.33	0.009
04/07/85	0.02	0.2	6.5	4.2	0.24	3.84	0.021
18/07/85	0.02	0.2	-	-	--	--	--
01/08/85	0.02	0.2	6.1	4.0	0.10	3.23	0.013
15/08/85	0.02	0.3	5.2	3.4	0.21	2.67	0.017
05/09/85	0.02	0.3	4.8	3.1	0.20	2.46	0.013
19/09/85	0.02	0.4	5.0	3.2	0.11	2.40	0.039
19/09/85	0.02	0.4	4.6	2.9	0.13	2.48	0.012
03/10/85	0.02	0.4	4.4	3.4	0.10	2.40	0.010
04/10/85	0.02	0.4	4.6	3.5	0.10	2.88	0.012
17/10/85	0.02	0.5	4.2	3.6	0.13	2.20	0.022
29/10/85	0.02	0.5	3.8	3.2	0.10	2.31	0.043
07/11/85	0.02	0.5	5.6	-	--	4.14	0.013
21/11/85	0.02	0.5	4.4	3.6	0.05	--	0.009
05/12/85	0.02	0.6	4.4	3.4	0.12	3.70	0.012
18/12/85	0.02	0.6	4.7	3.5	0.12	3.10	0.014
18/01/86	0.02	0.6	4.1	3.5	0.12	2.57	0.016
12/02/86	0.02	0.7	4.4	3.8	0.21	2.65	0.013
27/02/86	0.02	0.7	4.4	3.6	0.23	2.62	0.021
12/03/86	0.03	0.5	5.0	3.7	0.29	2.27	0.028
26/03/86	0.02	0.6	3.1	3.7	0.21	2.20	0.020

Date	Dissolved Copper	Dissolved Cadmium	Dissolved Aluminium $(mg\ l^{-1})$	Dissolved Lead	Dissolved Chromium	Dissolved Manganese	Dissolved Iron
05/10/83	0.007	0.0009	0.070	0.002	---	0.515	0.230
21/11/83	---	0.0004	0.140	0.002	---	0.530	0.258
13/12/83	---	0.0004	0.130	0.002	---	0.435	0.198
04/01/84	---	0.0004	0.070	0.002	---	0.316	0.190
23/01/84	---	---	--	---	---	---	---
02/02/84	---	0.0004	0.110	0.002	---	0.335	0.212
14/02/84	---	0.0004	0.160	0.002	---	0.340	0.212
06/03/84	---	0.0008	0.150	0.004	---	0.340	0.192
06/04/84	---	0.0008	0.078	0.005	---	0.311	0.827
18/04/84	0.001	0.0008	0.180	0.005	0.001	0.437	0.184
30/04/84	0.001	0.0008	0.162	0.005	0.001	0.425	0.172
18/05/84	0.001	0.0008	0.090	0.010	0.001	0.531	0.111
31/05/84	0.001	0.0008	0.153	0.005	0.001	0.551	0.099
12/06/84	0.001	0.0008	0.123	0.005	0.001	0.553	0.124
28/06/84	0.001	0.0008	0.161	0.006	0.001	0.648	0.104
04/07/84	0.001	0.0008	0.117	0.005	0.001	0.564	0.088
18/07/84	0.001	0.0008	0.093	0.005	0.001	0.497	0.158
03/08/84	0.001	0.0008	0.090	0.005	0.001	0.627	0.167
10/08/84	0.003	0.0014	0.082	0.022	0.001	0.579	0.111
07/09/84	0.001	0.0008	0.116	0.005	0.001	0.808	0.258
01/10/84	0.002	0.0010	0.108	0.013	0.003	0.582	0.245
19/10/84	0.001	0.0008	0.106	0.016	0.001	0.728	0.266
10/12/84	0.002	0.0010	0.159	0.015	0.003	0.495	0.311
28/01/85	0.002	0.0010	0.152	0.020	0.003	0.375	0.299
29/01/85	0.002	0.0010	0.113	0.002	0.003	0.030	0.380
27/02/85	0.003	0.0010	0.221	0.005	0.003	0.477	0.339
02/04/85	0.002	0.0010	0.117	0.005	0.003	0.427	.0239
10/04/85	0.002	0.0010	0.114	0.005	0.003	0.351	0.254
01/05/85	0.002	0.0010	0.097	0.005	0.003	0.296	0.310
22/05/85	0.002	0.0010	0.105	0.005	0.003	0.239	0.395
11/06/85	0.002	0.0010	0.094	0.008	0.003	0.138	0.541
20/06/85	0.003	0.0010	0.090	0.005	0.003	0.078	0.545
04/07/85	0.002	0.0010	0.080	0.005	0.003	0.046	0.505
18/07/85	---	----	---	---	---	---	---
01/08/85	0.002	0.0010	0.092	0.002	0.003	0.011	0.421
15/08/85	0.002	0.0010	0.086	0.002	0.003	0.015	0.416
05/09/85	0.004	0.0002	0.102	0.002	0.003	0.030	0.541
19/09/85	0.010	0.0010	0.110	0.002	0.003	0.040	0.549
19/09/85	0.002	0.0010	0.060	0.002	0.003	0.032	0.547
03/10/85	0.002	0.0010	0.100	0.002	0.003	0.004	0.620
04/10/85	0.002	0.0010	0.110	0.002	0.003	0.040	0.636
17/10/85	0.002	0.0010	0.110	0.002	0.003	0.050	0.600
29/10/85	0.002	0.0010	0.100	0.003	0.003	0.054	0.570
07/11/85	0.002	0.0010	0.137	0.002	0.003	0.021	0.695
21/11/85	0.002	0.0010	0.100	0.006	0.003	0.032	0.606
05/12/85	0.002	0.0010	0.099	0.002	0.003	0.029	0.570
18/12/85	0.002	0.0010	0.110	0.002	0.003	0.029	0.511
18/01/86	0.002	0.0010	0.111	0.001	0.003	0.022	0.598
12/02/86	0.002	0.0010	0.113	0.002	0.003	0.028	0.400
27/02/86	0.002	0.0010	0.129	0.002	0.003	0.023	0.459
12/03/86	0.002	0.0010	0.105	0.002	0.003	0.035	0.313
26/03/86	0.002	0.0010	0.116	0.018	0.003	0.032	0.151

Date	Dissolved Nickel $mg\ l^{-1}$	Humic acid $mg\ l^{-1}$
05/10/83	---	---
21/11/83	---	---
13/12/83	---	---
04/01/84	---	---
23/01/84	---	---
02/02/84	---	---
14/02/84	---	---
06/03/84	---	---
06/04/84	---	---
18/04/84	0.001	0.8
30/04/84	0.001	1.0
18/05/84	0.002	0.7
31/05/84	0.002	0.4
12/06/84	0.001	0.3
28/06/84	0.002	0.3
04/07/84	0.001	0.4
18/07/84	0.001	0.7
03/08/84	0.001	1.4
10/08/84	0.007	1.1
07/09/84	0.001	1.5
01/10/84	0.003	2.3
19/10/84	0.002	2.7
10/12/84	0.003	4.1
28/01/85	0.005	4.4
29/01/85	0.003	6.0
27/02/85	0.004	3.1
02/04/85	0.003	3.7
10/04/85	0.003	4.6
01/05/85	0.003	5.0
22/05/85	0.009	6.1
11/06/85	0.003	5.3
20/06/85	0.003	6.1
04/07/85	0.003	6.4
18/07/85	---	4.8
01/08/85	0.003	6.9
15/08/85	0.003	7.5
05/09/85	0.002	7.3
19/09/85	0.004	7.5
19/09/85	0.007	7.6
03/10/85	0.003	7.1
04/10/85	0.003	7.3
17/10/85	0.003	8.3
29/10/85	0.003	8.3
07/11/85	0.003	8.9
21/11/85	0.003	8.3
05/12/85	0.003	7.7
18/12/85	0.003	7.7
18/01/86	0.003	6.4
12/02/86	0.003	6.1
27/02/86	0.003	6.2
12/03/86	0.003	-
26/03/86	0.003	4.4

Appendix B <u>Invertebrate taxa found at Llyn Berwyn prior to liming</u>
(Courtesy of WWA)

	Log abundance rating
<u>Tricladida</u>	
Polycelis nigra/tenuis	3
Phagocata vitta	1
<u>Mollusca</u>	
Pisidium sp.	1
<u>Oligochaeta</u>	
Nais communis/variablis	1
Vjdovskyella connata	2
Enchytraedae	1
Lumbarius variegatus	3
Stylodrilus heringianus	3
<u>Ephemeroptera</u>	
Leptophlebia vespertina	2
L. vespertina	3
<u>Plecoptera</u>	
Nemoura cinerea	2
Nemoura cambrica	1
Leuctra hippopus	1
L. nigra	2
<u>Hemiptera</u>	
Notonecta glauca	1
Glaencorixa propingua	1
Callicorixa praeusta	1
C. woolastoni	3
Arctocorisa germari	2
Sigara doraslis	1
S. distincta	1
<u>Coleoptera</u>	
Potamonectes elegans	2
Stictotarsus duodecimpustulatus	1
Hydroporus palustris	1
Agabus guttatus	2
A. bipustulatus	1
Oliemius tuberculatus	2
<u>Megaloptera</u>	
Sialis lutaria	2
<u>Trichoptera</u>	
Plectrocnemia conspersa	2
P. geniculata	1
Polycentropus flavomaculatus	2
P. kingi	3
Cyrnus flavidus	2
Agtypnia obsoleta	2
Limnemephilus centralis	2
Cingulatus latipennis	1
Halesus radiatus	2
H. digitatus	1
<u>Diptera</u>	
Ceratopogonidae	2
Atrichopogon sp.	1
Macropelopia sp.	2
Procladius sp.	2
Ablabesymia sp.	3
Natarsia sp.	1
Heterotrissocladius marcidus	2
Limnophyes sp.	1
Zalutschia humphresiae	3
Psectrocladium limbellatus gp.	1
P. psilopterus	1
P. octomaculatus	2
P. octomaculatus/ limbatellus gp.	3

	Log abundance rating
<u>Diptera</u> ctd	
Chaetocladius	1
Coryneura lacustris	3
Cryptochironomus sp.	2
Glyptotendipes sp. A gp.	3
Dicrotendipes sp.	2
Microtendipes pedellus	3
Tantytarsus sp.	3

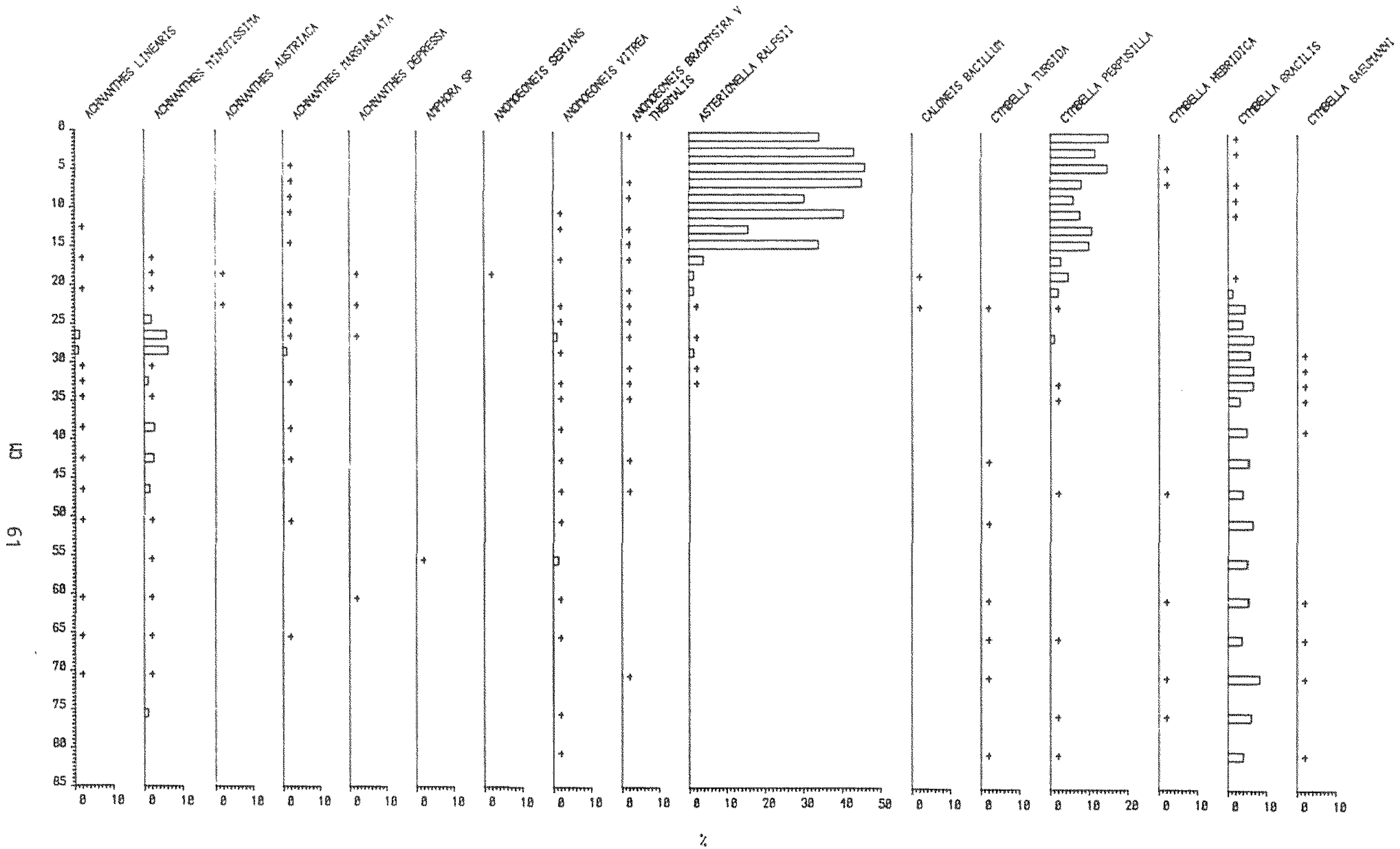
Abundance categories

1 = 1 - 10
2 = 11 - 100
3 = 101 - 1000

LLYN EERWYN SPECIES LIST

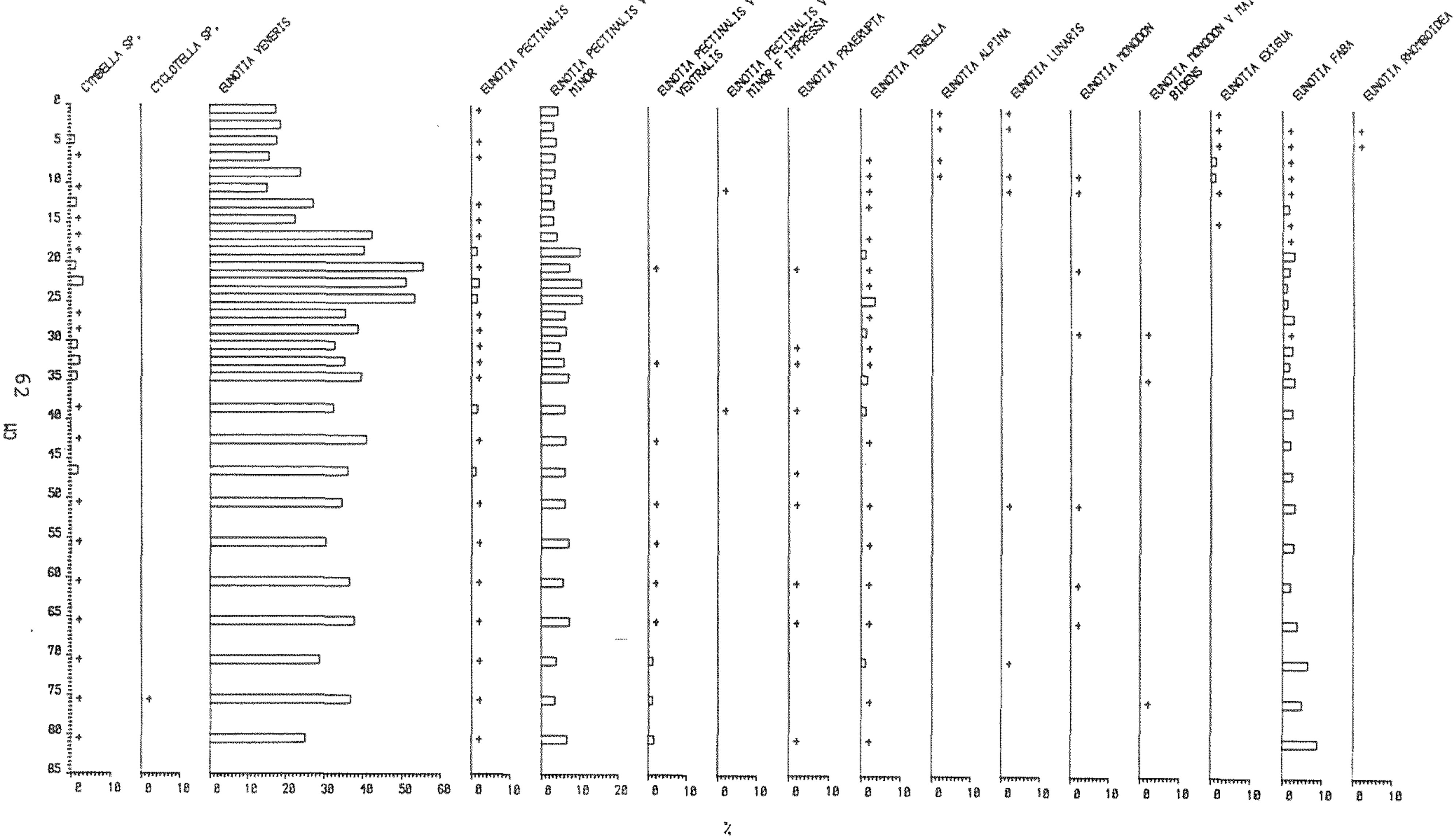
AC002A	ACHNANTHES LINEARIS	W. SMITH
AC013A	ACHNANTHES MINUTISSIMA	KUTZ.
AC014A	ACHNANTHES AUSTRIACA	HUST.
AC022A	ACHNANTHES MARGINULATA	GRUN.
AC024A	ACHNANTHES DEPRESSA	(CLEVE) HUST.
AM9999	AMPHORA SP	
AN003A	ANOMOEONEIS SERIANS	(BREB.) CLEVE
AN004A	ANOMOEONEIS VITREA	(GRUN.) ROSS
AN005B	ANOMOEONEIS BRACHYSIRA V THERMALIS	NOV. COMB.
AS003A	ASTERIONELLA RALFSII	W. SMITH
CA002A	CALONEIS BACILLUM	(GRUN.) MERESCHKOWSKY
CM002A	CYMBELLA TURGIDA	GREGORY
CM015A	CYMBELLA PERPUSILLA	A. CLEVE
CM017A	CYMBELLA MERIDICA	(GREGORY) GRUN.
CM018A	CYMBELLA GRACILIS	(RABH.) CLEVE
CM023A	CYMBELLA GAEUMANNI	MEISTER
CM9999	CYMBELLA SP.	
CY9999	CYCLOTELLA SP.	
EU001A	EUNOTIA VENERIS	(KUTZ.) O. MULLER
EU002A	EUNOTIA PECTINALIS	(KUTZ.) RABH.
EU002B	EUNOTIA PECTINALIS V MINOR	(KUTZ.) RABH.
EU002C	EUNOTIA PECTINALIS V VENTRALIS	(EHR.) HUST.
EU002E	EUNOTIA PECTINALIS V MINOR F IMPRESSA	(EHR.) HUST.
EU003A	EUNOTIA PRAERUPTA	EHR.
EU004A	EUNOTIA TENELLA	(GRUN). HUST.
EU005A	EUNOTIA ALPINA	(NAEGELI) HUST.
EU006A	EUNOTIA LUNARIS	(EHR.) GRUN.
EU008A	EUNOTIA MONODON	EHR.
EU008B	EUNOTIA MONODON V MAIOR F BIDENS	W. SMITH
EU009A	EUNOTIA EXIGUA	(BREB.) RABH.
EU010A	EUNOTIA FABA	(EHR.) GRUN.
EU011A	EUNOTIA RHOMBOIDEA	HUST.
EU012A	EUNOTIA ROBUSTA	RALFS
EU012C	EUNOTIA ROBUSTA V TETRAODON	(EHR.) RALFS
EU013A	EUNOTIA ARCUS	EHR.
EU016A	EUNOTIA DIODON	EHR.
EU021A	EUNOTIA SUDETICA	(O. MULLER) HUST.
EU027A	EUNOTIA TRINACRIA	KRASSKE
EU028B	EUNOTIA MICROCEPHALA V TRIDENTATA	(A. MAYER) HUST.
EU029A	EUNOTIA VALIDA	HUST.
EU031A	EUNOTIA SEPTENTRIONALIS	OSTRUP
EU9999	EUNOTIA SP	
FR001A	FRAGILARIA PINNATA	EHR.
FR002C	FRAGIALRIA CONSTRUENS V VENTER	(EHR.) GRUN.
FR005A	FRAGILARIA VIRESCENS	RALFS
FR010A	FRAGILARIA CONSTRICTA	EHR.
FR019A	FRAGILARIA INTERMEDIA	GRUN.
FR9999	FRAGILARIA SP	
FU002A	FRUSTULIA RHOMBOIDES	(EHR.) DE TONI
FU002B	FRUSTULIA RHOMBOIDES V SAXONICA	(RABH.) DE TONI
GO003A	GOMPHONEMA ANGUSTATUM	(KUTZ.) RABH.
GO004A	GOMPHONEMA GRACILE	EHR.
GO006A	GOMPHONEMA ACUMINATUM	EHR.
GO006C	GOMPHONEMA ACUMINATUM V CORONATA	(EHR.) W. SMITH
GO9999	GOMPHONEMA SP	
ME010A	MELOSIRA PERGLABRA	OSTRUP
ME010B	MELOSIRA PERGLABRA V FLORINIAE	CAMBURN
NA002A	NAVICULA JARNEFELTII	HUST.
NA003A	NAVILULA RADIOSA	KUTZ.
NA005A	NAVICULA SEMINULUM	GRUN.
NA006A	NAVICULA MEDIOCRIS	KRASSKE
NA013A	NAVICULA PSEUDOSCUTIFORMIS	HUST.
NA014A	NAVICULA PUPULA	KUTZ.
NA032A	NAVICULA COCCONEIFORMIS	GREGORY
NA037A	NAVICULA ANGUSTA	GRUN.
NA040A	NAVICULA HOFLERI	CHOLNOKY
NA045A	NAVICULA BRYOPHILA	PETERSEN
NA048A	NAVICULA SOHRENSIS	KRASSKE
NA051A	NAVICULA CARI	EHR.
NA075A	NAVICULA SUBHAMULATA	GRUN.
NA086A	NAVICULA TANTULA	HUST.
NA9999	NAVICULA SP	
NE001A	NEIDIUM IRIDIS	(EHR.) CLEVE
NE003A	NEIDIUM AFFINE	(EHR.) CLEVE
NE9999	NEIDIUM SP	
NI005A	NITZSCHIA PERMINUTA	GRUN.
PI002A	PINNULARIA ACUMINATA	SMITH SYN. PI003A
PI005A	PINNULARIA MAIOR	KUTZ.
PI007A	PINNULARIA VIRIDIS	(NITZSCH) EHR.
PI009A	PINNULARIA DIVERGENS	W. SMITH
PI011A	PINNULARIA MICROSTAURON	(EHR.) CLEVE
PI016A	PINNULARIA DIVERGENTISSIMA	(GRUN.) CLEVE
PI019A	PINNULARIA BICEPS	GREGORY
PI021A	PINNULARIA HILSEANA	(JANISCH) MULL.
PI022A	PINNULARIA SUBCAPITATA	GREGORY
PI023A	PINNULARIA IRRORATA	(GRUN.) HUST.
PI9999	PINNULARIA SP	
SA006A	STAURONEIS PHOENICENTERON	(NITZSCH) EHR.
SA9999	STAURONEIS SP	
SU005A	SURIRELLA LINEARIS	W. SMITH
SU006A	SURIRELLA DELICATISSIMA	LEWIS
SY9999	SYNEDRA SP	
TA001A	TABELLARIA FLOCCULOSA	(ROTH) KUTZ.

Appendix C



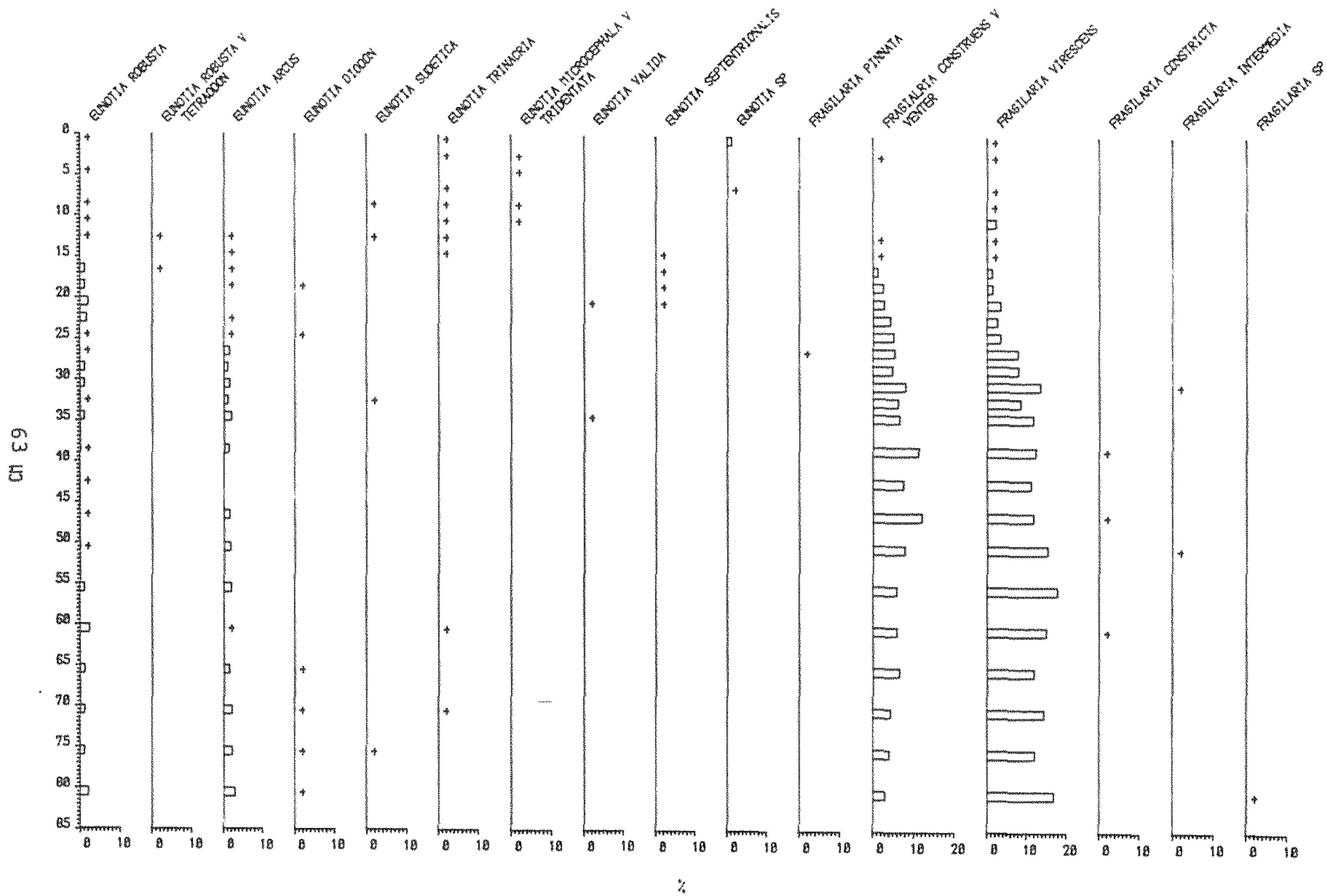
LLYN BERWYN DIATOM PERCENTAGE PROFILES

Appendix C



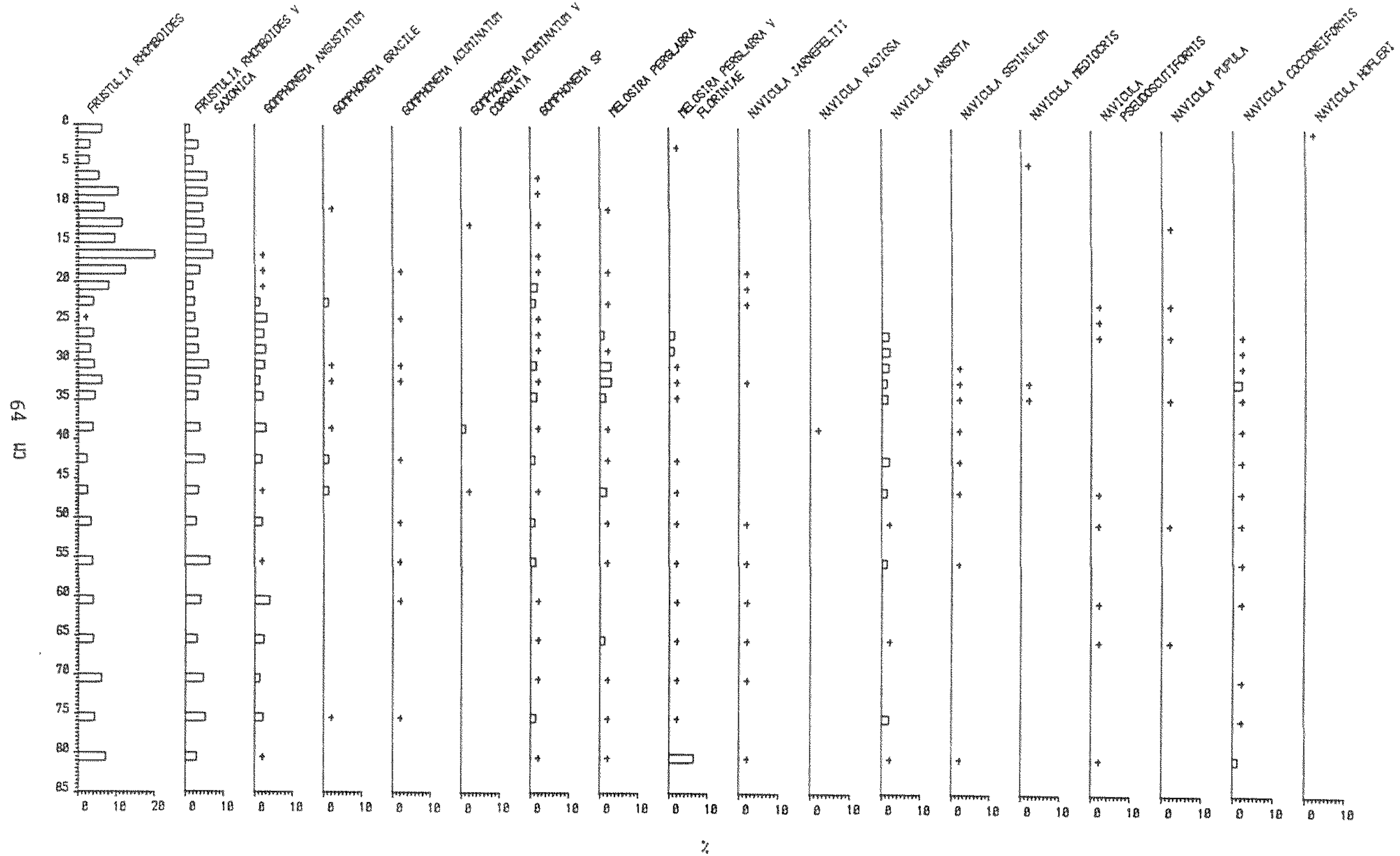
LLYN BERWYN DIATOM PERCENTAGE PROFILES

Appendix C



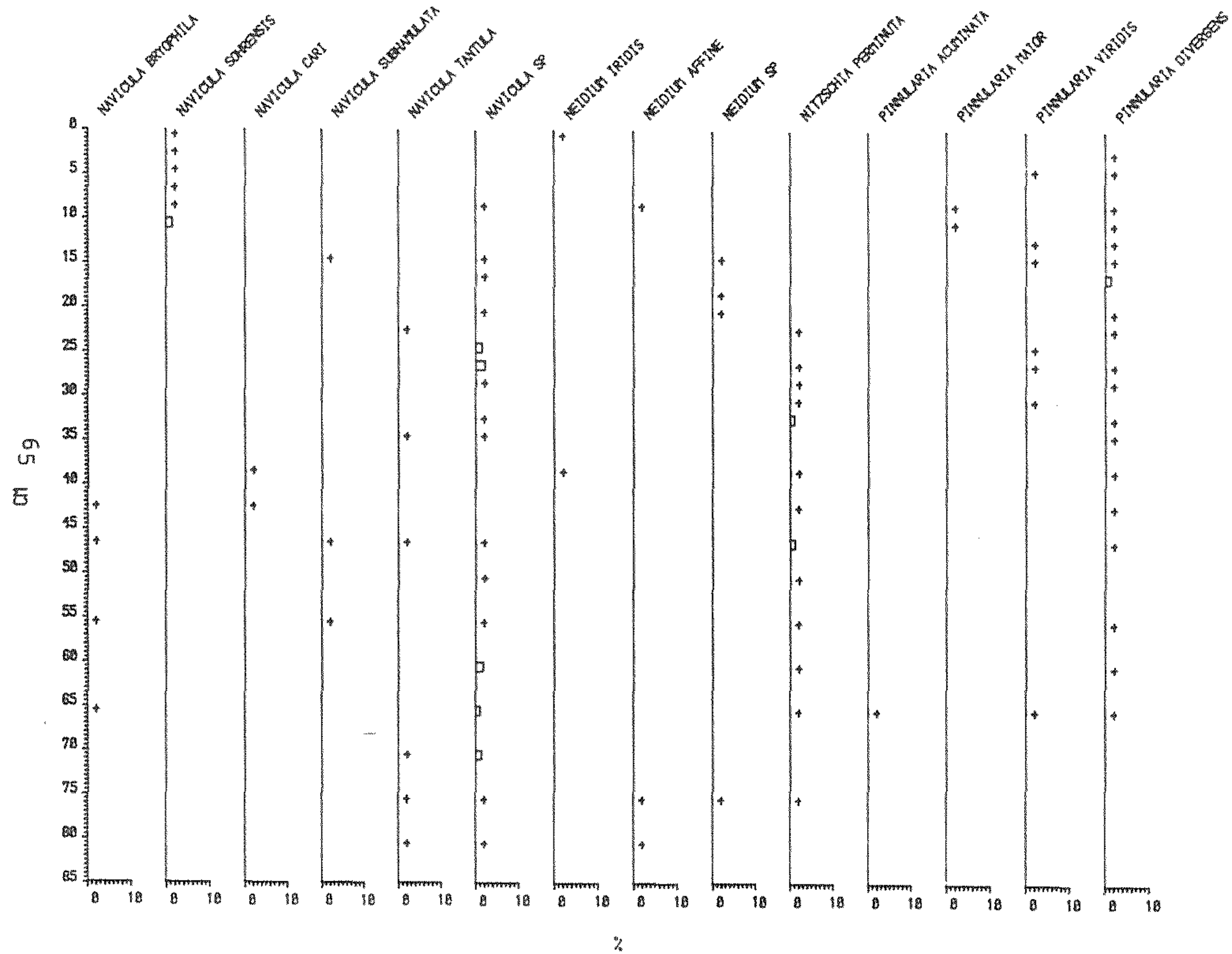
LLYN BERWYN DIATOM PERCENTAGE PROFILES

Appendix C



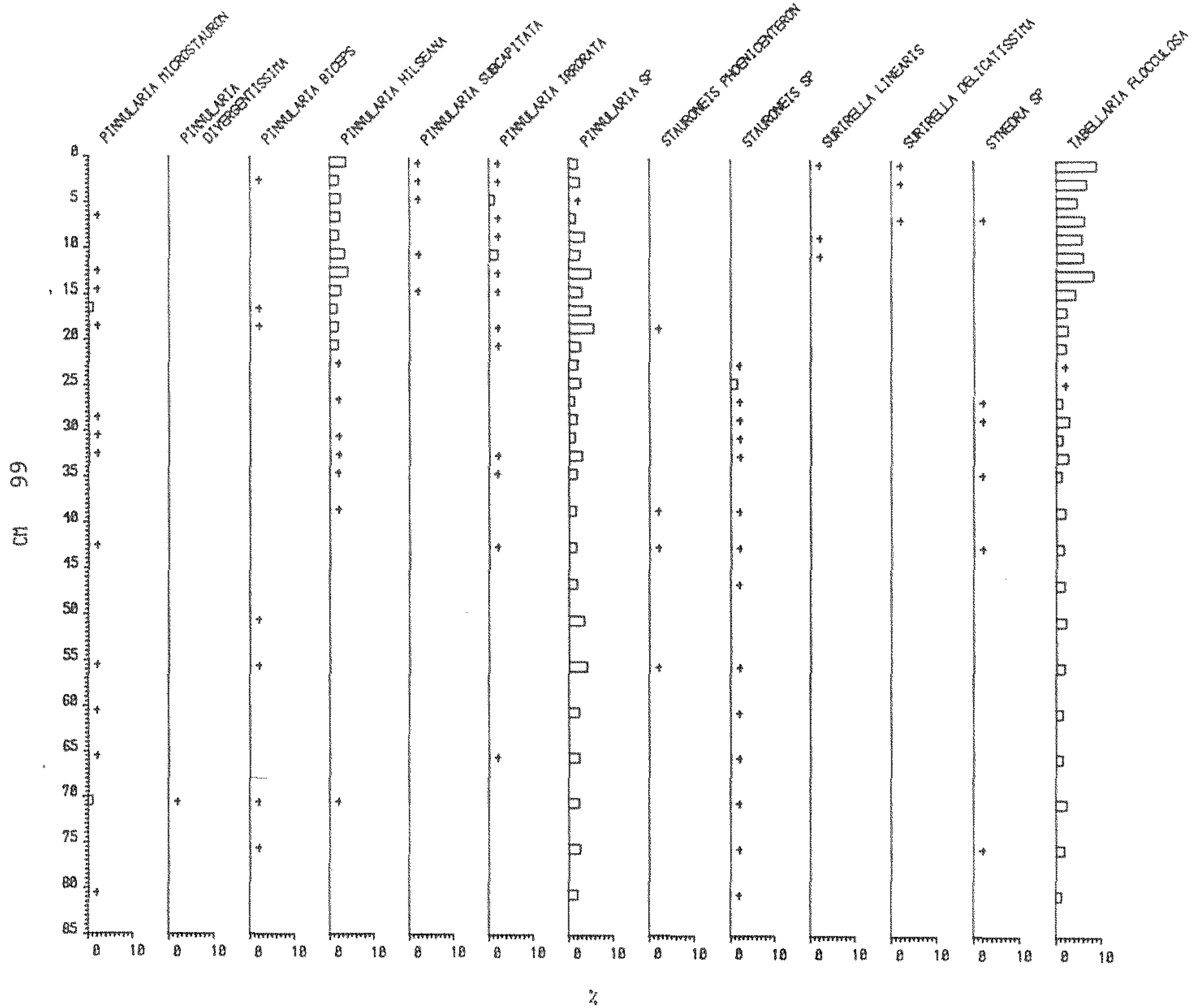
LLYN BERWYN DIATOM PERCENTAGE PROFILES

Appendix C



LLYN BERWYN DIATOM PERCENTAGE PROFILES

Appendix C



LLYN BERWYN DIATOM PERCENTAGE PROFILES

APPENDIX D

Depth cm	Density g/cm3	Dry Wt %	LOI %	µg Zn/g	µg Pb/g
0.5	1.07	10.6	50.7	127	159
1.5	1.072	9.3	51.7	298	181
2.5	1.074	9.9	46.7	287	155
3.5	1.077	11	48.4	219	138
4.5	1.076	11.6	50.8	290	131
5.5	1.078	11	57.1	373	159
6.5	1.07	9.8	64.2	354	181
7.5	1.074	12	60.2	223	104
8.5	1.076	10.9	56.4	235	145
9.5	1.07	10.3	65	232	178
10.5	1.075	11.8	72	213	206
11.5	1.073	10.8	69.4	244	193
13.5	1.056	9.7	68.3	294	210
14.5	1.068	9.4	73.3	279	269
15.5	1.069	9.1	72.9	282	248
17.5	1.07	10.3	72.3	153	168
18.5	1.068	11.9	71.3	149	147
19.5	1.057	13.3	47.9	189	145
20.5	1.085	15	47	201	112
21.5	1.129	17.2	32.9	142	65
22.5	1.148	19.5	27.4	132	26
23.5	1.175	21	19.5	121	11
24.5	1.184	21.6	24.9	119	8
25.5	1.179	21.7	19.6	121	34
26.5	1.181	21.7	20.4	117	15
27.5	1.159	20.9	20.4	144	27
28.5	1.147	18.8	24.3	137	38
29.5	1.144	17	25.3	176	38
30.5	1.119	16	27.1	151	12
31.5	1.117	15.2	28.1	149	7
33.5	1.118	16	28.2	137	28
34.5	1.124	16.5	26.6	137	40
35.5	1.123	16.4	28.2	132	11
37.5	1.132	17	28.7	128	24
38.5	1.129	17.4	27.2	129	28
39.5	1.133	17.5	28.8	134	38
40.5	1.124	17.2	27.7	131	29
41.5	1.129	17.4	29	129	31
42.5	1.126	17.4	27.3	128	47
43.5	1.129	17.6	27.1	128	40
44.5	1.129	17.8	26.5	122	25
45.5	1.129	18.1	27.5	125	29
46.5	1.138	18.5	27.2	126	38
47.5	1.133	18.8	26.2	123	46
48.5	1.132	18.9	27.9	128	29
49.5	1.138	19.1	29.1	128	42
50.5	1.135	19	27.4	144	48
51.5	1.129	19	26.4	144	32
52.5		19.1	27.8	130	9
53.5	1.133	18.9	28	128	18
54.5		18.8	28.6	116	21
55.5	1.129	18.5	28.8	120	19
56.5		18.3	26.7	122	10
57.5	1.127	18.2	29.1	125	43
58.5		18	29.5	118	17
59.5	1.126	17.8	29	118	12
60.5		17.8	29.2	114	13
61.5	1.124	17.5	28.4	113	35
62.5		17.2	30.7	112	10
63.5	1.119	17.4	31.2	131	11
64.5		17.5	29.7	122	2
65.5	1.12	17.5	28.7	129	46
66.5		17.6	29.4	122	23
67.5	1.125	17.6	28.8	125	23
68.5		17.6	30.8	119	41
69.5	1.125	17.6	30.3	120	61
70.5		17.6	29.9	114	32
71.5	1.12	18.2	28.1	115	34
72.5		17.7	30.9	111	18
73.5	1.116	17.8	30	116	17
74.5		16.5	30.1	110	102
75.5	1.123	17.9	30.8	115	74
76.5		18	30.5	109	32
77.5	1.129	18.4	28.2	112	3
78.5		18.3	28.1	106	19
79.5	1.132	18.3	30.2	108	99
80.5		18.3	31.5	104	40
81.5	1.124	18.4	32.6	108	43
82.5		18.3	31.8	108	43

Depth cm	µg Cu/g	µg Ni/g	mg Ca/g	mg Mg/g	mg Na/g
0.5	39	24	1.53	2.79	4.23
1.5	27	30	1.77	3.12	4.17
2.5	24	28	1.67	3.19	4
3.5	23	35	1.87	3.17	4.78
4.5	21	31	2.21	2.98	3.94
5.5	22	31	2.51	2.82	3.61
6.5	29	28	2.6	2.79	3.28
7.5	17	30	2	4.19	5.11
8.5	16	26	2.35	3.59	4.27
9.5	19	22	2.92	2.85	3.15
10.5	23	25	3.02	2.4	2.99
11.5	30	17	3.08	2.48	2.97
13.5	25	17	2.99	2.39	2.81
14.5	40	20	3.18	2.23	2.57
15.5	19	34	3.14	2.37	2.69
17.5	25	18	3.38	2.45	2.24
18.5	18	17	3.1	2.13	2.88
19.5	36	21	2.41	3.43	4.39
20.5	14	34	1.63	4.77	5.78
21.5	5	35	1.21	6.08	6.57
22.5	9	41	1.4	5.31	6.77
23.5	13	40	1.28	5.58	6.9
24.5	14	41	1.1	5.81	7.14
25.5	15	39	1.24	5.64	6.92
26.5	16	38	1.09	5.43	7.04
27.5	31	47	1.3	6.51	6.84
28.5	13	41	1.35	5.41	6.76
29.5	18	42	1.58	4.65	5.06
30.5	14	39	1.6	5.02	6.13
31.5	14	42	1.68	5.28	5.64
33.5	7	40	1.67	4.72	5.93
34.5	5	40	1.6	4.58	6.05
35.5	8	37	1.7	4.75	5.81
37.5	9	38	1.62	4.72	5.9
38.5	8	37	1.58	4.93	5.94
39.5	10	38	1.59	4.88	5.94
40.5	4	39	1.5	5.01	5.99
41.5	5	41	1.59	4.89	6.17
42.5	4	39	1.5	4.81	6.13
43.5	7	38	1.55	4.82	6.1
44.5	3	39	1.58	4.69	6.23
45.5	3	38	1.59	5.5	6.27
46.5	7	40	1.51	4.9	6.39
47.5	5	39	1.55	5.1	6.05
48.5	3	38	1.58	5.26	6.36
49.5	3	42	1.51	5.28	6.32
50.5	11	49	1.49	5.09	6.32
51.5	9	38	1.53	5.29	6.21
52.5	0	42	1.62	4.95	5.88
53.5	5	44	1.7	4.97	5.49
54.5	7	41	1.78	4.9	5.59
55.5	8	40	1.72	5.05	5.39
56.5	5	39	1.65	4.86	5.51
57.5	12	42	1.69	4.80	5.44
58.5	4	39	1.69	4.82	5.58
59.5	5	39	1.74	4.78	5.27
60.5	3	41	1.89	4.3	5.34
61.5	10	41	1.73	4.58	5.09
62.5	5	36	1.82	4.65	5.12
63.5	6	41	1.9	4.72	5.43
64.5	4	38	1.76	4.74	5.25
65.5	10	42	1.8	4.82	5.41
66.5	2	39	1.71	4.61	5.4
67.5	6	36	1.84	5.61	5.23
68.5	2	40	1.78	5.52	5.14
69.5	5	43	1.77	4.6	5.31
70.5	4	37	1.78	4.88	5.41
71.5	2	39	1.78	4.79	5.31
72.5	15	35	1.82	4.27	6.16
73.5	20	37	1.76	4.92	6.6
74.5	15	31	1.83	4.65	6.03
75.5	19	36	1.82	5.59	6.15
76.5	12	36	1.78	4.41	5.75
77.5	14	36	1.79	4.08	5.99
78.5	11	34	1.78	4.67	5.94
79.5	13	36	1.85	4.66	5.99
80.5	12	32	1.82	4.54	6.01
81.5	17	42	2.47	4.72	6.18
82.5	17	42	2.47	4.72	6.18

Depth cm	mg K/g	mg Fe/g	mg Mn/g	mg P/g	mg S/g
0.5	9.47	29.71	0.4	1.34	4.23
1.5	11.1	25.14	0.5	1.1	
2.5	10.4	22.16	0.52	0.9	3.74
3.5	10.93	21.56	0.61	0.73	
4.5	9.59	21.55	0.79	0.54	4.41
5.5	8.7	20.75	0.92	0.5	4.87
6.5	8.71	20.87	0.99	0.51	
7.5	13.58	27.9	0.87	0.48	
8.5	10.57	26.04	1.08	0.48	4.12
9.5	8.09	22.93	1.38	0.45	5.31
10.5	7.26	21.89	1.38	0.47	4.67
11.5	6.84	23.4	1.40	0.43	5.55
13.5	6.96	20.42	1.49	0.52	
14.5	5.79	20.3	1.8	0.48	
15.5	6.56	21.68	1.62	0.45	6.06
17.5	5.53	22.12	1.90	0.44	5.94
18.5	6.59	23.43	1.88	0.39	5.18
19.5	10.55	26.9	1.42	0.42	4.03
20.5	16.2	31.45	1.01	0.45	2.44
21.5	19.5	33.12	0.88	0.48	1.6
22.5	18.91	33.37	0.9		1.71
23.5	20.24	33.78	0.88		1.5
24.5	20.57	34.17	0.83	0.5	1.09
25.5	20.32	34.63	0.87		1.24
26.5	18.97	34.98	0.83		1.69
27.5	18.94	37.32	0.90	0.83	0.39
28.5	18.36	38.68	1.03		1.64
29.5	16.2	40.11	1.24		1.3
30.5	16.80	42.79	1.31	1.15	1.89
31.5	14.75	41.5	1.30		2.25
33.5	15.16	42.78	1.47		1.93
34.5	14.97	40.38	1.38	0.94	1.29
35.5	15.19	37.15	1.39		1.93
37.5	16.03	37.44	1.39		1.68
38.5	15.98	38.11	1.36	0.83	2.04
39.5	16.18	38.37	1.39		1.29
40.5	16.67	38.37	1.34		1.57
41.5	16.72	38.98	1.3	0.78	1.79
42.5	16.58	38.87	1.29		1.77
43.5	16.39	37.61	1.29		1.39
44.5	17.22	39.18	1.37	0.78	1.58
45.5	16.93	39.61	1.37		1.3
46.5	17.11	37.91	1.29		1.48
47.5	16.92	38.13	1.37	0.7	1.72
48.5	17.85	38.88	1.3		1.33
49.5	17.57	39.01	1.28		1.29
50.5	17.39	37.54	1.33	0.72	1.64
51.5	17.77	38.75	1.34		1.09
52.5	17.83	41.54	1.39		1.97
53.5	16.58	40.61	1.49	0.65	2.27
54.5	17.09	39.59	1.49		2.2
55.5	16.43	39.8	1.5		2.3
56.5	16.91	40.88	1.51	0.67	2.22
57.5	16.72	39.94	1.54		1.78
58.5	16.50	39.07	1.46		2.27
59.5	15.89	38.54	1.49	0.62	1.76
60.5	16.59	39.39	1.52		2.33
61.5	15.43	37.82	1.44		2.44
62.5	15.74	38.50	1.52	0.6	2.58
63.5	16.05	40.02	1.57		2.48
64.5	16	39.75	1.51		2.64
65.5	16.19	39.86	1.5	0.67	2.21
66.5	16.19	39.92	1.48		2.12
67.5	14.31	39.82	1.48		2.11
68.5	15.77	39.35	1.52		2.25
69.5	15.99	37.87	1.45		2.67
70.5	16.58	39.93	1.48		2.09
71.5	16.13	39.87	1.5		2.09
72.5	15.83	39.13	1.45		2.15
73.5	15.68	40.03	1.52		2.1
74.5	16.04	39.61	1.55		2.09
75.5	16.37	39.80	1.53		2.18
76.5	14.89	38.8	1.43		2.05
77.5	16.02	39.91	1.48		2.07
78.5	15.79	38.74	1.49		1.41
79.5	15.42	39.53	1.48		1.66
80.5	15.58	38.14	1.43		2
81.5	16.1	41.05	1.63		
82.5	16.1	41.05	1.63		

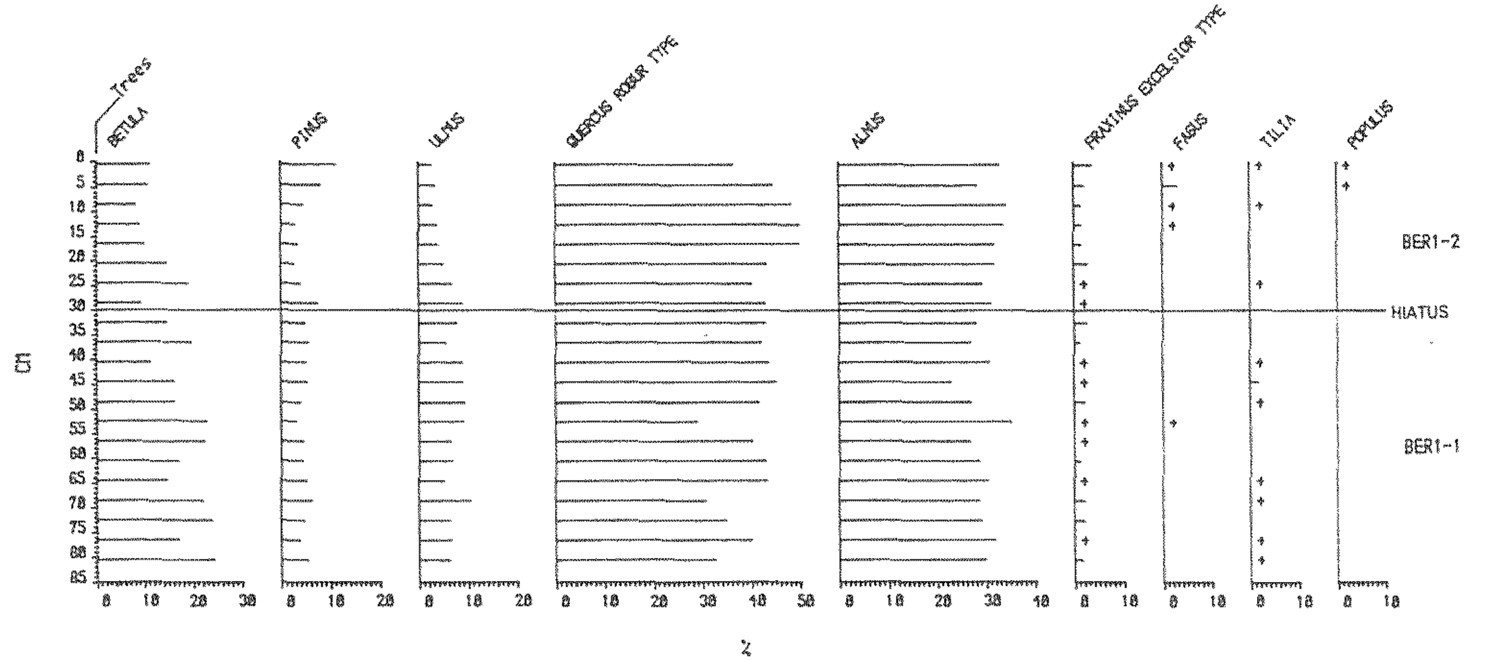
Depth cm	µg Zn/g min	µg Pb/g min	µg Cu/g min	µg Ni/g min	mg Ca/g min
0.5	257.61	322.52	79.11	48.68	3.10
1.5	612.04	374.74	55.90	62.11	3.68
2.5	538.48	290.81	45.03	52.53	3.13
3.5	424.42	267.44	44.57	67.83	3.62
4.5	589.43	266.28	42.68	63.01	4.49
5.5	869.40	370.63	51.20	72.20	5.89
6.5	988.03	505.59	81.01	78.21	7.26
7.5	560.30	261.31	42.71	73.30	5.03
8.5	535.31	325.74	36.49	59.23	5.39
9.5	827.03	481.08	51.39	59.48	7.09
10.5	760.71	735.71	82.14	89.29	10.79
11.5	797.39	530.72	98.04	55.56	10.07
13.5	927.44	682.48	78.88	53.63	9.31
14.5	1044.94	1007.49	149.81	74.91	11.84
15.5	1040.59	915.13	70.11	125.48	11.59
17.5	559.52	808.54	90.25	64.98	12.13
18.5	517.38	510.42	62.50	59.03	10.76
19.5	382.78	278.31	59.10	40.31	4.63
20.5	379.29	211.32	26.42	64.19	3.08
21.5	211.62	98.57	7.45	52.10	1.80
22.5	181.82	35.91	26.17	56.47	1.93
23.5	150.31	13.58	16.15	49.69	1.57
24.5	158.48	10.55	18.64	54.59	1.48
25.5	150.50	42.29	18.68	48.51	1.54
26.5	146.98	18.84	20.10	47.74	1.37
27.5	180.90	33.92	30.94	52.78	1.63
28.5	180.98	50.20	17.17	54.18	1.78
29.5	235.61	50.87	24.10	56.22	2.09
30.5	207.13	16.48	19.20	53.50	2.19
31.5	203.09	9.74	19.47	58.41	2.31
33.5	190.81	39.00	9.75	55.71	2.33
34.5	186.65	54.50	10.90	54.50	2.18
35.5	183.84	15.32	11.14	51.53	2.37
37.5	179.52	33.60	12.82	53.30	2.27
38.5	177.20	38.48	10.99	50.82	2.17
39.5	187.88	53.22	14.01	53.22	2.23
40.5	181.19	40.11	5.53	53.94	2.07
41.5	181.69	43.50	7.04	57.79	2.18
42.5	176.07	64.65	5.50	53.65	2.08
43.5	172.84	54.87	9.60	52.13	2.13
44.5	165.99	34.01	4.08	53.06	2.15
45.5	172.41	40.00	4.14	52.41	2.14
46.5	173.08	52.20	9.62	54.95	2.07
47.5	168.67	62.33	8.13	52.85	2.10
48.5	174.78	40.22	4.18	52.70	2.19
49.5	180.54	59.24	4.23	59.24	2.13
50.5	190.35	66.12	1.38	67.49	2.05
51.5	195.65	70.65	12.23	51.63	2.09
52.5	180.08	12.47	11.08	58.17	2.24
53.5	177.78	25.00	11.11	61.11	2.34
54.5	162.48	29.41	9.80	57.42	2.49
55.5	168.07	28.61	11.20	58.07	2.41
56.5	168.44	13.64	6.82	53.21	2.29
57.5	178.50	60.65	16.93	59.24	2.38
58.5	167.38	24.11	5.67	55.32	2.40
59.5	156.34	16.90	7.04	54.93	2.49
60.5	161.02	18.38	4.24	57.91	2.61
61.5	157.82	48.88	13.97	57.28	2.42
62.5	161.62	14.43	7.22	51.95	2.63
63.5	190.41	15.99	8.72	59.59	2.76
64.5	173.54	2.84	5.69	54.05	2.50
65.5	180.93	64.52	14.03	58.91	2.52
66.5	172.80	32.56	2.83	55.24	2.42
67.5	175.03	32.21	8.40	50.42	2.58
68.5	171.93	59.25	2.89	57.80	2.57
69.5	172.17	87.52	7.12	61.69	2.54
70.5	162.62	45.65	5.71	52.78	2.54
71.5	159.94	47.29	2.78	54.24	2.40
72.5	160.64	26.05	21.71	50.65	2.63
73.5	165.71	24.29	28.57	52.86	2.51
74.5	157.37	145.92	21.40	44.35	2.62
75.5	166.18	106.94	27.48	52.07	2.63
76.5	156.03	46.04	17.27	51.80	2.56
77.5	155.99	4.18	19.50	50.14	2.49
78.5	147.43	28.43	15.30	47.29	2.40
79.5	154.73	141.03	18.62	51.58	2.65
80.5	151.62	50.39	17.52	45.72	2.60
81.5	160.24	63.80	25.22	62.31	3.66
82.5				61.40	3.08

APPENDIX D

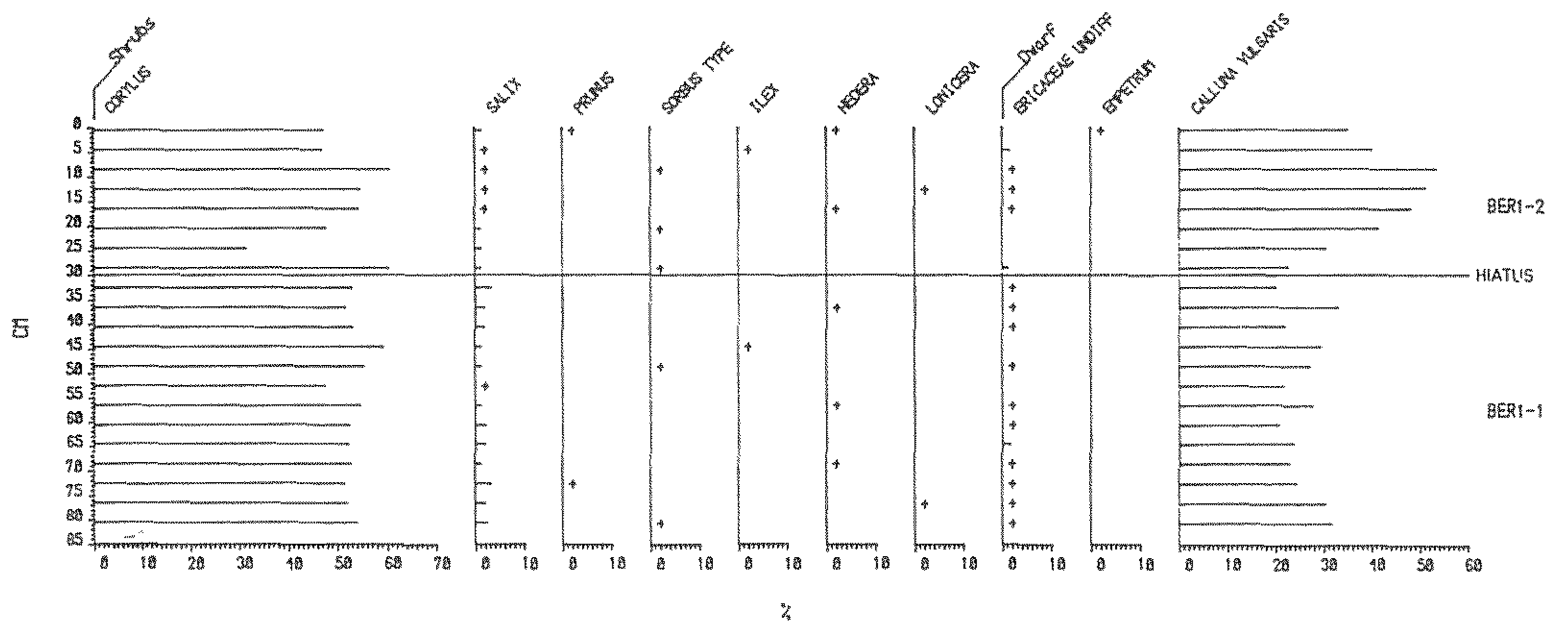
Depth cm	mg Mg/g min	mg Na/g min	mg K/g min	mg Fe/g min	mg Mn/g min
0.5	5.58	8.58	19.21	60.26	0.81
1.5	6.46	8.63	22.98	52.05	1.04
2.5	5.91	7.50	19.51	41.58	0.98
3.5	6.14	9.22	21.18	41.98	1.18
4.5	6.06	8.01	19.49	43.80	1.61
5.5	6.57	8.41	20.28	48.37	2.14
6.5	7.79	9.11	24.33	58.30	2.77
7.5	10.53	12.84	34.12	70.10	2.19
8.5	8.18	9.73	24.31	59.32	2.41
9.5	7.70	8.51	21.76	61.97	3.68
10.5	8.57	10.68	25.93	78.04	4.93
11.5	8.10	9.71	22.35	76.47	4.84
13.5	7.54	8.86	21.96	64.42	4.70
14.5	8.35	9.63	21.54	76.03	6.74
15.5	8.75	9.93	24.21	79.93	5.98
17.5	8.84	8.09	19.98	79.86	7.15
18.5	7.40	10.00	22.88	81.35	6.46
19.5	6.58	8.43	20.44	51.63	2.73
20.5	9.00	10.91	30.57	59.30	1.91
21.5	9.03	9.79	29.06	49.36	1.28
22.5	7.31	9.33	26.05	45.96	1.24
23.5	6.93	8.57	25.14	41.98	1.07
24.5	7.74	9.51	27.39	45.50	1.11
25.5	7.01	8.61	25.27	43.07	1.08
26.5	6.82	8.84	23.83	43.94	1.04
27.5	8.18	8.59	23.79	46.88	1.21
28.5	7.15	8.93	24.25	51.10	1.36
29.5	6.22	8.11	21.69	53.69	1.66
30.5	6.89	8.41	23.16	58.70	1.80
31.5	7.32	7.84	20.51	57.86	1.92
33.5	6.57	8.26	21.11	59.58	2.05
34.5	6.21	8.24	20.40	54.99	1.88
35.5	6.62	8.09	21.16	51.74	1.94
37.5	6.62	8.27	22.48	52.51	1.91
38.5	6.77	8.16	21.95	52.35	1.87
39.5	6.81	8.32	22.63	53.74	1.89
40.5	6.93	8.28	23.06	53.07	1.85
41.5	6.89	8.69	23.55	54.90	1.83
42.5	6.62	8.43	22.78	53.47	1.77
43.5	6.61	8.37	22.48	51.59	1.77
44.5	6.38	8.48	23.43	53.28	1.86
45.5	7.59	8.65	23.35	54.63	1.89
46.5	6.73	8.78	23.50	52.07	1.72
47.5	6.91	8.20	22.93	51.67	1.86
48.5	7.30	8.82	24.76	53.90	1.80
49.5	7.45	8.91	24.78	55.02	1.78
50.5	7.01	8.71	23.95	51.71	1.83
51.5	7.19	8.44	24.14	52.65	1.82
52.5	6.86	8.14	24.70	57.53	1.93
53.5	6.90	7.63	23.03	56.40	2.07
54.5	6.86	7.83	23.88	55.45	2.03
55.5	7.07	7.55	23.00	55.48	2.10
56.5	6.63	7.52	23.07	55.77	2.06
57.5	6.88	7.67	23.58	56.33	2.17
58.5	6.84	7.91	23.52	55.42	2.07
59.5	6.70	7.42	22.38	54.28	2.04
60.5	6.07	7.54	23.38	55.64	2.15
61.5	6.40	7.11	21.55	52.82	2.01
62.5	6.71	7.39	22.71	55.67	2.19
63.5	6.86	7.89	23.33	58.17	2.28
64.5	6.74	7.47	22.76	56.54	2.15
65.5	6.76	7.59	22.71	55.90	2.10
66.5	6.53	7.65	22.88	56.54	2.07
67.5	7.86	7.32	20.04	55.77	2.04
68.5	7.98	7.43	22.79	56.86	2.20
69.5	6.60	7.62	22.94	54.33	2.08
70.5	6.96	7.72	23.62	56.98	2.11
71.5	6.66	7.39	22.43	55.45	2.09
72.5	6.18	8.91	22.91	56.63	2.10
73.5	7.03	9.43	22.40	57.19	2.17
74.5	6.65	8.63	22.95	56.67	2.22
75.5	8.02	8.89	23.66	57.63	2.21
76.5	6.35	8.27	21.42	55.54	2.06
77.5	6.77	8.34	22.31	55.58	2.03
78.5	6.50	8.26	21.91	53.88	2.07
79.5	6.68	8.58	22.09	56.63	2.12
80.5	6.63	8.77	22.72	55.68	2.09
81.5	7.00	9.17	23.89	60.91	2.42
82.5	6.90	9.04	23.54	60.01	2.38

Depth cm	Fe/Mn	mg S/g min
0.5	74.28	8.56
1.5	50.28	0.00
2.5	42.62	7.02
3.5	35.51	0.00
4.5	27.28	8.96
5.5	22.55	11.35
6.5	21.08	0.00
7.5	32.07	0.00
8.5	24.57	9.38
9.5	16.86	14.35
10.5	15.83	16.68
11.5	15.81	18.24
13.5	13.70	0.00
14.5	11.28	0.00
15.5	13.37	22.36
17.5	11.17	21.44
18.5	12.60	17.99
19.5	18.94	7.74
20.5	31.12	4.60
21.5	38.51	2.38
22.5	37.08	2.36
23.5	39.28	1.86
24.5	41.17	1.45
25.5	39.80	1.54
26.5	42.14	2.12
27.5	38.88	0.49
28.5	37.55	2.17
29.5	32.35	1.74
30.5	32.66	2.54
31.5	30.14	3.13
33.5	29.10	2.69
34.5	29.25	1.76
35.5	26.73	2.69
37.5	27.53	2.36
38.5	28.02	2.80
39.5	28.42	1.81
40.5	28.63	2.17
41.5	29.98	2.52
42.5	30.13	2.43
43.5	29.16	1.87
44.5	28.58	2.15
45.5	28.91	2.07
46.5	30.33	2.01
47.5	27.83	2.33
48.5	29.89	1.84
49.5	30.96	1.76
50.5	28.23	2.26
51.5	28.92	1.48
52.5	29.88	2.73
53.5	27.26	3.15
54.5	27.30	3.08
55.5	26.40	3.22
56.5	27.07	3.03
57.5	25.94	2.41
58.5	26.76	3.22
59.5	26.58	2.48
60.5	25.91	3.29
61.5	26.26	3.41
62.5	25.38	3.72
63.5	25.49	3.60
64.5	26.32	3.76
65.5	26.57	3.10
66.5	27.34	3.00
67.5	27.27	2.96
68.5	25.89	3.25
69.5	26.12	3.83
70.5	26.98	2.98
71.5	26.58	2.91
72.5	26.99	3.11
73.5	26.34	3.00
74.5	25.55	2.99
75.5	26.07	3.15
76.5	26.99	2.95
77.5	27.34	2.88
78.5	26.00	1.96
79.5	26.71	2.38
80.5	26.67	2.92
81.5	25.18	0.00
82.5	25.18	0.00

Appendix E

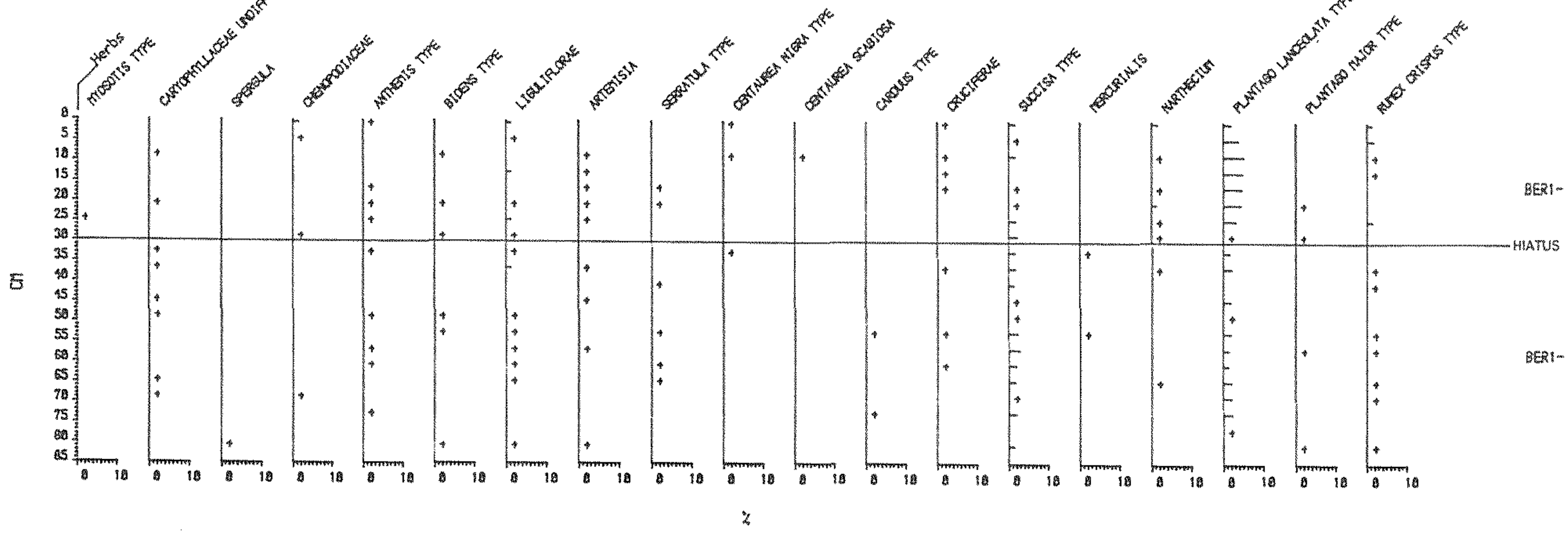


Trees
BETULA
PINUS
ULMUS
QUERCUS ROBUR TYPE
ALNUS
FRAXINUS EXCELSIOR TYPE
FAGUS
TILIA
POPULUS
BER1-2
HIATUS
BER1-1
CM
%

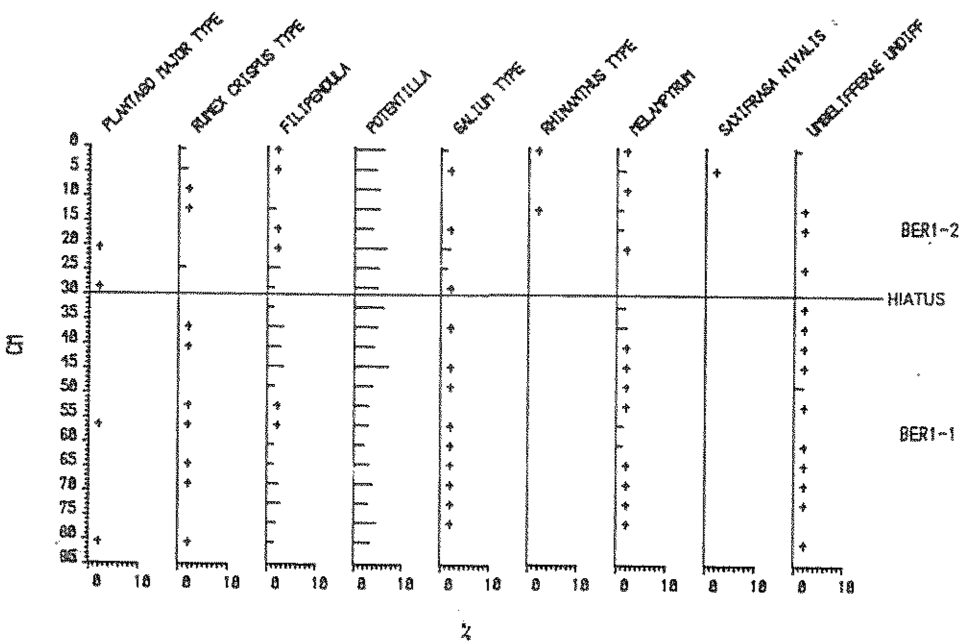


Shrubs
CORYLUS
SALIX
PRUNUS
SORBUS TYPE
ILEX
HEDERA
LONICERA
Dwarf
ERICACEAE UNDIFF
EMPETRUM
CALLUNA VULGARIS
BER1-2
HIATUS
BER1-1
CM
%

Appendix E

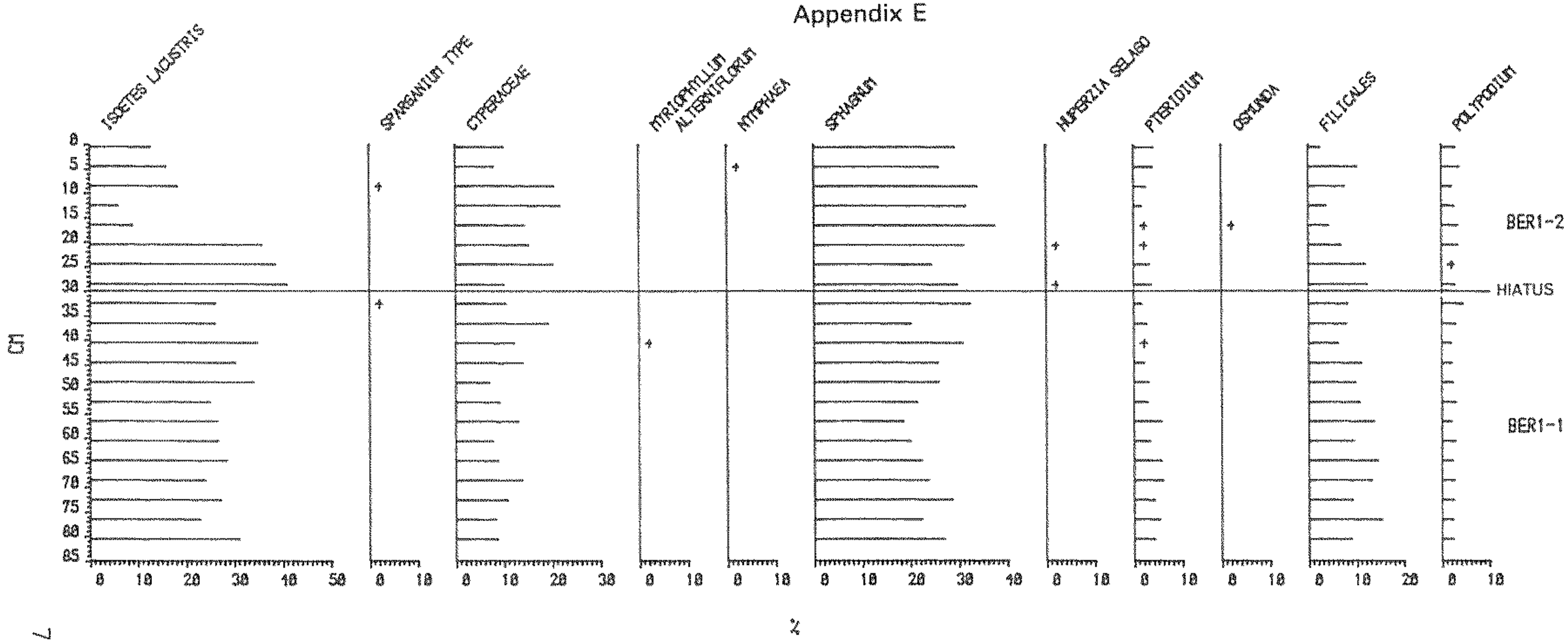


Herbs
MYOSOTIS TYPE
CARYOPHYLLACEAE UNDIFF.
SPERGULA
CHENOPODIACEAE
ANTHEMIS TYPE
BIDENS TYPE
LIGULIFLORAE
ARTEMISIA
SERRATULA TYPE
CENTAUREA NIGRA TYPE
CENTAUREA SCABIOSA
CARDUUS TYPE
CRUCIFERAE
SUCCISA TYPE
MERCURIALIS
NARTHECIUM
PLANTAGO LANCEOLATA TYPE
PLANTAGO MAJOR TYPE
RUMEX CRISPUS TYPE
CM
BER1-
HIATUS
BER1-
%



PLANTAGO MAJOR TYPE
RUMEX CRISPUS TYPE
FILIPENDULA
POTENTILLA
GALIUM TYPE
RHINANTHUS TYPE
MELAMPYRUM
SAXIFRAGA NIVALIS
UMBELLIFERAE UNDIFF
CM
BER1-2
HIATUS
BER1-1
%

Appendix E



ISOETES LACUSTRIS
SPARGANIUM TYPE
CYPERACEAE
MYRIOPHYLLUM ALTERNIFLORUM
NYMPHAEA
SPHAGNUM
HUPERZIA SELAGO
PTERIDIUM
OSMUNDA
FILICALES
POLYPODIUM
BER1-2
HIATUS
BER1-1
CM
%

PALAEOECOLOGY RESEARCH UNIT
RESEARCH PAPERS

No. 1 Patrick, S. & Battarbee, R.W. 1981 The influence of sanitary and other social changes on the eutrophication of Lough Erne since 1850: Project introduction and a consideration of the potential role of metabolic wastes. 43 pp.

No. 2 Battarbee, R.W. 1983 Diatom analysis of River Thames foreshore deposits exposed during the excavation of a Roman waterfront site at Pudding Lane, London. 18 pp.

No. 3 Patrick, S. & Battarbee, R.W. 1983 Rural sanitation in the Lough Erne catchment: History and influence on phosphorous loadings. 26 pp.

No. 4 Patrick, S. 1983 The calculation of per capita phosphorous outputs from detergents in the Lough Erne catchment. 23 pp.

No. 5 Patrick, S. 1983 Phosphorous loss at sewage works in the Lough Erne region. 36 pp.

No. 6 Flower, R.J. & Battarbee, R.W. 1983 Acid lakes in the Galloway uplands, South West Scotland: catchments, water quality and sediment characteristics. 56 pp.

No. 7 Patrick, S. 1984 The influence of industry on phosphorous loadings in the Loch Erne region. 46 pp

No. 8 Battarbee, R.W. & Flower, R.J. 1985 Palaeoecological evidence for the timing and causes of lake acidification in Galloway, South West Scotland. 79 pp.

No. 9 Raven, P.J. 1985 The use of aquatic macrophytes to assess water quality changes in some Galloway lochs: an exploratory study. 76 pp.

No. 10 Anderson, N.J. & Battarbee, R.W. 1985 Loch Fleet: bathymetry and sediment distribution. 18 pp.

No. 11 Battarbee, R.W. *et al.* 1985 Diatoms and acid lakes: proceedings of a workshop.

No. 12 Battarbee, R.W. and Renberg, I. 1985 Royal Society Surface Water Acidification Project (SWAP) Paleeolimnology Programme. 18 pp.

No. 13 Raven, P.J. 1986 Occurrence of *Sphagnum* moss in the sublittoral of several Galloway lochs, with particular reference to Loch Fleet. 40 pp.

No. 14 Flower, R.J., Rippey, B. & Tervet, D. 1986 34 Galloway Lakes: Bathymetries, Water quality & Diatoms.

No. 15 Flower, R.J. & Nicholson, A. 1986 Batymetries, water quality and diatoms of lochs on the island of South Uist, The Outer Hebrides, Scotland. 42pp

No. 16 Fritz, S.C., Stevenson, A.C., Patrick, S.T., Appleby, P.G., Oldfield, F., Rippey, B. & Darley, J. 1986 Palaeoecological evaluation of the acidification of Welsh lakes. I: Llyn Hir, Dyfed.

No. 17 Anderson, N.J.A., Battarbee, R.W., Appleby, P.G., Stevenson, A.C, Oldfield, F., Darley, J & Glover, G. (1986) Palaeolimnological evidence for the recent acidification of Loch Fleet, Galloway.

No. 18 Kreiser, A., Stevenson, A.C., Patrick, S.T. Appleby, P.G., Oldfield, F., Rippey, B., Darley, J. & Battarbee, R.W. (1986) Palaeoecological evaluation of the acidification of Welsh lakes. II. Llyn Berwyn, Dyfed.

For copies of Research Papers or further information, please contact Dr. R.W. Battarbee, Palaeoecology Research Unit, Department of Geography, University College London, 26 Bedford Way, London WC1H 0AP.