A Palaeolimnological Evaluation of Peatland Erosion

PEATLAND EROSION PROJECT: REPORT TO THE N.C.C.

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SUMMARY

1 The proposed causes of accelerated blanket peat erosion are briefly reviewed.

2. Lake sediments can be used in peat erosion studies since they record a history of catchment events.

3. This pilot study is concerned with developing techniques for sediment dating and for charcoal analysis, using the Round Loch of Glenhead, (Galloway) and its catchment as an example.

4. The catchment of the Round Loch of Glenhead is dominated by blanket mires which contain both active and revegetated haggs.

5. The history of peat erosion is represented in the lake sediment by the loss on ignition record. This shows minor peaks, probably reflecting individual erosion events, from 5000 years B.P. onwards, and a sustained increase in values over the last few hundred years.

6 Precise dating of this major erosional event using conventional techniques is difficult since it precedes the ^{210}Pb timescale, and because the peat inwash causes artificially old ^{14}C dates.

7. It is hoped that accelerator ^{14}C dating of selected organic fragments from both peat and lake sediment cores will overcome these difficulties.

8. Good pollen correlation between peat and lake sediment cores has been established and this will allow dates to be transferred between cores.

9. A range of techniques for charcoal analysis have been evaluated. Both the "Winkler" and point count techniques can be used. More experiments are required before a final method is selected, but the work has clearly demonstrated that a good charcoal record exists in both peat and lake sediment cores.

10. Although the work is at an early stage a number of the proposed mechanisms for peat erosion are briefly discussed. The data suggest that the peats were stable until a few hundred years ago indicating that the "inherent instability" hypothesis is invalid at this site. The main erosion is associated with high charcoal values in the catchment peat core which suggests that burning is important, but a climatic influence cannot yet be ruled out since the erosion period probably began during the Little Ice Age. Acid deposition is of little significance at this site since severe erosion began at least 100 years before the first evidence of significant air pollution in the lake sediment core.

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1.0 Introduction

Peat erosion in Britain has been recognised for hundreds of years. Serious attempts at explanation began with work in the Pennines (eg. Conway 1954), probably the most affected region in Britain. The need to identify the causes of peat erosion on a catchment basis is crucial to the long-term management of peat systems. In 1981, the Peak District Moorland erosion study report was published (Phillips *et al.* 1981). This contains a synthesis of work conducted under the project since 1979, as well as valuable literature reviews of many aspects of peat and soil erosion. However, attempts to date the onset of peat erosion in the Peak District and elsewhere, using pollen and macrofossil changes in uneroded peat profiles, have not been entirely satisfactory (Phillips *et al.* 1981, Tallis 1985, 1987). A more promising approach, at least in catchments with lakes, is to use the lake sediment record.

This report attempts to illustrate how lake sediments can be used: (a) to provide more accurate estimates of the date of onset of peat erosion and (b) to test alternative hypotheses about causes of peat erosion. A site where peat erosion is known to have occurred, the Round Loch of Glenhead (Galloway) (Fig. 1), was selected for a pilot study.

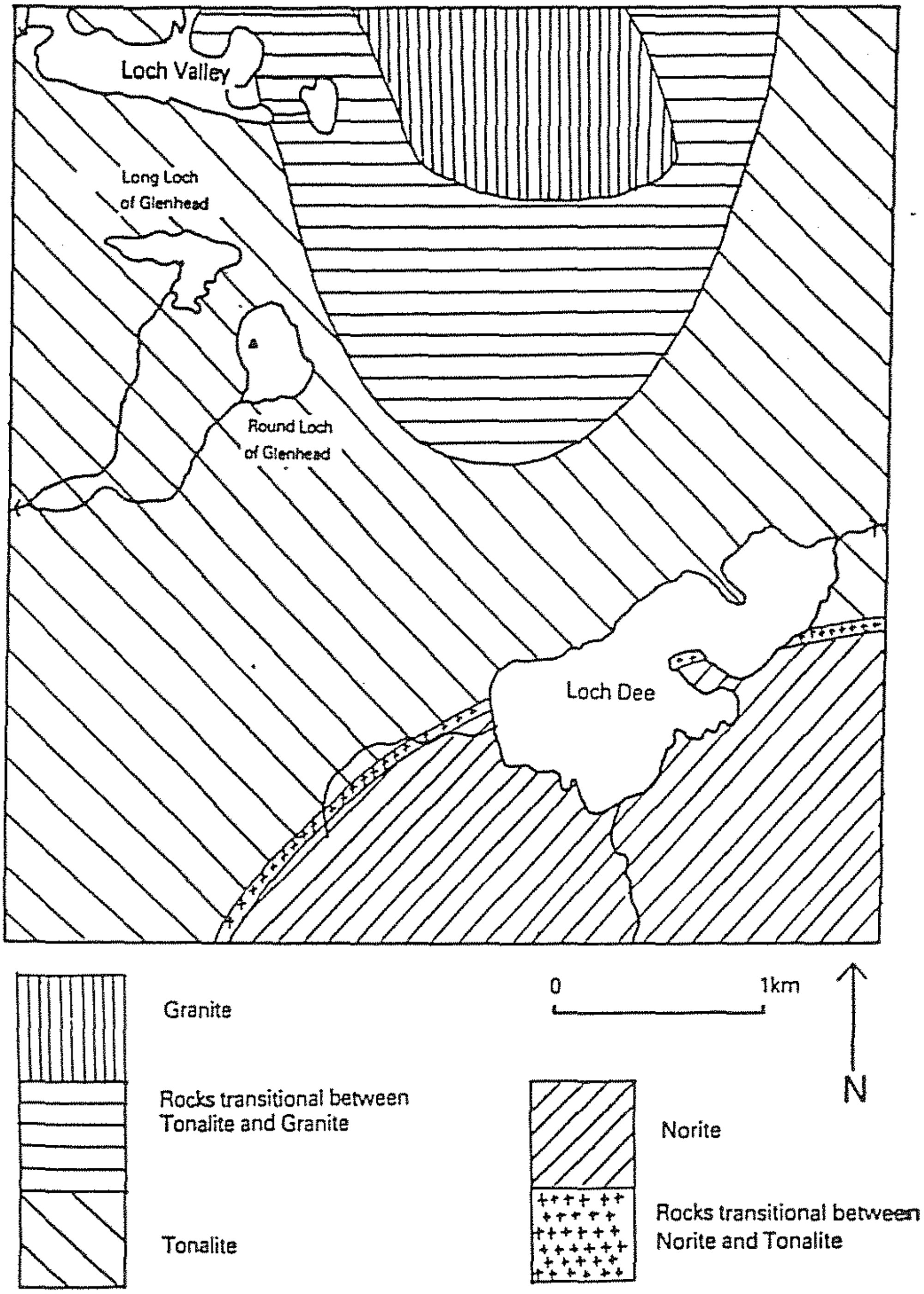

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Figure 1 Location of the Round Loch of Glenhead

2.0 Causes of peat erosion

Theories as to the major cause of peat erosion can be broadly divided into two main groups; those which relate peat erosion to natural processes and those which relate it to human influences. These are well documented in the literature and are briefly summarised below.

2.1 Natural processes

2.1.1 Inherent instability

Bower (1961, 1962) working in the Pennines, thought that peat erosion was the culmination of the build up of a geological unstable substrate in a climatically harsh environment.

2.1.2 Climatic change

Conway (1954) suggested that the wetter climate of the last 2500 years had resulted in the accumulation of wetter, less compacted peat on top of drier more compact peat which led to an unstable situation and ultimately to peat erosion. Tallis (1965, 1973, 1985, 1987) has also suggested that a drier climate would accelerate run-off and cause peat erosion.

2.2 Human influence

2.2.1 Moor-burning

A role for both serial burning and accidental fires in peat erosion has been suggested (Tallis 1981, 1987). Long-burning, accidental fires can have serious ecological consequences since the surface peat may ignite killing roots, rhizomes & shoot bases. Vegetation regeneration on bare ground exposed by such fires is slow and peat erosion can be severe (Tallis 1981, Imeson 1971, Kinako and Gimingham 1980). Indeed, Tallis (1981) has shown that up to 6 km^2 of peat erosion within the Peak District National Park was the result of extensive accidental burns.

Blanket peat is also burnt under controlled conditions for three major objectives (Phillips 1981):

i) to maintain hill grazing by suppressing trees and shrubs,
ii) to improve the nutrient status of the vegetation for grazing animals,
iii) to remove unpalatable vegetation.

Radley (1962) argued that regular burning causes an increase in bare ground and leads to peat erosion, although good burning management practices should have no botanical or erosional effects (Gimingham 1972). However, the extensive literature on the effects of burning wet bog communities shows that even the use of infrequent fire can have profound influences on the vegetation composition (cf. Rawes and Hobbs, 1979, Hobbs 1984). A change from Sphagnum/Calluna to domination by Molinia/Eriophorum is the most common pattern observed (Grant et al. 1985, Curral 1981), a pattern reflected by pollen analysis of lake sediments in many upland areas (Battarbee et al. 1985).

2.2.2 Sheep grazing

An extensive literature exists on the effects of grazing on blanket bog and moorland vegetation (Jones, 1967, Rawes 1983, Grant *et al.* 1985, Welch 1984a, 1984b, 1984c, 1986). Overgrazing by sheep can lead to the removal of the seed bank and the replacement of dwarf shrubs by graminoids (Tallis 1981). Typically, these graminoids have a tusssocky habit and rarely form a complete vegetation cover, thus creating a surface more susceptible to erosion. Sheep can also uproot plants and expose bare peat. Various workers have suggested relationships between sheep densities and bare ground (eg. Evans 1977). Shimwell (1974) has suggested that high sheep densities at around 1700 A.D. were coincident with peat erosion at Edale.

2.2.3 Sheep and human trampling

Since the work of Slater and Agnew (1971) it is well known that wet bog vegetation is very sensitive to trampling and takes a long time to recover. Furthermore, trampling on Borth Bog along pathways was thought to be responsible for the spread of *Rhyncospora alba*, which created a severe fire risk during the winter when the plants become tinder dry. Lately, Shimwell (1981) has demonstrated the severity of peat erosion associated with hikers along the Pennine Way, with eroded bands of up to 100 m created in the most heavily trampled areas.

2.2.4 Atmospheric Pollution

It has been demonstrated both in the field and the laboratory that gaseous pollution especially SO_2, markedly reduces the vigour of *Sphagnum* (Ferguson and Lee 1979, 1980, 1983). The disappearance of *Sphagnum* from blanket peat profiles in the southern Pennines over the last 200 years, has thus been linked to increasing SO_2 levels from industrial pollution (Lee 1981, Ferguson and Lee 1983). The result has been a change in the peat forming communities to pollution tolerant tussock forming plants eg. *Eriophorum vaginatum*.

2.2.5 Drainage

The lowering of the water table following drainage has been shown to reduce the vigour of the major bog forming plants (eg. *Sphagnum* and *Eriophorum*) and result in a general increase in shrubs and tussock plants such as *Empetrum* and *Vaccinium* (Tallis 1981) and in some cases *Racomitrium*.

2.2.6 Combined Effects

In any area a combination of the above factors may apply. For example, in the Peak District Peat Erosion Project Phillips *et al.* (1981) concluded that air pollution, sheep grazing, burning and recreation pressure all contributed to peat erosion. Climatic change may also have had a role to play and it is suggested that changes in the vegetation may have occurred as a result of prevailing warmer and drier periods in the 12th and 13th centuries, followed by a succession of severe winters from the 16th-18th centuries. On the other hand at Featherbed Moss, Tallis (1985) found that two erosion periods had occurred: one in 1000 A.D. which was the result of natural events (unstable peat mass) while the more recent erosion problems resulted from the death of *Sphagnum* by SO_2 pollution.

3.0 Lake sediments and the study of peat erosion

Lake sediments can be used in peat erosion studies since they record a history of catchment events (Oldfield *et al.* 1983).

The Round Loch of Glenhead (Fig. 1) was chosen to evaluate the use of lake sediments in peat erosion studies. Sediment cores (prefix = RLGH) were collected from this site in May 1985 and are described in Jones (1987) In this report we:

i) describe the lake sediment evidence for peat erosion ,
ii) indicate how the chronology of peat erosion can be ascertained,
iii) show how the history of burning can be reconstructed and
iv) demonstrate how the burning/grazing and air pollution hypotheses can be assessed.

3.1 Evidence for peat erosion in the catchment of the Round Loch of Glenhead

(1) Today, eroded and revegetated peat haggs are found in the catchment of the Round Loch of Glenhead, indicating that peat erosion has occurred in the past and is occurring at present.

(2) The lake sediment cores reflect the trends in erosion by their organic matter or loss on ignition (LOI) profiles (Fig. 2). For core RLGH3 below about 50cm the loss on ignition fluctuates at around 30%. From 50-40 cm values increase rapidly to 50% and from 40 cm to the top of the core values remain above 40%. This rapid increase is thought to be the result of inwash of organic material from the catchment into the lake, and probably represents the beginning of a major period of peatland erosion. Other smaller peaks in loss on ignition lower in the sediment could be related to earlier smaller erosion events (eg. at 76 cm).

(3) Textural analysis of the sediment supports this interpretation since in all the cores the sediment type changes from a mineral mud (Ld°3 Ag^1) to a blackish fine detritus mud (Ld°4 Dh+) as loss on ignition increases.

(4) The percentage abundance of the submerged aquatic macrophyte *Isoetes* (Fig. 3) decreases from >40% (% aquatics + trees) below 48 cm to <15% at 44cm. This species is known to be sensitive to siltation (Pennington 1964).

(5) The percentage abundance of planktonic diatom species also decreases between 52 and 44 cm (Fig. 3). This could also be related to an increased input of allochthonous material and a reduction in light penetration.

(6) A radiocarbon date of 1350±70 BP was obtained from a sample from 53-58 cm whereas a date of 2020±80 B.P. was obtained from 37-42 cm (Fig. 3). This inverted age is probably due to the inwash of old carbon from areas of eroded blanket peat in the lake catchment.

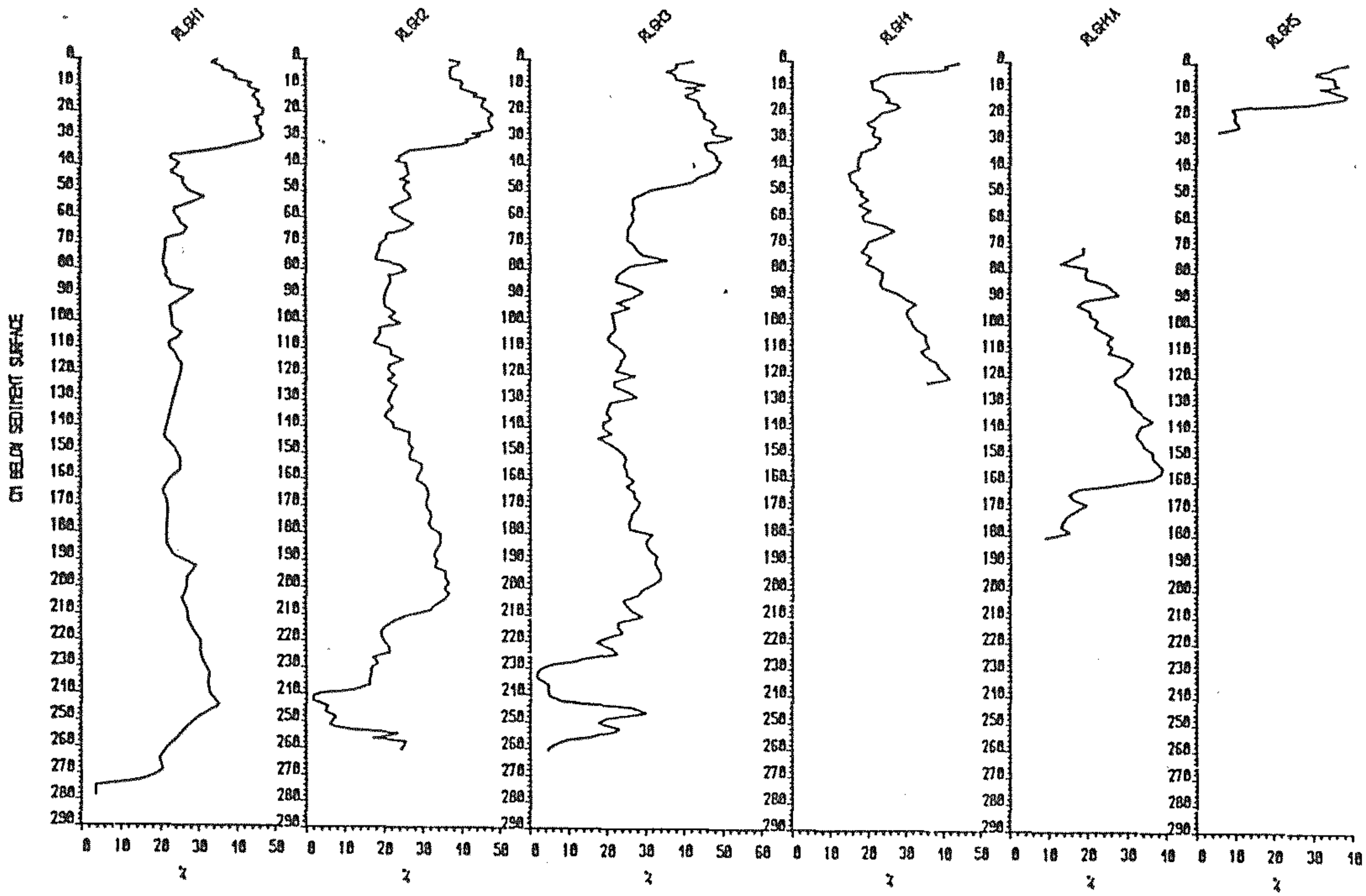


Figure 2 LOI profiles cores RLGH1 - RLGH5, Round Loch of Glenhead

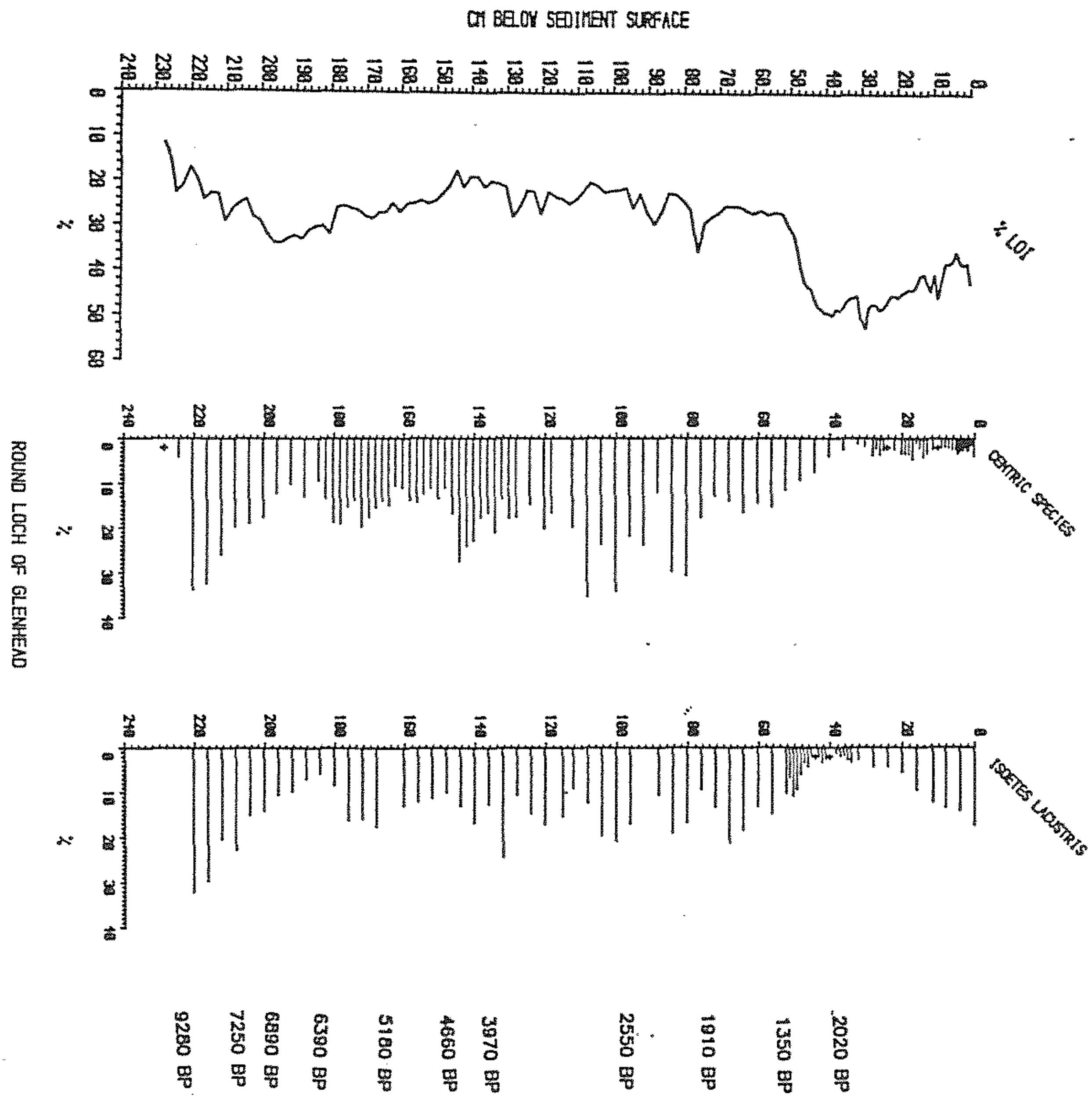


Figure 3 Summary of the palaeoecology of the Round Loch of Glenhead core RLGH3: showing the abundance of Isoetes spores and the centric diatom species, the LOI profile, and ^{14}C dates

4.0 Dating

4.1 Introduction

Five different methods are being used to provide a date for the onset of peat erosion as represented by the lake sediment core (RLGH3):

(1) ^{210}Pb dating of the lake core for the last 200 years.

(2) Conventional ^{14}C dating to provide a chronology for the last 2500 years of the lake core in an attempt to refine the date of ^{14}C inversion.

(3) Accelerator (AMS) dates of autochthonous material (eg. Chironomids, Cladocera, seeds) from the lake core to avoid the effects of older carbon contamination from the inwashed peat.

(4) AMS ^{14}C accelerator dating of charcoal fragments in the peat core.

(5) Pollen stratigraphic correlation of the lake sediment core with a dated catchment peat core. This will enable future ^{14}C dates from the peat core (4) to be transferred to the lake core, thus also avoiding the problems of old carbon contamination in the lake sediments.

4.2 ^{210}Pb results

Radiometric results for core RLGH3 are presented in Table 1 and show the concentration of ^{210}Pb, ^{226}Ra, ^{241}Am and ^{137}Cs. Table 2 shows the chronology and the sediment accumulation rate and a depth/age profile is shown in Fig. 4. The ^{210}Pb dates are in reasonably good agreement with the ^{137}Cs and ^{241}Am fallout data. The 1963 and 1954 peaks of ^{137}Cs occur at 4 and 5 cm respectively correspond to ^{210}Pb dates of 1961 and 1963. The ^{210}Pb results from RLGH3 reinforce the provisional chronology obtained from the diatom biostratigraphic correlation with core RLGHII. There appears to be a relatively high sediment accumulation rate from 19-8 cm (0.146 - 0.196 cm y^{-1}), from 8 - 3 cm there is a lower accumulation rate (0.112 - 0.127 cm y^{-1}) and from 3 cm to the top of the core the sediment accumulation rate increases (0.149 - 0.203 cm y^{-1}). The linear sediment accumulation rate of 0.196 cm y^{-1} can be extrapolated below 14.5 cm to give a date of 1706 A.D. at 50 cm, the start of the main period of peat erosion. However, too much emphasis should not be put on this extrapolated date since variations in the sediment accumulation rate may have occurred (Peter Appleby per. comm.).

4.3 ^{14}C results

4.3.1 Conventional ^{14}C dates

Conventional ^{14}C dates are shown in Table 3 and plotted in Figure 5. Unfortunately, they do not provide any further refinement of the date of the major loss on ignition increase because several ^{14}C inversions are recorded from above 120 cm. These inversions can readily be explained by the inwash of material from the catchment reflected in peaks in the LOI values (see section 3.1). However, it is difficult to envisage a source of younger carbon in the catchment and it is probable that the youngest dates are less contaminated and therefore more reliable eg. the date at 61 - 66 cm of 730±60 B.P. (which gives a corrected date between 1180 - 1400 A.D.).

Any further dating refinement must await the application of small sample ^{14}C accelerator dating of both the lake and peat sediments.

4.3.2 Accelerator dates

The possibility of using the facilities provided by the Oxford radiocarbon accelerator unit, in the Department of Archaeology at Oxford University was explored.

AMS dating of small samples of charcoal is a well established technique, and we do not forsee any problems in using samples of charcoal from the peat core. However, the dating of the lake core presents a new challenge for accelerator dating. The director of the unit, Dr R.E.M. Hedges has an interest in the project in which we propose dating the chitin of chironomid and cladocera remains in the lake sediment.

4.4 Pollen stratigraphic correlation results

4.4.1 Introduction

Chronological data, acquired as described above, can be transferred between the lake sediment and peat cores by correlation of their pollen stratigraphies.

4.4.2 Catchment peat core : field and laboratory methods

Two strategies were adopted to obtain catchment peat cores from the Round Loch of Glenhead. Firstly, three 1 m long waste pipes (diameter 10 cm) were sunk into the peat of a nearby uneroded subcatchment (Fig. 6) and the core manually excavated. Recoveries were of the order of 65 - 75 cm. Secondly, a sequence of Russian cores (Jowsey 1966) was taken from an uneroded hagg adjacent to the most extensive area of hagging in the Round Loch catchment (Fig. 6). One of the large diameter cores was chosen for analysis since a) the core was from an uneroded part of the catchment and therefore ought to have a full undisturbed pollen profile and b) the volume of sediment would be sufficient for macrofossil, charcoal, bulk ^{14}C dates and pollen. The Russian core from the uneroded haggs is the subject of a B.Sc. dissertation (Allott 1988) and results will be presented at a later stage.

The catchment core (NCC1) consists of a uniform matrix of unhumified sedge peat from 73 - 5 cm (Dh^{0} 3 Sh 1). Above 5 cm the the sediment was dominated by <u>Molinia</u> roots in a darker organic matrix (Dh^{2} 2 Sh 2). Samples from both the lake and peat cores were prepared for pollen analysis (Moore and Webb 1978), which included an HF treatment for the lake sediments. Pollen samples were counted every centimetre in the catchment peat core and every centimetre over the loss on ignition increase in the lake core (34-52 cm).

4.4.3 Results

Figures 7 and 8 present summary pollen diagrams for the top 75 cm of the lake core (RLGH3) and the catchment core (NCC1).

NCC1 has been zoned into five major zones on the basis of 13 mostly local pollen types using RBZONE a PRU zonation package.

NCC1-1 Calluna/Corylus/Alnus PAZ 73 cm - 54 cm

This zone of the catchment core is the most poorly described since the pollen concentration throughout this section is extremely low. Thus only a rough estimate of the constitution of the blanket peat communities at this time can be made. They appear to consist mainly of Calluna/ Myrica/ Molinia. The regional vegetation consists of a small amount of oak/birch and alder.

NCC1-2 Calluna/Sphagnum/Cyperaceae/Gramineae 53 - 27 cm

The initial stages of this zone are characterised by falling AP as Alnus values collapse, probably representing the final clearance of alder woodland from around the streams of many of the lower valleys.

The catchment pollen initially shows a Calluna/Sphagnum peat which gets progressively wetter as values of Cyperaceae and Narthecium increase. Grass values decline during this period while Calluna values rise to a peak at 45 cm. From 45 - 35 cm Calluna values collapse and Gramineae values increase until the situation reverses and Calluna peaks during the onset of zone 3.

The latter third of the zone is also characterised by loss of Narthecium from the pollen record at 35 cm and is possibly the result of drainage and burning.

NCC 1-3 Cyperaceae/Gramineae/Calluna/Sphagnum 27 - 10 cm

Values of Calluna decline while Sphagnum/Cyperaceae and Gramineae values increase dramatically throughout the zone, possibly indicating the development of a locally wetter peat mass at this time, although since the change is also picked up in other catchment and lake cores this appears to have been a catchment-wide phenomenon.

NCC 1-4/5 Gramineae/Calluna/Sphagnum/Pinus 10 cm - 0 cm

Calluna values rise for a while, Cyperaceae values decline and Gramineae values stabilise. However, this is very short lived before Zone 5 when Calluna values decrease even further and Gramineae values go even higher as extra-local pollen values of Pinus increase and Picea pollen appears as a result of afforestation in nearby catchments by the Forestry Commission in the 1920s. Sphagnum values fall to a very low level and may reflect acid deposition problems since this phenomenon is also recorded by the pollen spectra of the Russian cores from the catchment (Allott 1988).

4.4.4 Core correlation

The inwash of organic material into the lake would have included pollen preserved in the peats, potentially masking changes in the lake pollen profile. However, the pollen profiles of both the lake and peat cores are strikingly similar. In order to correlate the lake and peat cores nine points of similarity in the pollen curves were noted in both diagrams (Fig. 9 and Table 4).

A Shaw diagram (1964) of the points of similarity was constructed (Fig. 9) which shows that the sediment accumulation rate in both the chronology of the lake cores, especially if only conventional ^{14}C dates are available for the lake core, and it will provide an independent check on any AMS ^{14}C dates obtained from the lake core in future.

4.4.5 Chronology

Since the conventional ^{14}C dates from the lake core offer no further refinement of the date of the major loss on ignition increase and since the necessary ^{14}C dates of the catchment core are not yet available, the existing ^{210}Pb and ^{14}C chronology for the lake core can be used to provide a provisional chronology (See 5.4.2 below). Since the concordance between lake and peat cores has been shown and since Troels-Smith analysis of the catchment core shows consistently unhumified sedge peat throughout without any observable stratigraphic changes, it appears that there has been little change in the peat accumulation rate of the catchment core. Furthermore, since it is known that the present ^{14}C dating of the lake sediment is unsatisfactory owing to contamination problems from eroded material, it seems reasonable to transfer the existing ^{210}Pb chronology from the lake core to the catchment. Moreover, since the peat stratigraphy appears to be so uniform over the time-depth of the catchment core and since the pollen correlations appear to match almost 1:1 over both cores to at least 55 cm it is reasonable to extend the ^{210}Pb chronology back on the basis of a constant accumulation rate. In the future, an independent check of the validity of this approach will occur when ^{14}C AMS accelerator dating of both the lake and catchment core is available.

Table 1 Round Loch of Glenhead ^{210}Pb, ^{214}Am, and ^{137}Cs data
Core RLGH3

Depth	Dry Mass	^{210}Pb Concentration				^{226}Ra conc.	
		Total		Unsupported			
cm	g cm^{-2}	pCi g^{-1}	±	pCi g^{-1}	±	pCi g^{-1}	±
1.25	0.0535	31.08	0.56	27.61	0.57		
2.25	0.1225	20.32	0.59	16.85	0.60		
3.25	0.1995	18.26	0.51	14.79	0.53		
4.75	0.3192	11.71	0.48	8.24	0.50		
6.75	0.4727	8.25	0.28	4.78	0.31		
8.75	0.6350	6.06	0.22	2.59	0.26		
10.75	0.8059	4.68	0.17	1.21	0.21		
12.75	0.9871	4.44	0.12	0.97	0.18		
14.75	1.1675	4.03	0.17	0.56	0.21		
18.75	1.5293	3.61	0.12	0.14	0.18		
21.75	1.7995	3.54	0.10	0.07	0.16		
24.75	2.0786	3.32	0.15	-0.15	0.20		
30.25	2.5718	3.26	0.12	-0.21	0.18		
34.75	2.9775	3.66	0.10	0.19	0.16		
40.50	3.6233	3.50	0.09	0.03	0.16		
44.50	4.1261	3.45	0.13	-0.02	0.18		
60.50	6.0046	3.44	0.09	-0.03	0.16		
74.50	7.6922	3.41	0.13	-0.06	0.18	3.47	0.13

Depth	^{241}Am Conc.		^{137}Cs Conc.	
cm	pCi g^{-1}	±	pCi g^{-1}	±
0.50	0.00	0.00	13.48	0.72
2.75	0.20	0.04	16.30	0.39
3.25	0.28	0.04	16.82	0.40
4.75	0.11	0.02	10.92	0.27
6.25	0.00	0.00	5.89	0.21
7.75	0.00	0.00	6.89	0.19
9.75	0.00	0.00	2.59	0.13
11.75	0.00	0.00	1.97	0.13
15.50	0.00	0.00	1.01	0.05
19.75	0.00	0.00	0.81	0.06
25.75	0.00	0.00	0.33	0.04
31.50	0.00	0.00	0.15	0.04
39.50	0.00	0.00	0.05	0.07

Table 2 ^{210}Pb chronology of the Round Loch of Glenhead
Core RLGH3

Depth	Cum. Dry Mass	Chronology			Sedimentation rate		
cm	g cm^{-2}	Date A.D.	Age yr	±	g cm^{-2}y^{-1}	cm y^{-1}	±(%)
0.00	0.0000	1985	0				
0.25	0.0100	1984	1	1	0.0125	0.203	7.6
0.50	0.0201	1983	2	2	0.0124	0.200	7.7
0.75	0.0321	1982	3	2	0.0124	0.197	7.7
1.00	0.0535	1981	4	2	0.0123	0.194	7.7
1.25	0.0703	1979	6	2	0.0123	0.191	7.7
1.50	0.0870	1978	7	2	0.0122	0.188	7.7
1.75	0.1037	1977	8	2	0.0122	0.185	7.7
2.00	0.1204	1975	10	2	0.0121	0.182	7.7
2.25	0.1372	1974	11	2	0.0121	0.179	7.6
2.50	0.1539	1972	13	2	0.0121	0.177	7.6
2.75	0.1706	1971	14	2	0.0120	0.174	7.6
3.00	0.1905	1969	16	2	0.0115	0.149	7.7
3.25	0.2104	1968	17	2	0.0109	0.125	7.8
3.50	0.2328	1965	20	2	0.0108	0.123	8.2
3.75	0.2553	1963	22	2	0.0107	0.121	8.6
4.00	0.2777	1961	24	2	0.0105	0.119	9.0
4.25	0.3001	1959	26	2	0.0104	0.117	9.4
4.50	0.3226	1957	28	3	0.0103	0.115	9.9
4.75	0.3450	1955	30	3	0.0102	0.112	10.3
5.00	0.3678	1953	32	3	0.0104	0.114	11.0
5.50	0.4134	1948	37	3	0.0108	0.118	12.6
6.00	0.4591	1944	41	4	0.0122	0.122	14.1
6.50	0.5051	1940	45	4	0.0114	0.124	15.9
7.00	0.5514	1935	50	5	0.0116	0.126	17.8
7.50	0.5978	1931	54	6	0.0117	0.127	19.7
8.00	0.6440	1926	59	6	0.0137	0.146	21.5
8.50	0.6900	1922	63	7	0.0137	0.146	21.5
9.00	0.7359	1919	66	8	0.0137	0.146	21.5
9.50	0.7819	1916	69	8	0.0137	0.146	21.5
10.00	0.8282	1913	72	9	0.0137	0.146	21.5
10.50	0.8747	1910	75	9	0.0137	0.146	21.5
11.00	0.9212	1907	78	10	0.0137	0.146	21.5
11.50	0.9677	1904	81	11	0.0137	0.146	21.5
12.00	1.0154	1901	84	11	0.0137	0.146	21.5
12.50	1.0643	1898	87	12	0.0137	0.146	21.5
13.00	1.1132	1895	90	13	0.0137	0.146	21.5
13.50	1.1621	1892	93	14	0.0137	0.146	21.5
14.00	1.2110	1890	95	15	~0.0200	~0.196	
14.50	1.2598	1887	98	16	~0.0200	~0.196	
15.00	1.3087	1884	101	17	~0.0200	~0.196	
15.50	1.3576	1882	103	18	~0.0200	~0.196	
16.00	1.4094	1880	105	19	~0.0200	~0.196	
16.50	1.4613	1877	108	21	~0.0200	~0.196	
17.00	1.5131	1874	111	22	~0.0200	~0.196	
17.50	1.5650	1871	114	24	~0.0200	~0.196	
18.00	1.6168	1869	116	25	~0.0200	~0.196	
18.50	1.6687	1866	119	27	~0.0200	~0.196	
19.00	1.7205	1864	121	28	~0.0200	~0.196	

Table 3 ^{14}C dates for Round Loch of Glenhead core RLGH3

Lab. code	Depth (cm)	Date	$d^{13}C$ value (%)
SRR 3258	42 - 47	1440±60	-28.5
SRR 3259	48 - 53	1420±60	-28.7
SRR 3260	61 - 66	730±60	-28.4
SRR 3261	68 - 73	1690±60	-28.9
SRR 3262	82 - 87	2010±60	-28.1
SRR 3263	89 - 94	1570±60	-29.3
SRR 3264	103 - 108	1810±60	-28.7
SRR 3265	110 - 115	2720±60	-27.8

Table 4 Points of Correlation RLGH3 and NCC1

(1) Pine take off
12 cm in NCC1
12-8 cm in RLGH3

(2) Grass increase
28 cm in NCC1
32-28 cm in RLGH3

(3) Grass decrease
36 in NCC1
36 in RLGH3

(4) Corylus decrease
36 cm in NCC
32 cm in RLGH3

(5) Narthecium decline
36 cm in NCC1
40 cm in RLGH3

(6) Bottom of Calluna peak
46 cm NCC1
49 cm RLGH3

(7) Top of Calluna peak
32 cm NCC1
36 cm RLGH3

(8) End of Corylus plateau
20 cm NCC1
20 cm RLGH3

(9) Bottom of Cyperaceae
35 cm NCC1
34 cm RLGH3

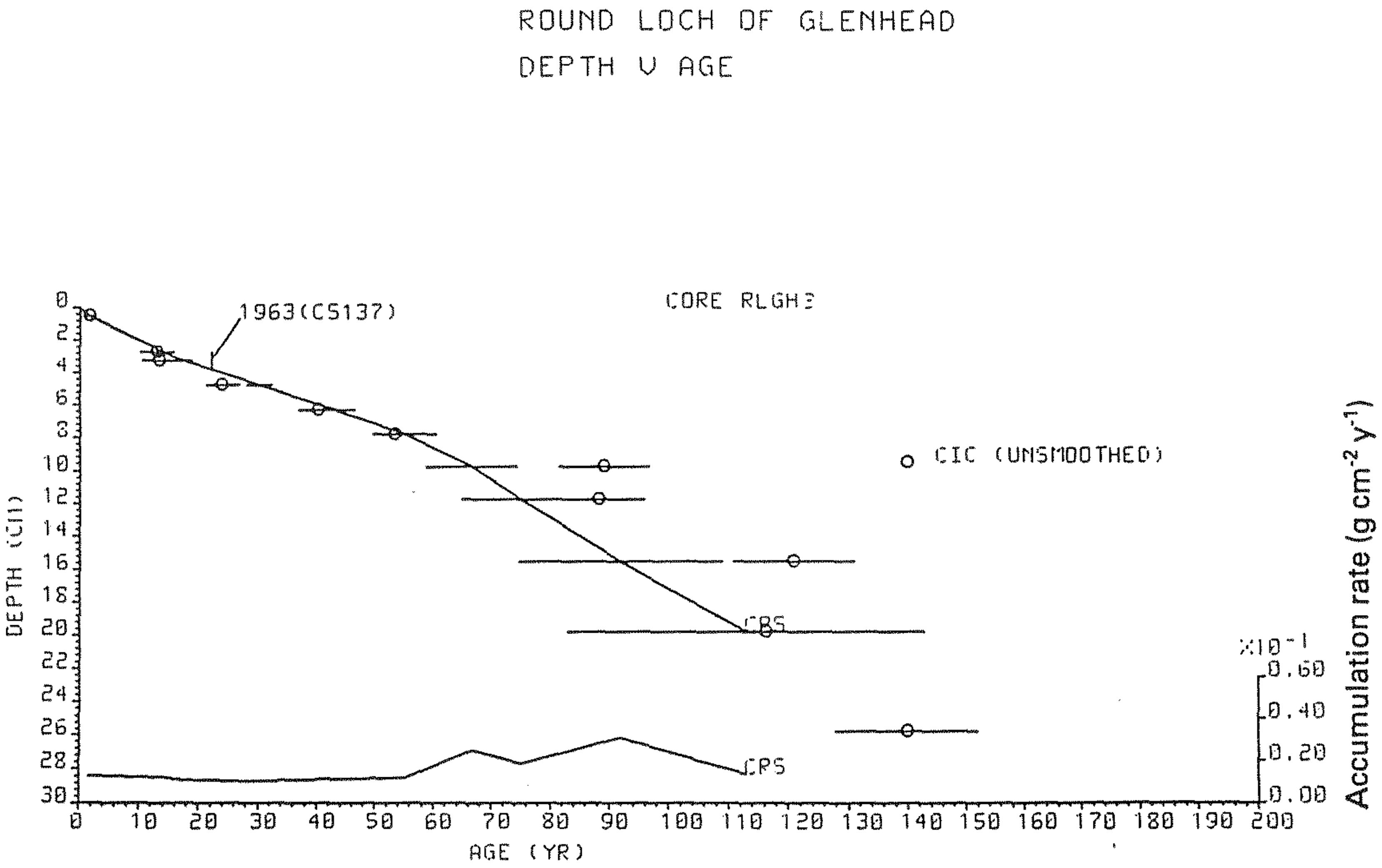


Figure 4 Age depth curve: ^{210}Pb dates

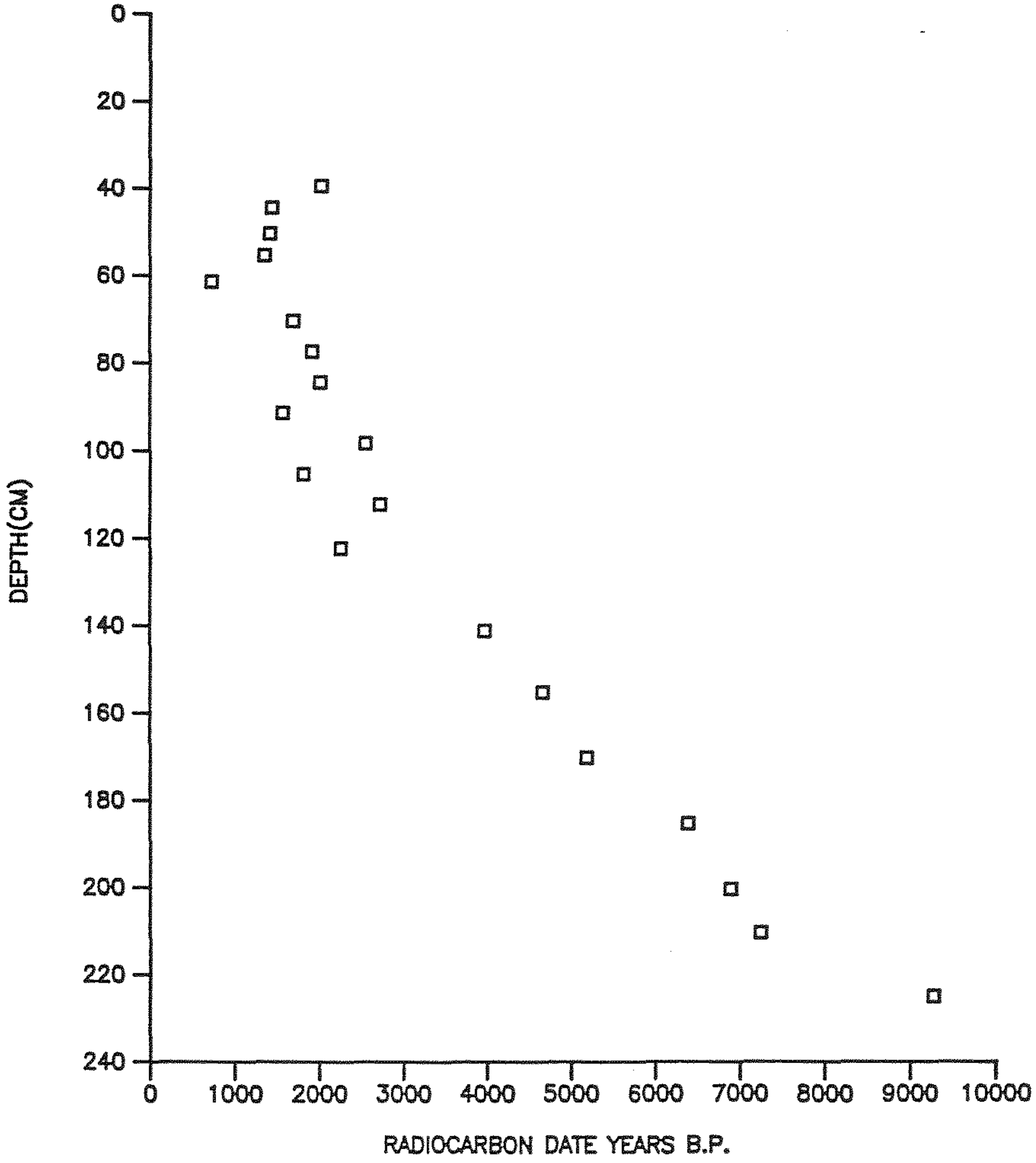


Figure 5 Age depth curve: ^{14}C dates

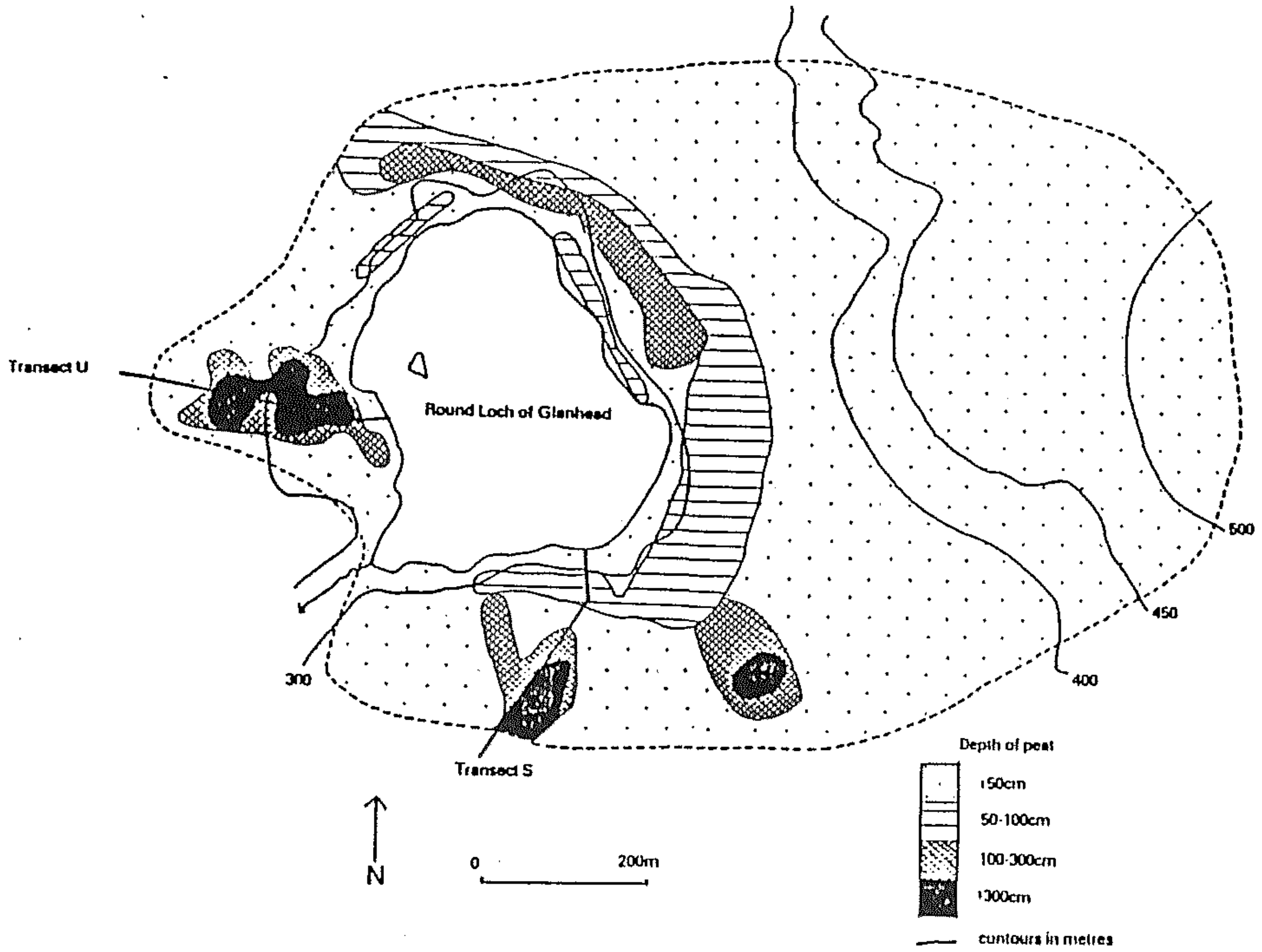
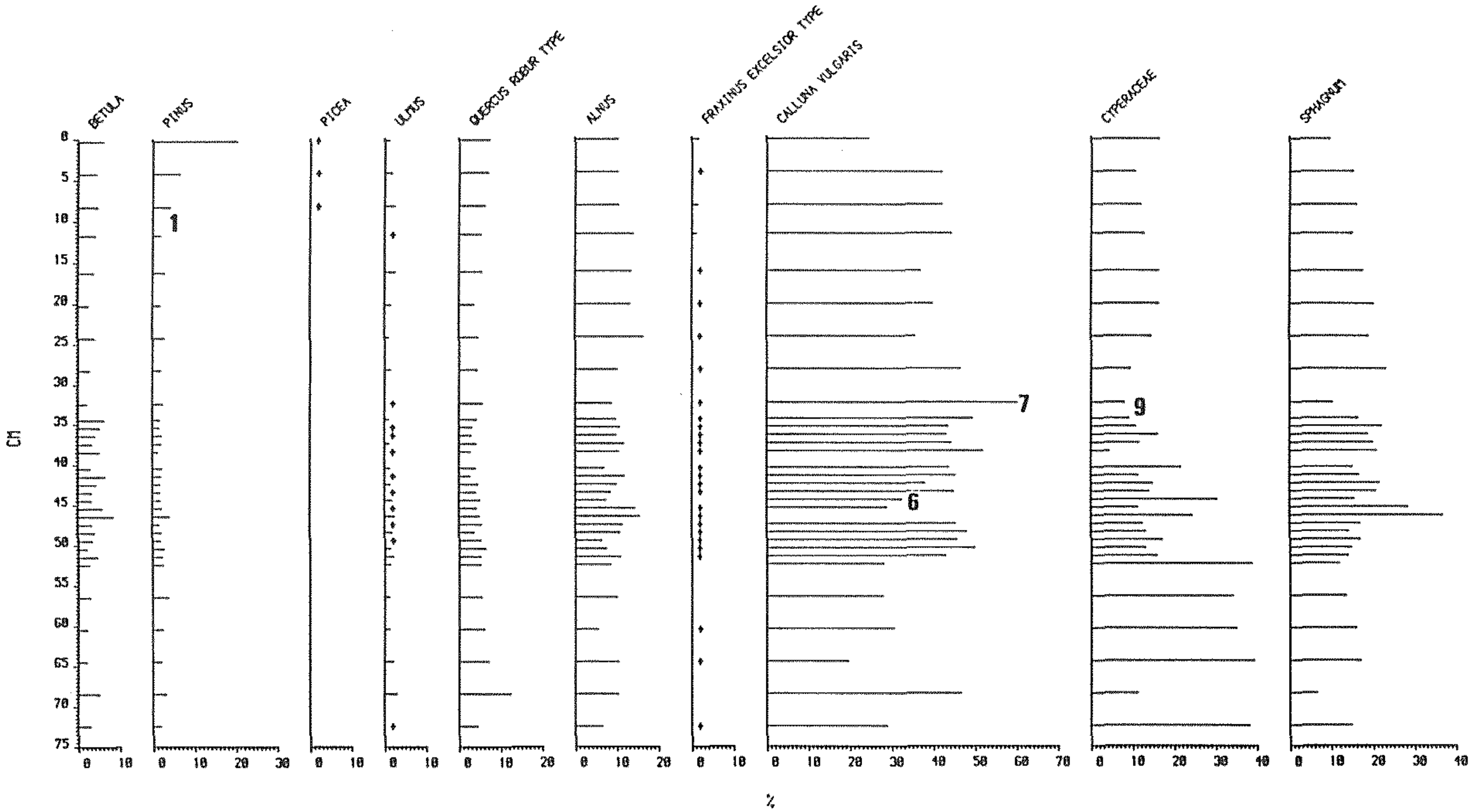
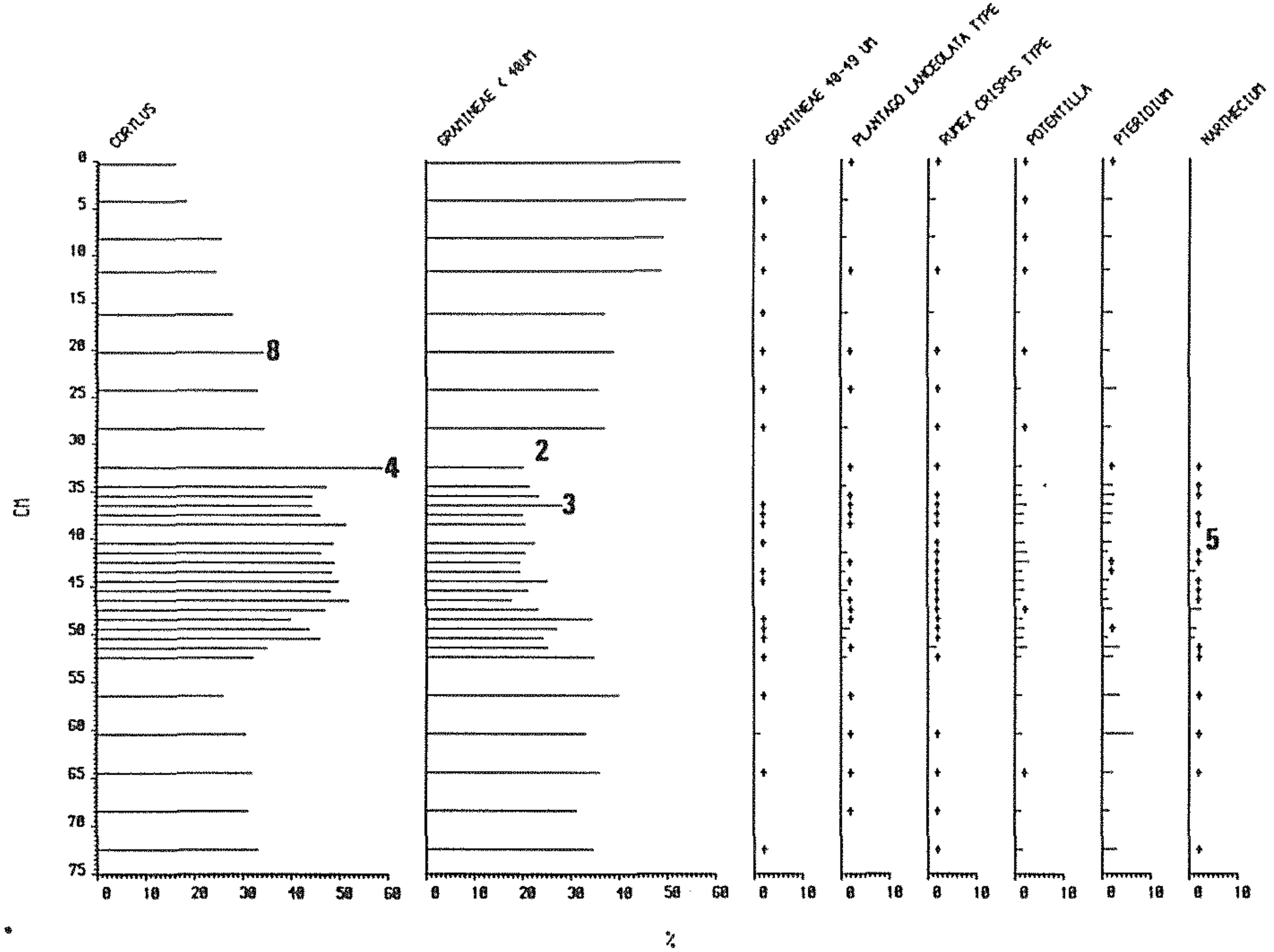


Figure 6 Location of catchment cores



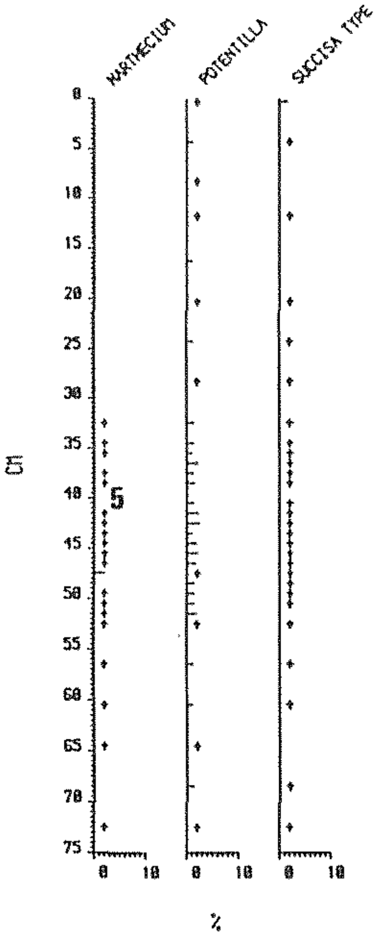
Round Loch Lake core 3 %AP+PI

Figure 7 Summary pollen diagram; lake core (RLGH3)



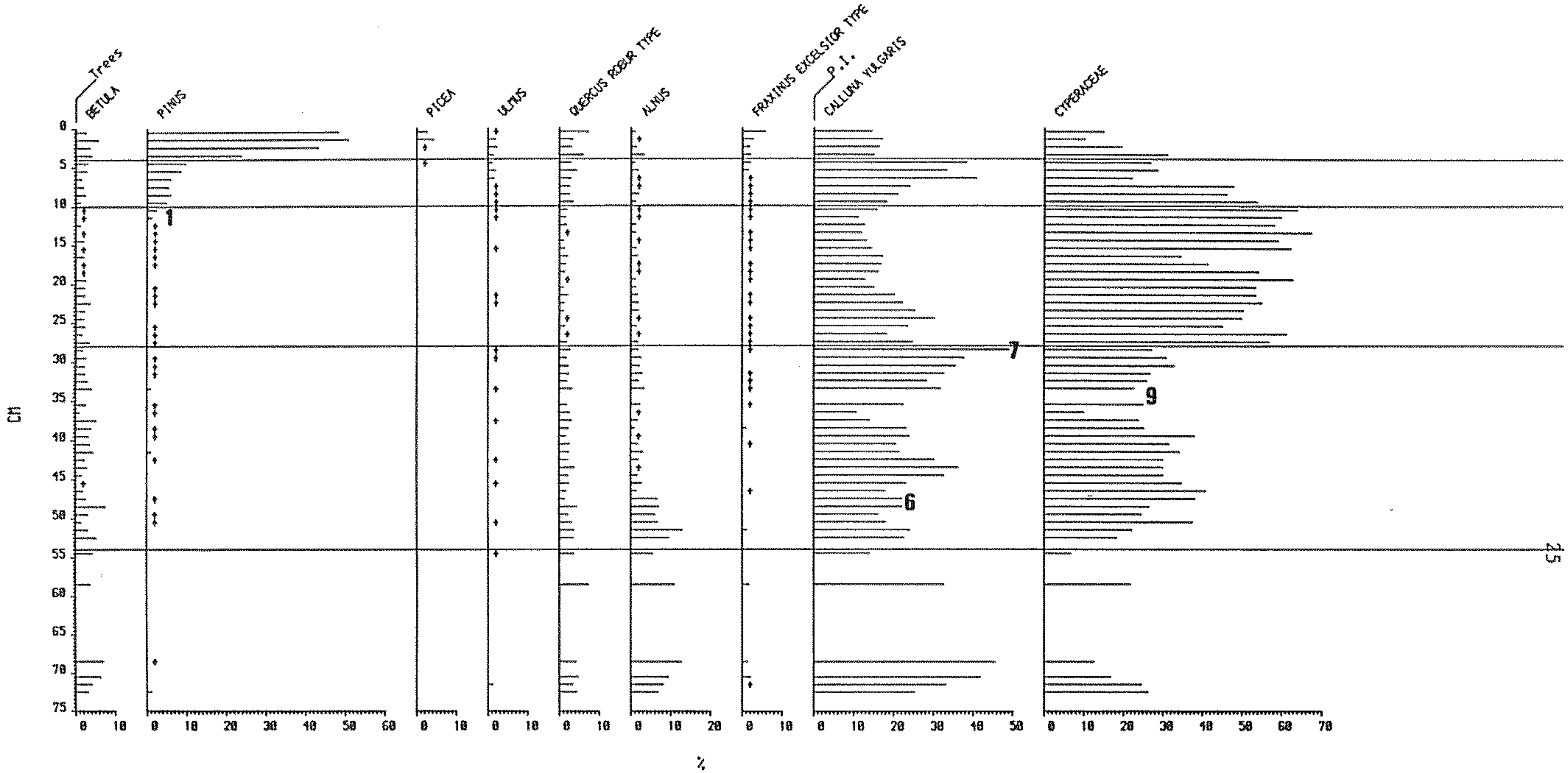
ROUND LOCH OF GLENHEAD %AP+THEM

Figure 7 cont.



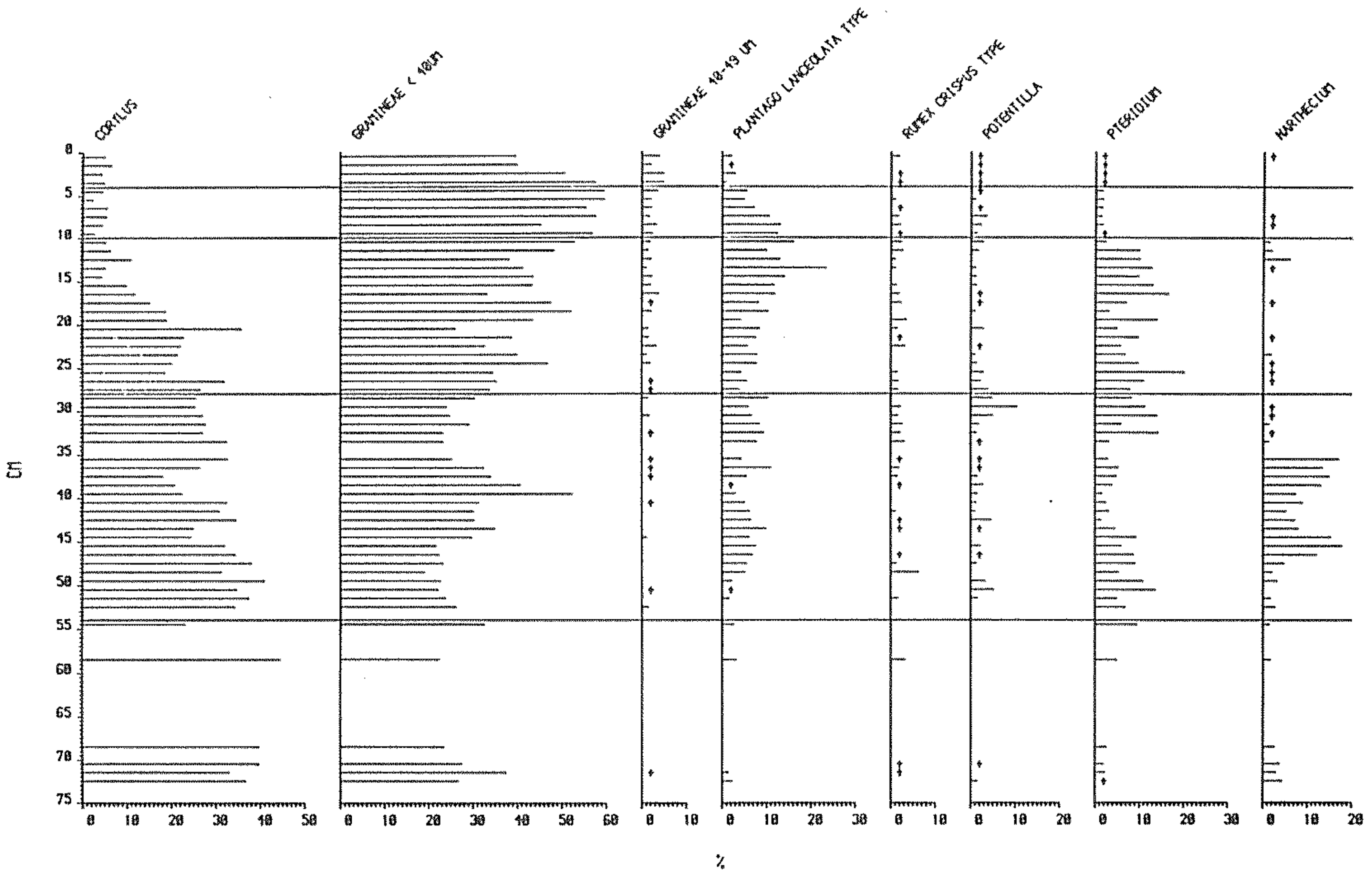
Round Loch Lake core

Figure 7 cont.



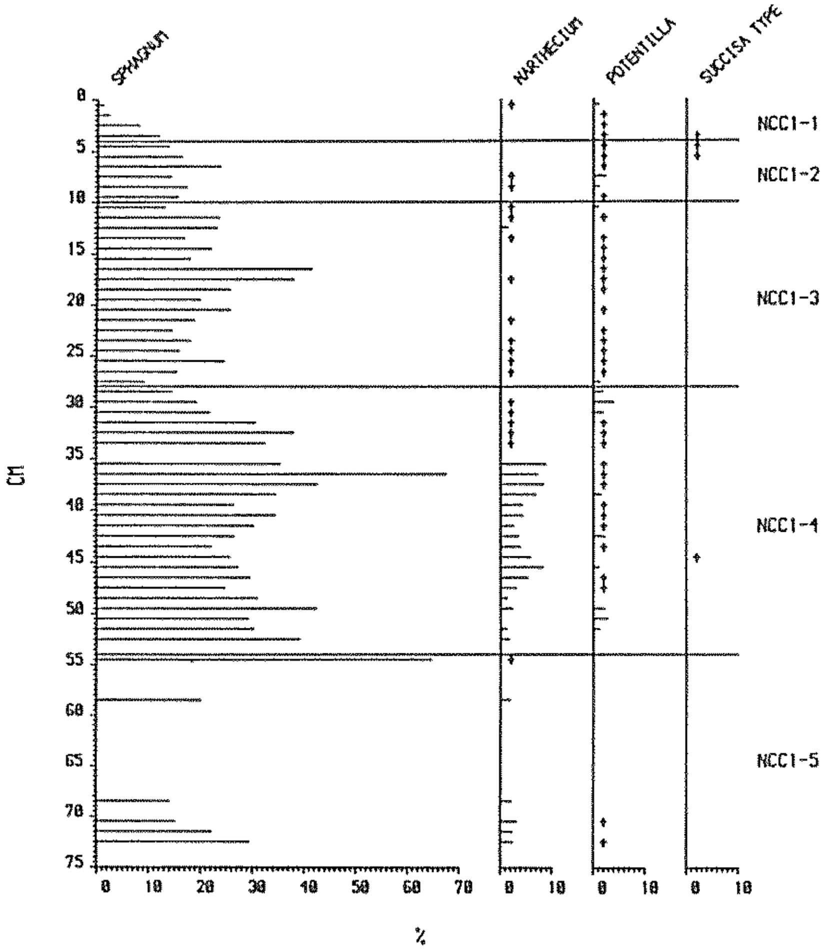
Round Loch Catchment Core NCC1 % AP+P.I.

Figure 8 Summary pollen diagram; catchment core (NCC1)



ROUND LOCH CATCHMENT CORE %AP +THEM

Figure 8 cont.



Round Loch Catchment core NCC1 %ap+P.I.

Figure 8 cont.

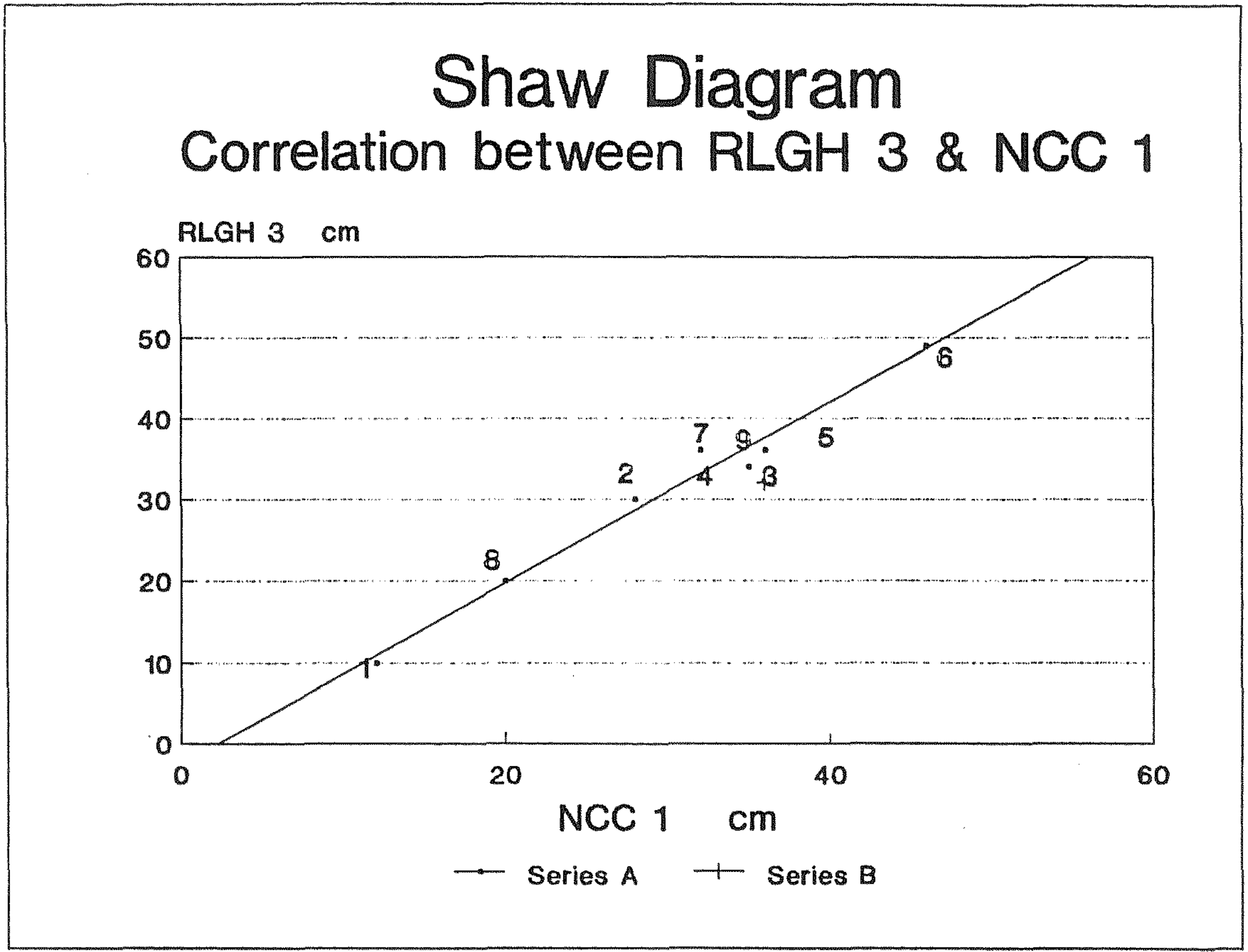


Figure 9 Shaw diagram: correlation between RLGH3 and NCC1

5.0 Charcoal analysis

Aims:

(1) To devise an accurate methodology of quantifying the charcoal content of the lake and peat cores.

(2) To obtain a record of the charcoal stratigraphy from the peat and lake cores to provide information on the burning history of the catchment.

5.1 Charcoal methodology

5.1.2 Review of the methods commonly used

Methods of quantifying charcoal fall into two main categories, those which use microscopical techniques and those which measure the amounts of elemental carbon. A thorough review of these is given in Patterson *et al.* (1987) and they will only be briefly described here.

A variety of methods have been used to quantify charcoal microscopically. Some workers have attempted to examine sediment which has not been chemically treated (except perhaps with dilute NaOH to break up the sediment) using a binocular microscope. More commonly however, workers have examined charcoal present on a slide prepared for pollen analysis, which has been subject to chemical treatment and has often been sieved. Historically both these methods have involved the time-consuming estimation of charcoal area by categorizing particles according to several size classes. Recently, the point-count technique (Clark 1982) has been used to quantify charcoal rapidly both on pollen slides and using the binocular stereomicroscope. In this study the point-count method was used.

Chemical digestion/combustion methods have been used to measure elemental carbon. In this study a modification of the "Winkler method" (Winkler 1985) was used.

5.2 The point-count method

The point-count method (Clark 1982) allows the expression of charcoal as surface area per unit weight of sediment, and is in theory, a simple and rapid method. It is based on the relationship between the number of points applied (eg. in the form of a grid) and the number of "hits" of charcoal encountered. If the numbers of a marker grain (eg. *Lycopodium* spores) are also enumerated the area of charcoal per gram of dry weight can be calculated. Further details and a worked example are given in Clark (1982). In this study the point count method was used on slides which had been prepared for pollen analysis.

Only particles which were black, opaque and angular were counted as charcoal. A microscopical comparison was made with samples which had been digested with HNO_3 to remove all the organic matter. Charcoal in these samples was found to be visually similar to that found on the pollen slides. All sizes of particles were counted.

5.2.1 Results from the lake core

The number of points (p) needed to give a relative error of ±10% can easily be estimated by counting one or more transects and recording the number of hits of charcoal, then:

$$P = \frac{\text{No. of hits of charcoal}}{\text{No. of points}}$$

and at a relative error (sp) of ±10% the number of points necessary can be calculated as:

$$N = \{(1-p)/p\ (sp/p)^2\}$$

For example at 20 - 20.5 cm, for a relative error of ±10%, 2000 points were needed. As each transect consists of 1617 points and it was thought that between five - six transects were needed across the slide to counter the effects of non-random distribution of particles, the number of points used in counting the slides was generally in excess of the number needed for a relative error of ±10%. At 20 - 20.5 cm it was found that nine transects were sufficient to give a reasonably reliable estimation of the area of charcoal (Table 5). However, this slide has a particularly low charcoal:Lycopodium ratio and where this ratio was higher even fewer transects were needed to give a reliable estimation. Basically, the number of transects counted on a individual slide was varied according to the number of charcoal particles and Lycopodium spores encountered. This in turn depends on the concentration of material on the slide as well as the concentration of charcoal and Lycopodium in the sample and consequently no hard and fast rules of the number of transects needed per slide was established.

5.3 Chemical digest/ignition "Winkler" method

The "Winkler method" was modified to use a hot plate and beakers for the digest instead of a water bath.

5.3.1 Standard methodology

(1) The sediment sample was placed in a weighed crucible, dried overnight at 100°C, left to cool in a desiccator and reweighed.
(2) The sediment was placed in a beaker, about 25 ml of nitric acid was added and the sediment was digested at 100°c on a hot plate.
(3) The material was centrifuged for five minutes at 3000 rpm and washed three times with distilled water.
(4) The sediment was placed back in the original crucible, dried overnight at 100°c, desiccated and reweighed. (5) The material was ignited at 550°c for 3 hours, desiccated and reweighed.

5.3.2 Replication experiments

Replication experiments were designed to determine the effect of differing digestion times, and variable sediment weights. 45 g of dried sediment from RLGH4 was amalgamated, crushed and mixed. Subsamples of this material were used for the replication experiments.

(1) effect of sediment weight

Eight subsamples of sediment weighing about 0.4 g, and eight subsamples weighing about 0.2 g were analysed in the same batch using a digestion time of one hour.

A worked example of how percentage charcoal is calculated is given in Table 6. Samples weighing approximately 0.2g have a larger S.D. of % charcoal than samples weighing 0.4 g, suggesting that it is preferable to use a relatively large sample size.

(2) Effect of digest time

In batch one, eight subsamples were digested for one hour and eight subsamples were digested for 1.5 hours. In batch two, eight subsamples were digested for 1.5 hours and eight subsamples were digested for two hours.

Table 7 shows the effect of different digest times on the percentage charcoal content of the samples. An increase in the time of digest from one hour to 1.5 hours gives a lower percentage charcoal result. This suggests that when a digest of one hour was used some organic matter remained which was subsequently burnt off in the ignition procedure, thus giving falsely high charcoal values. This was confirmed by microscopical examination of the material digested for one hour where particles of organic matter were observed. When the digest time was increased to two hours (in batch two) there was very little further decrease in the charcoal results obtained. In addition, the variation between batch one (digest time 1.5 hours) and batch two (digest time 1.5 and 2 hours) results was very low (Table 7). The results suggest that a digest time of 1.5 hours will produce repeatable results. However, as long as known standard digest times are used trends in charcoal content can be shown.

5.4 Stratigraphic results from the lake and peat cores

5.4.1 Lake core

(1) The point-count method

Figure 10 shows the variation in area of charcoal with depth in RLGH3. There is a slight trend of increasing charcoal area from 220 - 50 cm. Above 50 cm the area of charcoal is consistently higher, thus there appears to be evidence for increased burning above 50 cm.

(2) The "Winkler" method

Samples from core RLGH2 were analysed for a standard digest time of 1 hour. 0.4 g of sediment was used for the majority of samples, but for a few samples less material was available.

The results (Fig. 11, Table 8) show that there is a considerable degree of variation in the percentage charcoal in core RLGH2. This could partly be due to the amount of material and digest times used. We plan to do future work, using longer digest times to evaluate this problem. The results however, do suggest an increase in the percentage of charcoal above about 30 cm.

Although this is a different core from the core (RLGH3) used for pollen analysis and for charcoal quantification using the point count method, the cores can be cross-correlated using lithostratigraphic features. On this basis a depth of 30 cm in RLGH2 is probably equivalent to a depth of about 46 cm in RLGH3.

(3) Problems of these approaches

A number of problems associated with the two methods can be identified:

(a) The point count method was used on slides which had been prepared for pollen analysis and the sample therefore had been sieved (125 u). Wein et al. (1987) has demonstrated that small charcoal particles may not be useful for determining local fires. The charcoal preserved on these slides is likely to be over-representative of charcoal derived from long-distance "background" material.

(b) The "Winkler method" includes all six classes of charcoal particles and therefore gives a measure of both the background and locally produced charcoal. We therefore need to perfect techniques to quantify the amount of local charcoal in a sample.

(c) The data from the "Winkler method" are expressed as concentration of charcoal, we need accumulation rate data in order to calculate the influx of charcoal.

(d) It is very difficult to assess how much of the charcoal in the lake sediment has been derived from erosion of the catchment peats.

(4) Conclusions from the stratigraphic results

Both the point count and the "Winkler method" suggest an increase in the amount of charcoal at about the same time as peat erosion from the catchment became important. This could reflect (i) an increase in burning in the catchment at this time (ii) the input of non-contemporaneous charcoal from the eroded peats or (iii) a combination of the two processes.

5.4.2 The peat core

(1) The point count method

Charcoal estimation of the catchment core was performed using the point-count method of Clark (1982). Figure 12 presents the results of this charcoal analysis together with the provisional time chronology imposed from the transfer of the lake ^{210}Pb chronology.

The most striking feature of the diagram is the presence of three significant charcoal peaks. The lowermost of these is the least distinctive (63 cm c. 1650 A.D.) and it is difficult to assess the impact of this peak because of low pollen concentration within the catchment pollen diagram between 70 and 55 cm. However, a second major peak of charcoal occurs from 45 - 33 cm spanning the period 1700 - 1770 A.D., a time when it is known intensive burning of the uplands was occurring to enhance sheep production (Hulme pers. comm.). From 33 cm a period of reduced charcoal amounts occurs implying the absence of major fires from the subcatchment. At 12 cm the charcoal record takes off again, however this may be the result of 'soot' contamination from industrial sources rather than catchment derived carbon. This is currently being evaluated using the DIGISCAN facilities at Imperial College London.

It appears that unlike the lake core, which may be receiving significant quantities of background charcoal, the blanket peat is giving an accurate record of fires within the subcatchment. Interestingly, the same pollen and charcoal pattern is also picked up by the Russian core taken from an uneroded hagg close to a site of past erosion within the catchment (Allott pers. comm). Furthermore, the catchment core shows a charcoal peak at about the same time as the peat erosion is being detected in the lake. Since the charcoal analysis of the lake core by both the "Winkler" and point count methods reveals a major peak at this time as well, it is likely that these trends reflect a local, intensive firing of the catchment for sheep grazing which may have initiated the blanket peat erosion within the catchment.

The local pollen spectra also reflect the changes in charcoal quantities. The first major change occurs at 45 cm where grass values decline while Calluna values peak and perhaps indicate a relaxation of the burning pressure that was occuring in zone 1. With the appearance of high charcoal values in the peat from 45 cm onwards Calluna values rapidly collapse and Gramineae values increase. After 35 cm when peak burning intensities in catchment had subsided the situation reverses as Calluna peaks during the onset of zone 3.

With the appearance of charcoal in the sedimentary record once again Calluna values rise for a while, Cyperaceae values decline and Gramineae values stabilise. While the changes do appear consistent with previous charcoal peaks, it is uncertain whether this peak is charcoal rather than industrial contamination.

Table 5 Point count method. Effect of number of transects on charcoal area estimation, RLGH3 20-20.5 cm.

No. transects	Area of charcoal $mm^2\ g^{-1}$ (dry wt.)
1	2977
2	3808
3	4079
4	4765
5	4806
6	5342
7	5428
8	5235
9	5184
10	5184

Table 6 "Winkler method" replication results (a) effect of sediment weight

Cr. wt.	Cr. + sed.	Wt. after HNO3	Wt. after 550°C	Sed. Wt.	Wt. after HNO3	Wt. after 550°C	Wt. loss	% charcoal
15.2371	15.6353	15.5549	15.5322	.3982	.3178	.2951	.0227	5.7007
16.0490	16.4383	16.3601	16.3319	.3893	.3111	.2829	.0282	7.2438
16.5565	16.9414	16.8652	16.8432	.3849	.3087	.2867	.0220	5.7158
15.3853	15.7559	15.6859	15.6630	.3706	.3006	.2777	.0229	6.1792
15.6690	16.0719	15.9969	15.9727	.4029	.3279	.3037	.0242	6.0065
14.5361	14.9235	14.8419	14.8202	.3875	.3059	.2842	.0217	5.6000
15.6013	15.9626	15.8890	15.8698	.3613	.2877	.2685	.0192	5.3141
15.1453	15.5316	15.4486	15.4269	.3863	.3033	.2816	.0217	5.6174
x = 5.9222 ± 0.5950								
14.3647	14.6195	14.5688	14.5554	.2548	.2041	.1907	.0134	5.2590
15.5820	15.7751	15.7356	15.7244	.1931	.1536	.1424	.0112	5.8001
15.3484	15.5532	15.5086	15.4954	.2048	.1602	.1470	.0132	6.4453
14.5862	14.7650	14.7290	14.7161	.1788	.1428	.1299	.0129	7.2148
15.0516	15.2439	15.1991	15.1892	.1923	.1475	.1376	.0099	5.1482
15.7627	15.9461	15.9042	15.8954	.1834	.1415	.1327	.0088	4.7983
15.5080	15.7369	15.6894	15.6758	.2289	.1814	.1678	.0136	5.6415
15.0889	15.2830	15.2451	15.2289	.1941	.1562	.1400	.0162	8.3462
x = 6.1192 ± 1.1849								

Table 7 "Winkler method" replication results (b) The effect of digest time

BATCH I

DIGESTED FOR 1 HOUR

wt. of sed.	% Charcoal
.3987	5.9694
.4008	5.8383
.3972	5.8157
.3986	6.6232
.4014	6.0538
.4105	5.3253
.4127	7.0753
.4305	6.0395

x = 6.0926 ± 0.5341

DIGESTED FOR 1.5 HOURS

wt. of sed.	%Charcoal
.4062	4.2836
.4069	4.2762
.4402	5.0659
.4051	5.3073
.3857	5.0039
.4230	4.9173
.4049	4.9148
.4046	4.9184

X = 4.824 ± 0.3944

BATCH II

DIGESTED FOR 1.5 HOURS

wt. of sed.	%Charcoal
.3771	5.0650
.4242	5.5400
.3850	4.5974
.3789	4.2755
.3913	5.0089
.3919	5.2309
.3900	5.1538
*****	******

x = 4.9816 ± 0.4198

DIGESTED FOR 2 HOURS

wt. of sed.	%Charcoal
.3850	4.8312
.4487	4.3459
.3934	4.8043
.3864	5.0207
.4059	5.2476
.4029	4.8647
.4014	4.5092
.3852	5.4517

x = 4.8844 ± 0.3611

Table 8 "Winkler method" results (c) Stratigraphic results of charcoal analysis core RLGH2

Depth (cm)	%Charcoal
14-14.5	10.8
16-16.5	11.9
18-18.5	12.7
20.5-21	10.5
22-22.5	11.2
24-24.5	10.2
26-26.5	8.8
28-28.5	10.0
30-31	8.8
32-33	7.9
35-36	6.3
40-41	6.3
45-46	6.3
50-51	8.2
55-56	5.6
60-61	8.2
70-71	5.7
75-76	6.3
80-81	7.4
85-86	6.1
90-91	7.7
95-96	5.8
100-101	10.9
105-106	6.1
120-121	5.6
126-127	4.3
130-131	8.1
136-137	6.1
140-141	4.4
146-147	7.3
150-151	8.4
166-167	6.7
170-171	7.0
176-177	5.6
180-181	2.4
186-187	6.8
190-191	7.3
206-207	8.5
216-217	5.9
220-221	4.9
226-227	5.5

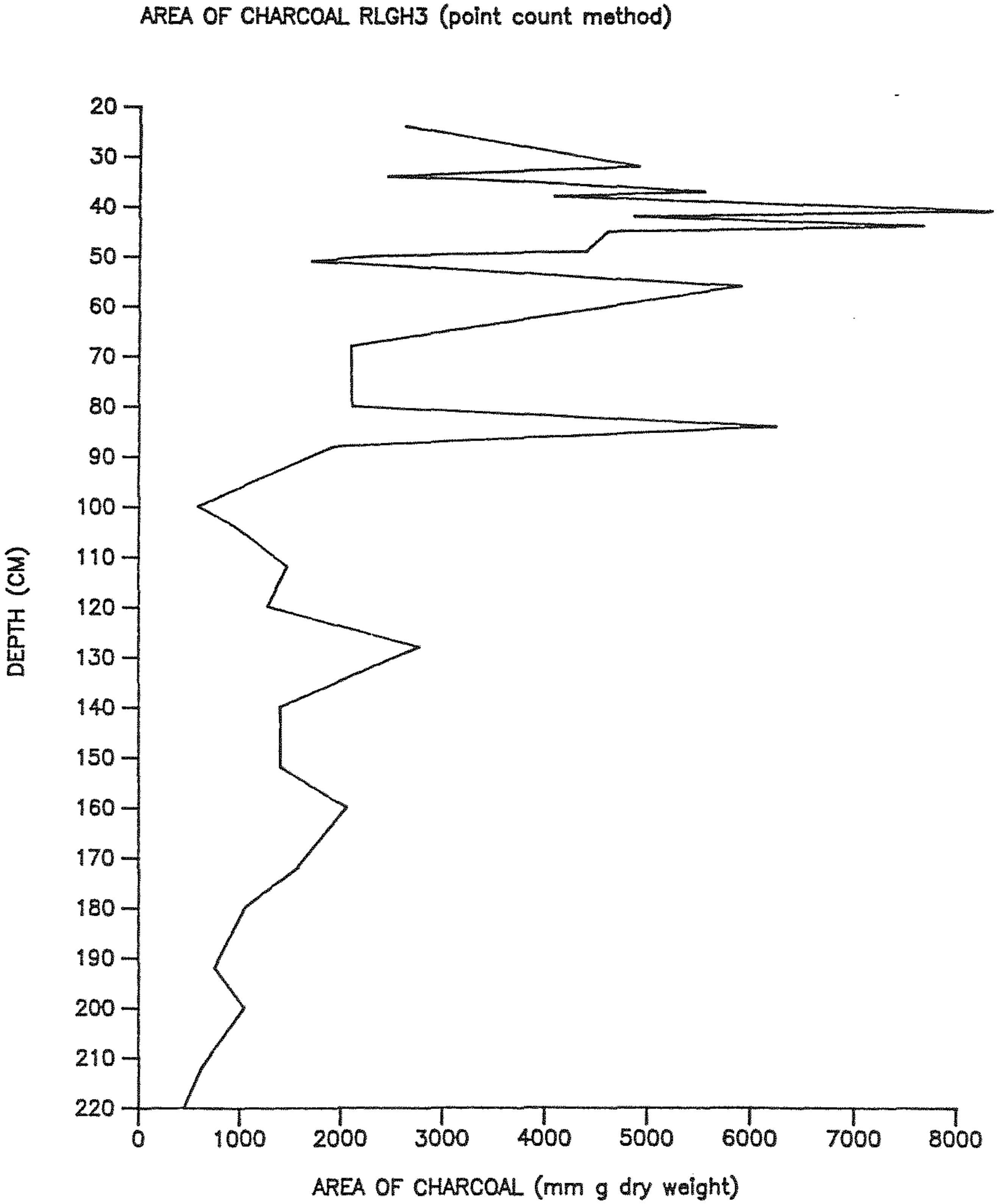


Figure 10 Charcoal profile from RLGH3 using the point count method

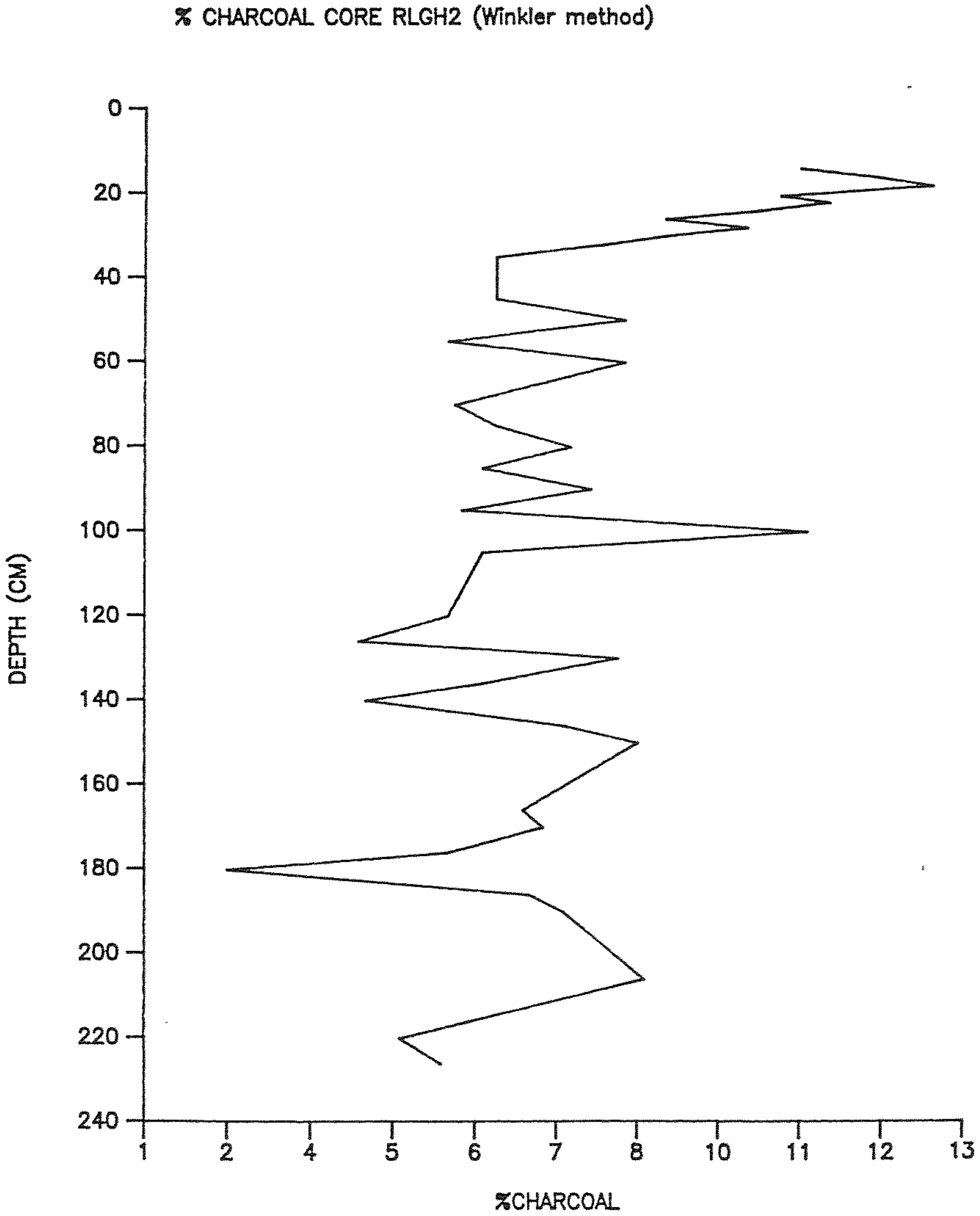


Figure 11 Charcoal profile from RLGH3 using the "Winkler method"

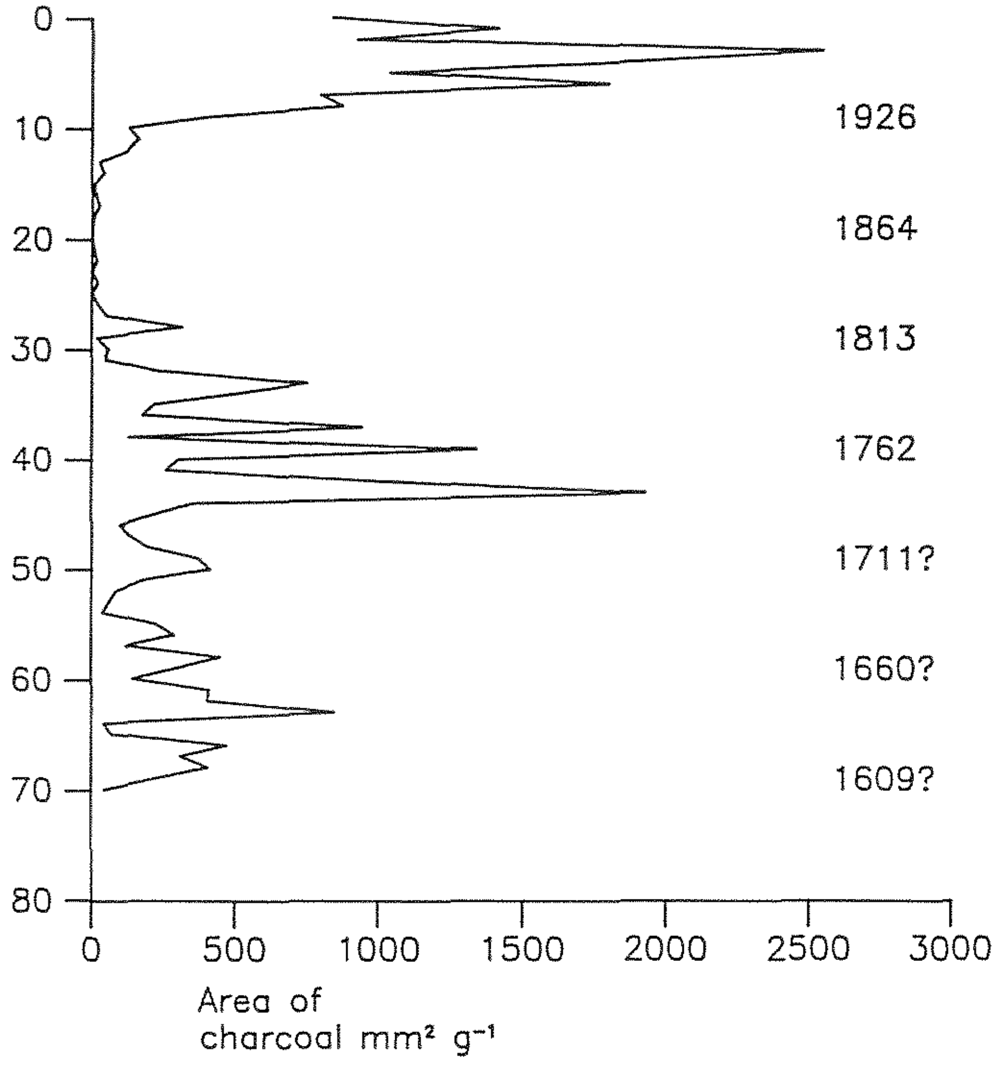


Figure 12 Charcoal profile from NCC1 using the point count method

6.0 Hypothesis Evaluation

In Section 2 we briefly described the range of mechanisms put forward in the literature for blanket mire erosion. These, individually and in combination, can be regarded as hypotheses that we should attempt to evaluate in the future at a number of different sites.

Although we have mainly been concerned with dating techniques and the methodology of charcoal analysis we are already in a position to consider some of the hypotheses.

6.1 Natural processes

Data from Jones (1987) show that peatland has been accumulating in wet hollows in the Round Loch catchment since approximately 9000 B.P. and that a rapid expansion of this peatland to form the blanket mires of today occurred at about 5000 B.P. In the last 5000 years peat has continued to accumulate. The lake sediment record suggests that for most of this period, until the last few hundred years, the peat in the catchment was stable. However, occasional erosional events probably occurred, reflected by individual sample peaks in organic matter in the sediment and the artificially older dates recorded by the additional conventional ^{14}C dates obtained from the lake core.

The cause of these individual events is not known. They could have been triggered by severe storms and/or major burning episodes and the burning could have been natural or the result of firing by early people. Charcoal analysis should help us evaluate these possibilities. However, we can say that these were isolated events which did not lead to sustained destabilisation of the peat. The idea that blanket peats are inherently unstable, accumulating and eroding in alternating cycles in time and space is not supported.

The later more sustained period of erosion began before 1700 A.D. and after 1350 B.P. Developments in the methodology described above will help us to refine these dates and thereby to improve our interpretation. On the one hand we might argue that nothing on the scale recorded here has occurred during the previous 5000 years of blanket mire history at this site and this supports an entirely anthropogenic explanation. On the other hand if the dates show that erosion began between 1550 and 1700 A.D. we cannot discount the influence of the Little Ice Age, either on its own or in conjunction with other factors (see below), since such climatic extremes have not previously occurred during the post-glacial period.

The climatic hypothesis can be further evaluated at sites in Galloway, but it is better tested by comparing a number of sites with differing human histories, on the assumption that climatic factors should cause peat erosion to occur synchronously between sites, but the chronology of human impact, such as burning and grazing, has differed between sites.

6.2 Burning

Many workers believe that poorly managed moorland burning is an important cause of erosion. We have almost perfected techniques of charcoal analysis which will allow local fires to be differentiated. Because of the problem of inwash the most useful fire record is held in the catchment peats. Already our provisional peat chronology and charcoal analysis suggests that intense burning took place at about the same time as erosion was recorded in the lake sediment. Correlations of this nature for other sites and at different time periods should allow us to make more confident statements, but the data so far are more consistent with the burning hypothesis than any other.

6.3 Acid deposition

Diatom analysis of cores from the Round Loch of Glenhead (Flower and Battarbee 1983, Jones 1987) has shown that the lake began to acidify about 130 years ago and trace metal analysis shows the beginning of increased Pb concentrations in the sediment about 200 years ago (Battarbee pers. comm.). In core RLGH3 these dates correspond to sediment depths of 12 cm and 15 cm respectively. The main period of peat erosion in Round Loch is recorded at 45 - 50 cm in this core (Fig. 3). Although we do not yet have a precise date for this level it is clear that the peat erosion began well before significant contamination of the catchment by acid deposition. Acid deposition can therefore be rejected as an important cause of peat erosion at this site. Moreover, since the trend in loss on ignition values is downwards during the period of acidification it is probable that atmospheric contamination has had little or no influence. Whereas these appear to be in conflict with ideas about peat erosion in the Pennines (Phillips et al. 1981) it must be stressed that the Pennines have much higher levels of dry deposition than Galloway.

7.0 Further work

i) The next proposal seeks to use accelerator (AMS) ^{14}C dating of authochthonous organic material to provide reliable dates directly over the period of peat erosion.

ii) ^{14}C dating and especially accelerator dating of the catchment core will provide a crucial independent check on the chronology of the lake core, using the pollen stratigraphy to transfer the dates. Dating the catchment core will not incur the problems of old carbon which are involved in the lake core since charcoal and seeds can be used.

iii) Evaluation of Winkler methods on peat.

iv) Continuing refinement of charcoal methodology especially to differentiate local from background charcoal.

v) It is proposed to develop methodology at sites in consultation with the NCC. Many sites from which lake sediment cores have already been taken appear suitable, including Loch Tanna, Loch Tinker and Llyn Gynon.

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