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THE HISTORY OF THE VEGETATION AND FLORA OF WIDDYBANK FELL AND THE COW GREEN RESERVOIR BASIN, UPPER TEESDALE

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(*Communicated by R. G. West, F.R.S. – Received* 6 *October* 1972)

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The stratigraphy of all the major peat deposits on Widdybank Fell and in the Cow Green Reservoir Basin, Upper Teesdale, has been investigated and pollen diagrams prepared. This evidence shows that peat has been forming in the area from the end of the late-glacial, zone III, until quite recently, zone VIII, with the exception of a short period between about 10000 and 8800 B.P. The late-glacial vegetation was replaced only slowly by woodlands which at this altitude never developed a closed canopy even during the post-glacial climatic optimum. From 5000 B.P. onwards these woods were gradually replaced by blanket bog on the drift derived soils and later by grassland on the more porous limestone. Pollen grains from many of the rare species which grow in the area today, e.g. *Gentiana verna* and *Dryas octopetala*, have been found in the post-glacial deposits at several different levels including those which formed when the woodlands were at their most dense, thus demonstrating their presence in the area throughout the post-glacial and confirming the relict nature of the Teesdale flora.

1. Introduction

Upper Teesdale, 54° 40′ N, 2° 20′ W (figure 1), has long been recognized as an area of major botanical importance containing as it does a number of species like *Gentiana verna* and *Kobresia simpliciuscula* which are found in only a few other localities in Britain, and *Minuartia stricta* which does not occur elsewhere. The Teesdale rare species aroused considerable interest amongst early plant geographers because they represent such a wide range of geographical elements and several theories have been put forward to account for their presence in the area. Discussion at first centred on the possibility of per-glacial survival (Wilmott 1930; Blackburn 1931), but nowadays it is accepted that they are a relict of the late-glacial flora which was so widespread in Britain at the end of the last glaciation. Godwin (1949) suggested that the relict species survived the post-glacial development of forest and peat bog in Teesdale, even though their distribution was severely restricted and Pigott (1956), in a paper describing the plant communities within which these species occur, discusses a number of ecological factors which may have played a part in maintaining the open conditions necessary for their survival throughout the post-glacial period. These include the peculiarly severe nature of the climate (Manley 1942), the unique sugar limestone rock which outcrops on some of the fells, the grazing and trampling by domesticated and wild animals and the continually eroding river.

Pigott (1956, p. 577) also points out that 'to complete the evidence that the Teesdale flora is relict from the late-glacial it must be hoped that it will be possible to find traces of the plants or their ecological associates throughout the post-glacial deposits close to their present-day habitats, and thus demonstrate the local persistence of open conditions'. He mentions, in this connexion, Blackburn's record for *Helianthemum* pollen from the post-glacial peats of Cronkley Fell, and recently Hutchinson (1966) has found *Betula nana*, not only growing on the blanket peat within the area but also fossil in the peat almost immediately beneath. It is somewhat surprising that no more investigations have been carried out in so floristically interesting an area to establish the general trends in the vegetational history and to look specifically for further post-glacial remains of the relict species. Johnson & Dunham (1963) have studied the peats of the Moor House National Nature Reserve high up above the Tees Valley to the west,

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but that area is well away from the sugar limestone outcrops and, although their results are a valuable contribution to the regional vegetational history, they are not concerned specifically with the Teesdale flora.

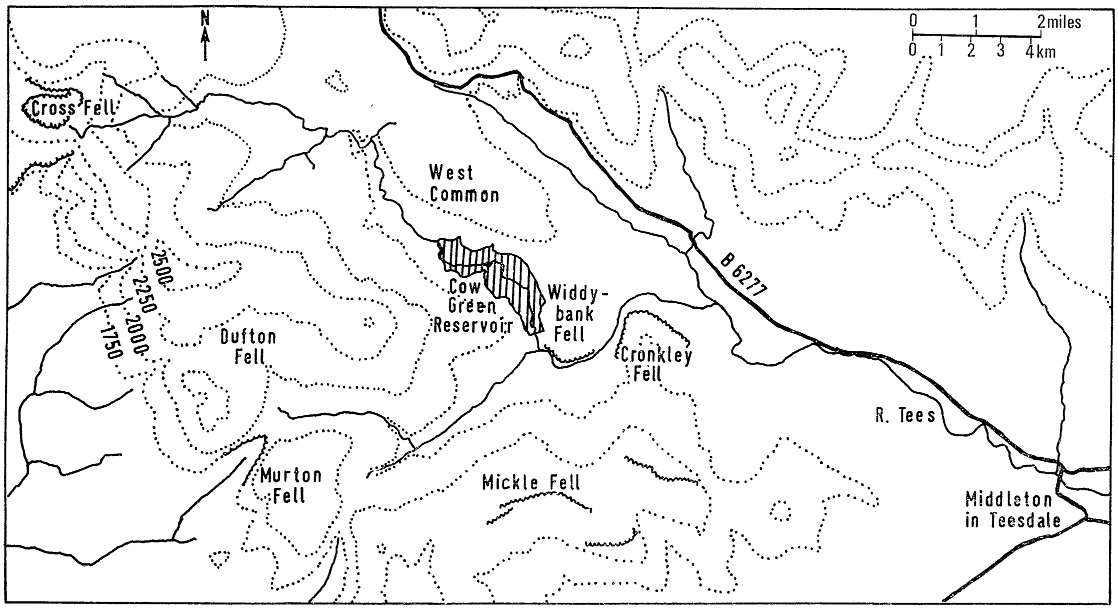

FIGURE 1. Map of upper Teesdale showing the position of Widdybank Fell and the Cow Green Reservoir in relation to the surrounding fells. (Contour heights are in feet.)

However, with the decision taken in 1966 by the Tees and Cleveland Water Board to build a reservoir on the flanks of Widdybank Fell, a reservoir which has now drowned the three-mile stretch of river above Cauldron Snout, including not only some of the floristically rich areas of limestone grassland and calcareous flushes, but also extensive areas of post-glacial peats in the valley bottom, it became apparent that if such investigations were to be carried out they must be done before the proposed flooding took place in 1970.

In 1966 the Natural Environment Research Council awarded Miss V. P. Hewetson and Mr R. Squires research studentships to study the peat stratigraphy and carry out pollen analysis of the deposits on Widdybank and Cronkley Fells respectively, and through the generosity of I.C.I. funds were made available for comparable studies in the reservoir basin itself. These latter were carried out initially, that is prior to the appeal against the Water Board's decision to build the dam, under the direction of Dr F. A. Hibbert in the sub-Department of Quaternary Research at the University of Cambridge and subsequently under the direction of Dr J. Turner in the Botany Department of the University of Durham. This paper includes all the results obtained from the reservoir basin together with those from Widdybank Fell. Dr Squires's results from Cronkley Fell have been published separately (1971).

The River Tees rises as a series of springs on the gently sloping eastern flanks of Cross Fell, the highest point (893 m) of the northern Pennine plateau. It flows in the wide peat-filled valley, now the Cow Green reservoir, along the western slopes of Widdybank Fell and then over the Whin Sill intrusion at Cauldron Snout in a series of waterfalls below which it is joined by the Maize Beck. It then passes through the narrow steep-sided valley between Widdybank and Cronkley Fells before forming another spectacular waterfall at High Force.

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Widdybank Fell is a raised plateau area between 5 and 8 km², reaching only 523 m O.D. on its rather flat summit. It is much lower than the fells which form the main escarpment ridge to the west. It is separated from West Common to the north by a low-lying col through which runs the main access road to both the Fell and the reservoir basin. To the west is the reservoir basin and the ground to the south and southeast falls sharply down to the river forming cliffs, the Falcon Clints, in places. The plateau is drained by a number of sikes or small streams, Tinkler's, Red and Slapestone sikes flowing into the Tees to the west, Fold sike and Wildscar, Moss and Sand sikes draining it to the east.

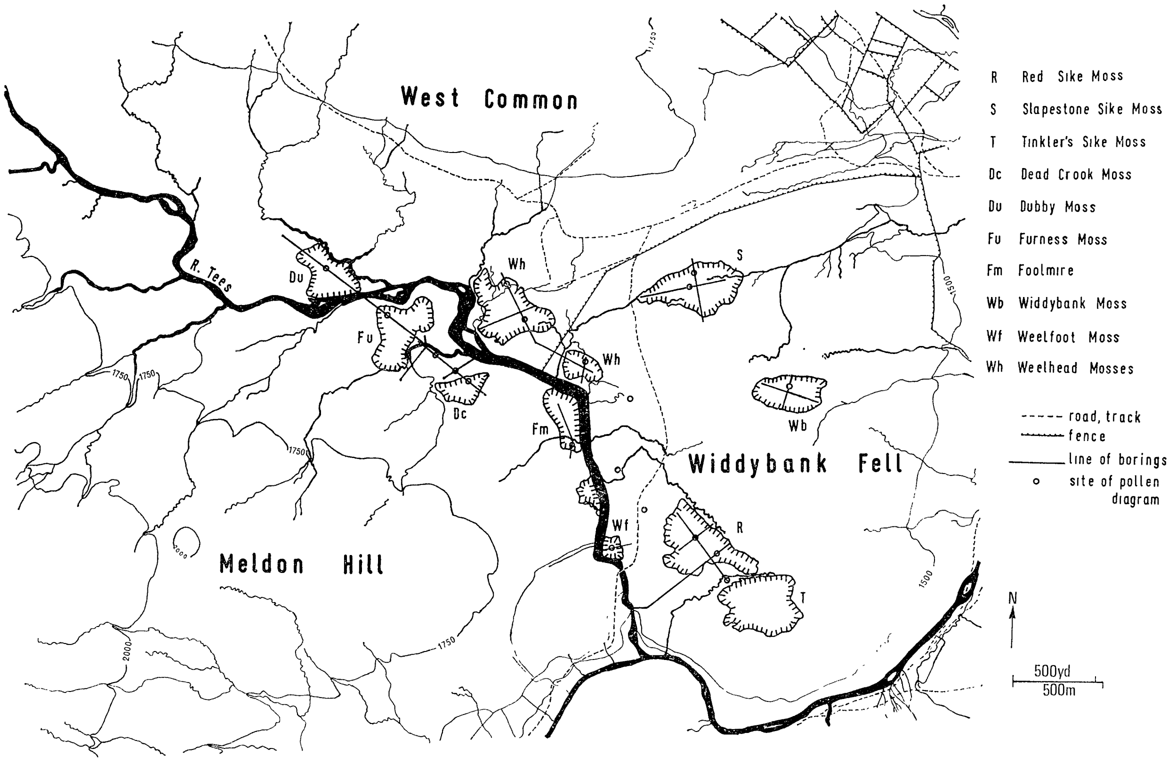

FIGURE 2. Map of Widdybank Fell and the Reservoir basin before flooding showing the position of all the major deep peat deposits, transects along which borings were made and the positions of all the pollen diagrams. (Contour heights are in feet.)

Both Widdybank Fell and the reservoir basin are formed partly of the Melmersby Scar limestone of the lower Carboniferous limestone series and partly of Whin Sill, a quartz-dolerite rock which was intruded into the limestone at the end of the Carboniferous. On either side of the Whin Sill the limestone was partially metamorphosed to form a rock with a distinctly sugary consistency, the so-called sugar limestone. It is this sugar limestone which makes Widdybank and Cronkley Fells so much more interesting floristically than the higher fells to the west which are formed only of the middle limestone series, alternating bands of limestone, shale, sandstone and coal.

There is ample evidence for glacial activity in the form of patches of boulder clay which occur over large parts of the area. The most conspicuous feature is a hummock of morainic material on either side of the Tees at the Weel in the reservoir basin. A detailed account of the geology is given by Johnson, Robinson & Hornung (1971).

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In the reservoir basin there are also extensive deposits of alluvial silts overlying either the boulder clay or bed rock, but a considerable amount of this is hidden beneath peat (figure 2). On the Fell there are three major areas of deep peat as well as extensive areas of shallow blanket peat. Similarly, in the reservoir basin there are several large areas of deep peat and a considerable amount of shallower blanket peat. The stratigraphy of each of these areas of peat has been examined and pollen analyses of several of them have been made. The major areas of peat will be described in turn.

2. STRATIGRAPHY AND POLLEN ANALYSIS

(*a*) *Note on the zonation of the pollen diagrams*

On every diagram several pollen assemblages can be recognized and the major ones can easily be correlated from one diagram to another. These major assemblages, starting with the youngest, are:

a grass–plantain–heather assemblage	zone G
an oak–alder assemblage	zone A
an oak–elm–hazel assemblage	zone O
a hazel–pine assemblage	zone H
a juniper–willow–herb assemblage	zone J

These assemblage zones are shown on the diagrams and are labelled G, A, O, H and J respectively. It is, of course, hardly surprising that these major assemblages can be correlated because the sites are very close to each other and must all have been receiving a substantial amount of their pollen from the same source, i.e. the vegetation in the reservoir basin and on the adjacent fells. It therefore follows that these major pollen assemblage zones may also be regarded as chronological periods and the radiocarbon determinations that are available support this view.

Some diagrams, however, have in addition one or two other pollen assemblages and this is particularly noticeable in the early part of the post-glacial when there was either very little or no peat growth. At Foolmire and Red Sikes, for example, there is a hazel–juniper–willow assemblage, HJ, between zones J and H and at Dead Crook a pine assemblage, P, at that level. On the other diagrams it is apparent from the abrupt change in pollen frequencies that there is a hiatus in the peat between J and H. This hiatus presumably occurred at the same time as the vegetation represented by the assemblages P and HJ was flourishing.

Although the five major assemblages can easily be recognized they do differ somewhat in detail from one diagram to another, in particular zone O, which, in some but not all of the diagrams, can be subdivided into two or three distinct pollen assemblages. These minor assemblages have been shown on the diagrams and labelled Oa, Ob, etc. They are thought to be due to local variations in the vegetation from one site to another and do not therefore necessarily represent chronological periods.

The relations between the local pollen assemblage zones and those of Godwin (1940) and the chronozones of West (1970) are set out in table 1. These correlations are based partly upon the similarities between the pollen assemblages concerned and partly upon the available radiocarbon dates. The dates for Godwin's pollen assemblage zones are those suggested by West (1961) and the dates for the local zones are based on those from the two sites, Red Sike Moss, TS I and Weelhead Moss II. The detailed evidence for these correlations is, of course, contained

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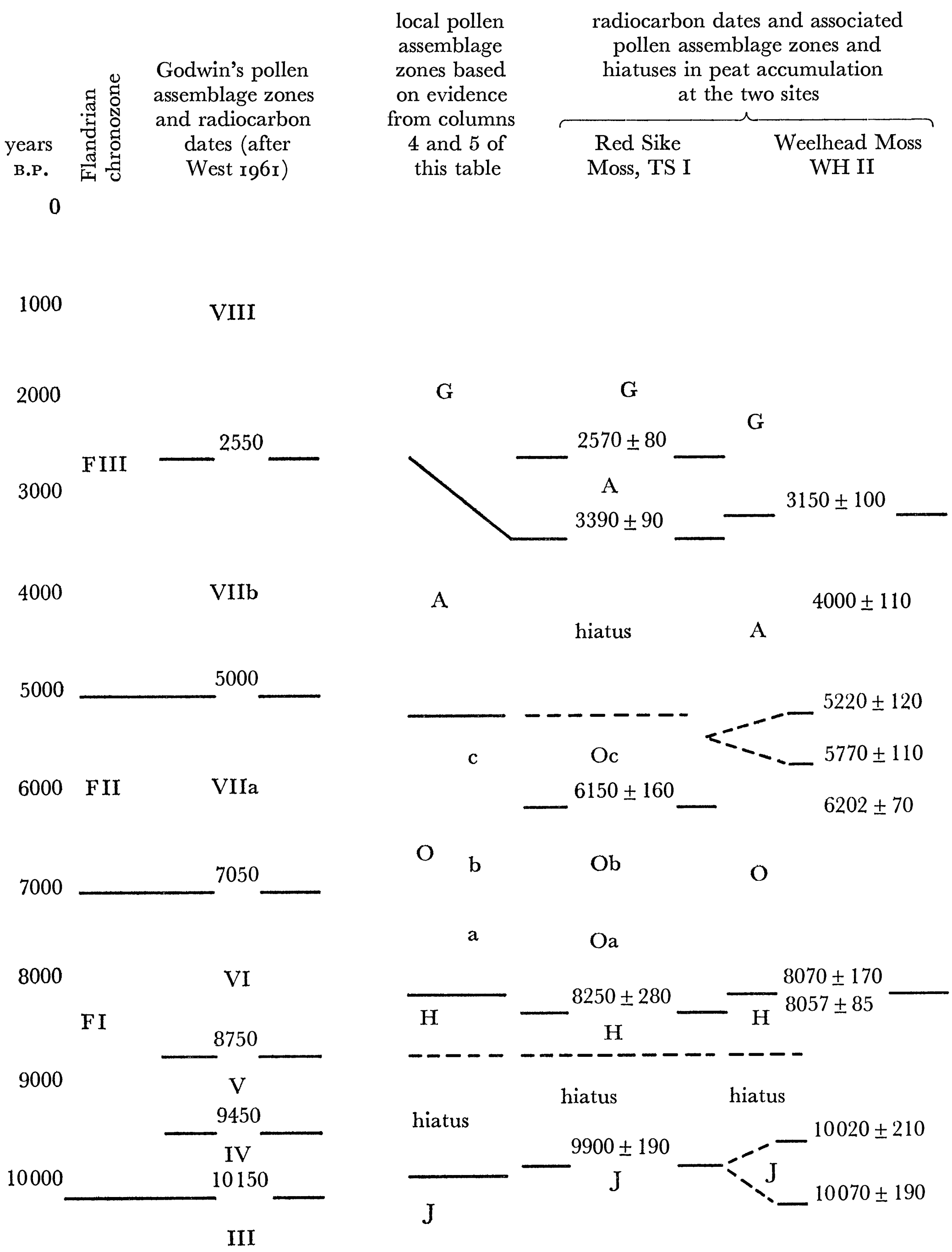
Table 1



years B.P.	Flandrian chronozone	Godwin's pollen assemblage zones and radiocarbon dates (after West 1961)	local pollen assemblage zones based on evidence from columns 4 and 5 of this table	radiocarbon dates and associated pollen assemblage zones and hiatuses in peat accumulation at the two sites: Red Sike Moss, TS I	radiocarbon dates and associated pollen assemblage zones and hiatuses in peat accumulation at the two sites: Weelhead Moss WH II
0					
1000		VIII			
2000			G	G	
					G
	FIII	2550		2570 ± 80	
3000				A	
					3150 ± 100
				3390 ± 90	
4000		VIIb	A		4000 ± 110
				hiatus	A
5000		5000			
					5220 ± 120
					5770 ± 110
			c	Oc	
6000	FII	VIIa		6150 ± 160	6202 ± 70
7000		7050	O b	Ob	O
			a	Oa	
8000		VI			8070 ± 170
	FI		H	8250 ± 280	8057 ± 85 H
		8750		H	
9000		V		hiatus	hiatus
		9450	hiatus		
		IV		9900 ± 190	10020 ± 210
10000		10150		J	J
		III	J		10070 ± 190

—— radiocarbon dated pollen assemblage zone boundaries

- - - estimated pollen assemblage zone boundaries

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in the sections which follow. Here it is sufficient to draw attention to the fact that the end of the local pollen assemblage zone J and the end of Godwin's zone III both have similar dates and that zone H corresponds with part of zone VI and the beginning of zone A with the beginning of zone VII b. Zone G has a similar pollen assemblage to that of zone VIII although it did not necessarily begin at the same time. Zone O is correlated with the latter part of zone VI and the whole of zone VII a.

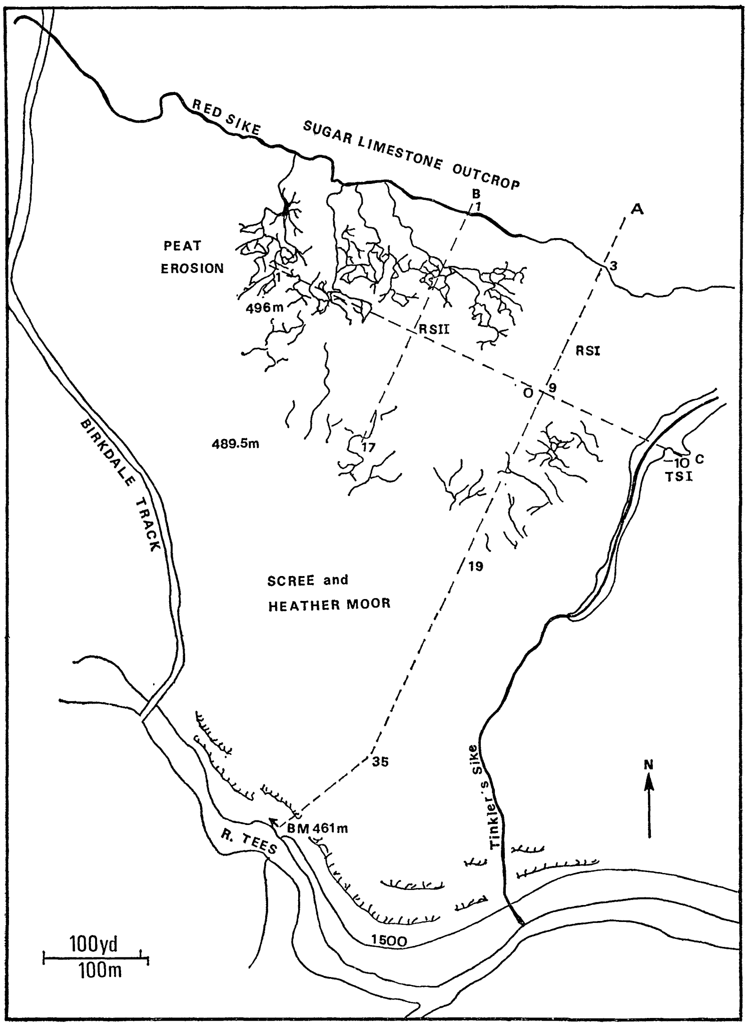

FIGURE 3. Sketch map showing Red Sike Moss, transects along which borings were made and the positions of the three pollen diagrams, TS I, RS I and RS II. (Contour heights are in feet.)

(b) *Red Sike Moss*

Between Red Sike and Tinkler's Sike on Widdybank Fell is an extensive area of peat with an actively growing surface (figure 3) which is here called Red Sike Moss. Various species of *Sphagna*, *S. papillosum*, *S. cuspidatum* and *S. rubellum* are present together with *Calluna vulgaris*, *Eriophorum vaginatum* and *angustifolium*, *Erica tetralix*, *Narthecium ossifragum*, *Drosera rotundifolia* and many species of *Carex*.

The western end of the moss has been eroded, is dissected by drainage channels and has a drier surface with less *Sphagna* than the central part. So too has the eastern end beyond Tinkler's Sike, here called Tinkler's Sike Moss. There lichens are abundant, particularly *Cladonia* spp.

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Red Sike Moss lies just south and at the foot of the slope of one of the larger outcrops of sugar limestone, and one would expect it to be one of the most promising from the point of view of pollen records of the relict species.

Its stratigraphy can be seen along the edge of Tinkler's Sike where the stream has eroded for itself quite a wide channel in the peat down to solid rock. It was also examined along three transects, one, C, parallel with the edge of the sugar limestone outcrop, and two, A and B, at right angles to this (figure 3). One of the latter, A, was extended south–southwestwards over the patchy blanket peat covering down the slope to the bench mark beside the Tees just above the Cauldron Snout waterfalls. The results are given in figures 4 to 7. They show that the total depth of peat varies from 100 cm at the margin to a maximum of 400 cm in the centre. At the northern end of transects A and B overlying bed-rock there is a basal layer of grey silt containing sand and pebbles. This stratum never exceeds 10 cm in thickness and is not present in the centre of the moss. At two points on transect B this grey silt band grades into a stiff, blue clay 5 to 10 cm deep. At the northern edge of the moss this silt layer is overlain by 5 to 10 cm of detritus mud. Patches of detritus mud were also found on the steep slope south of the moss on transect A and also at the eastern edge of transect C. Above these thin patches of silt and detritus mud is a layer of *Phragmites* peat. Elsewhere over much of the central part of the moss the *Phragmites* peat rests directly on the bed rock. It is light brown in colour, stiff in texture and contains birch wood and bark, seeds of *Menyanthes trifoliata* and *Carex* sp. as well as *Phragmites*.

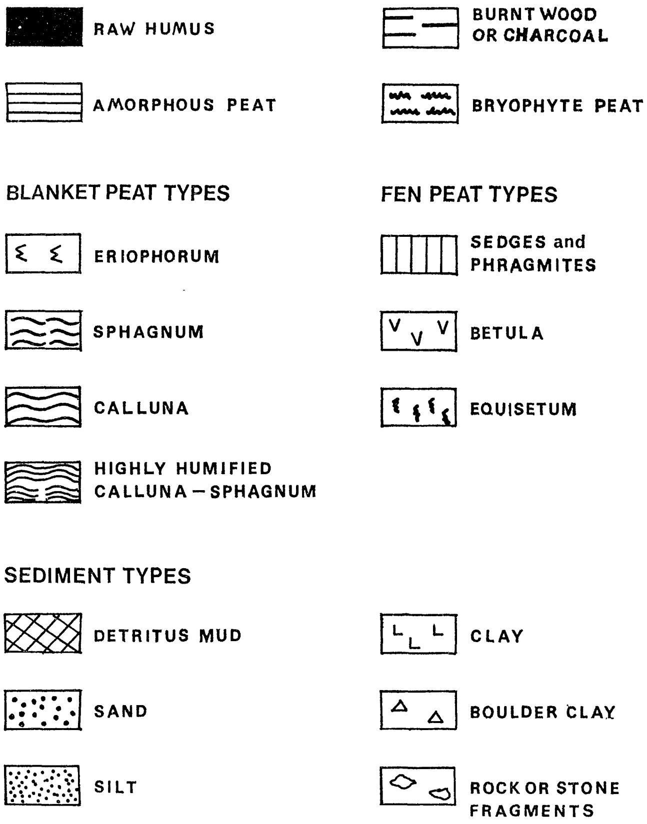

Figure 4. Key to stratigraphic symbols used in the figures in this paper.

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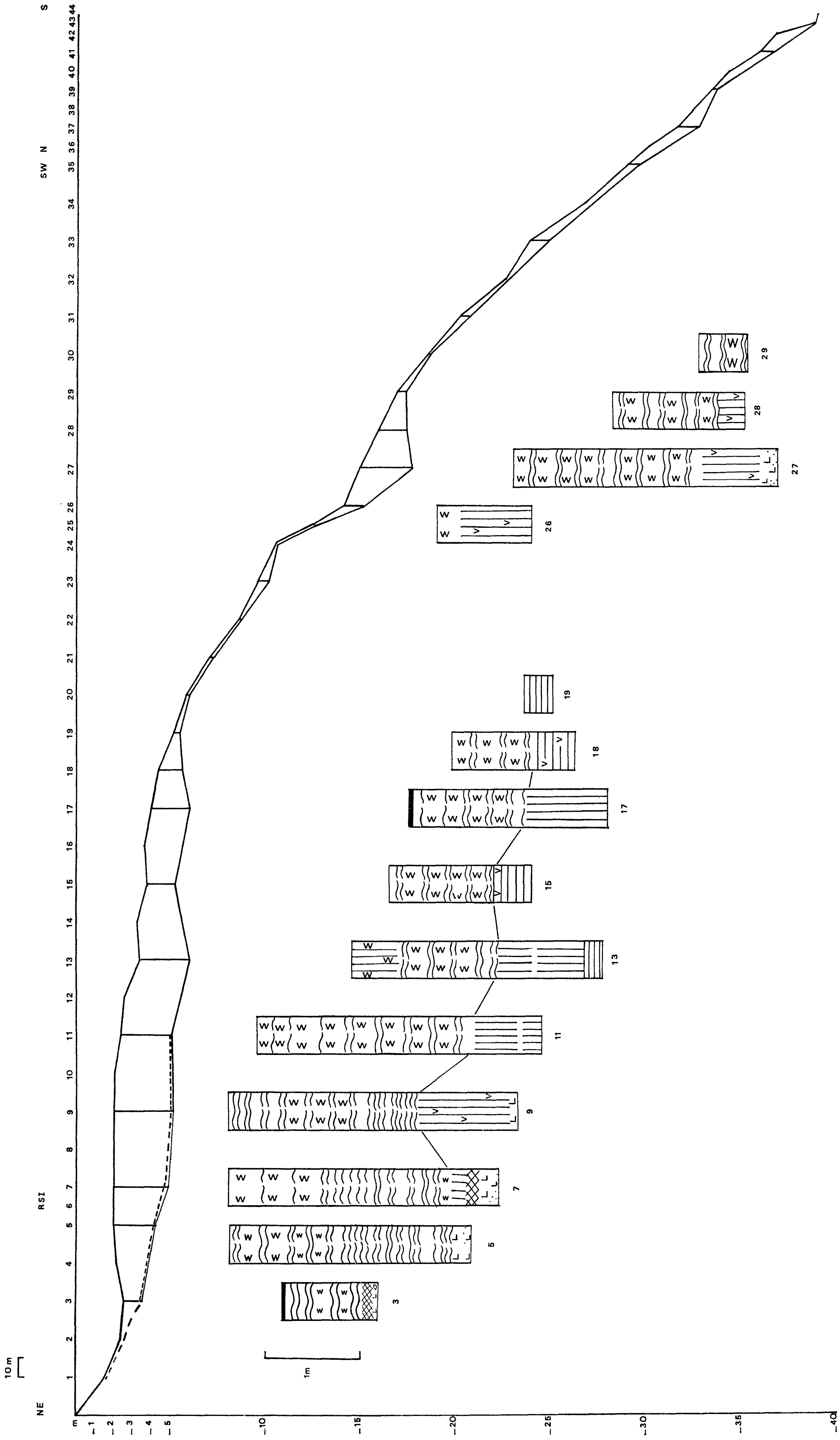

FIGURE 5. Stratigraphy of Red Sike Moss along transect A. Symbols for the deposits are given in figure 4.

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Towards the edges of the moss this layer passes into a well humified sedge peat. This basal layer of *Phragmites* and sedge peat varies in depth from 130 cm in the centre to only a few cm at the margins. It is overlain everywhere by a *Sphagnum–Calluna–Eriophorum* peat which contains sedges and is very highly humified at its base.

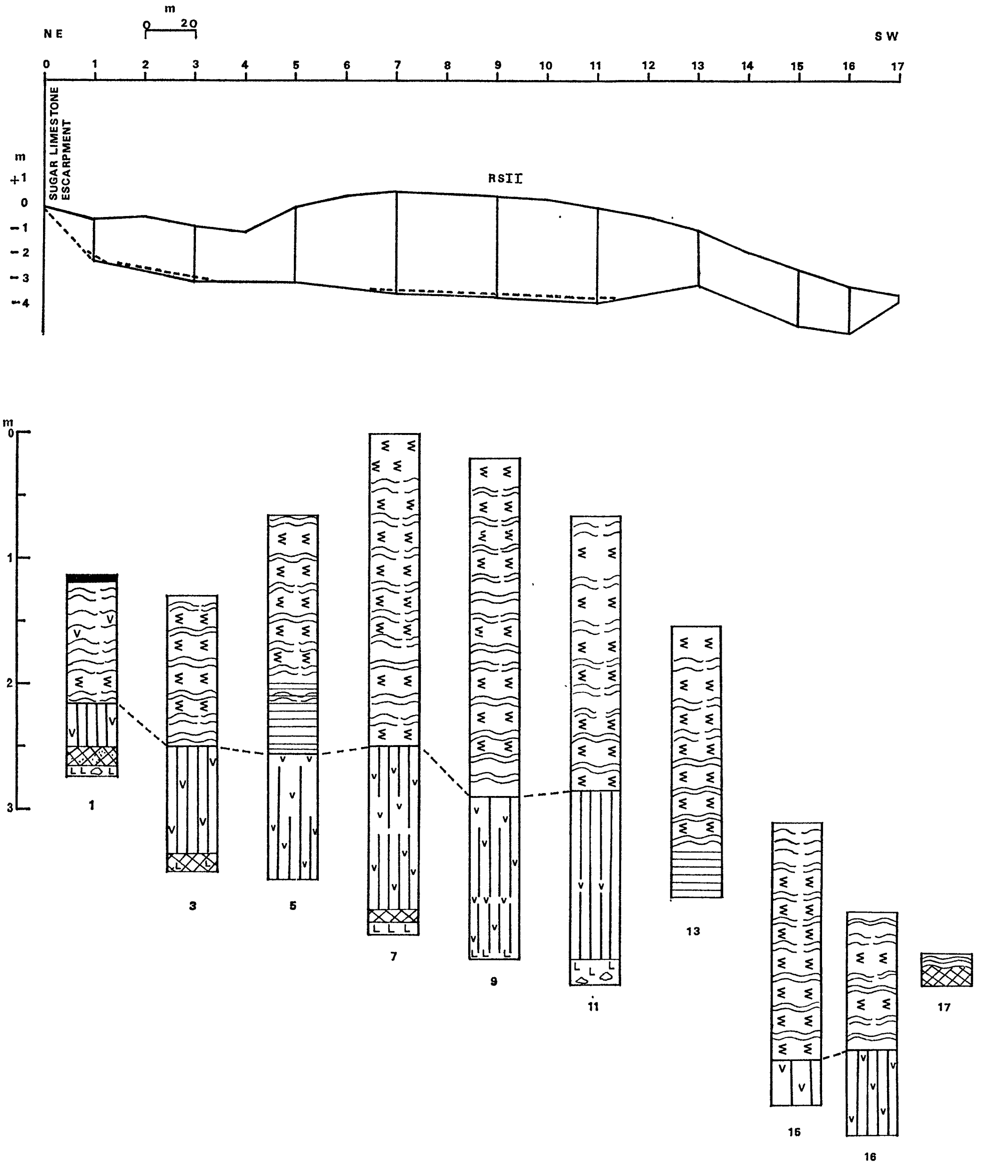

FIGURE 6. Statigraphy of Red Sike Moss along transect B. Symbols for the deposits are given in figure 4.

Samples for pollen analysis were collected from the points marked TS I (Tinkler's Sike I), RS I and RS II (Red Sike I and II) on figure 3. Those at RS I and RS II were collected with a Hiller borer. RS I is only 50 m from the sugar limestone. Beneath the peat at this point the basal gravelly silt gave a positive reaction with 10% HCl. Those at TS I were taken in the form of peat blocks cut from an exposed face so that critical horizons of the peat could be submitted subsequently for radiocarbon analysis.

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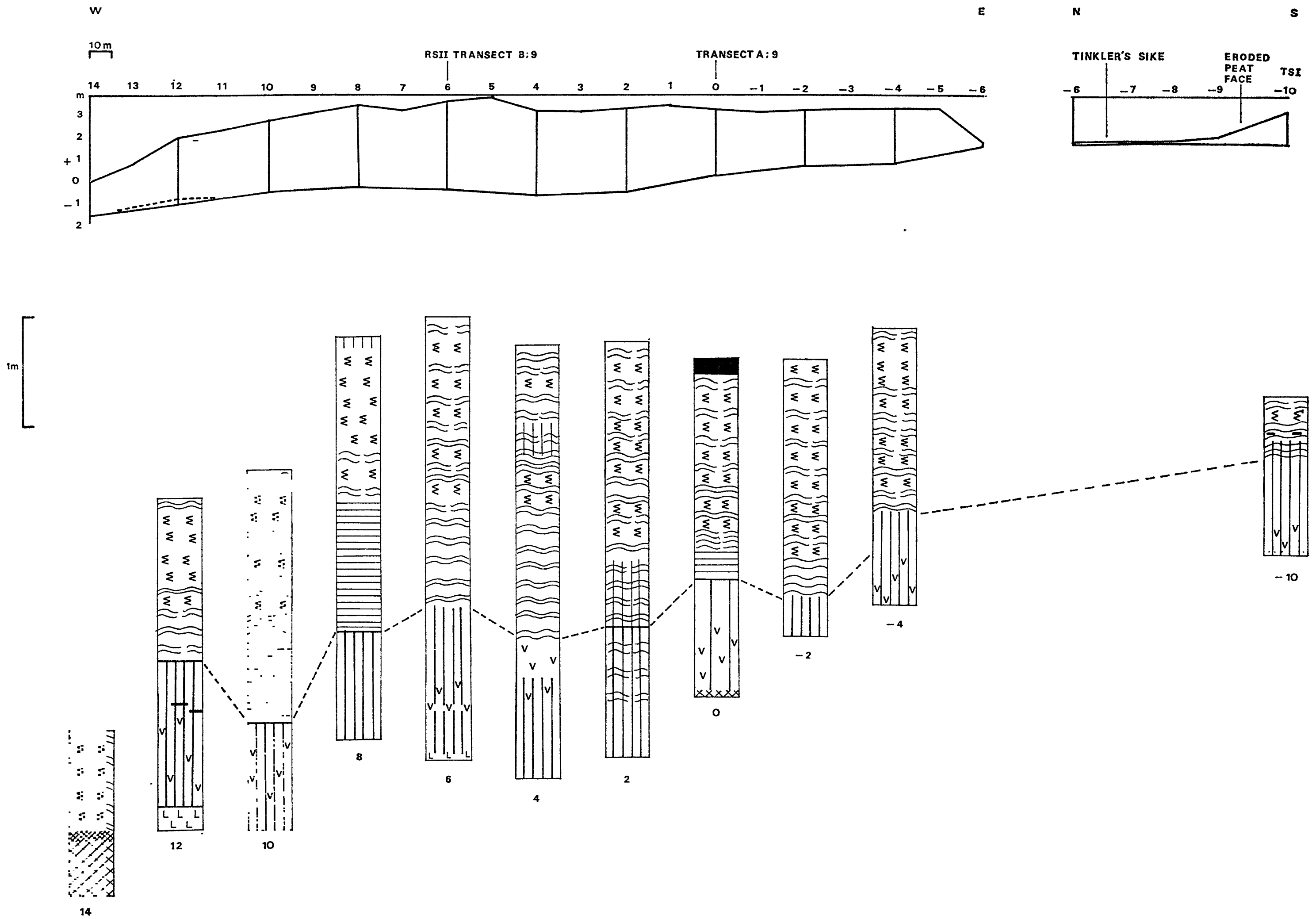

FIGURE 7. Stratigraphy of Red Sike Moss along Transect C. Symbols for the deposits are given in figure 4.

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The detailed stratigraphy at TS I is as follows:

cm	
0 to 12	dark brown crumbly *Calluna* peat with some *Eriophorum* remains, *Juncus* seeds, megaspores of *Selaginella selaginoïdes* with *Carex* seeds
12 to 25	light brown, *Calluna–Eriophorum* peat containing remains of sedges and megaspores of *Selaginella*
25 to 40	dark brown peat containing burnt *Calluna* stems
40 to 112	dry, moderately humified, light brown *Phragmites* peat with burnt *Calluna* stems, seeds of *Carex* sp. and *Menyanthes trifoliata* and megaspores of *Selaginella*
112 to 135	light brown *Phragmites* peat containing twigs of *Betula*, leaves and seeds of *B. nana*, seeds of *Menyanthes* and *Carex* sp., a single seed of *Lychnis flos-cuculi*, *Chara* oospores and megaspores of *Selaginella*.
135 to 143	*Phragmites* peat with a few *Betula* fragments and seeds of *Carex* sp., *Carduus Cirsium* sp., *Viola* sp. and *Lychnis flos-cuculi* and megaspores of *Selaginella*.

The results of the pollen analyses from TS I are given in figures 8 and 9.

Peat from certain levels on this diagram was radiocarbon dated at the Gakushuin laboratory in Japan with the following results. The dates are based on the Libby half life, 5570 ± 30 years.

laboratory code	depth of sample in cm	pollen horizon	age in radiocarbon years B.P. (before 1950)
GaK-2027	14	rise in Gramineae *Calluna* and *Plantago* beginning of zone G	2570 ± 80
GaK-2028	44	beginning of zone A	3390 ± 90
GaK-2029	70	beginning of subzone Oc	6150 ± 160
GaK-2030	120	end of zone H	8250 ± 280
GaK-2031	135	end of zone J	9900 ± 190

The diagram from this site, TS I, has been zoned by the method already described.

The basal few centimetres, (below 135 cm), are thought to have formed during the late-glacial zone J, corresponding to very late in Godwin's zone III. The evidence for this comes from the pollen spectrum, very low tree pollen percentages and over 20% of *Juniperus* pollen, together with the radiocarbon date of 9900 B.P. for the level of 135 cm.

The peat immediately above 135 cm, however, contains a different pollen assemblage. The *Corylus* frequency is high and both *Quercus* and *Ulmus* pollen are well represented, up to 10% for each genus. This assemblage together with the radiocarbon date of 8250 B.P. for 120 cm, the end of this zone H, indicates that it is part of Godwin's zone VI.

This means that peat growth was not continuous at this site and that there was a break

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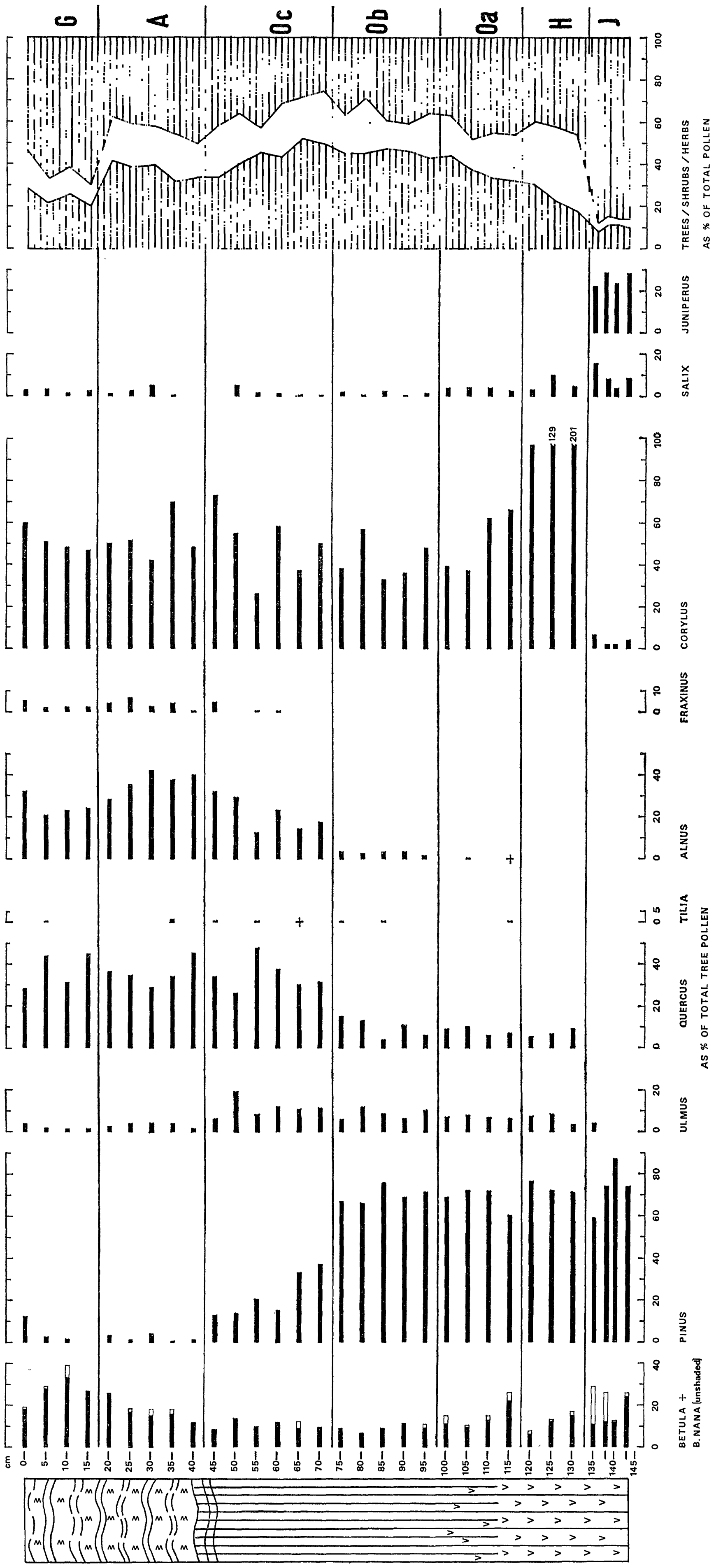

FIGURE 8. Tree pollen diagram from Red Sike Moss, TS I. Frequencies are plotted as a percentage of the total tree pollen excluding *Corylus*, *Salix* and *Juniperus*. Local pollen assemblage zones are given on the right.

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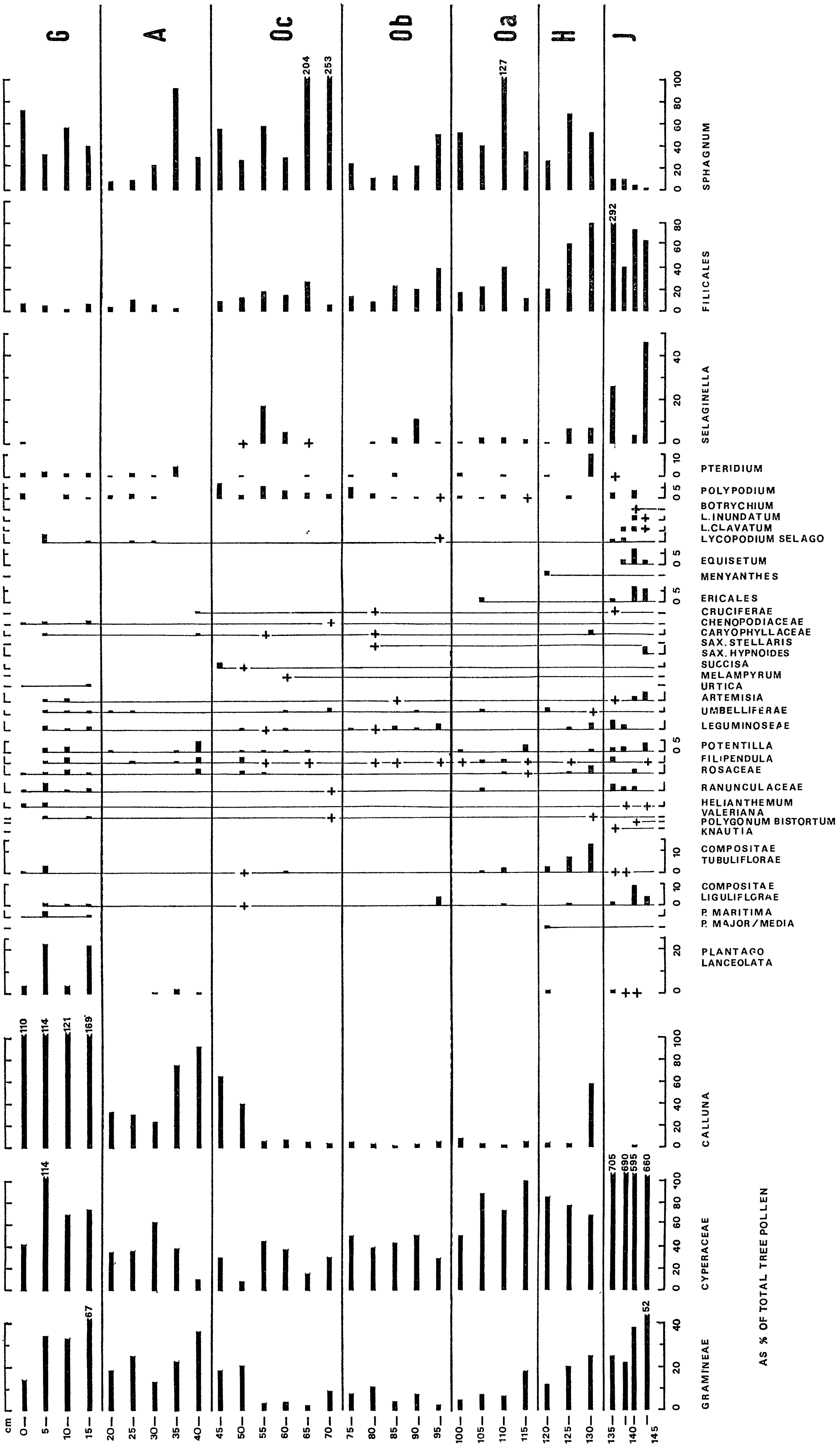

Figure 9. Herb pollen diagram from Red Sike Moss, TS I. Frequencies are plotted as a percentage of the total tree pollen.

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during Godwin's zones IV and V. This break accounts for the surprisingly rapid rise in the *Corylus* and fall in the *Juniperus* frequencies at 135 cm. There is also stratigraphic evidence for this hiatus, although this was not originally apparent in the field. At the level of 135 cm there are a number of fine mineral particles in the peat. These were observed in a monolith cut from the bottom of the moss which was allowed to dry out in the laboratory. The basal 15 cm of this monolith shrank less than the peat above and on drying out two mineral layers, one 15 cm and the other 12 cm from the base, could be seen. The particles were white, opaque, up to 1 mm in diameter and effervesced with dilute HCl. Presumably they had been derived from the nearby limestone by being blown, or possibly carried by surface run off, onto the dried out peat surface during zones IV and V. The wind speeds in the area are high today and there are bare patches of sugar limestone from which such particles are easily blown. Conditions could not have been substantially different in the early post-glacial with an incomplete tree cover at this altitude and with perhaps as much as a thousand years without peat formation it is easy to imagine how such calcareous particles were strewn over the moss surface in sufficient quantity to form a visible layer today.

The hiatus in peat formation indicates drier conditions on the Fell during the early post-glacial than either just before, during the latter part of the late-glacial, or afterwards.

The major oak–elm–hazel pollen assemblage zone O, can be subdivided on this diagram into Oa, an assemblage with no alder, Ob, one with a little alder, and Oc, with higher values for oak and alder and lower ones for pine. The break in the smooth pollen curves between Ob and Oc may well mean that there is another hiatus in the peat at that level, although there is no stratigraphic evidence for this.

There is another major pollen assemblage, A, from 40 cm upwards, with low elm frequencies. This clearly corresponds to part of Godwin's zone VII b. There is stratigraphic evidence for a hiatus between Oc and A and the radiocarbon date of 3390 B.P. is much too young for the elm decline at the beginning of VII b. It seems there was a break of at least 1600 years in peat growth. The fresh peat that began forming at about 3390 B.P. is different from that below, being less humified and composed mainly of *Sphagnum* species.

A pollen assemblage G is recognized in the top 15 cm of the diagram on the basis of high grass and plantain frequencies and a lower tree pollen frequency. According to the one radiocarbon date available it began at 2570 B.P. Zone G can be correlated with Godwin's zone VIII.

The significance of these changes in the pollen frequencies will be discussed later when the evidence from the other sites has been presented. It is worth noting, however, that although the diagram represents much of the late- and post-glacial there is only 145 cm of deposit. The peat is not particularly compressed compared with that of the deeper deposits in the reservoir basin and so it is hardly surprising that there is evidence for a number of breaks in peat formation. We attribute the intermittent peat formation to the fact that this moss, compared with those of the reservoir basin, receives drainage water from a much smaller area, the adjacent slopes of Widdybank Fell rather than the extensive catchment area of the River Tees above the reservoir basin, and that it is therefore more sensitive to drier periods of climate.

A wide variety of herbaceous pollen grains are present in the peat throughout the post-glacial (figure 9). These grains are worth special attention, but again will be discussed when the evidence from the other sites has been presented.

The results of the pollen analyses from RS II are given in figures 10 and 11 and those from RS I in figure 12.

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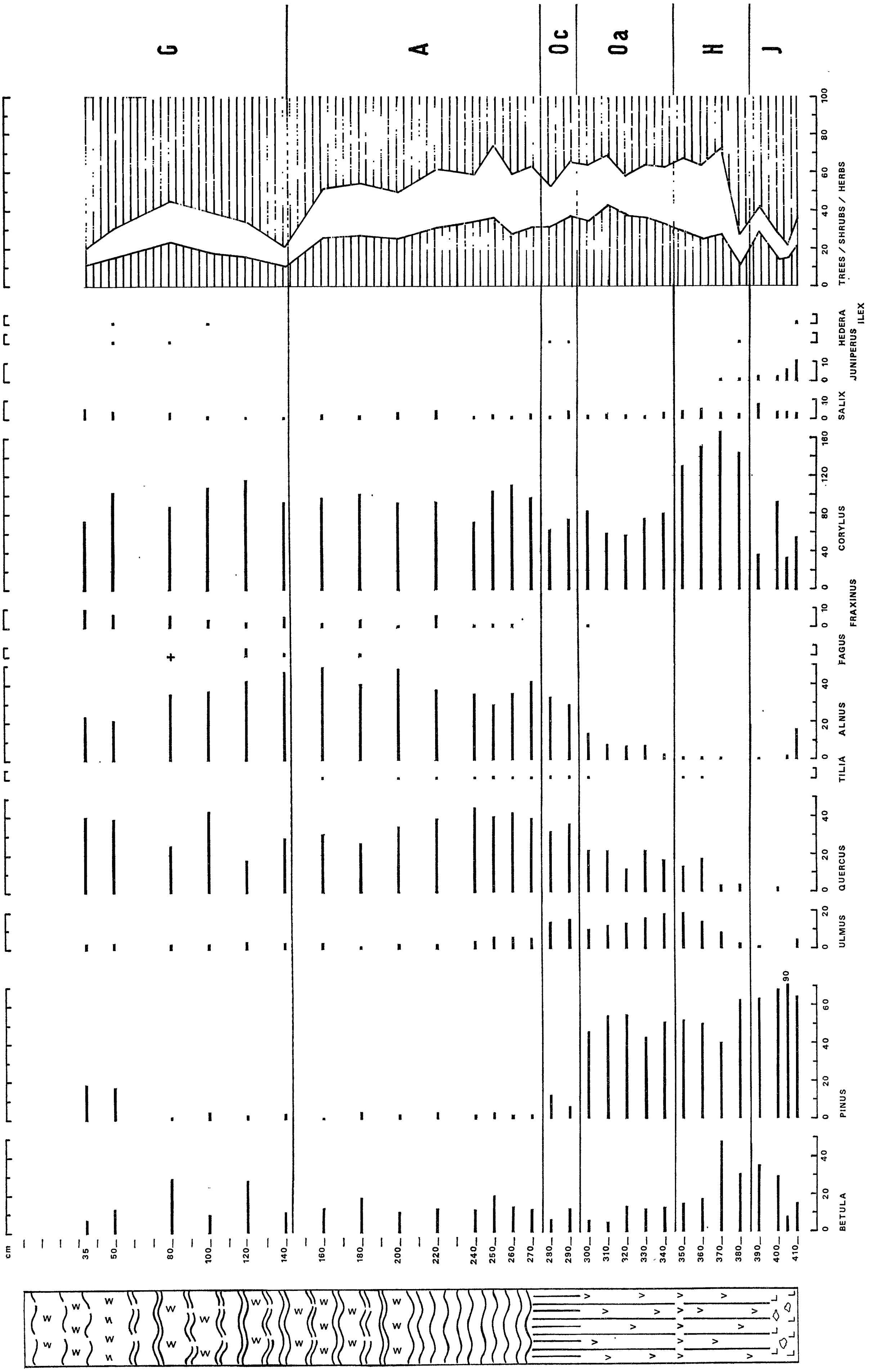

FIGURE 10. Tree pollen diagram from Red Sike Moss, RS II. Frequencies are plotted as a percentage of the total tree pollen excluding *Corylus*, *Juniperus* and *Salix*.

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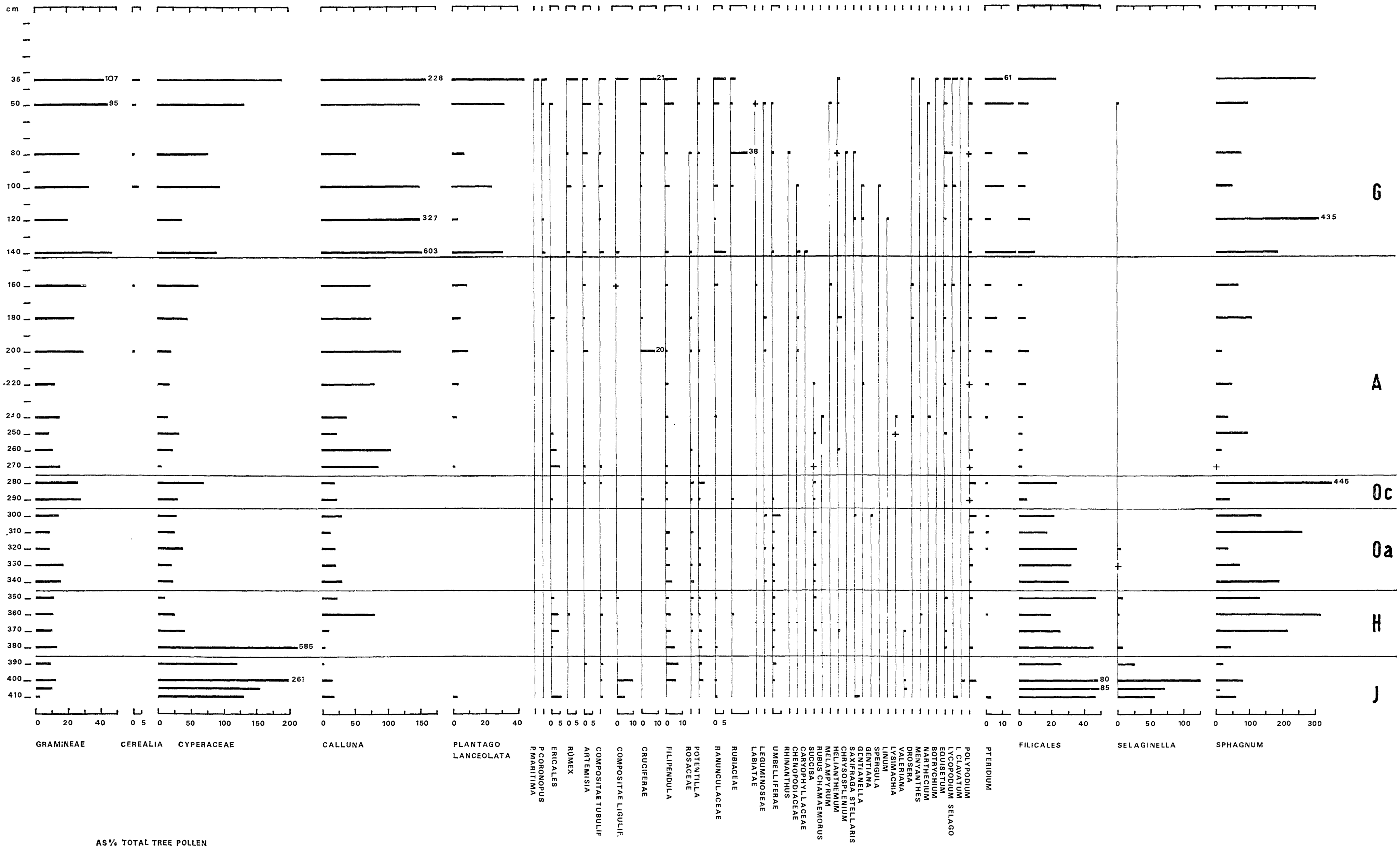

FIGURE 11. Herb pollen diagram from Red Sike Moss, RS II. Frequencies are plotted as a percentage of the total tree pollen.

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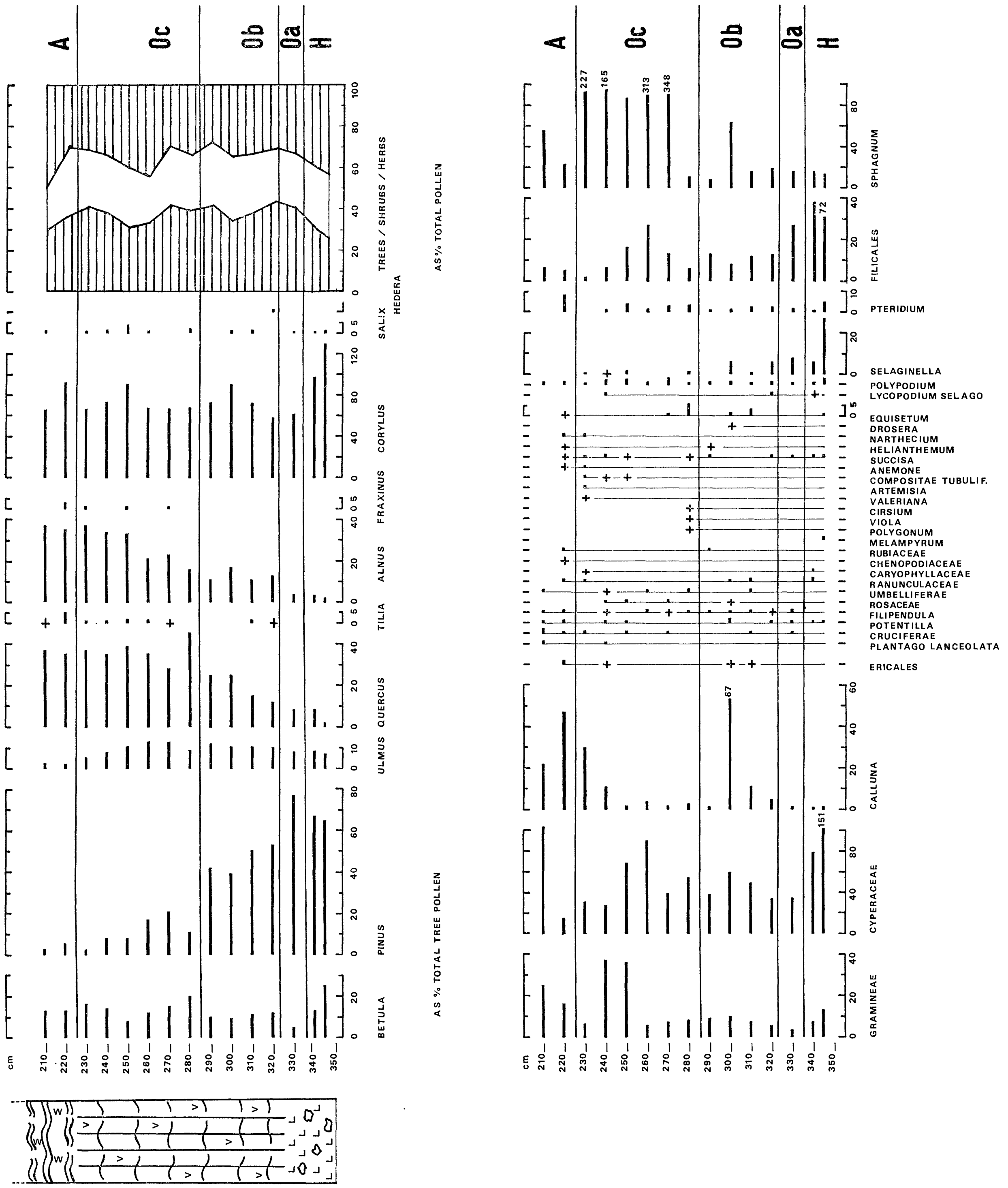

FIGURE 12. Pollen diagram from Red Sike Moss, RS I. Frequencies are plotted as a percentage of the total tree pollen excluding *Corylus* and *Salix*.

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The detailed stratigraphy at RS II is as follows:

cm	
0 to 50	fresh, reddish-brown *Sphagnum–Eriophorum* peat
50 to 100	well humified *Sphagnum–Eriophorum* peat
100 to 200	well humified *Sphagnum–Calluna–Eriophorum* peat
200 to 270	dryish *Calluna* peat containing many rootlets
270 to 295	dark brown sedge peat

The results of the pollen analyses from RS II are similar to those from TS I. They show that there was a little peat formation during J, the last part of the late-glacial, and some more in H, part of zone VI. Two subdivisions can be recognized in zone O, with a distinct hiatus between them. In this the diagram differs from TS I. There is, however, a similar change in stratigraphy between zones O and A at the two sites.

The results from RS I show only the bottom part of the profile. Peat formation did not begin there until zone H. Site RS I is of course nearer the edge of the moss than the other two sites and so it is hardly surprising that peat began growing there later. As at the other two sites there is a change in stratigraphy corresponding with the Oc A pollen zone boundary.

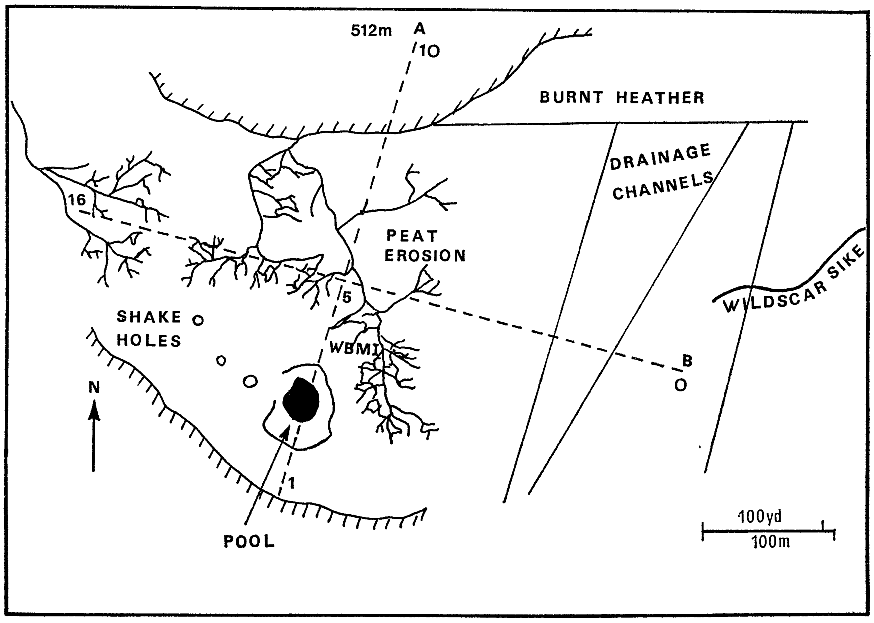

Figure 13. Sketch map showing Widdybank Moss, transects along which borings were made and the position of the pollen diagram, WBM I.

(*c*) *Widdybank Moss*

On the top of the plateau of Widdybank Fell at 503 m o.d., there is another large area of peat, Widdybank Moss. Its surface is co-dominated by *Calluna vulgaris* and *Eriophorum vaginatum* with local patches of *Trichophorum caespitosum*. The peat mass has been extensively eroded and deep erosion channels drain it to the northeast. South and north of the moss the ground rises steeply some 10 to 13 m, whereas to the west the surface slopes gently for about 200 m before

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dropping away to Wildscar Sike. Near the southern margin of the moss are a number of *Sphagnum*-filled shake holes.

The stratigraphy of this moss was examined along two transects A and B running at right-angles to each other, the former northwest–southeast and the latter southwest–northeast (figures 13 to 15). They show that the peat varies considerably in depth from between 100 and 150 cm near the edges to a maximum of 350 cm near the centre. At the base, sandstone or rotten limestone is overlain by a thin layer of blue-grey or light grey clay containing angular stones and sand lenses. In some places this clay layer is iron stained. It grades into a layer of detritus mud containing remains of sedges. In the centre of the moss this is overlain by a stiff, dryish *Sphagnum* peat with sedges and occasional seeds of *Chenopodium* sp. Within this peat in places along transect B, thin bands of carbonized material were found. The top of this layer of *Sphagnum* peat grades into a well-humified *Sphagnum–Eriophorum–Calluna* peat which becomes less humified and with bands of pure *Sphagnum* towards the surface. On the peat haggs the surface peat is a dry crumbly *Calluna* peat.

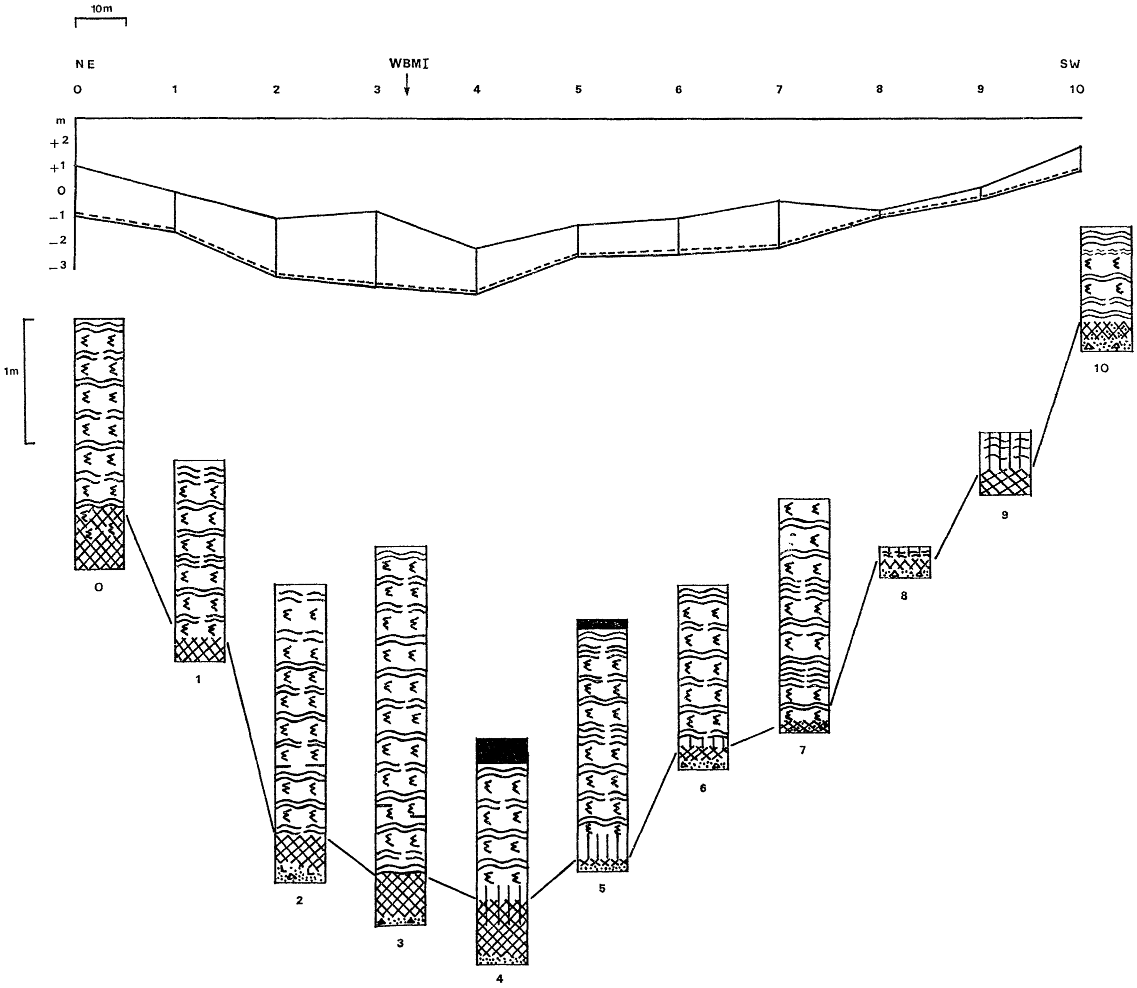

FIGURE 14. Stratigraphy of Widdybank Moss along transect A. Symbols for the deposits are given in figure 4.

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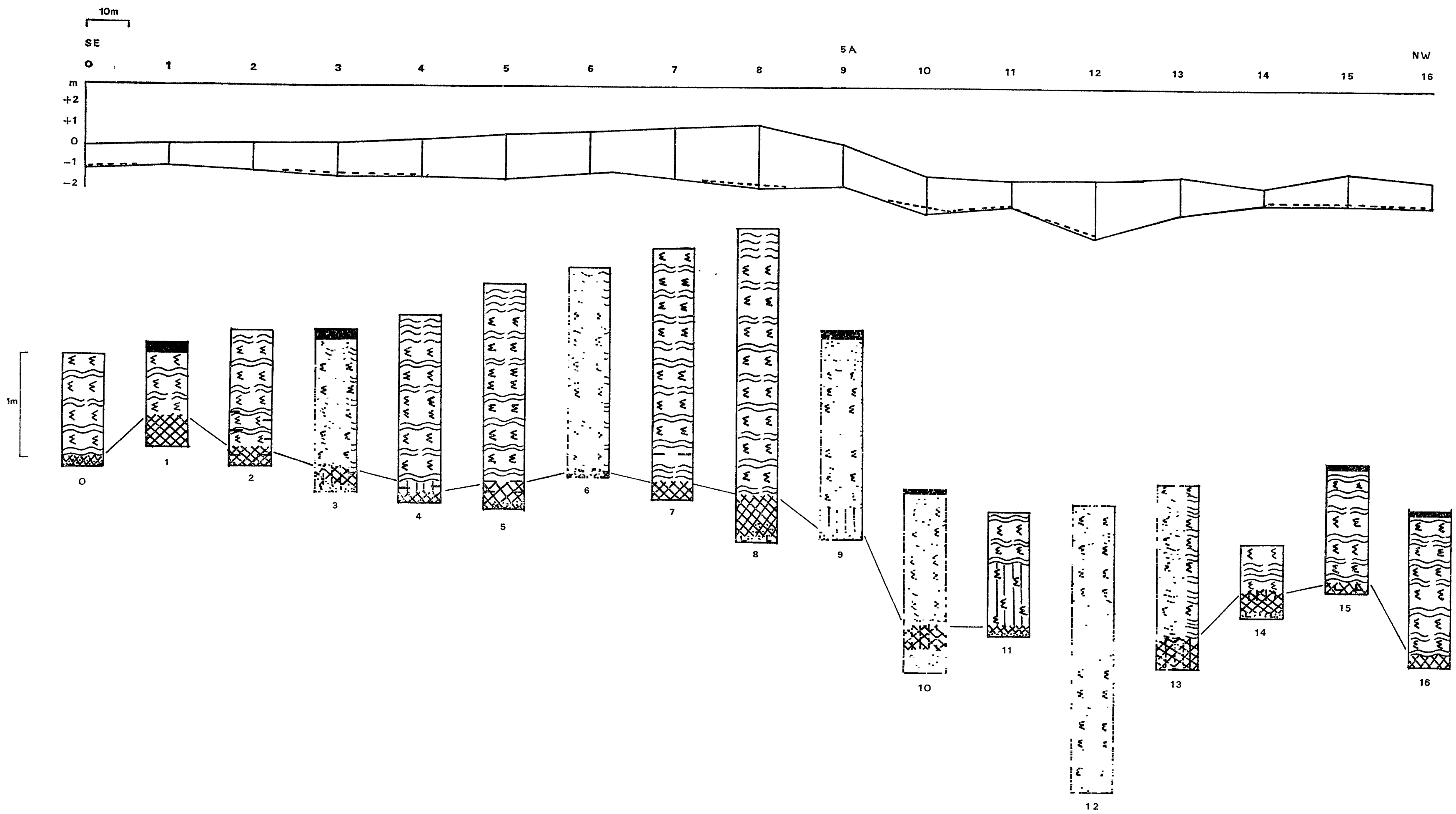

FIGURE 15. Stratigraphy of Widdybank Moss along transect B. Symbols for the deposits are given in figure 4.

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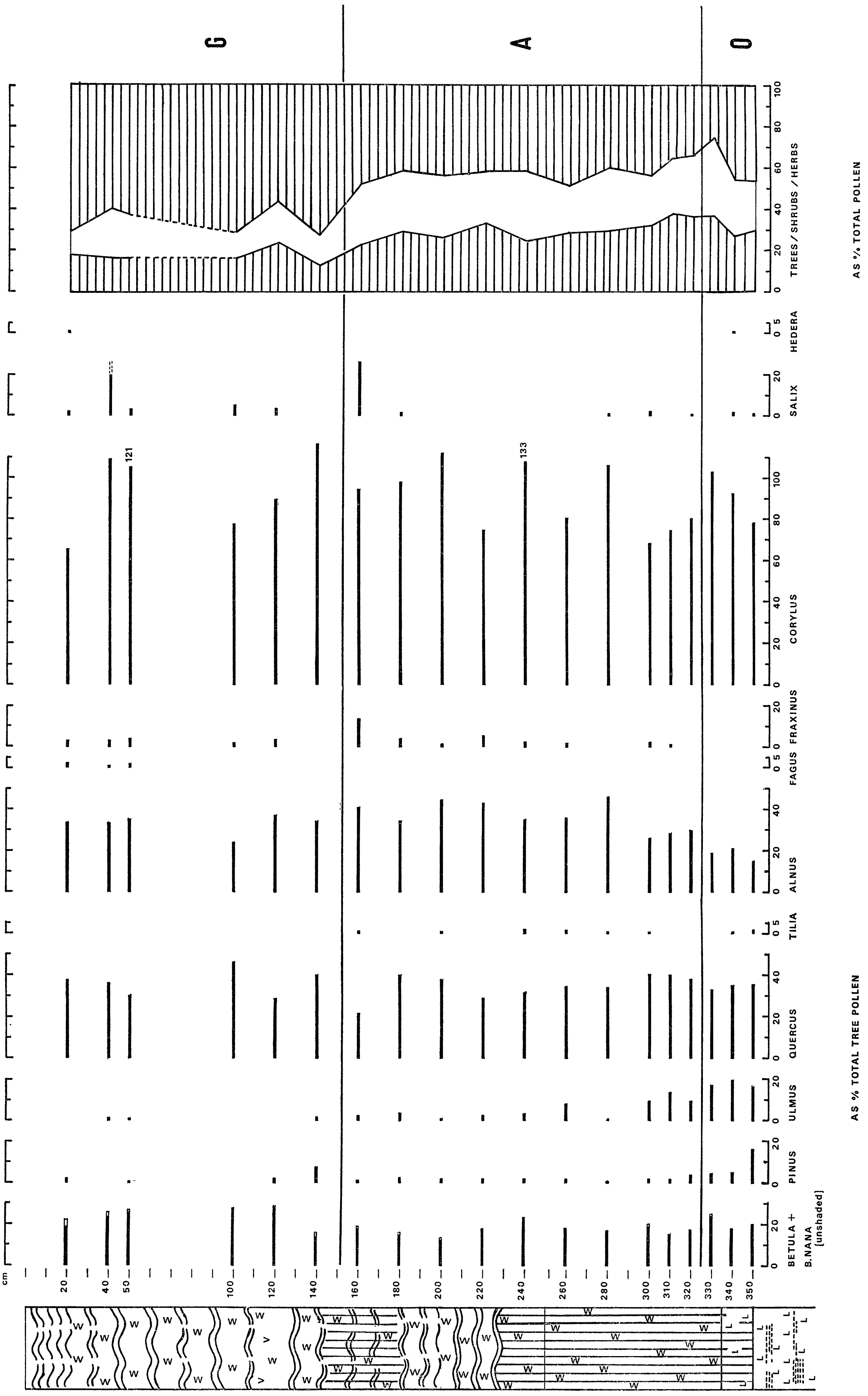

FIGURE 16. Tree pollen diagram from Widdybank Moss. Frequencies are plotted as a percentage of the total tree pollen excluding *Corylus* and *Salix*.

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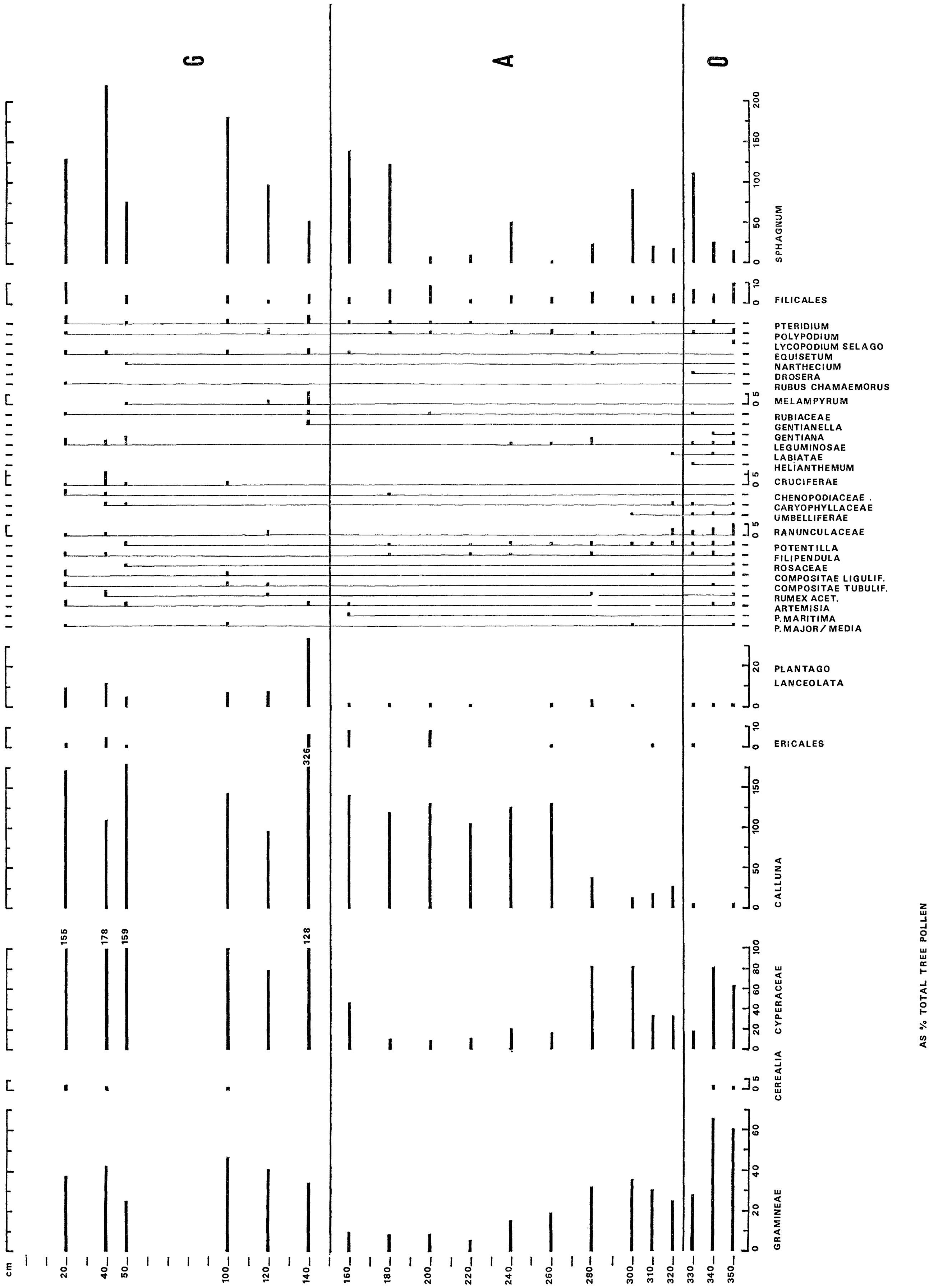

Figure 17. Herb pollen diagram from Widdybank Moss. Frequencies are plotted as a percentage of the total tree pollen.

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Samples for pollen analysis were collected with a Hiller borer from the point marked WBM I on figures 13 and 14. The detailed stratigraphy at that point is as follows:

cm	
0 to 20	very dry crumbly *Calluna–Eriophorum* peat
20 to 50	dark brown, well-humified, wet *Sphagnum–Eriophorum* peat
50 to 150	mid-brown, moderately humified *Sphagnum–Calluna–Eriophorum* peat
150 to 230	dark brown, well-humified *Calluna–Eriophorum* peat containing some *Sphagnum* and patches of carbonized material.
230 to 295	stiff dark brown peat with remains of *Sphagnum–Calluna* and sedges
295 to 325	very stiff detritus mud containing angular pebbles.
325 to 330	orange-grey stoney clay with blue-grey and grey pebbles.

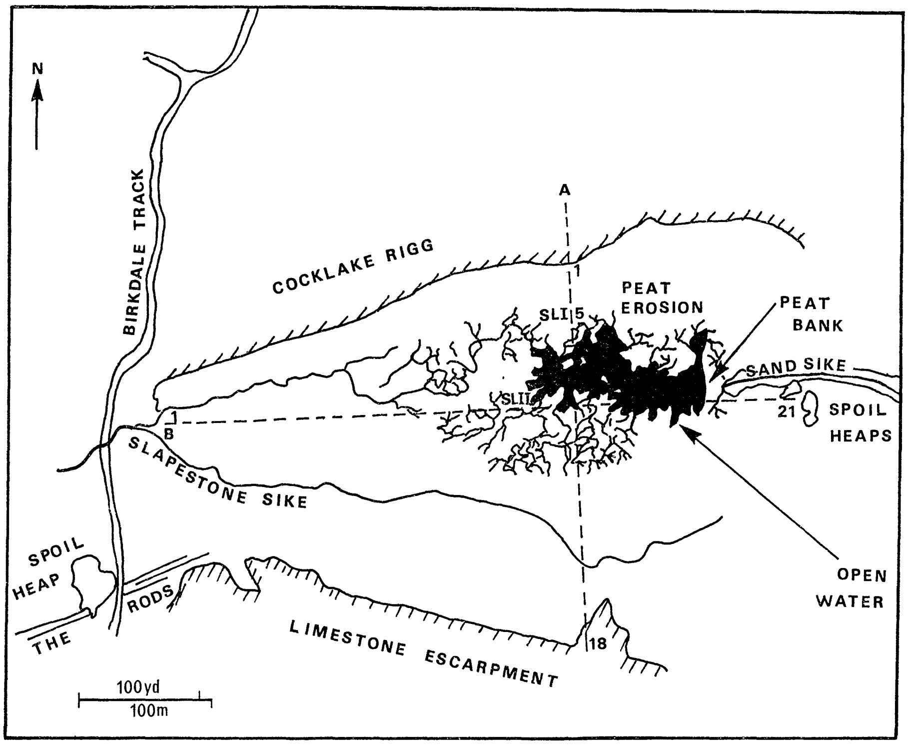

FIGURE 18. Sketch map showing Slapestone Sike Moss, transects along which borings were made and the positions of the pollen diagrams, SL I and SL II.

The results of the pollen analyses are given in figures 16 and 17. They show that peat began forming at this site towards the end of pollen zone O. The O/A zone boundary has been placed between 320 and 330 cm, but it could equally well have been placed a little higher between 300 and 280 cm. In any case it is worth noting that towards the end of zone O elm was contributing almost 20% of the total tree pollen, somewhat higher than the average of its values on the other diagrams. Zone G has been defined on the basis of rises in the Gramineae, Cyperaceae and *Plantago* frequencies. Samples between 50 and 100 cm could not be analysed as the borer failed to sample the wet peat between those depths. The wide variety of herbaceous pollen frequencies will again be discussed at a later stage.

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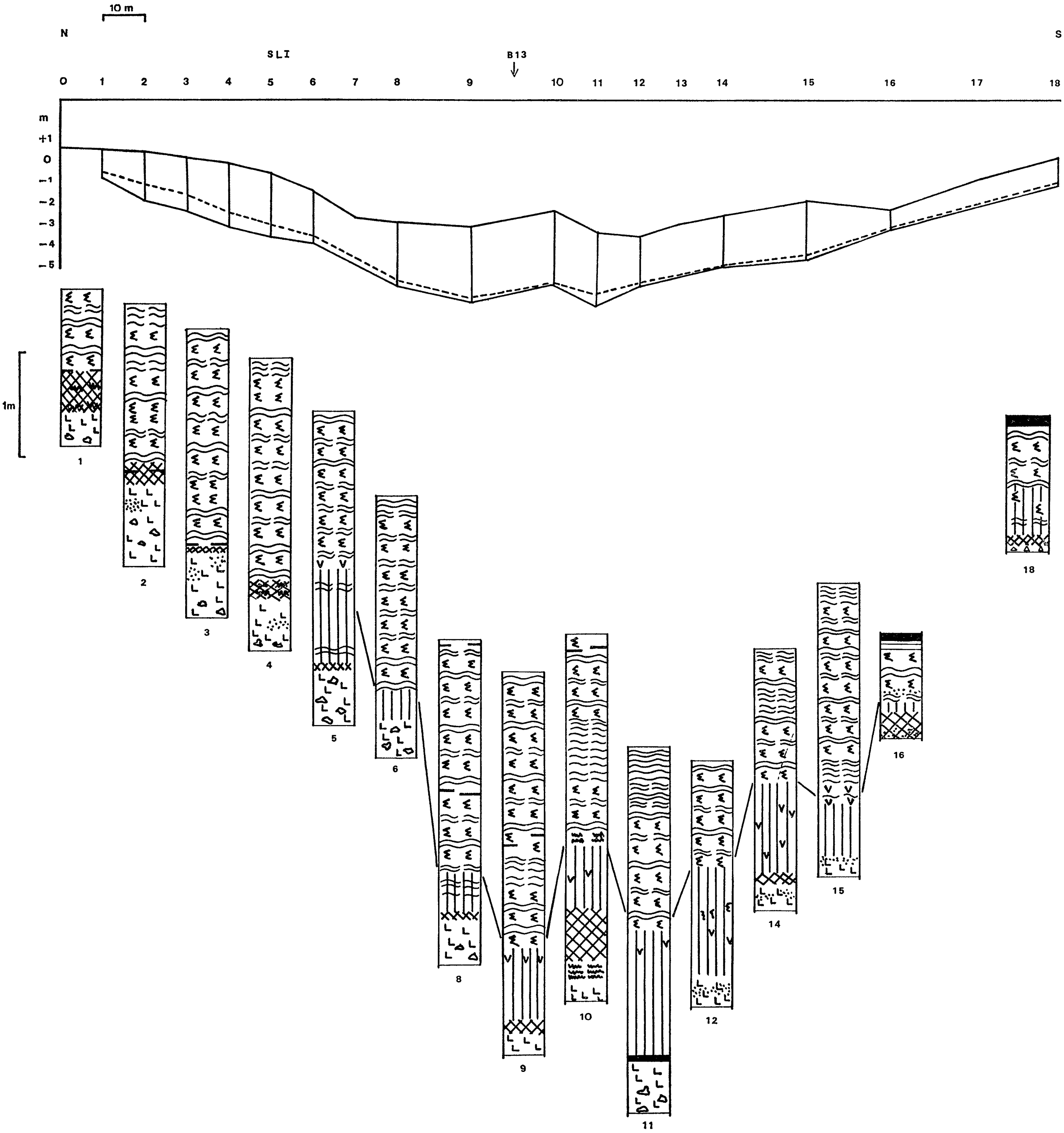

FIGURE 19. Stratigraphy of Slapestone Sike Moss along transect A. Symbols for the deposits are given in figure 4.

(*d*) *Slapestone Sike Moss*

The third extensive area of peat on Widdybank Fell is on the watershed between Slapestone and Sand Sikes at the northern end of the Fell (figure 18). The north edge of this moss abuts into a sandstone ridge, Cocklake Rigg, and to the south it slopes gently up onto an escarpment of Melmersby Scar limestone. The surface vegetation consists of *Calluna vulgaris* and *Eriophorum vaginatum* with local areas of actively growing *Sphagnum papillosum* and *rubellum*. In the pools *S. cuspidatum* flourishes, and in the erosion channels there is plenty of *Eriophorum angustifolium*.

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The moss has been deeply dissected in the centre and there are numerous drainage channels leading from this central area westwards, which eventually merge into a channel which drains into Slapestone Sike. An artificial peat bank now prevents drainage into Sand Sike.

The stratigraphy was examined by means of two transects at right-angles to each other, A running north–south across the most deeply dissected part and B running east–west along the main axis of the bog (figures 19, 20).

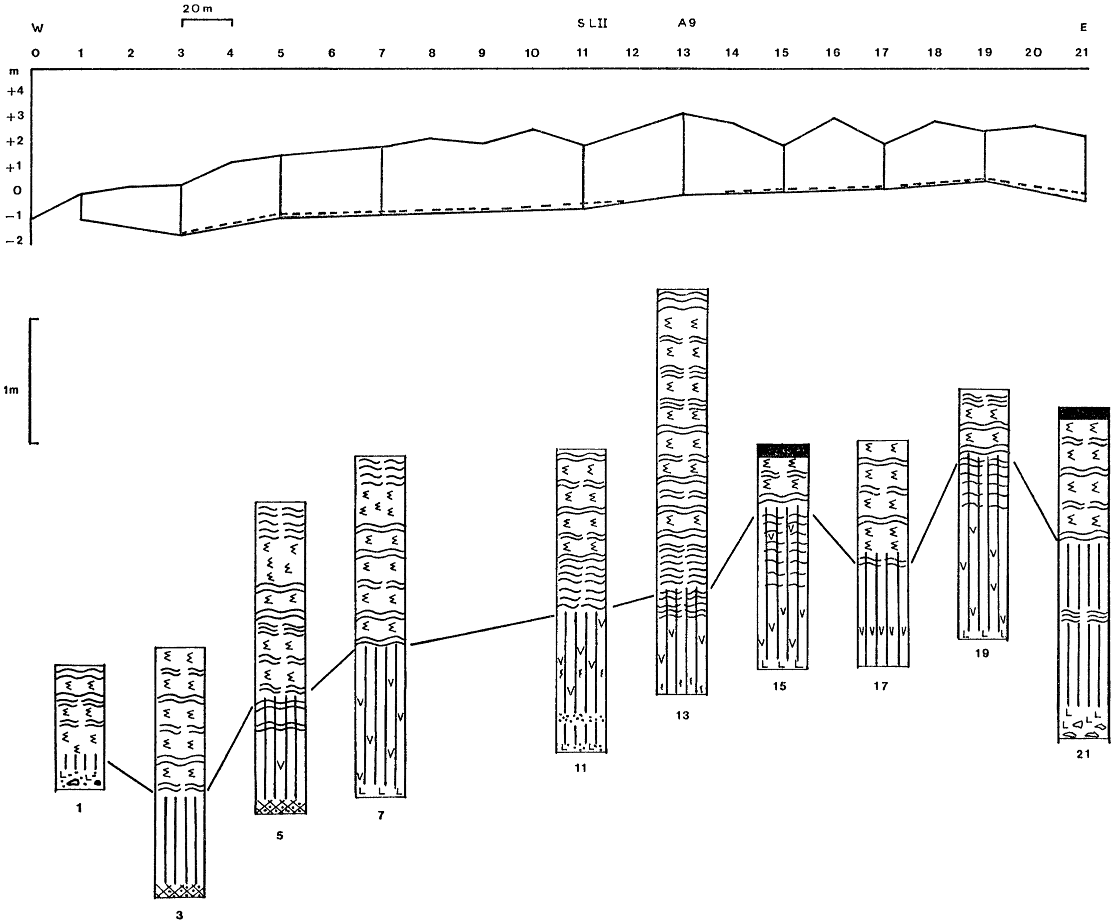

Figure 20. Stratigraphy of Slapestone Sike Moss along transect B. Symbols for the deposits are given in figure 4.

These show that the peat is 345 cm deep in the central area and that it thins out towards the northern and southern margins. Beneath the peat is a basal layer of blue-grey or greenish-grey clay containing angular pebbles and sand lenses. This is about 20 cm thick at the margins, but in the centre it appears to be deeper, the Hiller borer penetrating 50 cm into it. The surface of this clay deposit contained numerous seeds of *Juncus effusus* and *J. squarrosus* and oospores of *Chara*. Above the basal clay is a layer of detritus mud between 10 and 30 cm thick containing stems and leaves of *Hylocomnium splendens*, together with roots, fragments and occasional bits of burnt wood.

In the deeper parts of the moss, that is in the central part of transect A and along the entire length of transect B, the mud layer is overlain by a light brown sedge peat with isolated bands of *Sphagnum papillosum*. This sedge peat contains numerous mosses, *Hylocomnium splendens*, *Mnium*

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punctatum, *Aulacomnium palustre*, *Rhytidiadelphus squarrosus* and *Drepanocladus* sp. Seeds of *Ranunculus flammula*, *Lychnis flos-cuculi*, *Empetrum nigrum*, *Menyanthes trifoliata*, *Betula* sp., *Viola* sp., *Luzula sylvatica*, *Carex* sp. and megaspores of *Selaginella* and oospores of *Chara* were also found, as were bark fragments and cone scales of birch and rhizomes of *Phragmites*.

Above this light brown sedge peat is a well humified *Sphagnum–Calluna–Eriophorum* peat containing bands of fresh *S. papillosum* and *cuspidatum* and occasional fragments of *Hylocomnium splendens*, *Rhytidiadelphus squarrosus* and *Rhacomitrium lanuginosum*. Burnt fragments of *Calluna* were common throughout this layer.

Along the northern end of transect A, from 0 to 80 m, there is no sedge peat and the *Sphagnum–Calluna–Eriophorum* peat grades directly into the detritus mud at its base. A few birch fragments and bands of *Sphagnum* are present in it and towards the surface it becomes fibrous *Eriophorum* peat with *Sphagnum imbricatum* and pieces of burnt *Calluna* wood.

Samples for pollen analysis were collected from SL I on transect A (figures 18 and 19) for counting during the winter season, before the stratigraphy was investigated, and when it became apparent that this was not the deepest part of the moss, a second core was taken from SL II on transect B (figures 18, 20) and the bottom 60 cm of this analysed.

The results of these pollen analyses are given in figures 21 to 23. They show that the peat began forming at various times. In the deepest part of the moss (figure 23), the basal peat has a zone O spectrum with over 40 % *Pinus* and less than 20 % *Alnus*. At the slightly shallower site of the main pollen diagram (figures 21, 22) the peat did not begin forming until zone A. One imagines therefore a small area of actively growing peat, probably where the moss now carries open water at times, during zone O and peat growth spreading from there to its present extent during early zone A.

Zone G is not easy to define at this site. It has been placed between 120 and 130 cm on the basis of the *Plantago* curve.

(*e*) *Foolmire Sike Moss*

This is an extensive area of peat on the Westmorland bank of the river. Towards its southern limit it slopes down from a small hill of glacial material to the area known as Low Moss, where Foolmire Sike divides this area from Far Foolmire which extends north towards the Weel. The surface vegetation of the area may be divided into two main parts. The steeper slopes to the south of Foolmire Sike, which are well drained, are dominated by *Calluna vulgaris* with only occasional *Eriophorum vaginatum* and local patches of *Trichophorum caespitosum*. *Vaccinium myrtilus* and *Rubus chamaemorus* are also principal components of the vegetation. Around the Sike, and in particular on the area known as Far Foolmire, conditions are very much wetter; here *Eriophorum vaginatum* becomes a significant component of the vegetation and in the wetter areas there are pools with *Sphagnum cuspidatum* and hummocks with *S. papillosum* and *S. rubellum*. Erosion has taken place around the Sike itself and here *Eriophorum angustifolium* is found.

The stratigraphy of the area was determined by means of a long transect, beginning in the south on top of the small glacial feature, running north towards the Sike from which point it runs more northwesterly across Far Foolmire towards the Weel (figures 24, 25).

The results show that on the steeper slopes the deposits are entirely ombrogenous, a *Calluna–Eriophorum–Sphagnum* peat. Where the subsurface contour levels out on a base of sticky, blue clay, there is a monocotyledonous peat overlain by a *Phragmites* sedge peat with wood remains. On top of this is *Calluna–Eriophorum–Sphagnum* peat. Close by the margins of the steepsided glacial hill there is a layer of sand which lies between the monocotyledonous peat and the sedge

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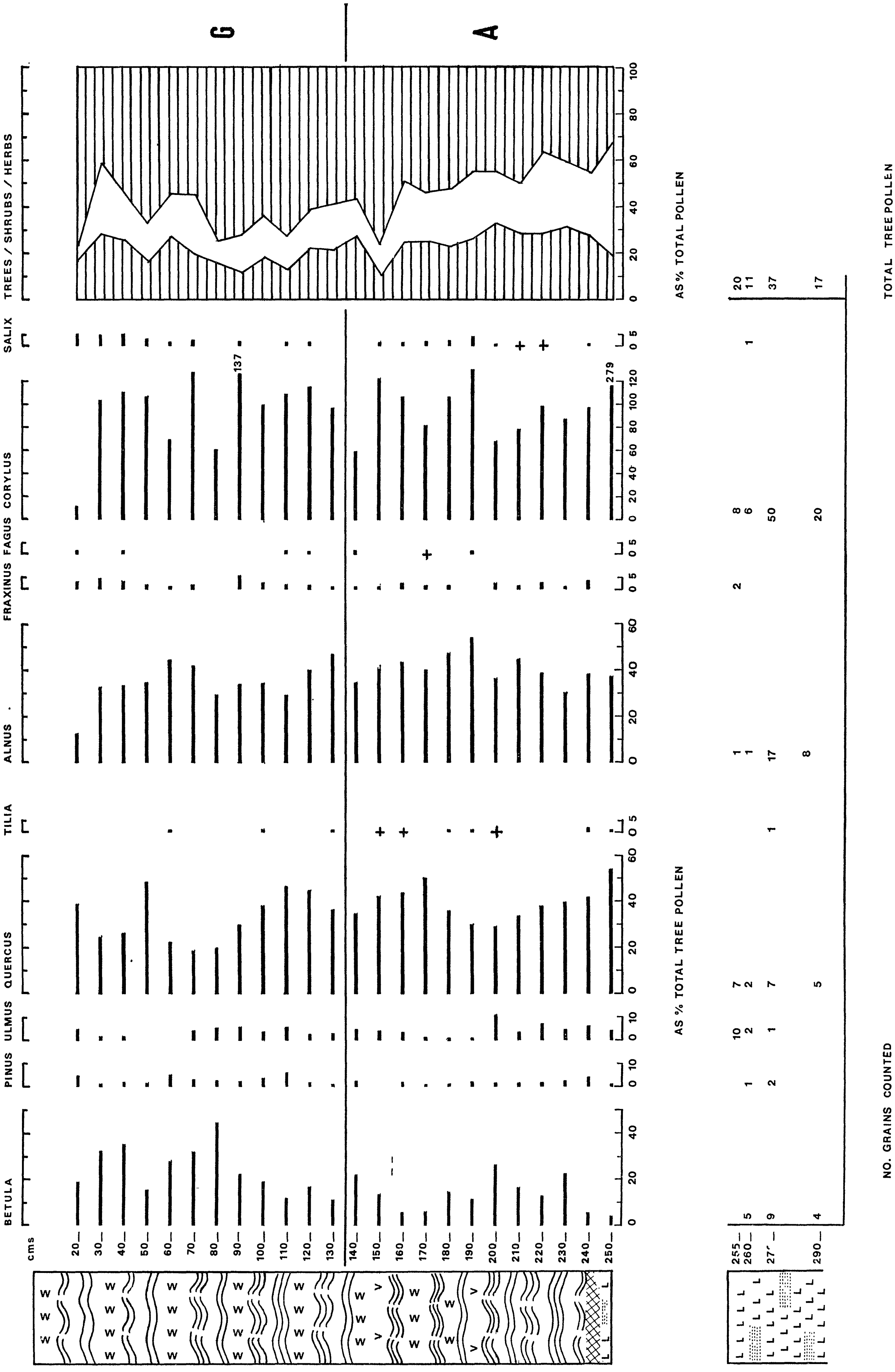

FIGURE 21. Tree pollen diagram from Slapestone Sike Moss, SL I. Frequencies are plotted as a percentage of the total tree pollen excluding *Corylus* and *Salix*.

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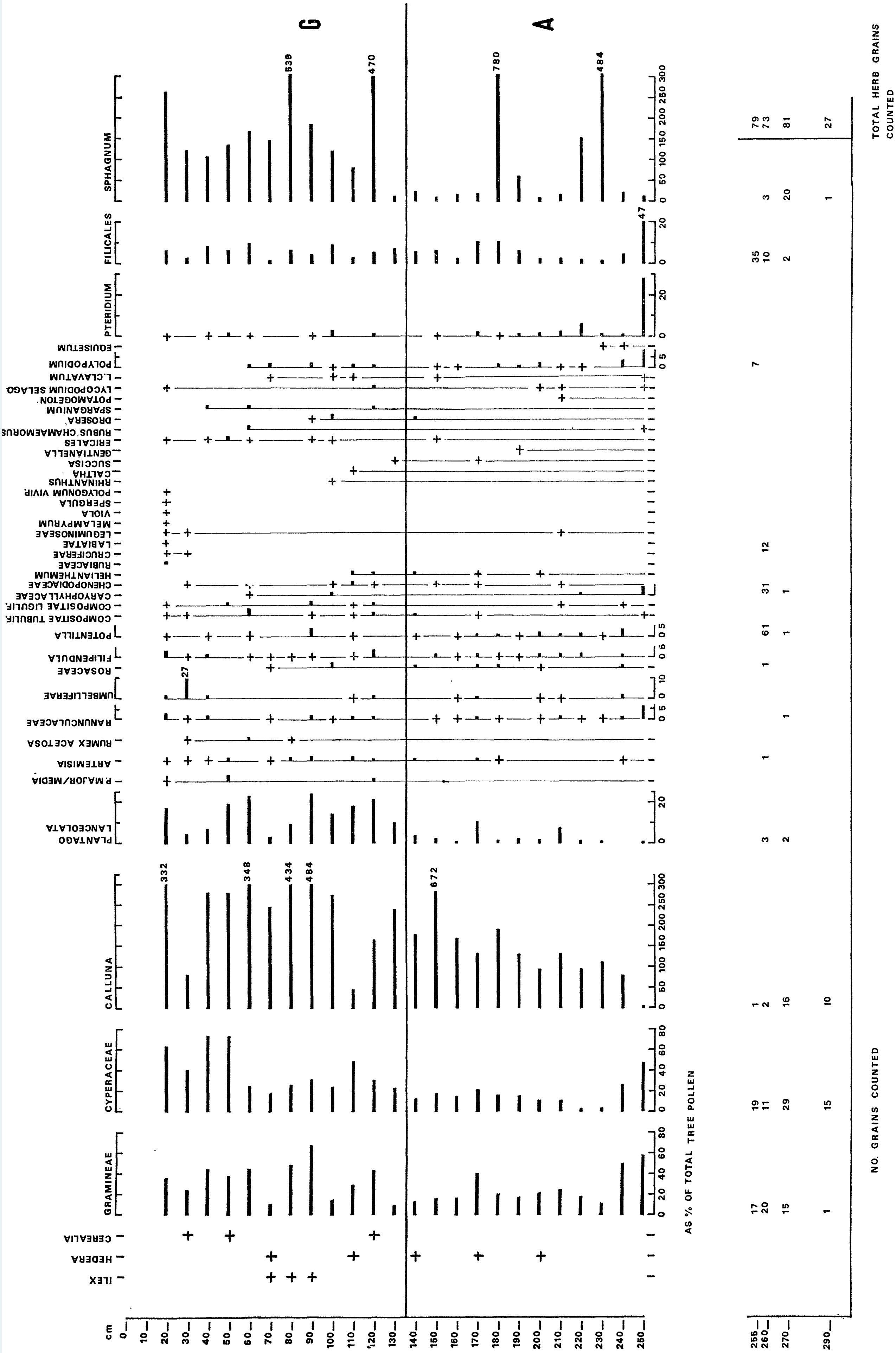

FIGURE 22. Herb pollen diagram from Slapestone Sike Moss, SL I. Frequencies are plotted as a percentage of the total tree pollen.

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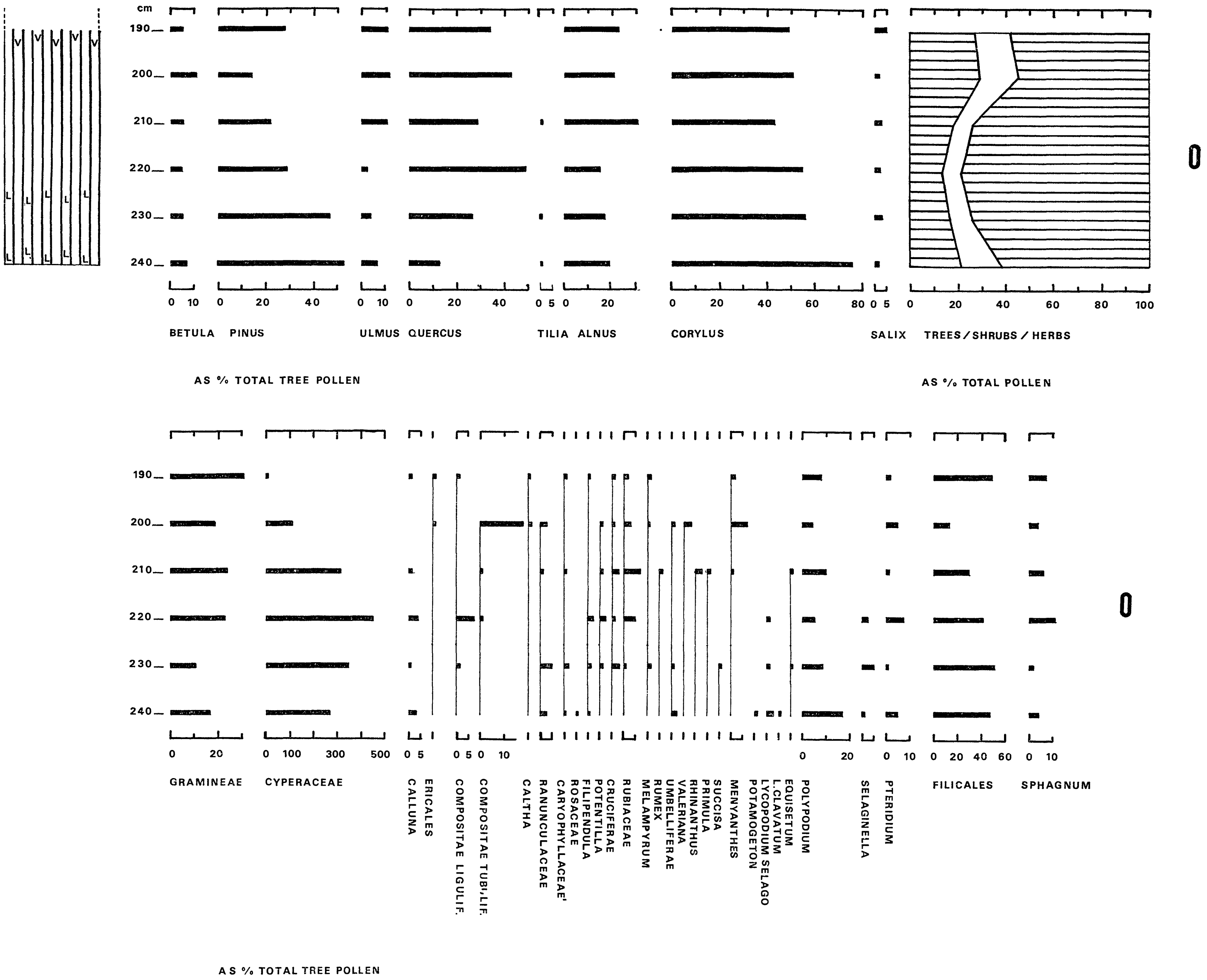

Figure 23. Pollen diagram from Slapestone Sike Moss, SL II. Frequencies are plotted as a percentage of the total tree pollen excluding *Corylus* and *Salix*.

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peat. This is taken as recording a period of erosion during which this inwash material was deposited.

The maximum depth of peat is 570 cm in the Far Foolmire area, which in section resembles the characteristic umbrella shape of a raised bog. Beneath the present course of the Sike there is considerable unconformity in the deposits and signs of previous periods of erosion, all of which indicates that the Sike had long been the major drainage channel in the area. Towards the northern end of the transect the basal grey clay disappears and the peat deposits lie directly on the bed-rock. Gravel and sands were found beneath the transect at the southern end on the flanks of the morainic feature.

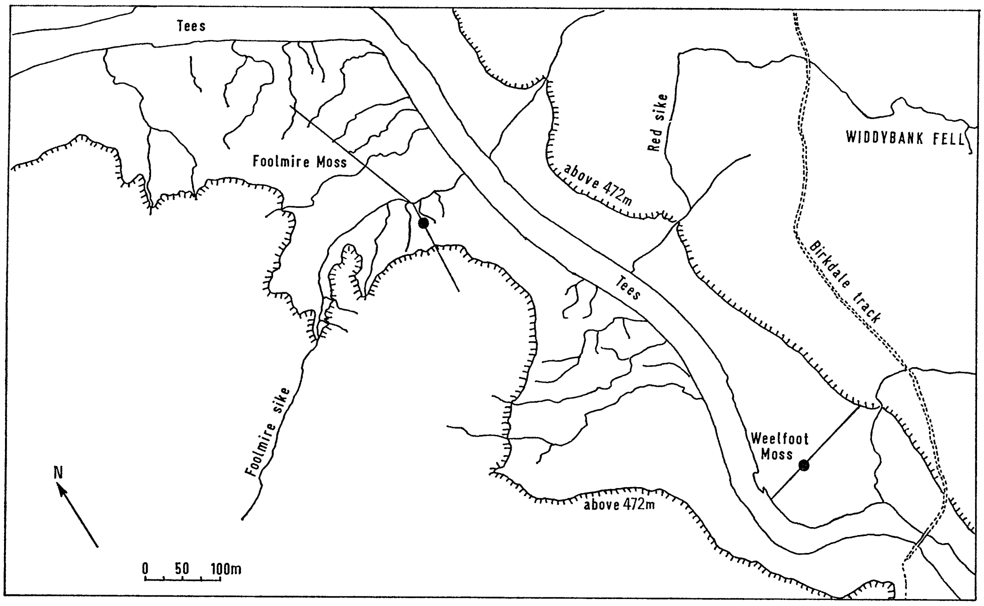

FIGURE 24. Sketch map showing Weelfoot Moss and Foolmire Moss, transects along which borings were made and the position of the pollen diagrams from each moss.

In the monocotyledonous peat, at the base of the organic deposits, megaspores of *Selaginella selaginoides* were found, along with remains of tree birches, Cyperaceae sp. and stems of *Equisetum*. Scattered throughout the sedge peat were seeds of *Potentilla palustris* and nutlets referable to *Carex paniculata*. In the uppermost sedge peat, between 210 and 150 cm, were seeds of *Menyanthes trifoliata*, *Cirsium* cf. *heterophyllum*, *Viola palustris* and nutlets of *Carex paniculata*. There was also an isolated seed of cf. *Sambucus nigra*. Isolated peaks of fern sporangia of the *Dryopteris* type were noted, together with occasional megaspores of *Selaginella*. Moss remains were abundant throughout the *Phragmites* peat, in particular *Aulacomnium palustre*, *Hylocomnium splendens* and *Drepanocladus* sp. *Sphagnum* spores were found in this peat, most likely from *Sphagnum papillosum*, which was locally abundant.

The *Calluna–Eriophorum–Sphagnum* peat was well humified and contained remains of *Sphagnum imbricatum*, *S. papillosum*, and *S. cuspidatum*, with fragments of *Rhacomitrium lanuginosum*. There were also fruit stones and wood of *Betula*, flowers and shoots, some carbonized, of *Calluna vulgaris*, fruits of *Juncus effusus* or *conglomeratus*, seeds of *Potentilla* cf. *erecta* and seeds of *Viola palustris*.

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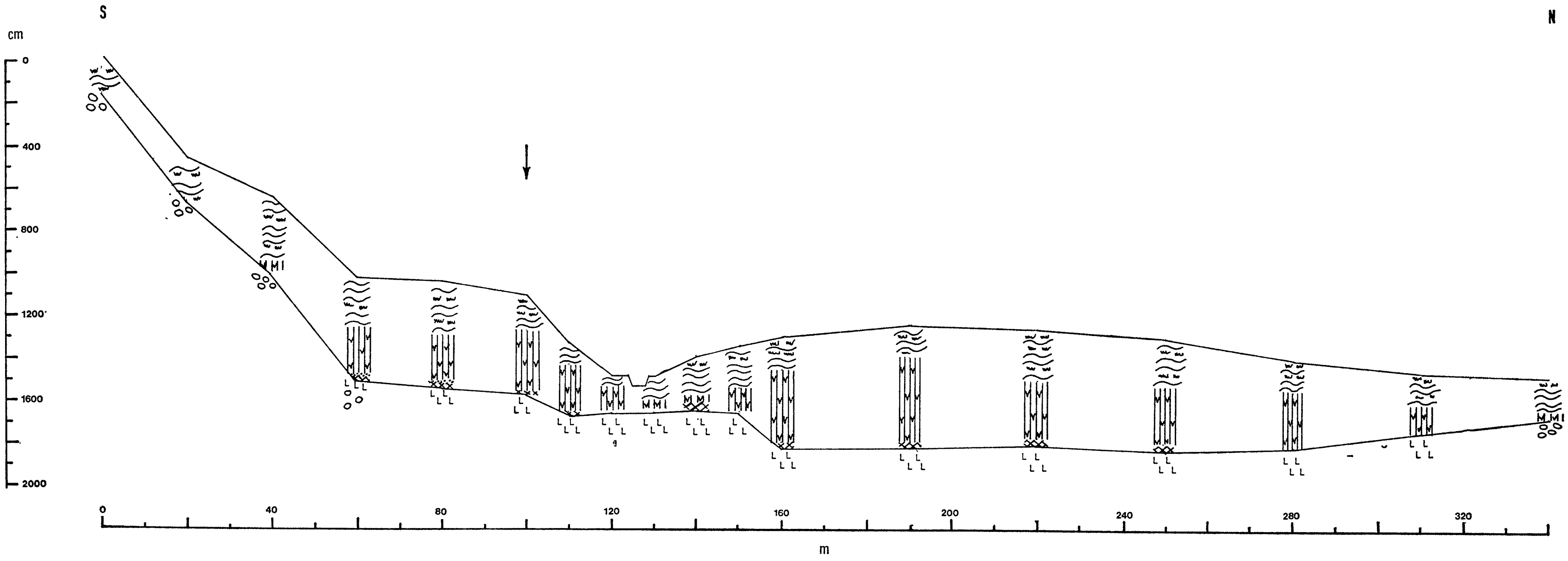

FIGURE 25. Stratigraphy of Foolmire Moss. Symbols for the deposits are given in figure 4.

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The detailed stratigraphy of the boring at 100 m is as follows:

cm	
0 to 8	disturbed ground, well humified *Calluna–Eriophorum–Sphagnum* peat
8 to 66	humified *Calluna–Eriophorum–Sphagnum* peat with carbonized remains of *Calluna*
66 to 150	more fibrous *Calluna–Eriophorum–Sphagnum* peat, less humified than above. Localized bands of *Eriophorum* and occasional birch wood
150 to 154	concentration of *Betula* wood
154 to 450	yellow-brown, fibrous sedge peat, with rhizomes of *Phragmites* and pieces of wood
450 to 480	humified monocotyledonous peat with few discernable macroscopic remains
480 to	silty clay with gravel, grading into a stiff grey-blue stoneless clay

Pollen samples were taken from the top 350 cm by means of a 'Russian' borer; beyond this depth penetration with this borer was impossible and a Hiller borer was used to sample to the bottom of the deposit. The site chosen for pollen analysis at 100 m is indicated on figure 25.

The results of the analysis are given in the pollen diagram (figures 26, 27).

The basal assemblages on the pollen diagram indicate that the peat began forming during the late-glacial period. There are high values of *Juniperus* and *Salix* with a large representation of pollen from herbs. Tree pollen percentages remain low throughout this assemblage zone, zone J.

Values for *Corylus* pollen then rise and give an assemblage in which *Corylus*, *Salix* and *Juniperus* are present, zone HJ. The values for herbaceous pollen are still high, yet are falling from the high values of zone J. During both of these zones the values of birch and pine pollen remain constant; the appearance of thermophilous trees is recorded by the low yet constant values for elm and oak. *Empetrum* pollen is also characteristic of these zones, as are high values for grass pollen.

There is some evidence for a hiatus in peat formation at the end of zone HJ which is marked by the large change in representation of certain pollen taxa between samples 420 and 430. The opening of zone H is, however, clearly marked by the characteristic assemblage of hazel and pine together with a high representation of birch pollen. Oak, elm and alder become established and it is of interest to note the continuous, yet low, representation of alder pollen at this time a feature unique to this diagram. Values of elm pollen exceed those of oak and the *Salix–Juniperus* component falls off considerably. In the total pollen diagram it can be seen that the representation of forest trees continues to expand at the expense of herbaceous pollen.

Zone O is characterized by a pollen assemblage dominated by oak, elm and hazel. In the deposits at Foolmire the zone is further subdivided into three subzones which are characteristic of the local conditions. Zone Oa is determined on the basis of a fall in *Corylus* values from the previous high values in zone H and the maintenance of high values for pine pollen in association with a continuous but gradual expansion of alder. Subzone Ob is marked by the further expansion of alder as the values for pine fall away. Subzone Oc represents the time at which elm, oak and hazel together reach a dominant position.

The decline in elm pollen and the increase in the total representation of herbaceous pollen marks the opening of the oak–alder zone, zone A.

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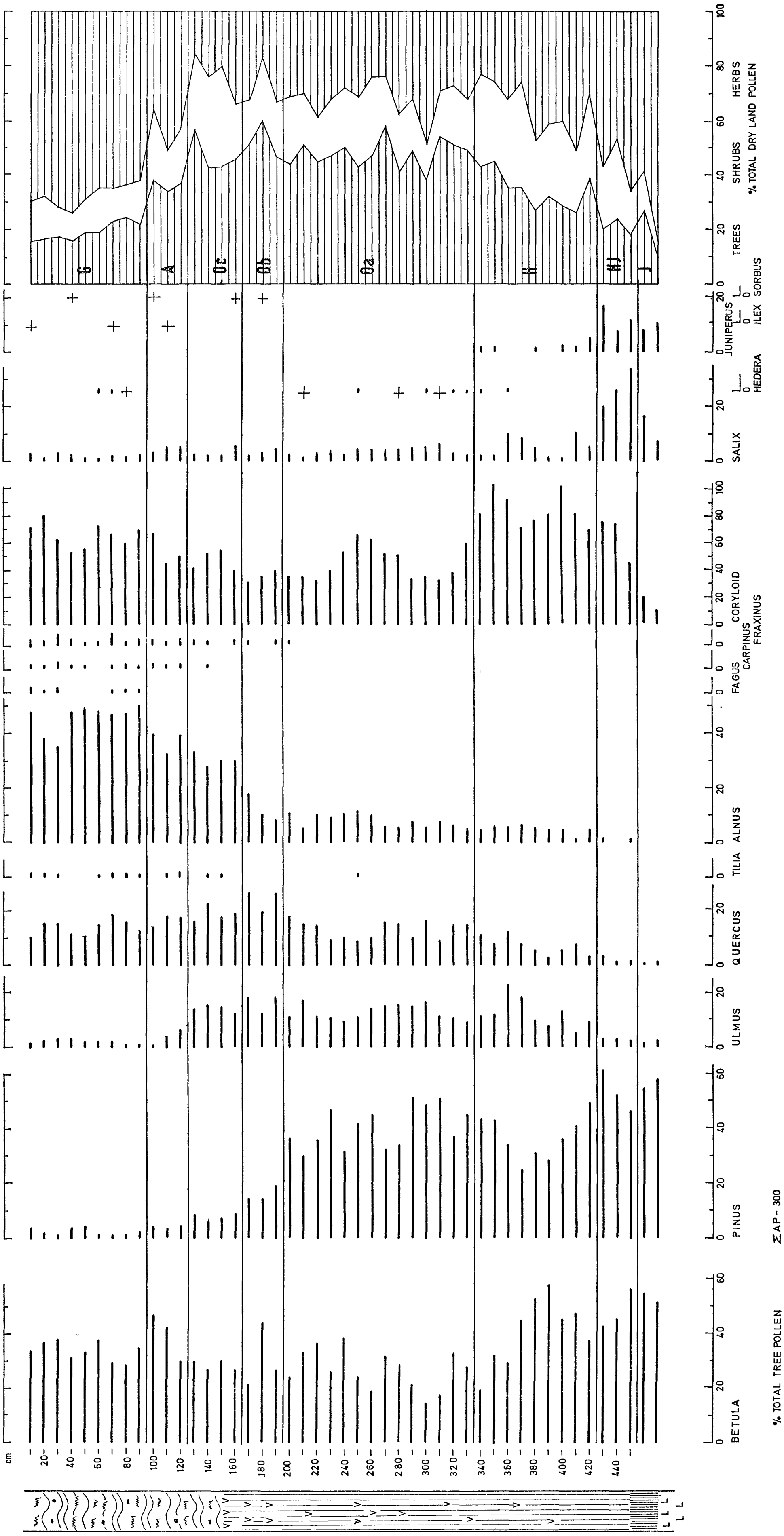

FIGURE 26. Tree pollen diagram Foolmire Sike. Frequencies are plotted as a percentage of the total tree pollen excluding *Corylus*, *Salix* and *Juniperus*.

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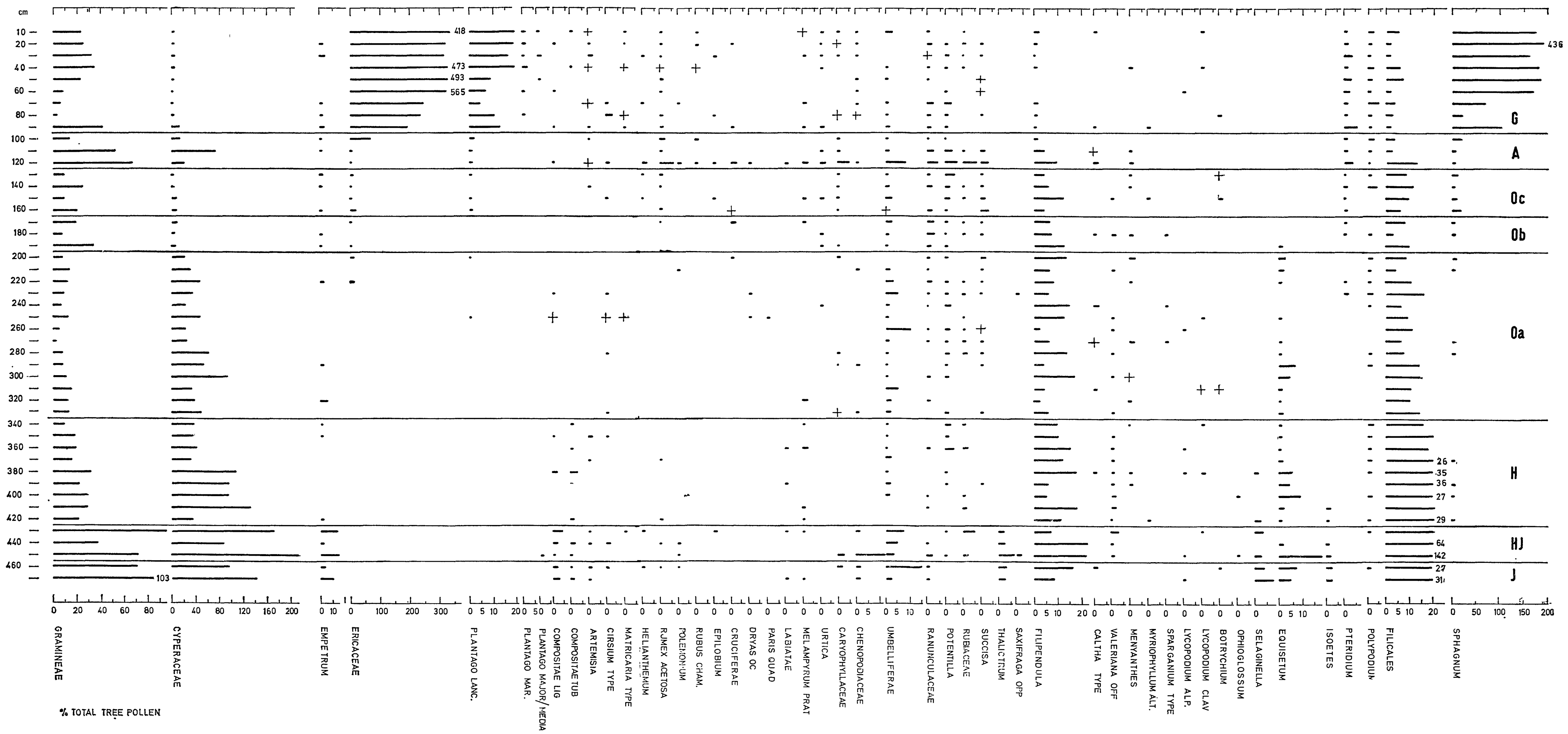

FIGURE 27. Herb pollen diagram from Foolmire Sike. Frequencies are plotted as a percentage of the total tree pollen.

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A further marked expansion of herbaceous pollen, in particular grass, heather and plantain pollen, marks the opening of assemblage zone G, hazel and alder being the principal trees at this time.

(*f*) *Weelfoot Moss*

Weelfoot Moss is an area of peat extending from the Birkdale track down towards the river bank above Cauldron Snout (figure 24). It has its most extensive development close by the river, where the gradient flattens somewhat and the depth of peat is 320 cm. The principal drainage pattern is across the long axis of the Moss from the higher ground to the east down to the river. The surface of the bog is relatively dry with few wetter areas. The vegetation is dominated by *Calluna vulgaris* and *Eriophorum vaginatum*, together with *Sphagnum papillosum*, *S. cuspidatum*, *S. imbricatum* and *S. rubellum*. Other plants growing on the bog are *Drosera rotundifolia*, *Narthecium ossifragum* and *Carex* sp. On the drier slopes towards the Birkdale track *Vaccinium myrtilus* and *Rubus chamaemorus* were found.

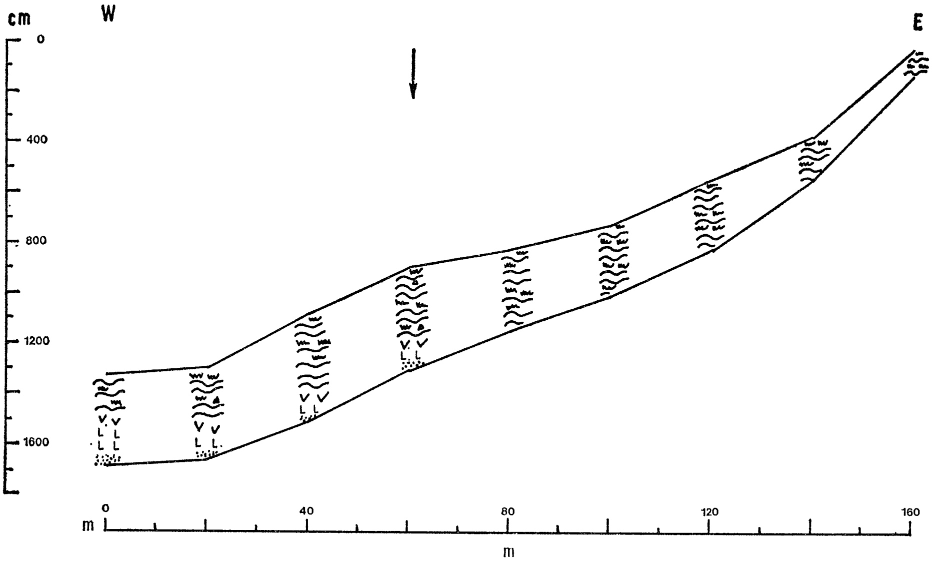

FIGURE 28. Stratigraphy of Weelfoot Moss. Symbols for the deposits are given in figure 4.

The stratigraphy of the deposits was examined by one transect running down from the track towards the river, approximately at right-angles to the river. The results are given in figure 28. They show that towards the river the organic deposits formed above a basal clay which is very stiff and blue-grey in colour. Farther away from the river bank there is a sandy layer beneath the organic deposits and where the subsurface contour rises yet more steeply, the peat deposits sit directly upon bed-rock. Pollen analysis has shown that these latter deposits were formed at a later time than those towards the river. With the exception of a basal wood layer the organic deposits are entirely of *Calluna–Eriophorum–Sphagnum* peat. The basal wood peat deposit grades out as the underlying basal clay is replaced by bed-rock. Associated with the wood peat are occasional rhizomes of *Phragmites*, but there is no extensive development of sedge peat in the area.

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Samples for pollen analysis were taken at 60 m on the transect and were collected by means of both 'Russian' and Hiller borers. The detailed stratigraphy is as follows:

cm	
0 to 18	humified, dark *Calluna* peat with some *Eriophorum*, *Juncus* seeds, megaspores of *Selaginella selaginoides*; remains of *Carex* sp., *Viola* sp., *Potentilla* sp. and *Erica tetralix*
18 to 200	moderately humified *Calluna–Eriophorum–Sphagnum* peat containing the remains of *Juncus* sp., *Carex* sp., *Potentilla* cf. *reptans*, *Potentilla* sp. and *Viola* sp.
200 to 290	dark, well-humified *Calluna–Eriophorum–Sphagnum* peat with fruits of *Erica tetralix*, seeds of *Potentilla* sp., *Juncus* sp. and carbonized *Calluna* towards 250 to 270 cm
290 to 322	*Betula* wood peat with remains of *Phragmites*, fruits of *Carex* sp. and seeds of *Viola* sp.
322 to 380	inorganic, plastic blue-grey clay
380 to 443	grey sand
443	bed-rock

The results of pollen analysis are given in figures 29 and 30. They indicate that deposition began in the area sometime in zone O. The basal centimetres of the deposit have relatively low oak and alder and are assigned to the subzone Oa. It is difficult to subdivide further the remainder of the zone since the alder values show a continuous and gradual rise; however, it is most characteristic of zone Oc.

The oak–alder assemblage zone is clearly distinguished by the fall in the values of elm pollen and the rise of alder values which then remain consistently high throughout. Total representation of herbaceous pollen also rises, as that of trees falls.

The opening of pollen zone G is characterized by the rapid expansion of grass, heather and plantain values which combine to give the very high values for herbaceous pollen characteristic of the zone.

(*g*) *Dead Crook, Dead Crook Moss and Furness Moss*

Dead Crook is one of the most conspicuous parts of the reservoir basin, partly because it is covered with species of *Carex* which at many times of the year contrast sharply in colour with the surrounding areas of heather-covered peat and partly because it is approximately circular in outline. It is a low-lying depression, just upstream from the morainic feature on the southwest bank of the river opposite the Isle of Man (figure 31). Around it to the west and north flows a sike which takes its name from the depression. When its level is particularly high, water can be seen lying on the part of Dead Crook farthest from the river, and it is at such times that Dead Crook looks most like an abandoned meander, the old channel still flooding the most easily. To the northwest and southeast of Dead Crook itself are large mounds of heather-covered peat with numerous erosion channels. To the southwest the ground rises steeply and there is only a thin cover of blanket peat.

The stratigraphy of Dead Crook and the peat mass, Dead Crook Moss, to the southeast of it was examined by means of a long transect of borings from the top of the morainic feature, northwestwards across Dead Crook Moss and Dead Crook to the edge of Furness Moss and two shorter transects approximately at right-angles to the long transect (figures 32 to 34). Furness

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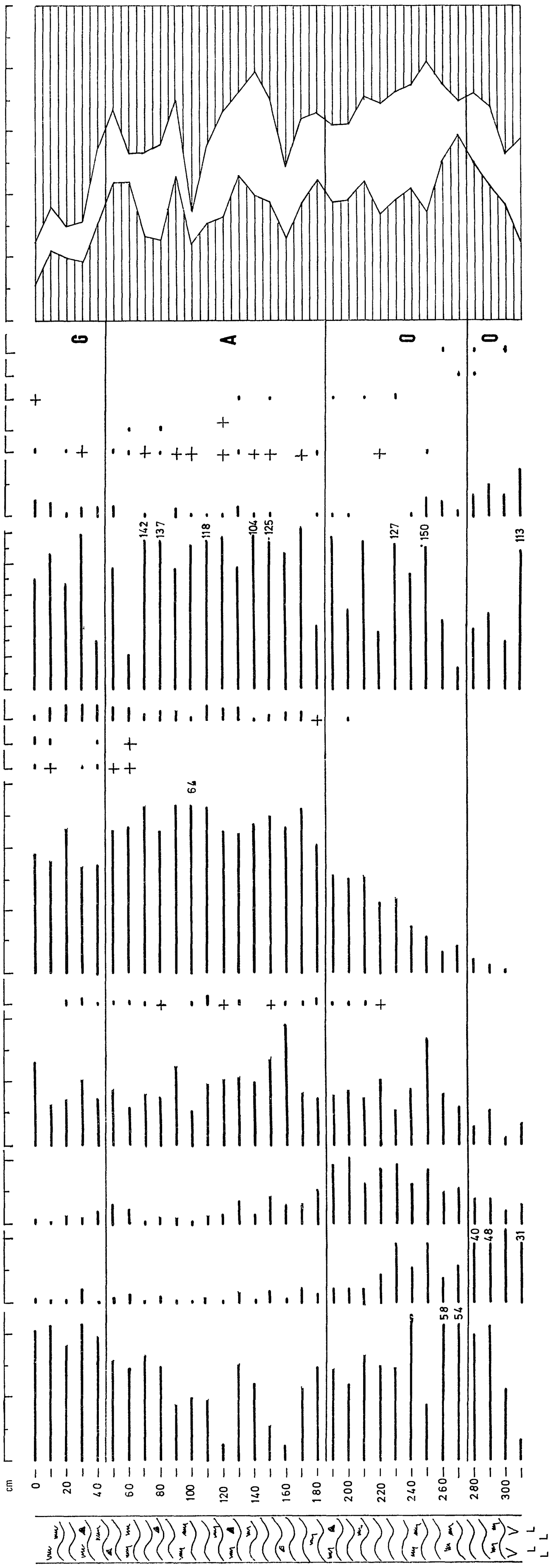

FIGURE 29. Tree pollen diagram from Weelfoot Moss. Frequencies are plotted as a percentage of the total tree pollen excluding *Corylus* and *Salix*.

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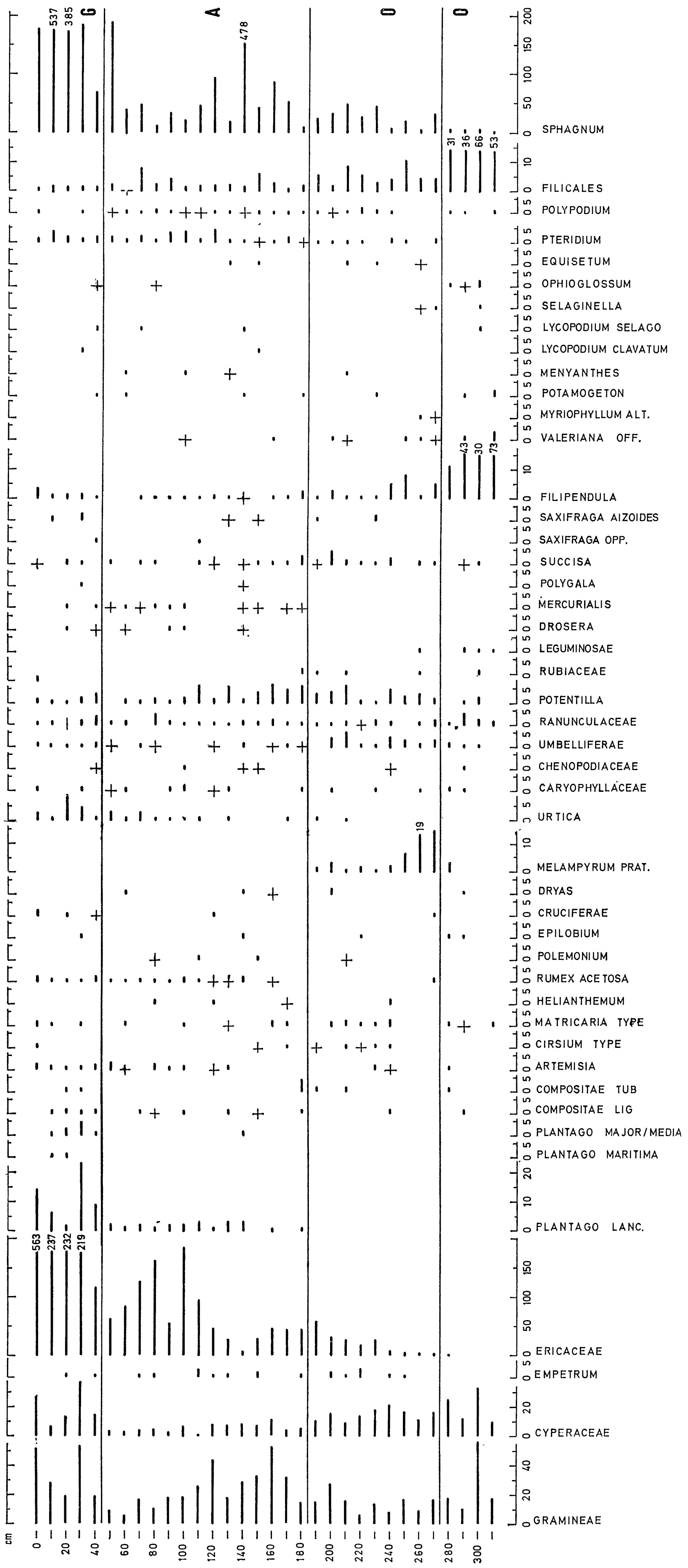

FIGURE 30. Herb pollen diagram from Weelfoot Moss. Frequencies are plotted as a percentage of the total tree pollen.

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Moss was examined by means of a transect of borings along the same line as the Dead Crook long transect, but on a later occasion (figure 35). The two transects overlap slightly and the region of overlap can be identified from the positions of the channel of Dead Crook Sike at 500 m on the Dead Crook transect and 0 m on that of Furness Moss.

They show that there is only about 20 cm of peat covering the morainic feature and that this thickens towards the bottom of the slope forming Dead Crook Moss which is 6 m at its deepest point. The organic deposits are much shallower over the centre of the Dead Crook depression, rarely exceeding 2 m. At the southeast edge of Furness Moss there is 3 m of peat.

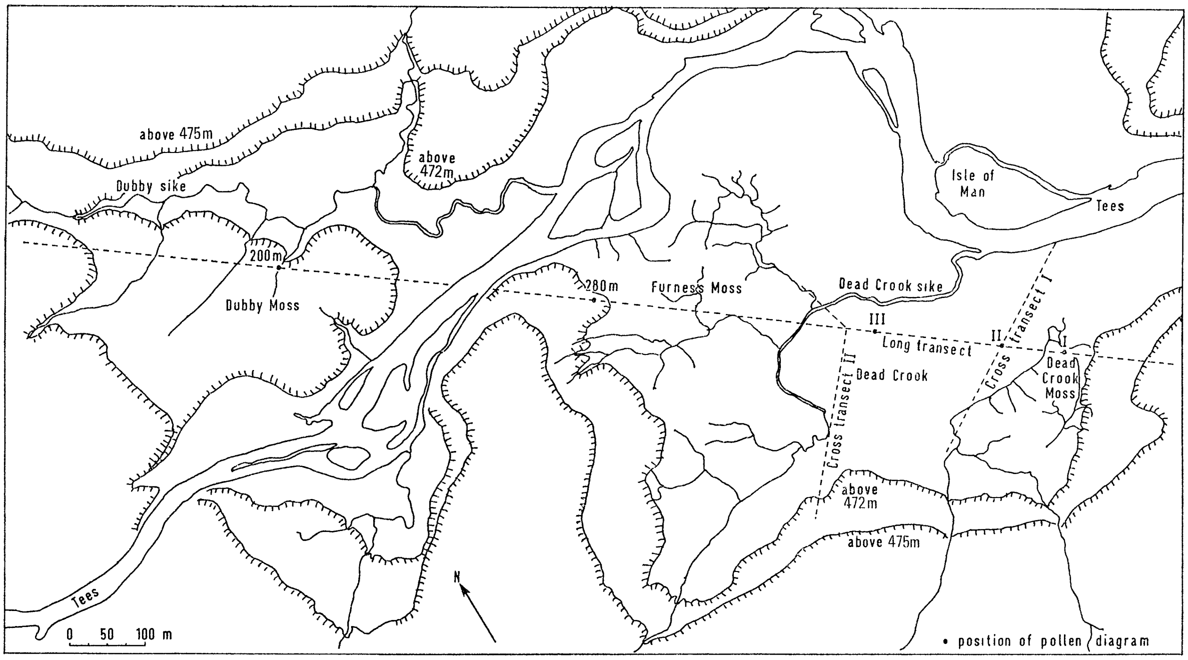

Figure 31. Sketch map showing Dead Crook Moss, Dead Crook, Furness Moss and Dubby Moss, transects along which borings were made and the positions of pollen diagrams DC I, DC II and DC III and pollen samples from 280 m on Furness Moss and 200 m on Dubby Moss.

Underlying Dead Crook the northwestern half of Dead Crook Moss and the southeastern part of Furness Moss is a deposit of alluvium, which is clayey in places, silty in places and sandy or gravelly in places. The surface of this alluvium is relatively even. It lies some 1200 to 1300 cm lower than the top of the moraine. At the southeastern edge, however, there is a channel, up to 2 m deep and 20 m wide, in this alluvium and at the northwestern edge there is a shallower and wider depression, up to 1 m deep and about 40 m wide. The positions of these depressions in the alluvium correspond with the places on the surface where water lies in wet weather and they are undoubtedly part of an old meander of the river. This channel can also be seen in cross-transect II between 120 and 130 m. Cross-transect I runs down the length of it; note that between 130 and 300 m the peat alluvium contact lies 1400 cm rather than 1200 cm below the top of the moraine.

Above the alluvium there is a detritus mud with remains of sedges and occasional pieces of birch, *Menyanthes* seeds and stems of *Equisetum*. Towards the edges of Dead Crook this grades into a peat with *Sphagnum* sp. and a little *Calluna*.

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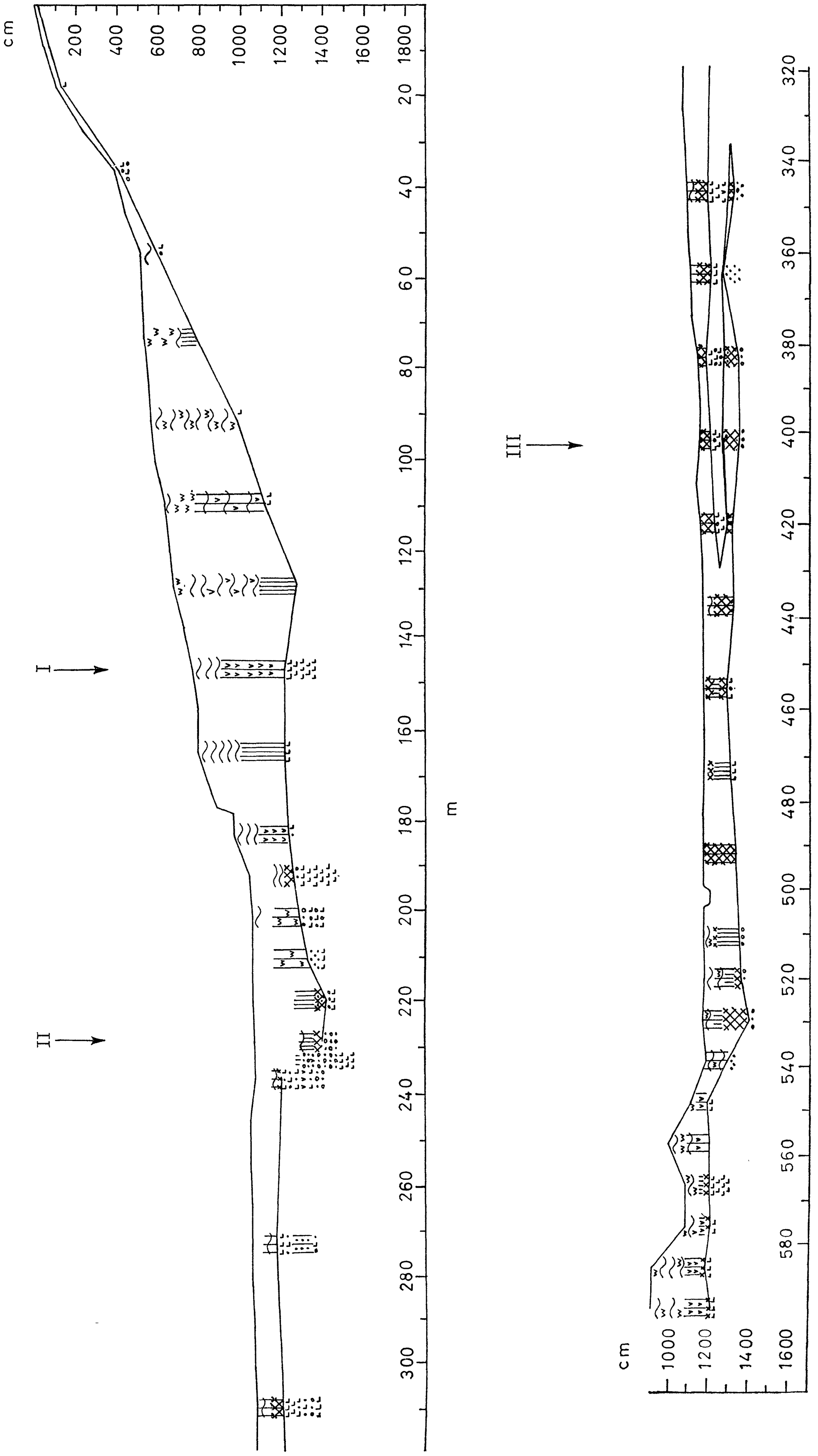

FIGURE 32. Stratigraphy of Dead Crook Moss and Dead Crook along the Long transect. Symbols for the deposits are given in figure 4.

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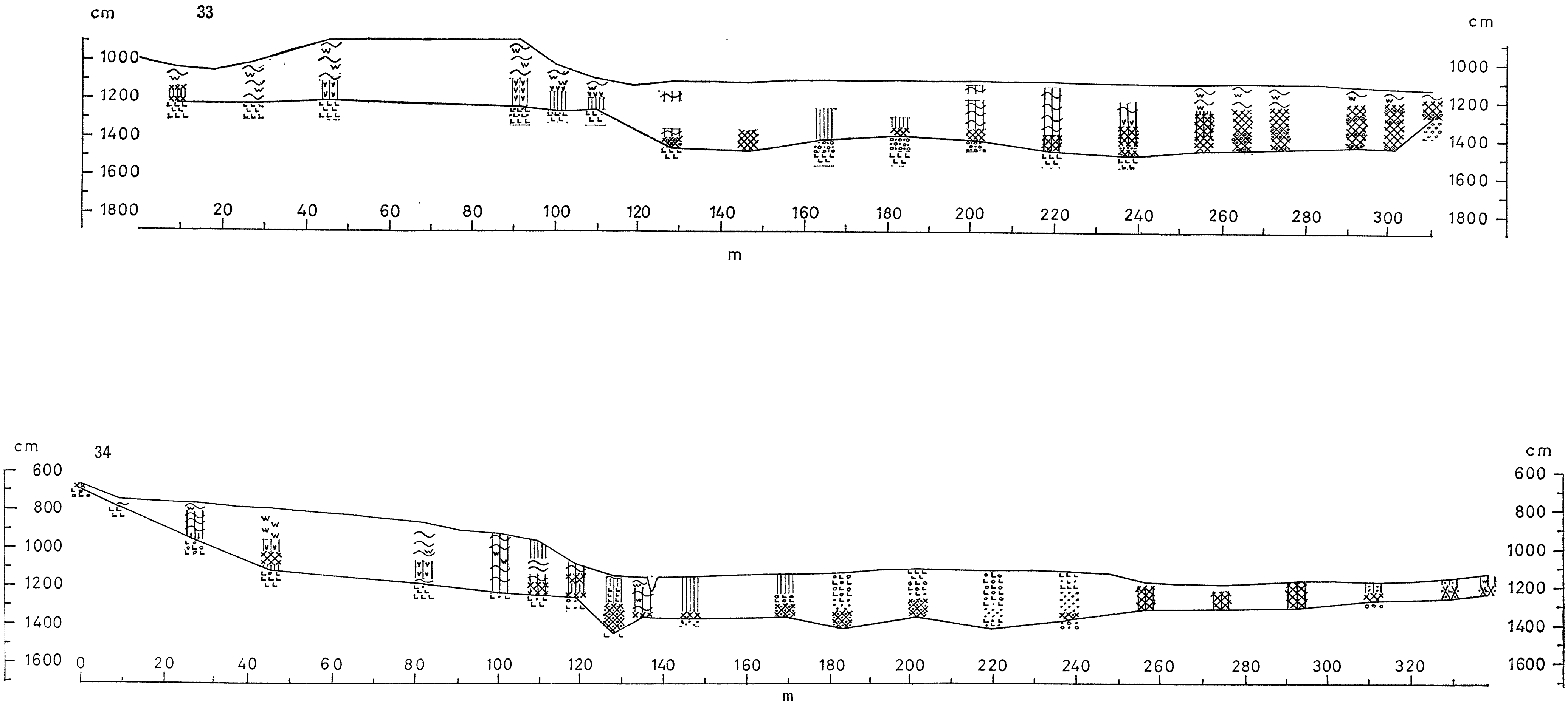

FIGURES 33, 34. Stratigraphy of Dead Crook along Cross transect I and II. Symbols for the deposits are given in figure 4.

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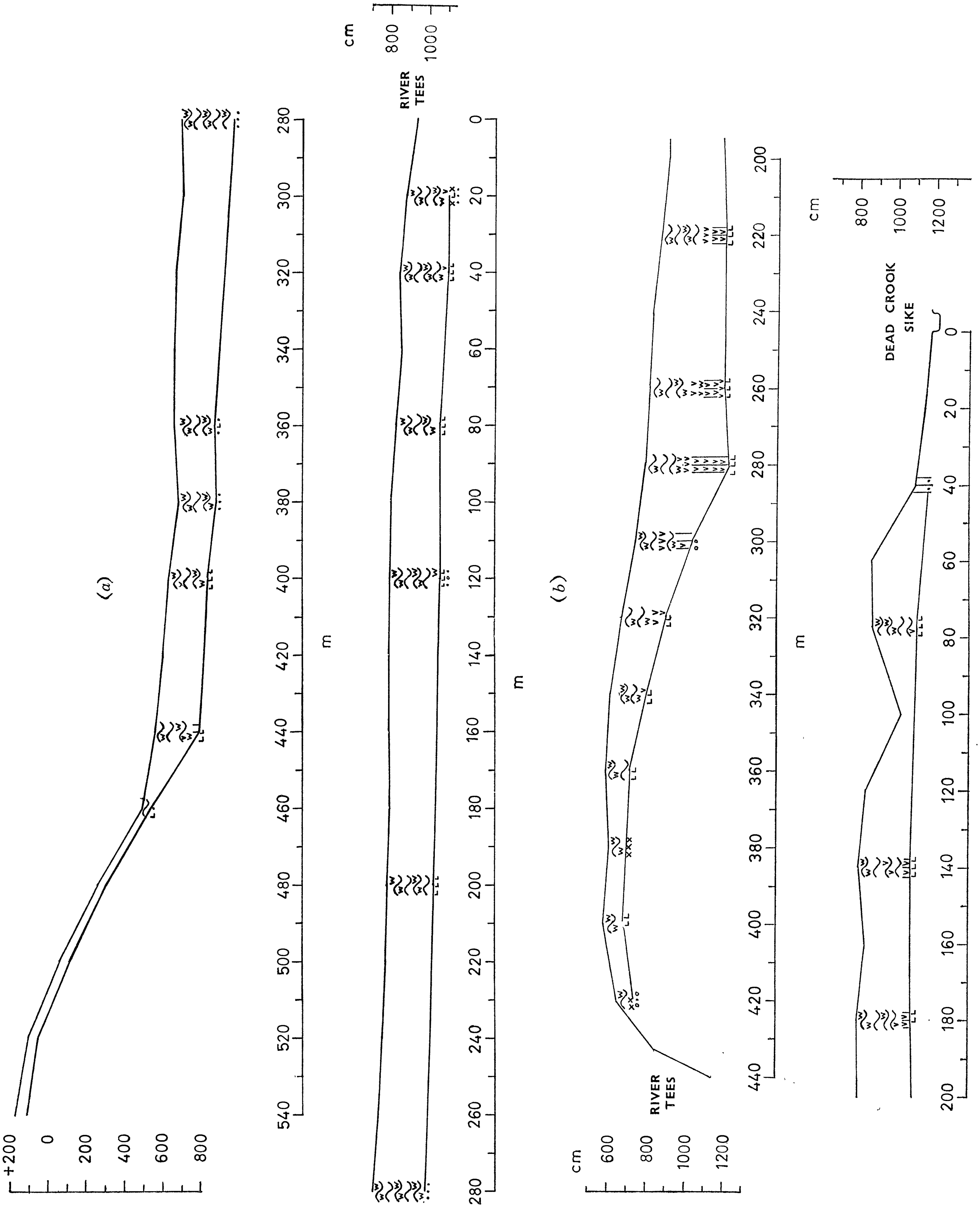

FIGURE 35 (*a*, *b*). Stratigraphy of Dubby and Furness Mosses. Symbols for the deposits are given in figure 4.

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The contact between the alluvium and organic deposits is unlikely to be of the same age everywhere as between 340 and 420 m there is a wedge of alluvium about half-way between the base and top of the organic deposits. This wedge appears to be continuous with the alluvium to the southeast end of Dead Crook and its presence accounts for the variation of a metre mentioned earlier in the depth of the alluvium organic deposit contact. It probably represents a later deposition of alluvium from the southeast. The alluvium organic deposit contact is therefore probably more recent in the southeast than in the northwest of Dead Crook.

The deepest point of Furness Moss is at 280 m where the peat is 4.5 m deep. Northwest of this the ground rises gradually some 5 m and the peat cover thins until it is only 1 m deep between 380 and 420 m. The stratigraphy of Furness and Dead Crook Mosses requires little comment as it resembles that of the Red Sike Moss, that is, there is a lower layer of sedge peat with wood fragments which is overlain by a *Sphagnum–Calluna–Eriophorum* peat.

Samples for pollen analysis were collected from Dead Crook Moss at 144 m (DC I), from the old river channel at 230 m (DC II), and from near the centre of Dead Crook where the alluvium wedges out over the organic deposits at 400 m (DC III), all on the long transect. The bottom 50 cm of peat was collected from the deepest point on Furness Moss, 280 m, for pollen analysis.

The detailed statigraphy at these places is as follows:

DC I

cm	
0 to 10	dark brown well-humified peat, penetrated by modern rootlets
10 to 25	mid-brown moderately humified *Sphagnum* peat, penetrated by modern rootlets
25 to 85	dark brown well-humified peat with *Calluna* twigs, penetrated by modern roots
85 to 134	dark reddish-brown fibrous peat with many fine rootlets
134 to 137	pieces of birch up to 1 cm diameter
138 to 167	dark reddish-brown fibrous sedge peat with pieces of birch and a few rhizomes of *Phragmites*
167 to 180	mid-brown fibrous peat with wood fragments
180 to 400	yellow-brown fibrous sedge peat with occasional rhizomes of *Phragmites* and pieces of wood at 285, 330 and 338–347 and charcoal at 390 cm
400 to 455	reddish-brown highly humified peat with no recognizable plant remains
455 to 465	transition
465 to 480	blue-grey clay with pieces of gravel up to 1 cm in diameter
480 to 600	blue-grey stoneless plastic clay

DC II

cm	
0 to 220	borer failed to sample because the peat was too sloppy
220 to 240	water and a peat comprised partly of *Sphagna* and partly of sedges
240 to 280	dark brown sedge peat
280 to 300	greyish peaty mud with sedge fragments
300 to 350	grey sandy silt
350 to 410	dark grey stiff silt, coarse in texture with sand and micaceous grains

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DC III

cm	
0 to 20	brown peaty mud with sedge fragments and numerous modern roots
20 to 50	grey-brown mud similar to above, but with sand lenses and a clayey consistency towards 50 cm
50 to 85	grey clay with sand and roots and black mineral material between 80 and 85 cm
85 to 110	light grey plastic clay with organic material
110 to 125	brown-grey mud with roots and remains of sedges
125 to 148	brown sandy mud
148 to 150	grey silt with many sedge fragments
150 to 175	brown-grey mud with organic material
175 to 195	silty brown-grey mud with very little organic material
195	gravel

Furness Moss 280 m

cm	
0 to 20	fresh brown *Sphagnum* peat
20 to 210	moderately humified brown *Sphagnum–Eriophorum* peat with *Calluna* also with small pieces of birch wood and solid layers of birch between 195 and 200 cm
210 to 225	very highly humified dark brown peat with no recognizable plant remains
225 to 235	wood peat
235 to 410	a highly humified wood peat with sedges and between 350 and 400 cm with numerous *Phragmites* rhizomes
410 to 430	a highly humified peat with very little recognizable material
430 to 450	bluish-grey clay

The results of the pollen analyses are given in figures 36 and 37 for Dead Crook I, in figures 38 and 39 for Dead Crook II and in figures 40 and 41 for Dead Crook III. The results from Furness Moss are given in table 2.

Attention has already been drawn to the fact that the stratigraphy of Dead Crook and Furness Mosses is similar to that of Red Sike Moss, TS I. The pollen diagram from Dead Crook Moss (figures 36, 37) is also similar. Pollen assemblage zones J, H, O, A and G are present, but between zones J and H at this site a pollen assemblage with high pine values, but no hazel, can be recognized. This is called zone P and presumably represents the time of the hiatus in the peats at TS I.

There are, however, several other differences between the two diagrams and these are worth noting at this point.

At DC I during zone H when the *Corylus* frequency is at its maximum, *Quercus* and *Ulmus* are not consistently contributing 10% of the tree pollen. Also the *Alnus* curve rises a little more gradually than at TS I. Higher up the diagram the *Calluna* frequency reaches and maintains very high values earlier than it does at TS I, well before, instead of at the same time, as the rises in the Gramineae, Cyperaceae and *Plantago* curves.

The differences between the two diagrams will be discussed in more detail after all the diagrams have been presented.

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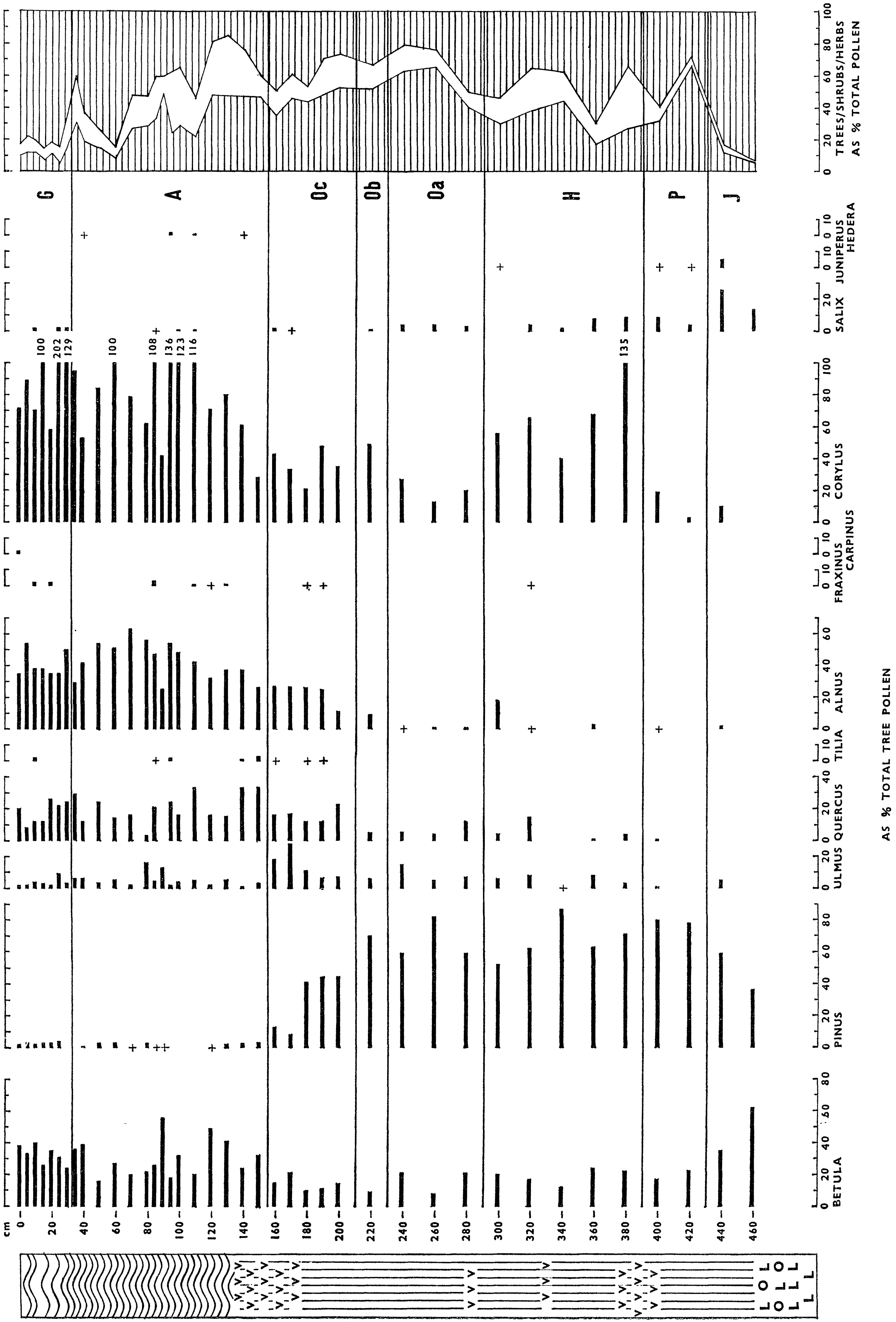

FIGURE 36. Tree pollen diagram from Dead Crook Moss, DC I. Frequencies are plotted as a percentage of the total tree pollen excluding *Corylus*, *Salix* and *Juniperus*.

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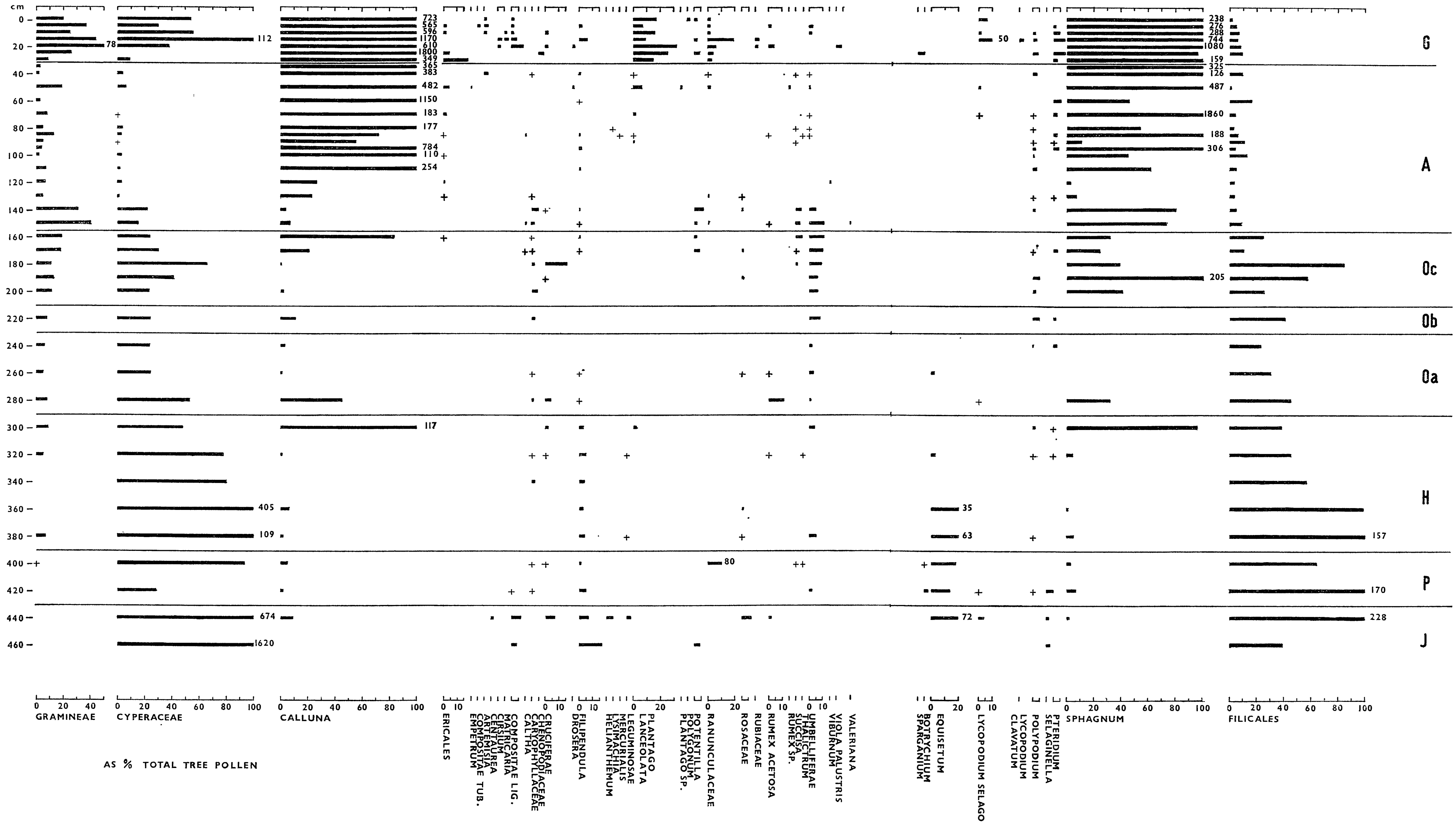

Figure 37. Herb pollen diagram from Dead Crook Moss, DC I. Frequencies are plotted as a percentage of the total tree pollen.

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The pollen diagrams from Dead Crook II (figures 38, 39) show that the peat there was forming only during zone A. It corresponds with the top 100 cm of the DC I diagram. Note the high *Calluna* frequencies throughout, the low *Ulmus* and the rise in *Plantago* at 120 cm. Unfortunately owing to the extremely soupy nature of the upper metre of peat at DC II it was impossible to obtain samples for pollen analysis. Presumably though this upper metre is of recent origin. This evidence from DC II indicates that the meander of the Tees had been abandoned as the main river channel by zone A. It may of course have been abandoned earlier than this, but the fact that peat has been accumulating there throughout zone A means it was not later.

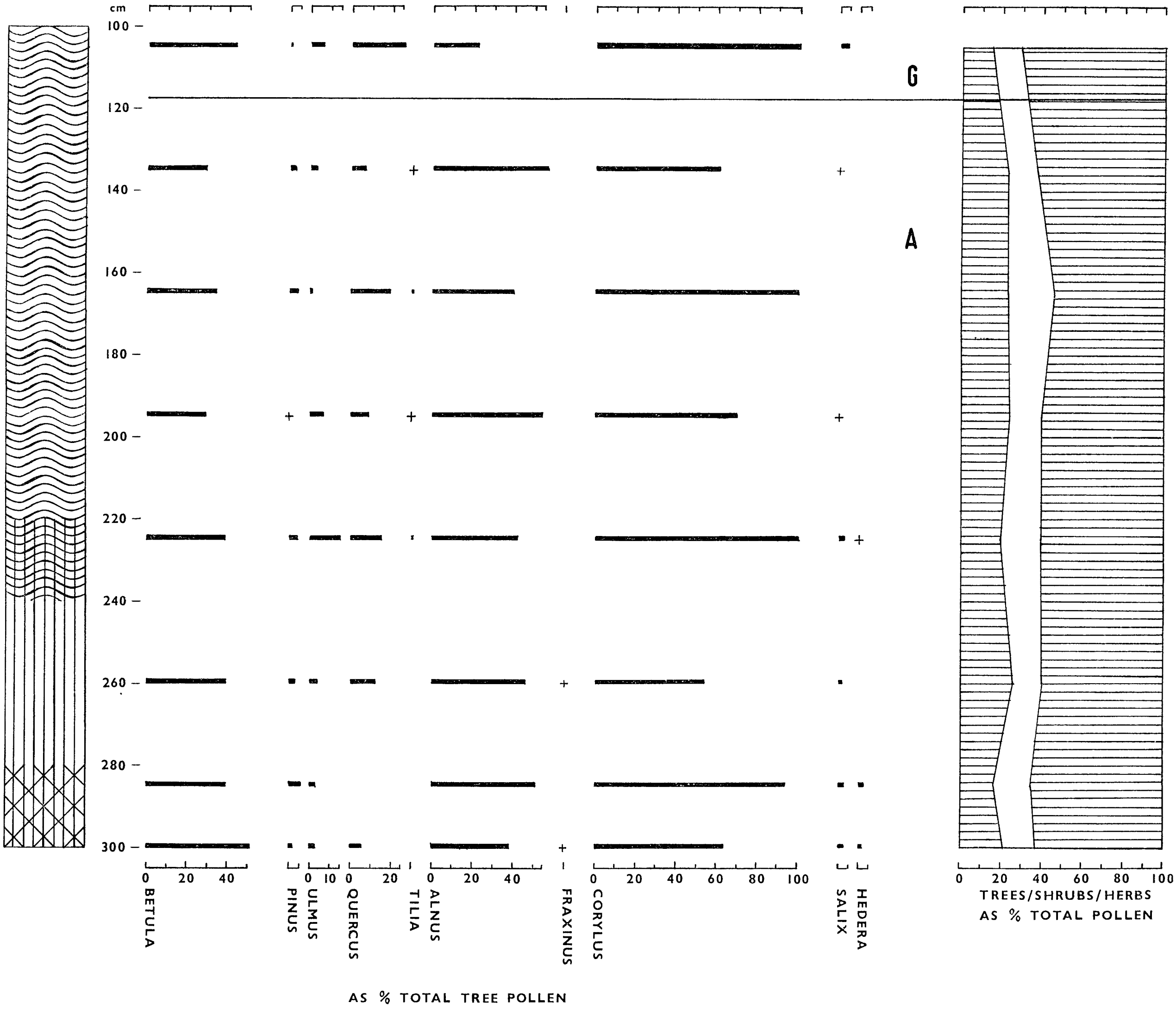

FIGURE 38. Tree pollen diagram from Dead Crook, DC II. Frequencies are plotted as a percentage of total tree pollen excluding *Corylus* and *Salix*.

Figures 40 and 41, the diagrams from the centre of Dead Crook, appear to represent a similar period, certainly post-elm decline. The rise in the *Calluna* frequency at this site, however, takes place at the same time as the rise in the *Plantago* frequency and marginally later than the rise in Gramineae. Thus it differs considerably from the DC I diagram and this makes it difficult to be more precise than post zone O or post-elm decline in dating it.

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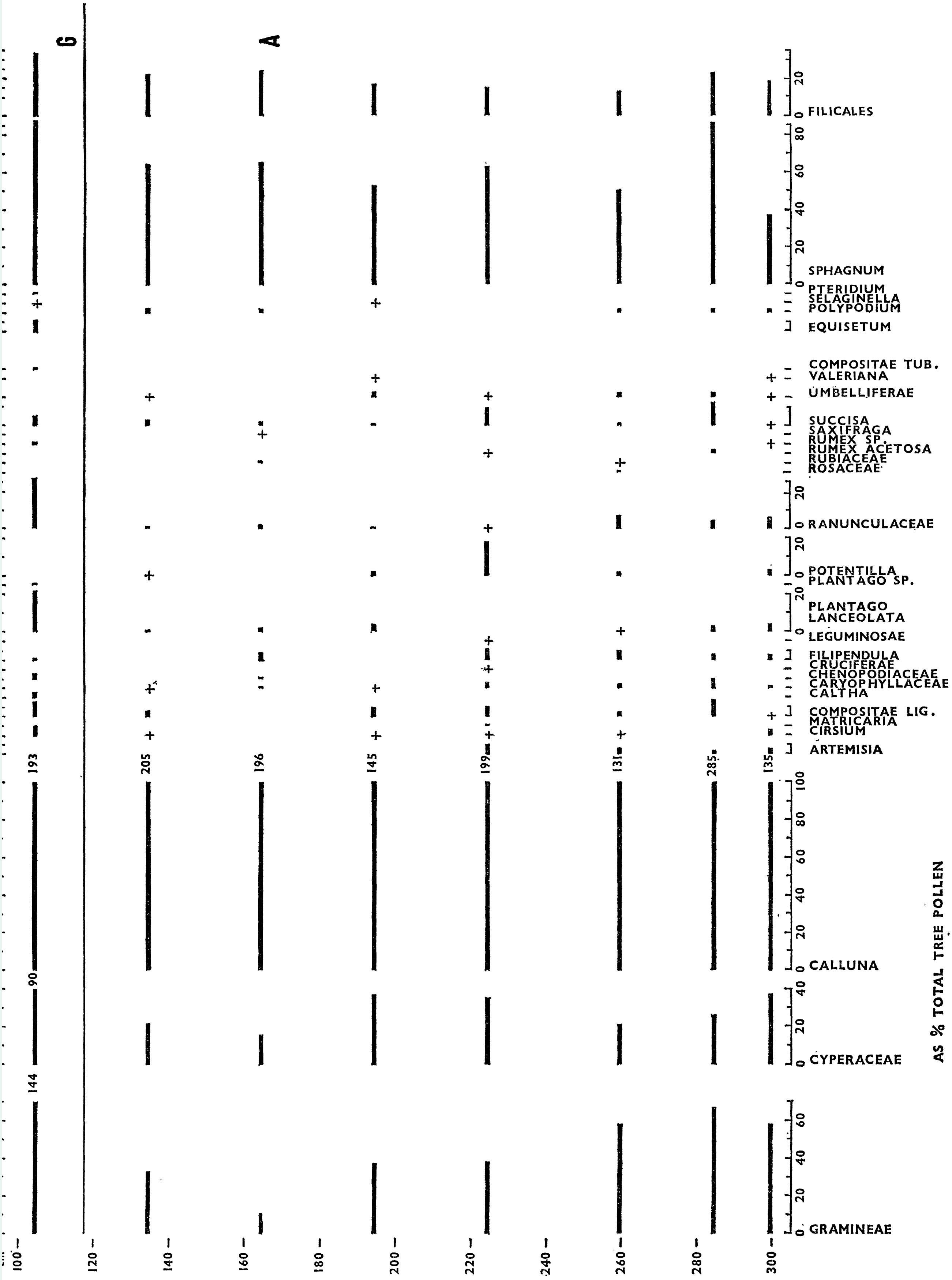

Figure 39. Herb pollen diagram from Dead Crook, DC II. Frequencies are plotted as a percentage of the total tree pollen.

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One would imagine that once the meander had been abandoned water carrying inorganic particles occasionally flooded the centre of Dead Crook giving the muddy organic deposits described. The clay band from 50 to 110 cm and the silty deposits below 180 cm presumably indicate periods when this was happening regularly and the more organic deposits between, slightly quieter periods. It is noticeable that *Filipendula ulmaria* grew well on Dead Crook up until the time the *Calluna* and *Plantago* frequencies rise. *Caltha* and presumably aquatic Ranunculaceae species occur with it.

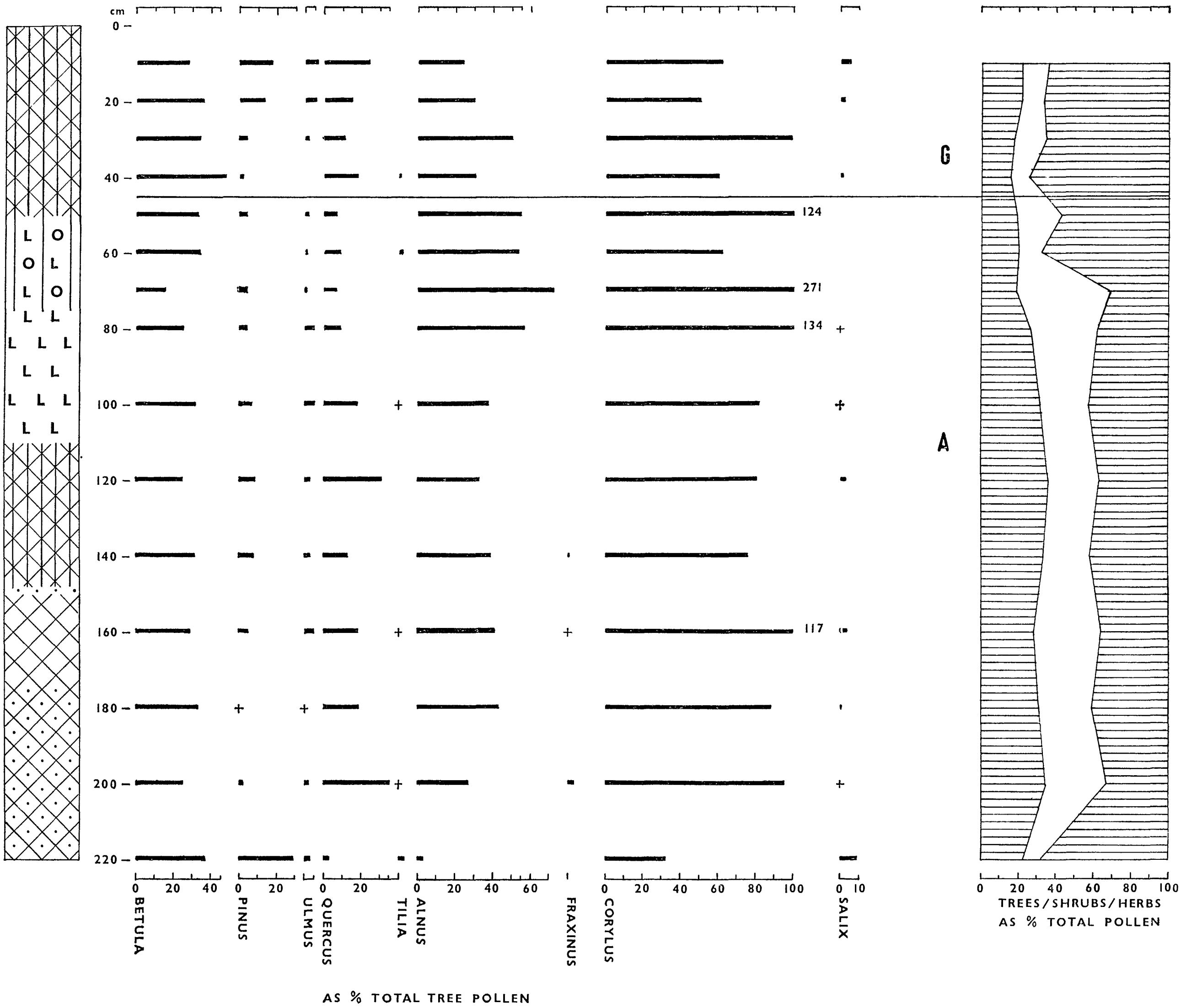

Figure 40. Tree pollen diagram from Dead Crook, DC III. Frequencies are plotted as a percentage of the total tree pollen excluding *Corylus* and *Salix*.

The results of the two deepest samples from Furness Moss (table 2) indicate that Furness Moss is of the same age as Dead Crook Moss. A full diagram was not prepared from that site.

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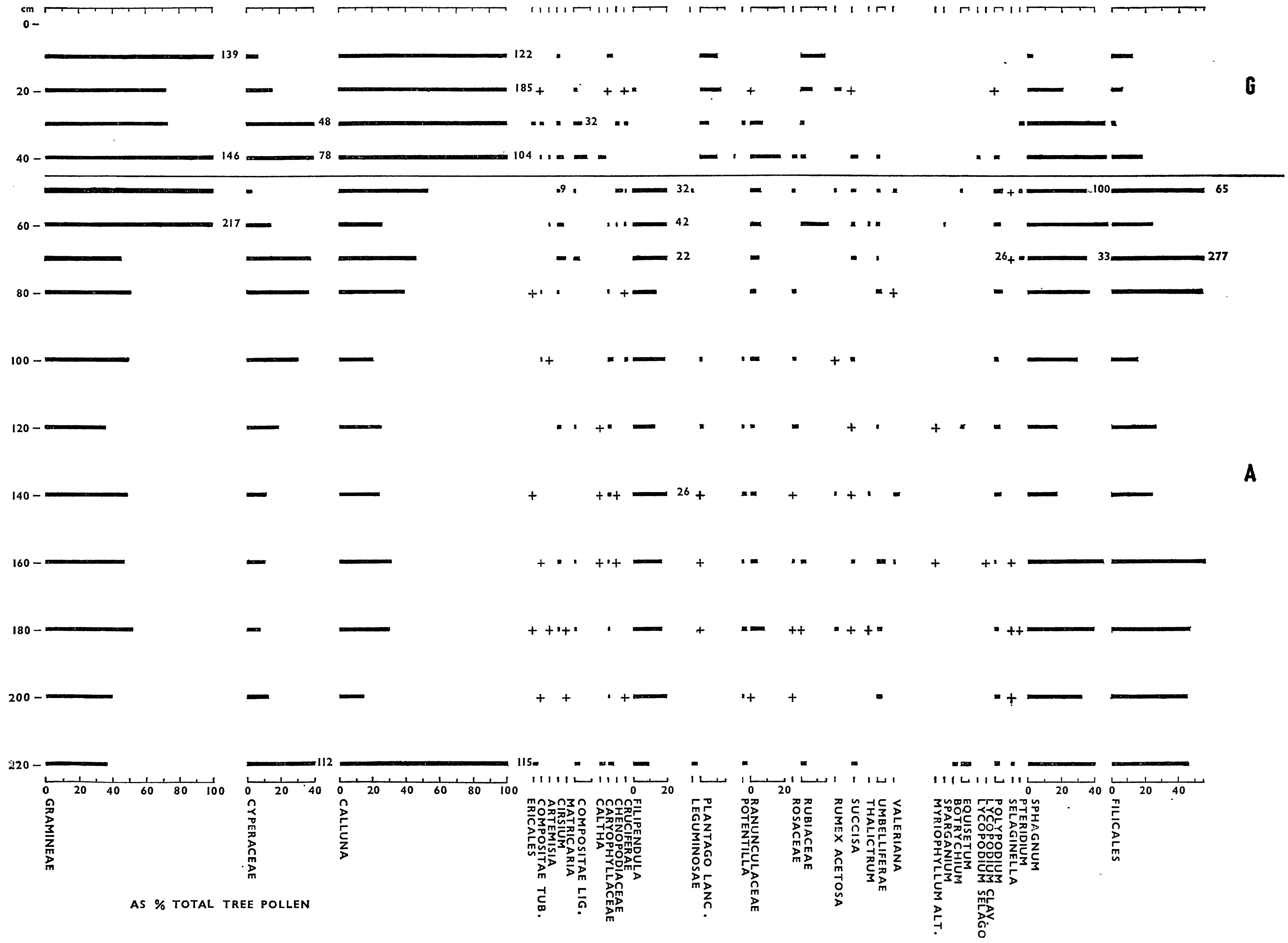

FIGURE 41. Herb pollen diagram from Dead Crook, DC III. Frequencies are plotted as a percentage of the total tree pollen.

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TABLE 2. FURNESS MOSS 280 M: RESULTS OF POLLEN ANALYSIS, AS PERCENTAGE OF TOTAL TREE POLLEN, FOR SAMPLES FROM TWO DEPTHS

	430 cm	425 cm
Betula	15	10
Pinus	85	78
Ulmus	+	7
Quercus	–	+
Alnus	–	5
Corylus	18	55
Gramineae	5	–
Cyperaceae	101	12
Calluna	–	+
Compositae (Tubuliflorae)	+	–
Cirsium type	–	+
Caryophyllaceae	–	+
Filipendula	19	10
Umbelliferae	2	+
Valeriana	3	–
Botrychium	2	1
Polypodium	1	3
Selaginella	+	–
Pteridium	2	3
Sphagnum	126	+
Filicales	–	59

(*h*) *Dubby Moss*

Dubby Moss lies on the northern bank of the river well upstream from Weelhead Moss and only just across the river from Furness Moss. It is an extensive area of peat which thins out on the rising ground to the north and west and is bounded by Dubby Sike and the Tees to the south and east. Its surface is reasonably intact and dominated by *Calluna*, *Eriophorum* and *Sphagnum* species.

The stratigraphy was examined by a transect which continued the very long one from Dead Crook over Furness Moss northwestwards (figure 31). The results are given in figure 35.

It is apparent that this mass of peat differs from the others in that it is composed entirely of a *Sphagnum–Eriophorum–Calluna* peat, which varies between 2.0 and 2.75 m in depth. In only three borings was birch wood recorded, at 20 and 40 m at the river end of the transect, and at 440 m just before the peat thins out against the steeply rising ground to the west of the moss. In this latter boring, too, 10 cm of sedge peat containing seeds of *Ranunculus* cf. *flammula* was found underlying the *Sphagnum–Eriophorum–Calluna* peat. Elsewhere there was no sign of such sedge peat. Underlying the peat is a greenish grey silt or clay, sometimes with sand.

Samples for pollen analysis were collected from the boring at 200 m near the centre of the moss. The stratigraphy at this point is as follows:

cm	
0 to 240	*Sphagnum–Eriophorum–Calluna* peat increasing in humification with depth from *H* 2 to 3 between 1 and 120 cm, to *H* 3 to 4 from 120 to 150 cm, to *H* 5 from 150 to 180 cm, to *H* 8 from 180 to 200 cm, and *H* 9 to 10 from 200 to 240 cm.
240 to 250	transition
250 to 260	greenish-grey clay

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Only three samples were analysed for pollen, those collected from 220, 225 and 230 cm respectively. The results of these analyses are set out in table 3. Both the *Pinus* and *Ulmus* frequencies are low, the tree pollen spectra being dominated by *Quercus*, *Alnus* and *Betula*. This indicates that the peat began forming sometime during zone A, much later than on Furness Moss. It is interesting to note that all the peat at Dubby Moss is composed of *Sphagnum*, *Calluna* and *Eriophorum* and that the wood-sedge peat which formed during zone O at Dead Crook, Furness and Red Sike mosses is missing at Dubby Moss.

TABLE 3. RESULTS OF POLLEN ANALYSES FROM DUBBY MOSS (POLLEN FREQUENCIES ARE GIVEN AS A PERCENTAGE OF TOTAL TREE POLLEN)

	230 cm	225 cm	220 cm
Betula	24	35	25
Pinus	1	1	+
Ulmus	3	3	1
Quercus	33	15	25
Tilia	1	–	–
Alnus	37	47	39
Fraxinus	–	–	2
Corylus	83	63	57
Salix	–	+	–
Gramineae	73	23	27
Cyperaceae	23	8	7
Calluna	59	123	172
Ericales	–	–	+
Cirsium	3	+	–
Matricaria	6	+	–
Caltha	+	–	+
Caryophyllaceae	+	–	–
Chenopodiaceae	–	–	+
Cruciferae	–	1	–
Filipendula	4	2	+
Plantago lanceolata	–	1	1
Potentilla	–	3	7
Ranunculaceae	2	1	+
Rosaceae	+	2	1
Rumex acetosa type	–	–	+
Succisa	4	2	+
Umbelliferae	6	+	+
Valeriana	1	–	–
Polypodium	4	–	–
Pteridium	1	1	1
Sphagnum	10	18	86
Filicales	3	3	+

(*i*) *Weelhead Moss*

Opposite Dead Crook on the northeast bank of the river and just upstream from the morainic feature is a large expanse of peat, called Weelhead Moss. It is at present deeply dissected with the remaining peat haggs dominated by *Calluna vulgaris*. It slopes gently to the northwest becoming more fen-like.

Downstream from the morainic feature and on the same side of the river is another but smaller mass of peat, which thins out against the rising ground to the northeast. These two areas were investigated by means of four transects, I and II northwest of the moraine and III and IV southeast of it (figure 42). The results of the borings are given in figures 43 to 46.

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They show that both slight depressions are covered by a uniform sheet of alluvium much like that found on the other side of the river. No channels or double layers of alluvium were observed.

The peat which has formed on top of the alluvium upstream from the moraine (transects I and II) varies in depth from 2.5 to 4.0 m except where it shallows to the northwest under the fen vegetation and where it thins to a few centimetres of blanket peat on top of the moraine. The main area of this moss as seen on transect II is composed of a *Sphagnum–Eriophorum–Calluna* peat, although in the lower part there are plenty of wood fragments and remains of sedges.

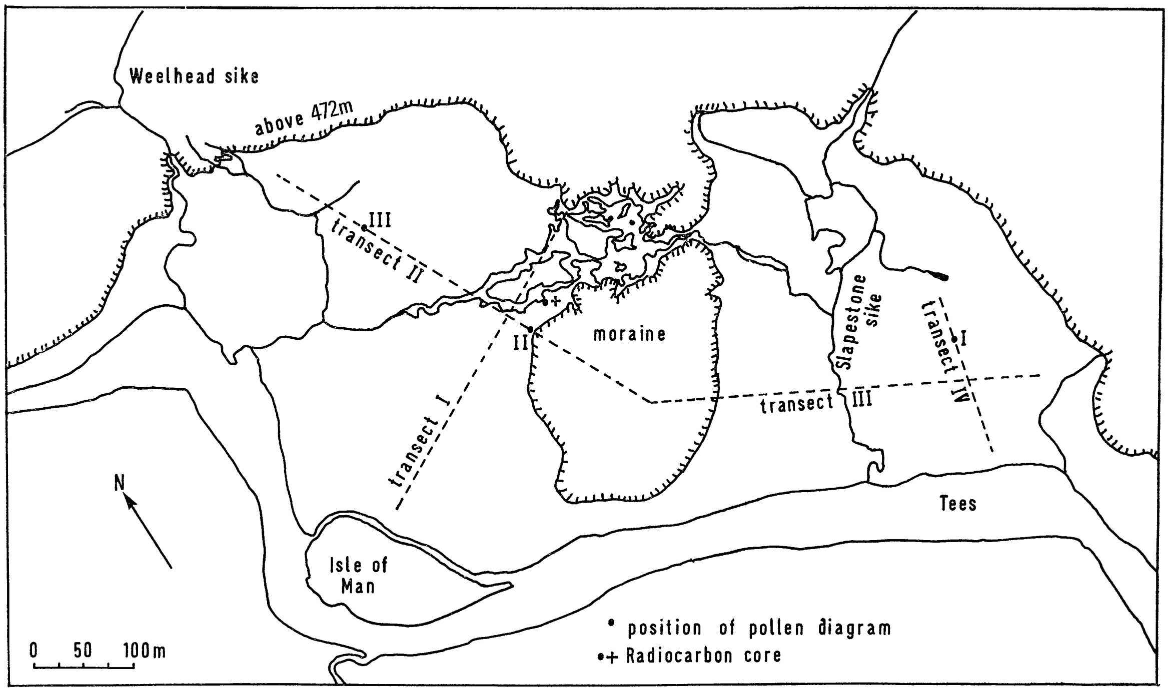

FIGURE 42. Sketch map showing Weelhead Mosses, transects along which borings were made and the positions of pollen diagrams WH I (I on the map) and the radiocarbon core WH II and pollen samples from 140 and 365 m on transect II (II and III respectively on the map).

On transect I this deep *Sphagnum–Eriophorum–Calluna* peat occurs between 100 and 340 m, but near the river between 0 and 60 m it does not rest directly on the alluvium, but overlies a sedge peat. Samples for pollen analysis were collected from the points 140 and 365 m on transect II, the former in the area of deep *Sphagnum–Eriophorum–Calluna* peat, the latter in the area of fen vegetation.

The detailed stratigraphy at these places is as follows:

140 m

cm	
0 to 7	dry light brown, soily peat penetrated by modern roots
7 to 35	dark brown moderately humified *Eriophorum–Calluna* peat with remains of sedges
35 to 140	mid-brown highly humified *Sphagnum–Eriophorum* peat with some *Calluna*
140 to 165	dark brown highly humified *Sphagnum–Eriophorum* peat with some sedge remains

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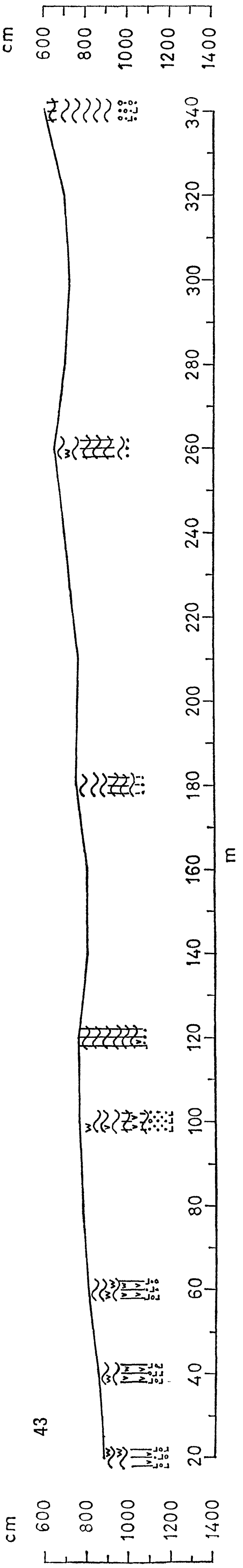

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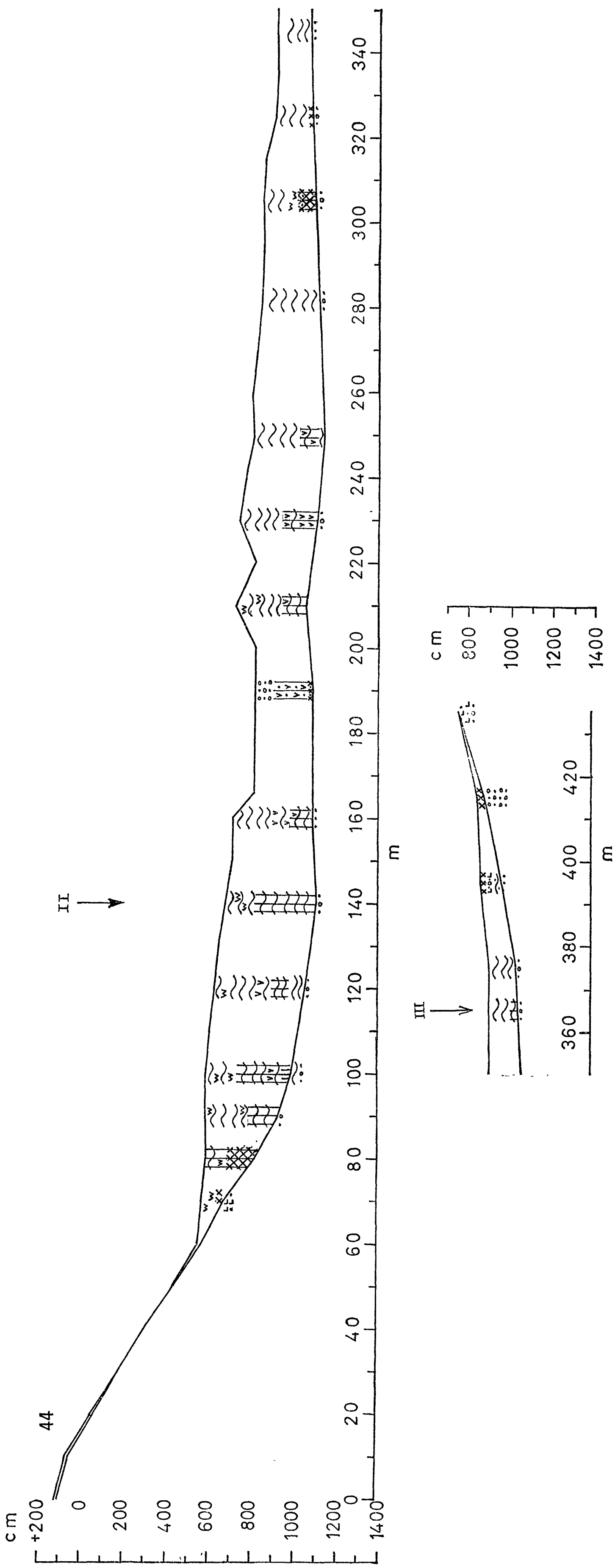

FIGURE 43, 44. Stratigraphy of Weelhead Moss along transects I and II. Symbols for the deposits are given in figure 4.

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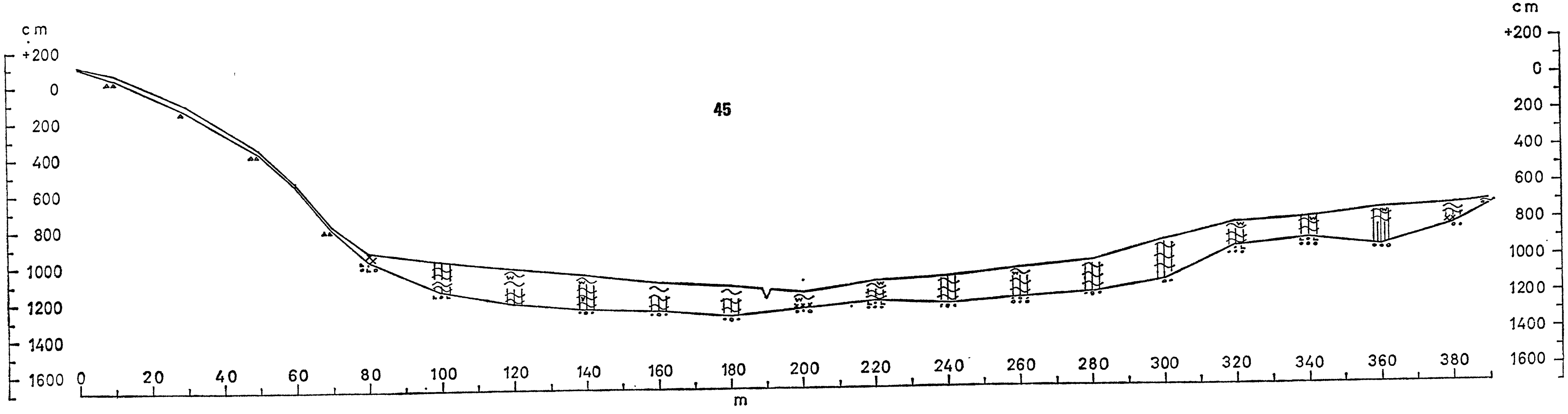

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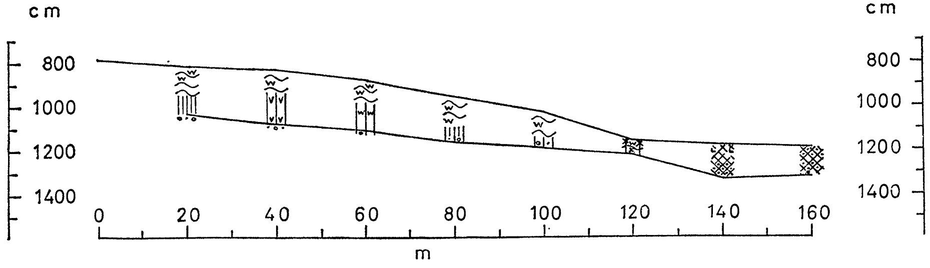

Figures 45, 46. Stratigraphy of Weelhead Moss along transects III and IV. Symbols for the deposits are given in figure 4.

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cm	
165 to 200	lighter-brown highly humified sedge peat with *Sphagnum* and some charcoal fragments at 185 cm
200 to 235	dark brown moderately humified sedge peat with *Calluna*
235 to 248	light brown sedge peat with birch wood
248 to 250	*Sphagnum cuspidatum* peat
250 to 270	light brown *Sphagnum* sedge-birch peat with a layer of birch at 270 cm
270 to 300	light brown sedge-birch peat
300 to 330	light brown *Sphagnum*-sedge peat
330 to 350	light brown sedge peat with dark bands of *Sphagnum cuspidatum*
350 to 360	dark brown highly humified peat
360 to 380	dark brown peat with bands of *Sphagnum cuspidatum* and carbonized fragments
380 to 394	very stiff dark brown peat with *Sphagnum cuspidatum* and sedges
394 to 397	band of white clay
397 to 430	dark brown stiff sedge peat with a band of white clay between 403 and 406 cm
430 to 450	light grey silty sand with rounded pebbles

365 m

cm	
0 to 25	whitish clay mixed with a little peat
25 to 50	mid-brown moderately humified *Sphagnum* peat
50 to 130	well humified mid-brown *Sphagnum* peat with bands of carbonized material below 80 cm and increasing amounts of sedge below 100 cm
130 to 150	grey sandy silt with large pebbles

Downstream from the moraine the peat is composed of a similar complex of *Sphagna* and sedges with bands of birch wood, although in many places there is a clearer division into a lower mainly sedge peat and an upper mainly *Sphagnum–Calluna–Eriophorum* peat. Rarely is the total depth of this peat mass more than 2 m.

Samples for pollen analysis were also collected from the point 40 m on transect IV downstream from the moraine, where the stratigraphy was as follows:

cm	
0 to 10	dark brown *Sphagnum* peat
10 to 75	mid-brown well preserved *Sphagnum–Eriophorum* peat with *Calluna* between 50 and 75 cm
75 to 215	light brown sedge with *Sphagnum* and *Eriophorum* between 75 and 100 cm, abundant birch fragments between 130 and 140 cm, *Phragmites* between 150 and 215 cm and patches of carbonized material towards 200 cm
215 to 218	greyish-white clay band with sedges
218 to 240	mid-brown crumbly sedge peat, with some carbonized patches and pieces of birch

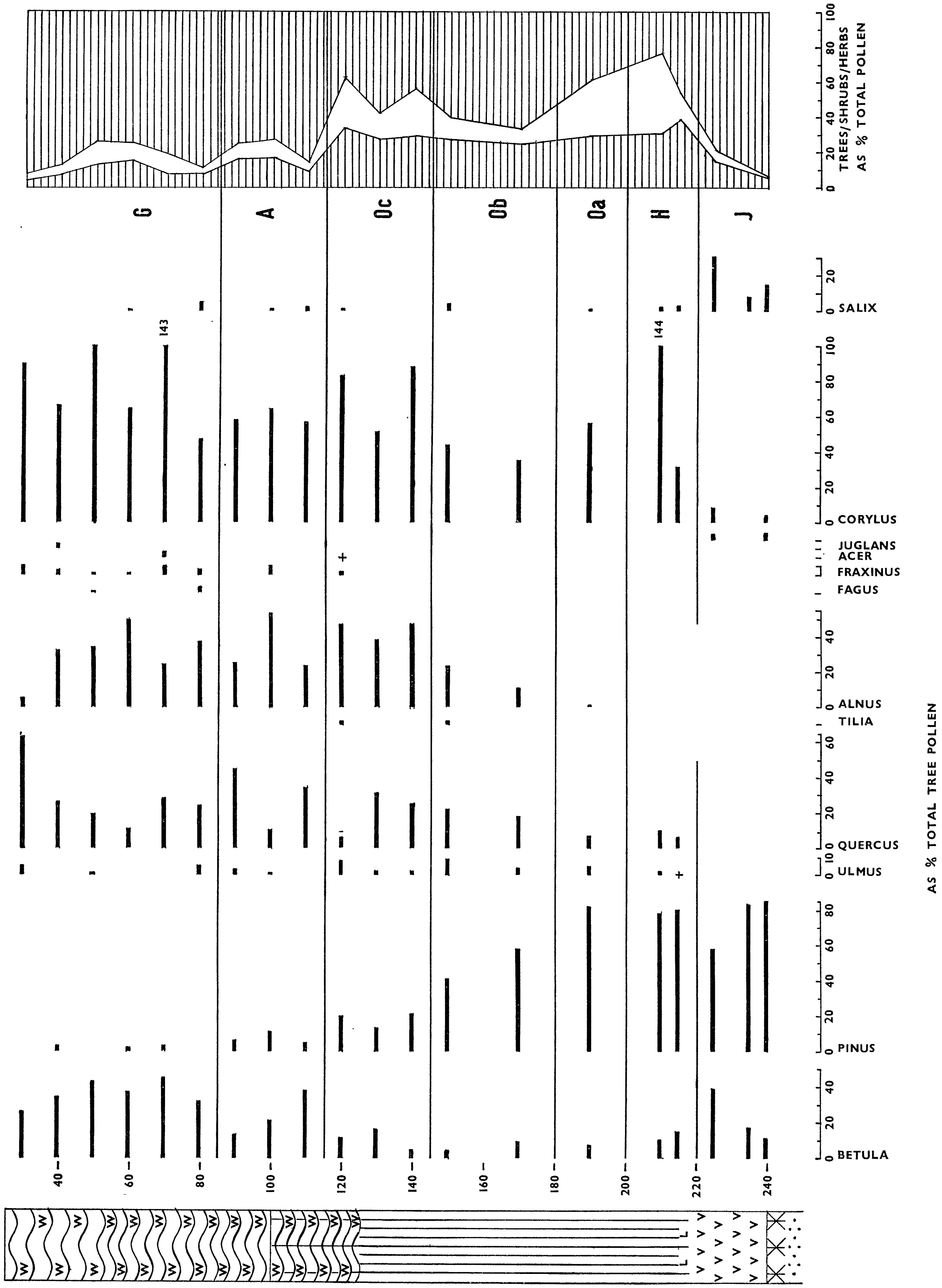

FIGURE 47. Tree pollen diagram from Weelhead Moss, WH I. Frequencies are plotted as a percentage of the total tree pollen excluding *Corylus* and *Salix*.

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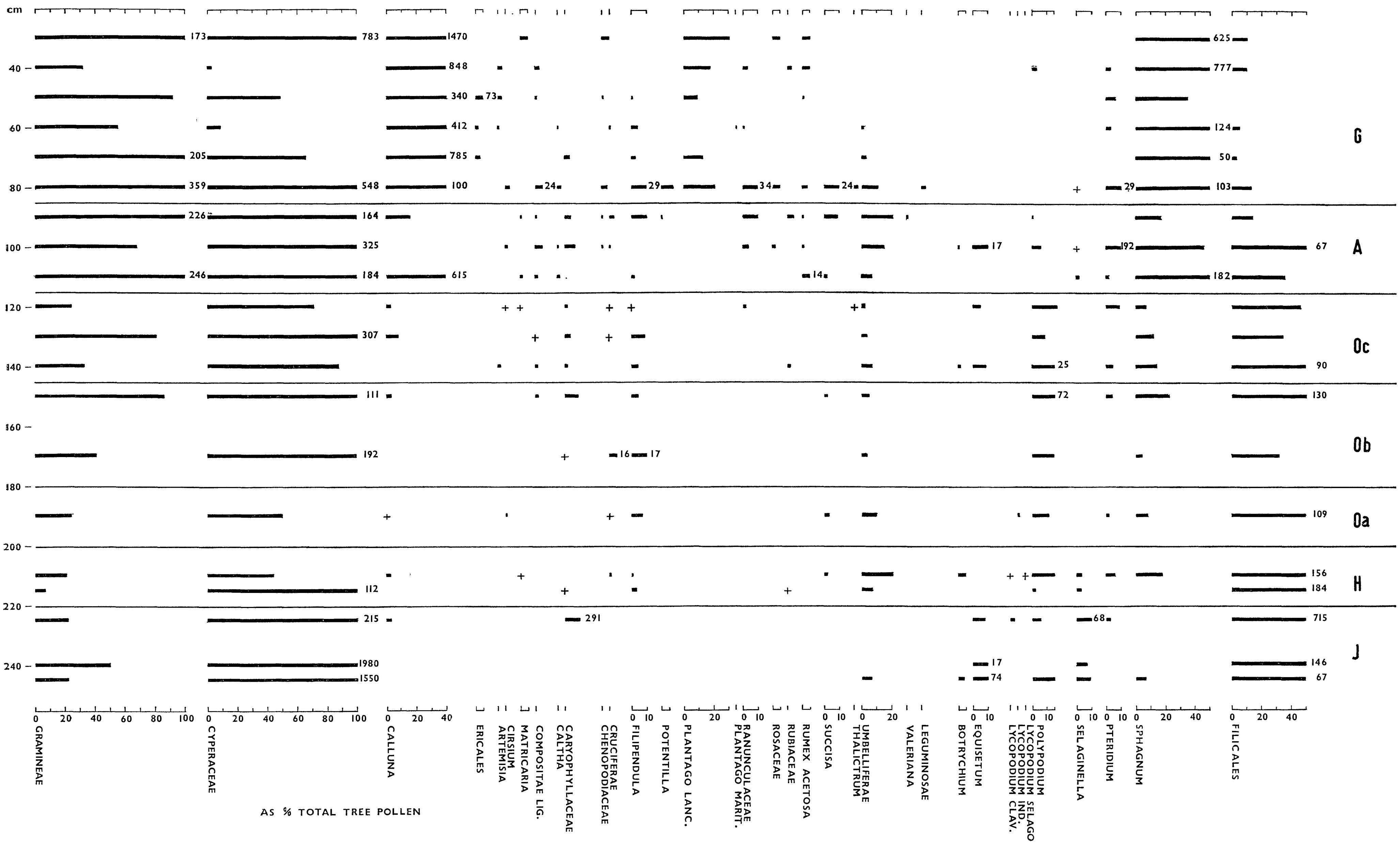

FIGURE 48. Herb pollen diagram from Weelhead Moss, WH I. Frequencies are plotted as a percentage of the total tree pollen.

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cm	
240 to 245	blackish-brown band of muddy peat with numerous fine rootlets and remains of sedges
245 to 250	blue-grey silt

The pollen diagram WH I from 40 m on transect IV is shown in figures 47 and 48. It shows that the moss has a similar history to that of Dead Crook Moss beginning to grow at the end of the late or very early post-glacial and growing well during the later part of the post-glacial, zones A and G.

TABLE 4. RESULTS OF POLLEN ANALYSES FROM 140 M ON TRANSECT II WEELHEAD MOSS (POLLEN FREQUENCIES ARE GIVEN AS A PERCENTAGE OF TOTAL TREE POLLEN)

sample depth/cm ...	450	440	430	420	410	400	390	370
Betula	72	40	21	22	30	11	43	69
Pinus	27	54	68	73	62	88	53	21
Ulmus	.	1	.	1	3	.	3	6
Quercus	.	2	3	1	1	+	1	4
Alnus	.	3	3	2	.	.	.	.
Fraxinus	.	.	6	1	5	.	.	.
Corylus	2	26	21	13	37	4	70	97
Salix	14	4	3	13	17	5	1	1
Juniperus	2	.	.	.	.	.	.	9
Frangula	.	.	.	.	.	+	.	.
Gramineae	39	11	27	3	13	5	3	5
Cyperaceae	3390	286	1270	318	446	115	366	19
Calluna	7	3	.	1	.	.	.	.
Empetrum	2	.	.	.	.	.	.	.
Ericales	2	.	.	.	.	.	.	.
Compositae Lig.	.	2	3	.	1	.	.	.
Caryophyllaceae	7	2	.	.	.	.	.	.
Cruciferae	7	100	35	64	116	37	3	8
Filipendula	14	.	6	.	16	.	.	3
Leguminosae	.	.	.	.	1	.	.	.
Potentilla	2	.	.	.	.	.	.	.
Ranunculaceae	2	1	.	.	4	+	.	+
Rumex acetosa type	2	.	.	1	3	+	2	6
Saxifragaceae	2	.	.	.	.	.	.	.
Thalictrum	2	.	.	.	.	.	.	.
Umbelliferae	.	.	.	.	1	+	.	.
Menyanthes	.	.	3	.	.	.	.	.
Botrychium	.	.	.	.	3	.	.	.
Equisetum	66	34	47	77	12	9	2	12
Lycopodium selago	.	.	3	.	.	.	.	.
Selaginella	.	.	+	+	.	.	.	.
Pteridium	.	.	3	.	1	.	.	.
Sphagnum	2	4	6	7	3	4	5	.
Filicales	23	75	88	156	98	75	37	2
% trees	2.9	18.6	6.9	19.5	13.4	38.4	18.4	40.2
% trees and shrubs	3.2	24.2	9.3	24.7	20.2	42.2	31.4	83.1

The results of the samples analysed from 140 and 365 m on transect II are tabulated below. Only four samples were analysed from the point 365 m and the eight deepest samples from 140 m. Those from 140 m (table 4) show that the peat began forming in the late or early post-glacial as it did at 40 m on transect IV. Those from 365 m (table 5) are harder to interpret.

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The high *Pinus* and low *Quercus* frequencies indicate a zone H or earlier origin but the fluctuating *Alnus* frequency, 17 % at 150 cm, 2 % at 130 cm, 11 % at 110 cm and 1 % at 90 cm, fluctuations hardly paralleled elsewhere in the area, indicates that deposition may not have been uniform in that part of the moss. This is not surprising when one remembers that this is the river end of the moss which today is often partially under water and which may well in the past have been flooded fairly regularly. Any peat forming there would have been liable to a certain amount of erosion and redeposition.

TABLE 5. RESULTS OF POLLEN ANALYSES FROM 365 M ON TRANSECT II WEELHEAD MOSS (POLLEN FREQUENCIES ARE GIVEN AS A PERCENTAGE OF TOTAL TREE POLLEN)

sample depth/cm ...	150	130	110	90
Betula	31	14	37	39
Pinus	45	84	45	57
Ulmus	.	.	+	1
Quercus	7	.	7	1
Alnus	17	2	11	1
Corylus	48	12	64	57
Salix	.	12	5	7
Gramineae	30	29	14	9
Cyperaceae	49	488	246	105
Calluna	48	16	33	4
Empetrum	.	.	+	.
Ericales	.	.	+	.
Compositae Lig.	.	.	+	1
Caryophyllaceae	.	12	+	+
Chenopodiaceae	.	2	.	.
Cruciferae	3	.	+	+
Filipendula	7	4	6	8
Lysimachia	3	.	.	.
Potentilla	.	.	2	.
Ranunculaceae	.	2	+	.
Rosaceae	.	4	.	.
Rubiaceae	.	2	.	.
Rumex acetosa type	.	.	.	+
Succisa	.	.	+	.
Thalictrum	.	.	+	.
Umbelliferae	.	.	+	1
Botrychium	.	2	2	.
Equisetum	28	18	4	5
Lycopodium selago	3	.	.	.
Polypodium	3	2	+	.
Selaginella	+	2	2	.
Pteridium	14	.	.	.
Sphagnum	121	14	364	16
Filicales	23	84	158	84
% trees	14.1	14.8	21.0	44.1
% trees and shrubs	20.1	18.3	34.5	72.0

After these pollen analyses had been carried out it was decided to recover a complete core from the deepest part of Weelhead Moss for radiocarbon dating the major pollen zone boundaries. The summer of 1969 was unusually dry and in late August the water table in the moss was much lower than usual. We were therefore able to dig a pit in the moss at a point near 140 m on transect II (figure 42) and cut blocks of peat some 20 × 20 cm in cross-section

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from its side. These blocks were cut into slices 2 cm thick and a sample for pollen analysis taken from each slice. When the diagram, WH II (figures 49 to 51) had been prepared the following samples were sent to the Gakushuin Radiocarbon Laboratory in Japan for assay. The results of the assay are given in radiocarbon years B.P. and are based on the Libby half life, 5570 ± 30 years.

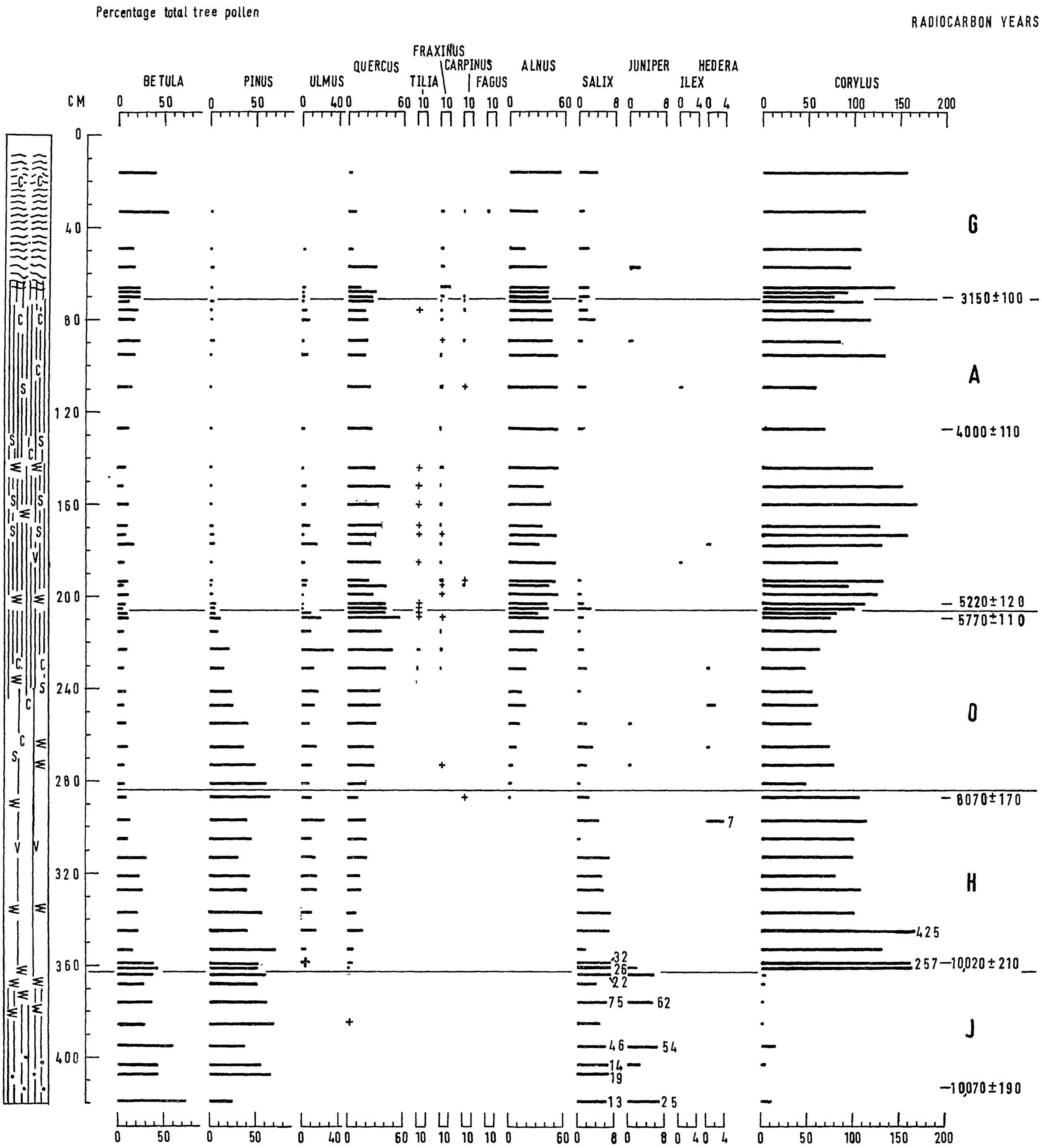

FIGURE 49. Tree pollen diagram from Weelhead Moss, WH II. Frequencies are plotted as a percentage of the total tree pollen excluding *Corylus*, *Juniperus* and *Salix* and radiocarbon dates are given in years B.P. on the right-hand side of the diagram.

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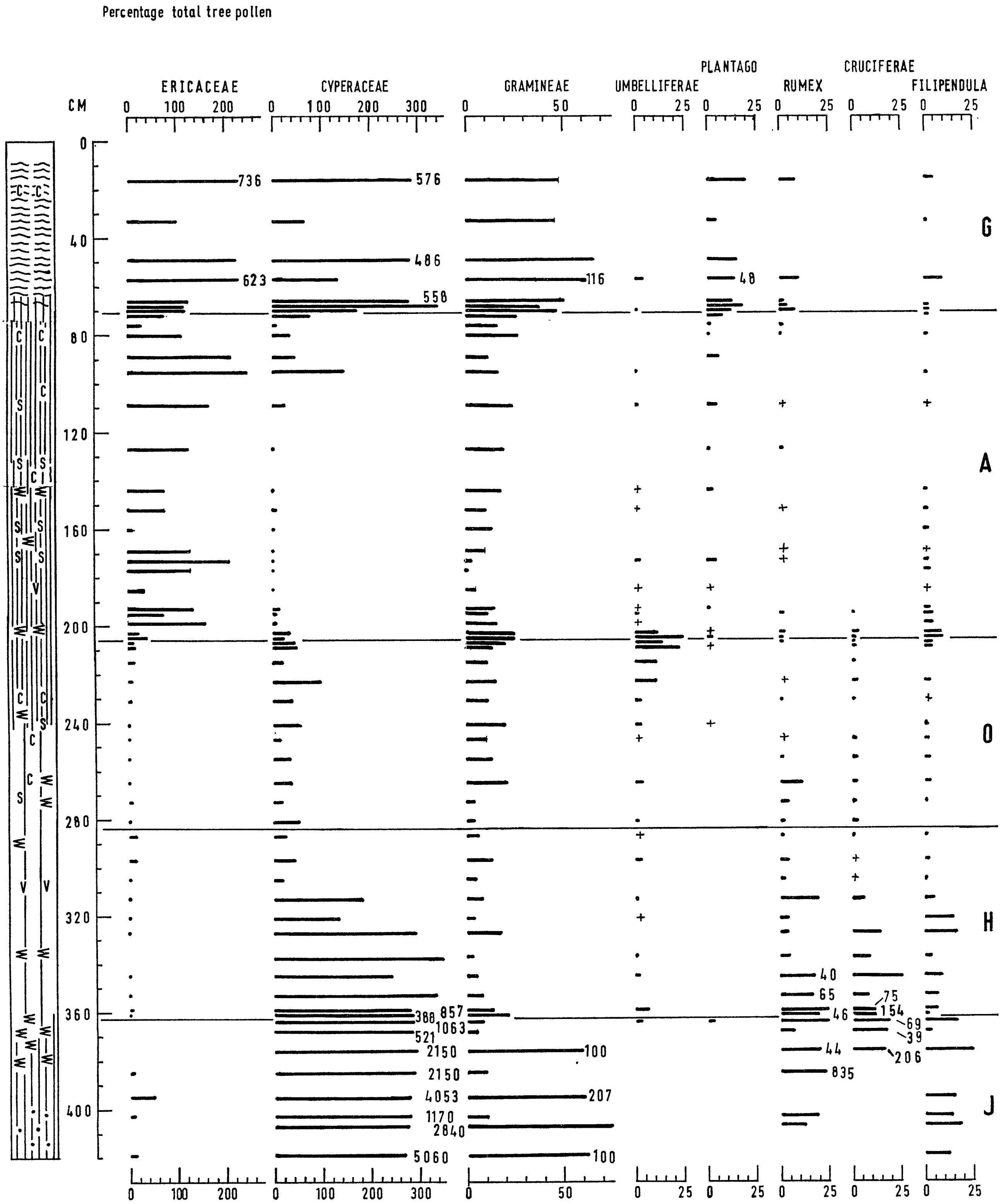

Figure 50. Herb pollen diagram A from Weelhead Moss, WH II. Frequencies are plotted as a percentage of the total tree pollen.

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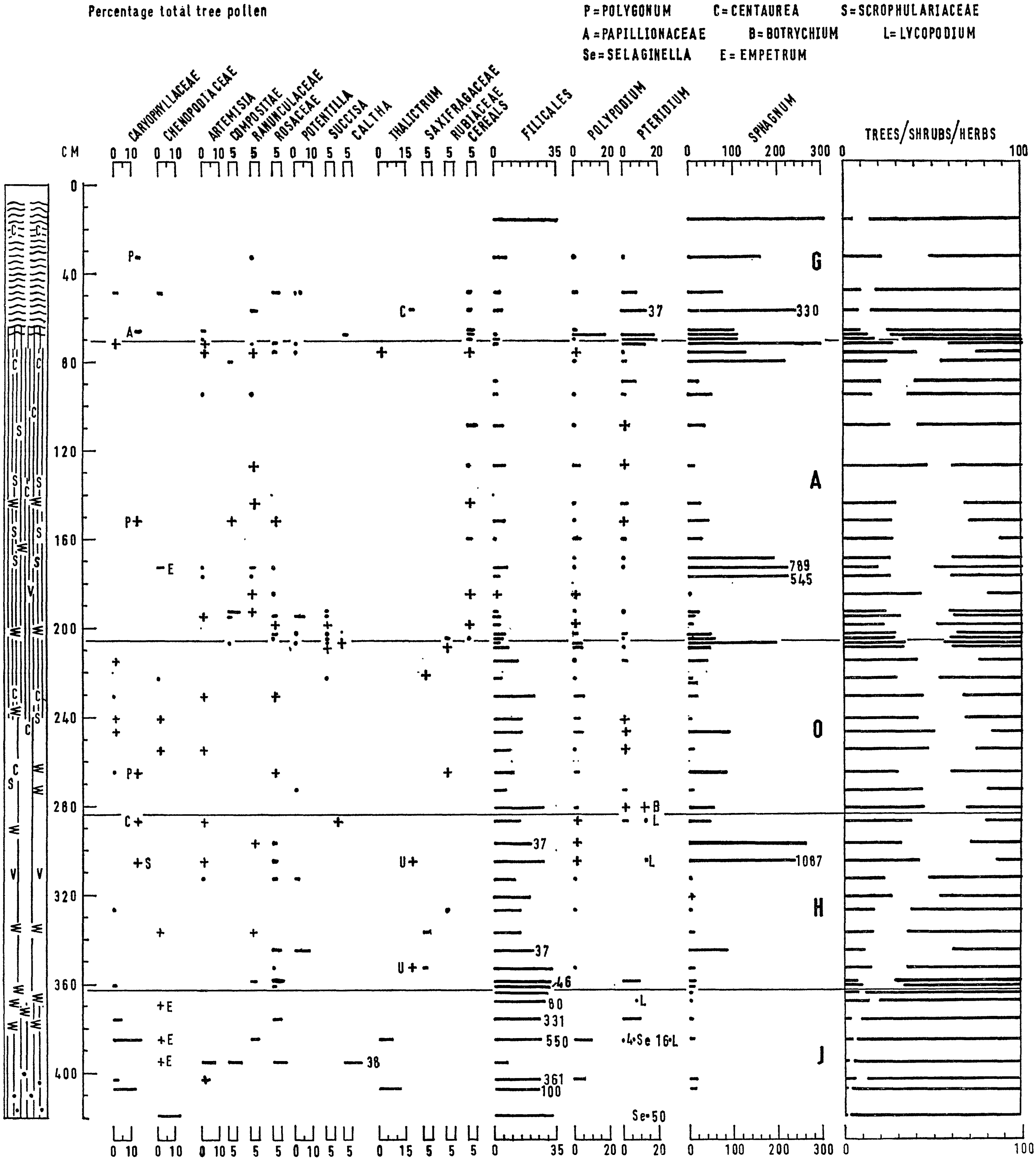

FIGURE 51. Herb pollen diagram B from Weelhead Moss, WH II. Frequencies are plotted as a percentage of the total tree pollen.

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1. GaK–2913, peat from 70 cm, the lowest sample with high Gramineae and *Plantago* pollen frequencies, 3150 ± 100.
2. GaK–2914, peat from 127 cm, where the *Betula* frequency is rising and the *Quercus* frequency is falling, 4000 ± 110.
3. GaK–2915, peat from 203 cm, the lowest sample with low *Ulmus* frequencies, 5220 ± 120.
4. GaK–2916, peat from 209 cm, the highest sample with high *Ulmus* frequencies, 5770 ± 110.
5. GaK–2917, peat from 287 cm, where the *Pinus* frequency is beginning to fall and the *Alnus* frequency increase, 8070 ± 170.
6. GaK–2918, peat from 359 cm, where the *Corylus* frequency rises, 10020 ± 210.
7. GaK–2919, peat from 413 cm, the lowest sample of peat 10070 ± 190.

Two other levels were then dated by Dr D. D. Harkness at the Scottish Research Reactor Centre at East Kilbride with the following results:

sample from 239 cm, zone O, 6202 ± 70
sample from 337 cm, zone H, 8057 ± 85

The pollen diagram from the pit is the most detailed from the reservoir basin and resembles that from Red Sike Moss, TS I, in several ways. The two sites also differ in a few important respects, the most obvious, perhaps, being the depth of peat, over 400 cm at Weelhead Moss, WH II, as opposed to 145 cm at Red Sike Moss, TS I.

The pollen assemblage J below 359 cm is late-glacial and the two radiocarbon dates, 10070 ± 190 for 413 cm and 10020 ± 210 for 359 cm, confirm that the peat began forming on Weelhead Moss towards the end of zone III. These radiocarbon dates are similar to that of 9900 ± 190 (GaK–2031) for the onset of peat growth at TS I.

Also between J and H there is evidence for a break in peat formation as at TS I, for the pollen assemblage above 359 cm is clearly zone H with high *Corylus* and *Pinus* and with some *Ulmus* and *Quercus*.

During zone O the pollen frequencies for *Alnus* and *Quercus* rise much more gradually than on most of the other long diagrams from the area and the zone cannot be subdivided. Compare, for example, with the TS I diagram (figure 8) on which the *Pinus* frequency drops and those of *Quercus* and *Alnus* rise sharply between 75 and 70 cm and there is another sharp drop in *Pinus* between 45 and 60 cm. It seems from the WH II diagram that from 8070 ± 170 B.P. until 5770 ± 110 B.P. oak and alder were slowly replacing pine as the major trees in the area. This was presumably also happening near Tinkler's Sike and if so confirms our interpretation (p. 341) that the sharp change in the tree frequencies seen between 75 and 70 cm on the diagram from that site is the result of a hiatus in peat growth which must have occurred between about 8000 and 6000 B.P.

There is evidence for either a hiatus or very slow peat formation at Weelhead around 5770 ± 110 B.P. The dates for 209 cm and 203 cm, 5770 ± 110 and 5220 ± 120 mean that 6 cm of peat formed in 550 ± 120 years and this is much slower than the average rate for the whole post-glacial. The date of 5220 ± 120 agrees well with the range of dates which has been obtained from a large number of sites throughout Britain for the elm decline. This confirmation that the elm decline in the reservoir basin was at the same time as elsewhere in Britain is in accordance with the idea that there was a hiatus in peat at TS I from then until 3390 ± 90 B.P. Peat growth must have all but stopped at Weelhead between 5770 and 5220 B.P. and continued again sometime after thus differing from TS I where it actually stopped and did not begin again until 3390 ± 90 B.P.

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(*j*) *The blanket peat*

As well as the areas of relatively deep peat already described, a fair proportion of the steeper ground within and around the reservoir basin and also on the Fell is now covered with blanket peat which varies in depth and often merges into the deeper areas of basin peat. This blanket peat tends to be highly humified and, where plant structure can be seen, to consist of *Calluna vulgaris*, *Eriophorum vaginatum* and *Sphagnum* species.

In the main it has formed over the scattered drift deposits and not where the solid rock was exposed directly at the surface. There is one exception to this. Oval or elongated mounds have formed on top of the porcellanite which outcrops along the foot of the sugar limestone above the Red Sike Moss. The porcellanite is an impervious metamorphic rock which was formed from marls associated with the limestone at the same time as the sugar limestone was formed. In some places the peat appears to be directly over the sugar limestone, for example, there are a few almost circular patches of it on the limestone above Tinkler's Sike. However, in these places the soil between the peat and the sugar limestone rock contains chips of porcellanite which could only be derived from drift deposits. There is also a thin clayey transition layer between the soil and the underlying sugar limestone. It seems that these areas of peat have formed on top of very thin layers of drift-derived soils and not directly over the limestone. The following stratigraphy was seen in a pit dug through such a mound.

cm	
0 to 12	dark brown peat. *H* 4
12 to 58	light mid-brown *Sphagnum* peat. *H* 1–2
58 to 65	mid-brown peat. *H* 5–6
65 to 72	dark brown compact peat
72 to 77	black greasy organic layer
77 to 79.5	light grey soil
77 to 79.5	iron pan with numerous flat rounded and angular stones embedded in and below it
79.5 to 102.5	light yellowish-brown loam with porcellanite stones in it
102.5 to 107	grey clayey sugar limestone
107	white sugar limestone

It is to be expected too that a large mass of blanket peat which had already begun forming over drift-derived soils would easily spread over small areas of better drained soils.

At three places on Widdybank Fell the bottom 50 cm of blanket peat was collected for pollen analysis. Basal sample I was collected from the western slope of the Fell between Slapestone Sike and Red Sike above the reservoir access road (figure 52). The peat there was 90 cm deep and overlying a greyish, stony clay. Basal sample II was collected from below the access road on the northern bank of Red Sike about 100 m from where the Sike flowed into the Tees. The peat there was 100 cm deep, again overlying a greyish stony clay. Basal sample III was taken from cuttings made during the building of the site huts immediately to the southeast of the Birkdale track where it crossed the access road. The blanket peat there was shallower, barely

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50 cm deep and overlying 10 cm of boulder clay which was itself resting on limestone. The results of the pollen analyses are given in figures 53 to 55.

During the construction of the dam we had plenty of opportunity to examine the blanket peat to the west of the river from below the dam to Farfool mire. It was exposed in long sections as the peat and underlying boulder clay was stripped off for use as building material.

The peat varied in depth from 0.5 to 1 m and there was a distinct positive correlation between the depth and the amount of birch wood at its base. The deeper the peat, the more wood there was. At a point 3 m upstream from the centre line of the dam and 593 m from its northern end, site W, we collected samples of peat for pollen analysis and a piece of basal wood for radiocarbon dating. The total depth of peat at site W was 64 cm. The results of the analyses are given in table 6 and the radiocarbon assay was as follows: (GaK–2920) wood from base of peat at site W, 3370 ± 110 B.P.

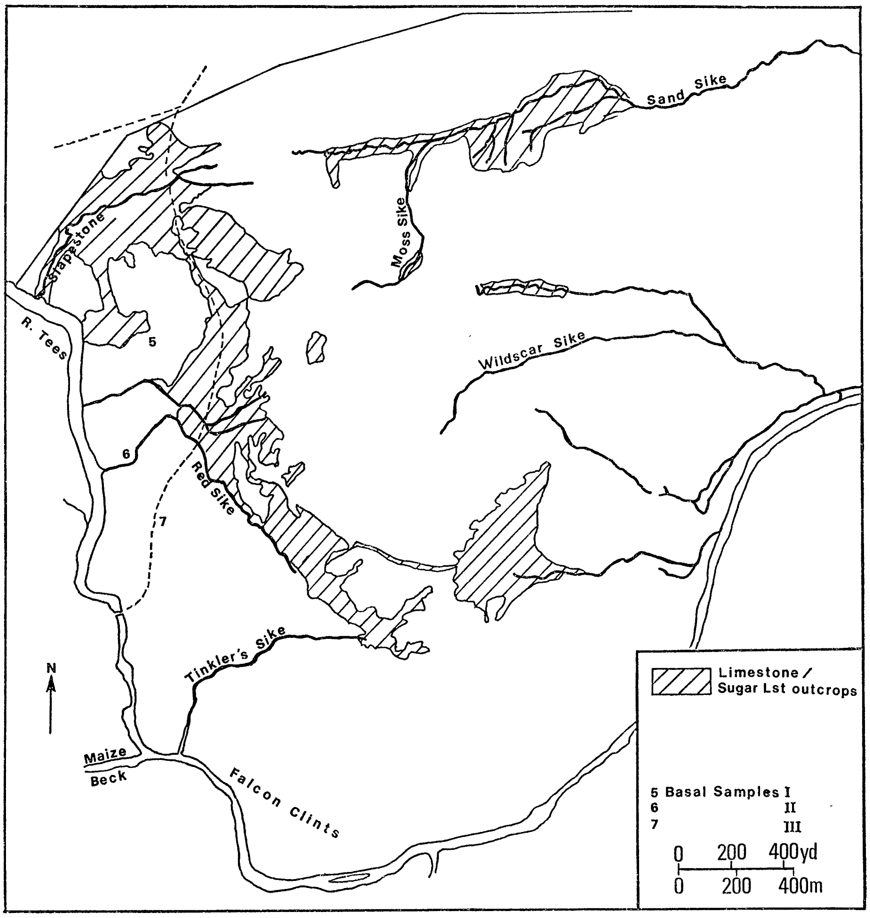

FIGURE 52. Sketch map of Widdybank Fell showing the position of Basal samples I, II and III.

The bottom of the blanket peat in all three basal samples contains a zone A pollen assemblage and the upper peat, above 80 cm in BS I, above 70 cm in BS II and above 35 cm in BS III, one from zone G. At site W too, the lower four samples are zone A and the upper three zone G in age and at this site there is also the radiocarbon determination of 3370 ± 110 B.P. for wood from the base of the peat. It seems quite clear therefore that the blanket peat began forming everywhere sometime during zone A; the exact time probably varying slightly from place to place according to local topography.

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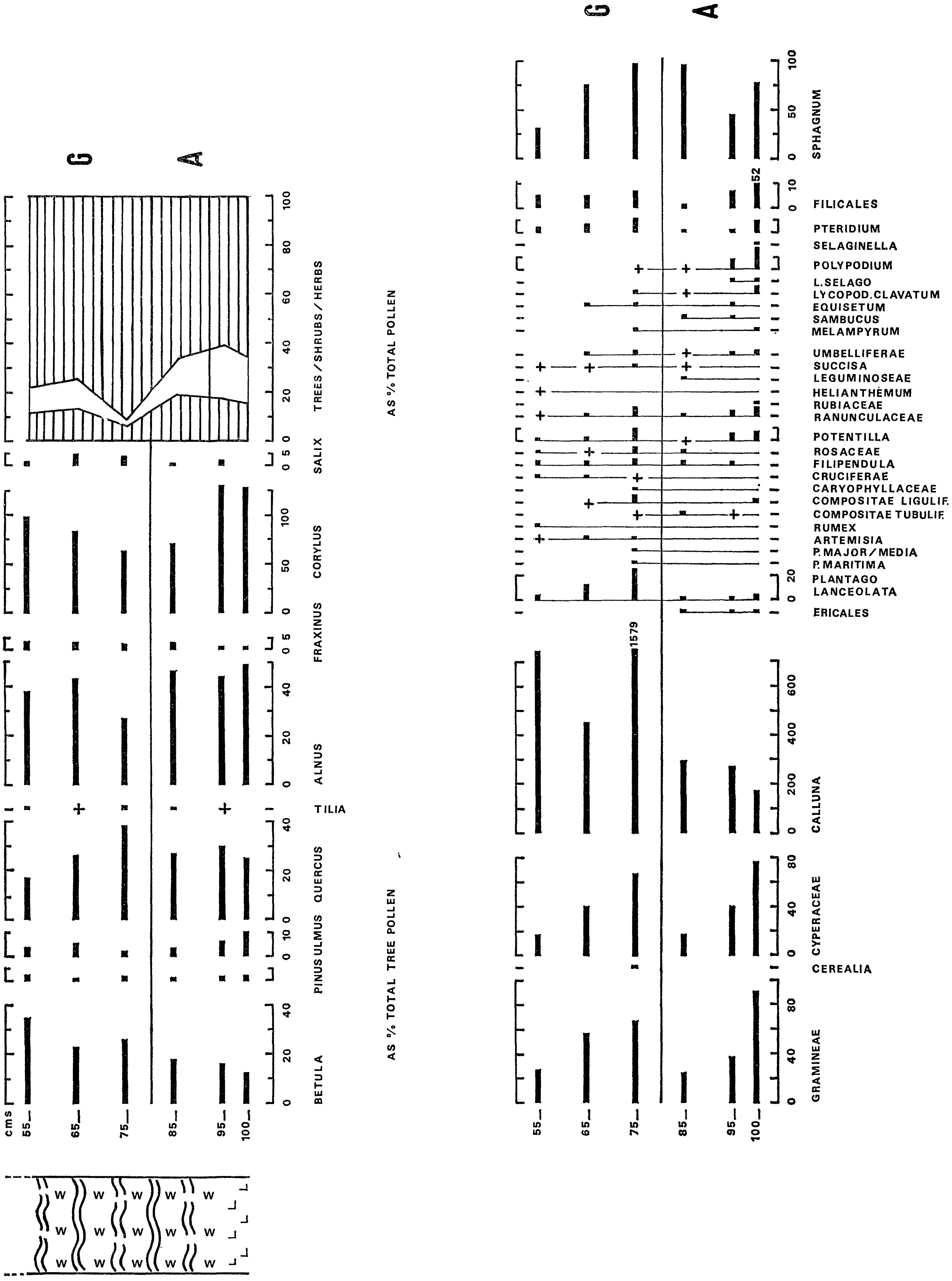

Figure 53. Pollen diagram from blanket peat, site BS I. Frequencies are plotted as a percentage of the total tree pollen excluding *Corylus* and *Salix*.

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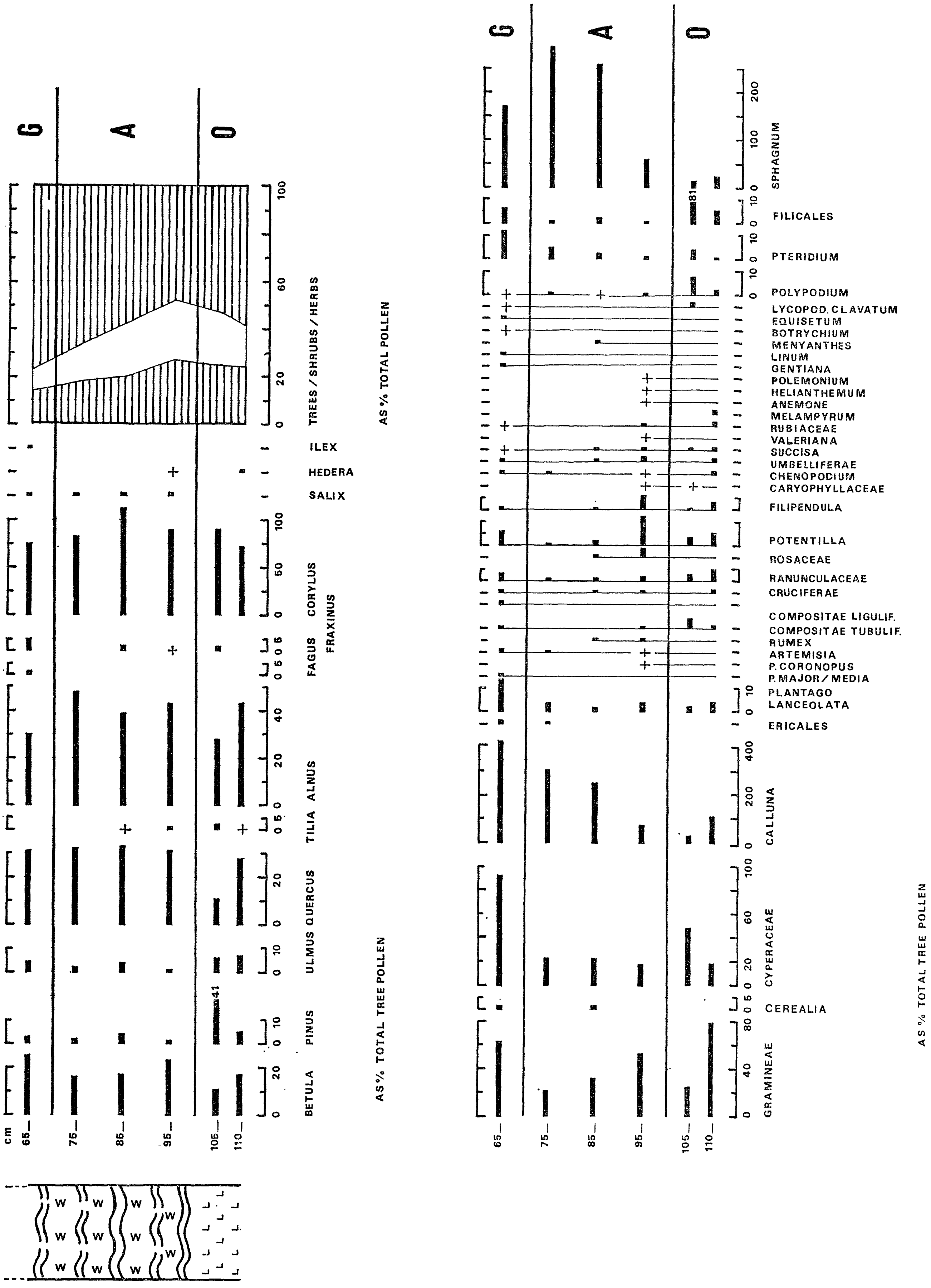

FIGURE 54. Pollen diagram from blanket peat, site BS II. Frequencies are plotted as a percentage of the total tree pollen excluding *Corylus* and *Salix*.

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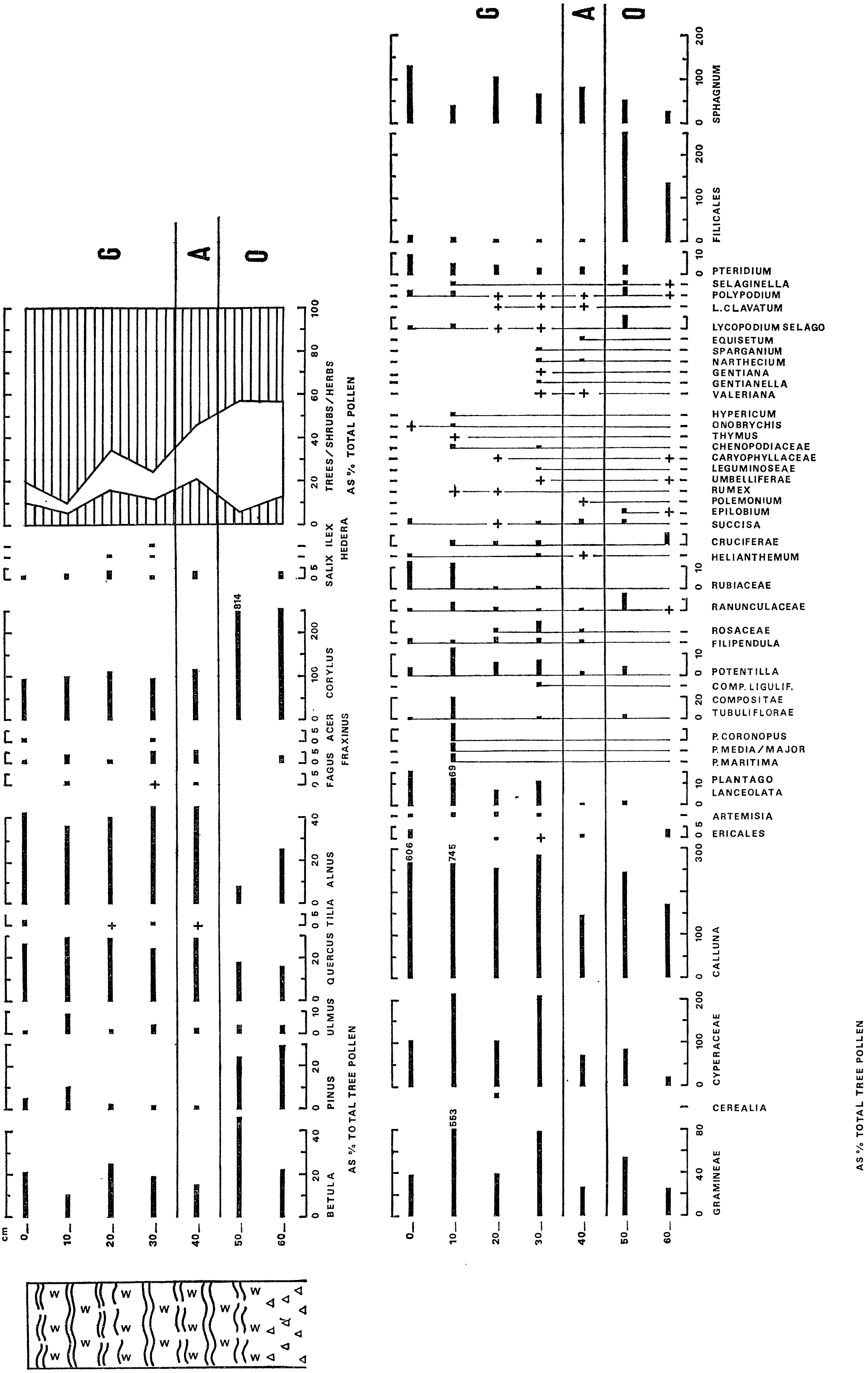

Figure 55. Pollen diagram from blanket peat, site BS III. Frequencies are plotted as a percentage of the total tree pollen excluding *Corylus* and *Salix*.

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Table 6. Results of pollen analyses from site W (pollen frequencies are given as a percentage of total tree pollen)

sample number …	9	8	7	6	5	3	1
Betula	69	44	43	31	56	42	26
Pinus	1	+	+	2	.	1	.
Ulmus	.	+	1	2	2	.	.
Quercus	7	18	18	25	7	36	47
Alnus	22	37	35	41	33	20	26
Fagus	.	.	+	.	.	.	.
Fraxinus	.	.	1	.	2	1	.
Corylus	48	92	71	107	60	77	79
Salix	.	.	.	.	2	.	.
Ilex	.	.	.	.	.	1	.
Gramineae	45	112	3	12	44	32	53
Cyperaceae	1	4	6	9	27	21	42
Calluna	36	216	151	481	647	456	2295
Ericales	.	.	+	.	.	.	.
Artemisia	1	2	.	.	4	4	11
Matricaria	.	.	.	.	.	3	.
Compositae Lig.	.	.	.	.	.	.	5
Chenopodiaceae	.	.	.	.	2	.	.
Cruciferae	.	.	+	.	.	.	5
Filipendula	2	.	+	.	.	3	5
Mercurialis	.	.	.	2	.	.	.
Plantago lanc.	1	4	2	6	20	6	21
Plantago major	.	.	.	.	.	.	5
Potentilla	1	+	.	.	.	.	5
Ranunculaceae	+	3	2	3	2	.	.
Rosaceae	5	.	.	2	.	.	.
Rumex acetosa type	1	.	.	.	.	.	11
Succisa	11	.	.	2	.	.	.
Umbelliferae	.	.	.	.	4	.	.
Equisetum	.	+	.	.	.	.	.
Polypodium	.	2	.	9	.	.	5
Pteridium	1	5	2	3	5	3	.
Sphagnum	6	42	11	12	223	420	248
Filicales	5	3	1	2	13	1	.
% trees	39.4	23.1	29.1	13.6	11.0	14.2	3.8
% trees and shrubs	58.2	44.3	47.7	28.2	17.8	25.4	6.8

3. Discussion of results

From the data presented in the first part of this paper it has been possible to deduce in varying amounts of detail what the vegetation of the area has been like throughout the post-glacial. The discussion which follows presents these deductions chronologically starting with the end of the late-glacial and finishing with the modern vegetation. It concludes with a section on particularly interesting fossil records and their significance in relation to the survival of the Teesdale rarities.

(*a*) *Late-glacial, approaching* 10000 B.P.

There is little palaeobotanical evidence concerning conditions during the late-glacial because very little peat formed in the area at that time. There was some near Red and Tinkler's Sikes, some in the Foolmire Sike area, some in the Dead Crook Moss area and just over 50 cm on the area now occupied by Weelhead Moss. It seems that this peat only began to form at the end of zone J for it is late zone III in age at the two sites where it has been radiocarbon dated. Its

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pollen spectrum indicates a predominantly herbaceous vegetation with abundant grasses and sedges and a wide variety of other species. Thirty other herbaceous pollen taxa have been recorded including such common late-glacial types as *Artemisia*, *Filipendula*, *Helianthemum*, *Rumex* and *Thalictrum*. *Betula nana*, *Juniperus* and *Salix* species pollen occur in high enough frequencies to indicate that these shrubs were flourishing locally. There is only a little tree pollen, of *Betula* and *Pinus*, and so it is doubtful if there were any trees in the area. This pollen had probably blown in from the lowlands.

At this stage of its history, therefore, the vegetation of upper Teesdale did not differ from that of other upland areas of northern Britain, being a typical late-glacial vegetation. The area would have provided a wide variety of microhabitats from the wet peaty areas on the river alluvium and near the sikes to the well-drained outcrops of sugar limestone on the Fell, from the windy exposed summit of Widdybank to the relatively sheltered area of Dead Crook. The extensive areas now covered in blanket peat would have been carrying the much more varied late-glacial flora.

(*b*) *Post-glacial*

(i) 10000–8800 B.P.

There is evidence from Weelhead Moss and Red Sike Moss, TS I, that the peat stopped forming at about 10000 B.P. and so there is a gap in the vegetational record at these sites from then until it began again in zone H. We attempted to date this renewed peat growth at Weelhead Moss with the sample from 359 cm in which the *Corylus* frequency was over 150% of the total tree pollen but unfortunately it gave a zone III date. This may well be because the radiocarbon sample was taken from too close to the hiatus and because of this contained a lot of reworked late-glacial material together with its later zone H pollen assemblage. So there is no accurate date for when the peat did begin to form again. However, the dates we have, one of 8070 ± 170 on Weelhead for 72 cm above the hiatus and one of 8250 ± 280 at Red Sike Moss, TS I for 15 cm above the hiatus mean that it began well before 8000 B.P. The date of 8800 B.P. which is widely accepted for the beginning of zone VI is probably the most reasonable estimate for the end of the hiatus at Weelhead, although it may have been a little later at Red Sike Moss.

The diagram from Foolmire Sike, however, does appear to have a few centimetres of peat from this 'hiatus' period; the samples from 450, 440 and 430 cm containing a pollen assemblage HJ intermediate in character between the zone J and the zone H assemblages on the other diagrams. *Corylus* rises from 50 to 80% and *Juniperus* is present contributing approximately 10% throughout. Hazel scrub was clearly invading the area and becoming an important element in the vegetation and apparently without seriously competing with the juniper.

By the beginning of zone H on all the diagrams the total tree pollen appears only marginally higher than at the end of the late-glacial. This does not mean, however, that the absolute number of tree grains falling on the bog surface each year remained constant. As Davis (1967) has demonstrated absolute increases are easily masked in relative frequency diagrams especially at the late- and post-glacial boundary. Birch and pine probably migrated into the area during these 1200 years but not in such large quantities as the hazel, the absolute increase in their pollen being masked in the relative diagram by the large increase in *Corylus* pollen.

Gramineae, Cyperaceae and other herbaceous type pollen frequencies have decreased correspondingly, but are still well represented at the end of the period. There is no question of closed woodlands having formed.

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(ii) 8800–8000 B.P.

This is the period containing the zone H pollen assemblage. *Quercus* and *Ulmus* pollen appear and the *Corylus* frequency is high. There is no *Juniperus* pollen but *Salix* and herbaceous pollen types are still abundant. The end of this period has been radiocarbon dated at Weelhead Moss to 8070 ± 170 B.P. and at Red Sike Moss, TS I to 8250 ± 280 B.P. Approximately 80 cm of peat formed at Foolmire Sike, Dead Crook and Weelhead mosses, 15 cm at Red Sike Moss, TS I.

The total tree pollen frequency rises steadily on the TS I diagram, although on several of the others the rise is more variable. By 8000 B.P. the frequency is between 30 and 40 %. Again it seems unlikely that there is a closed woodland in the area. Birch and particularly pine are increasing, presumably both on the Fell and in the reservoir basin. Not all the diagrams, however, are the same. The most obvious difference between them is in the *Alnus* frequency. There is about 5 % throughout on the Foolmire Sike diagram but virtually none on the others, except for an isolated occurrence of 18 % at 300 cm on DC I from Dead Crook. One can hardly avoid the conclusion that alder was growing locally near Foolmire Sike from about 8800 B.P. onwards. The gentle slopes around the sike which are now covered with peat and also all the flattish low lying ground along the Westmorland bank of the Tees above Cauldron Snout would have been damp enough and indeed the most suitable place in the area for it. Alder does not however appear to have grown as far up the valley as Dead Crook at this time except perhaps for a brief period represented by the sample from 300 cm on that diagram.

There are also quantitative differences in the *Pinus* pollen frequency between the various sites. On the TS I diagram, for example, it varies from 71 to 77 % of the total tree pollen, whereas on the Weelhead Moss, WH II diagram it varies between 30 and 70 %. The mean values with their standard deviations are as follows:

Red Sike Moss, TS I	73.1 ± 2.3
Red Sike II	51.0 ± 8.0
Foolmire Sike	35.8 ± 7.5
Dead Crook I	67.0 ± 11.7
Weelhead Moss I	78.8 ± 0.8
Weelhead Moss II	49.9 ± 11.3

Pine appears therefore to have been well established near Tinkler's Sike and also near Weelhead Moss I and Dead Crook I, hence its highish frequencies at those sites. It was probably also flourishing on the steeper slopes above the alder woods near Foolmire Sike but too far away to be dominating the tree pollen spectrum there. Similarly, it does not appear to have been strongly established near Weelhead Moss II.

Whether oak and elm were growing in the area at this time is harder to say. The small amounts of their pollen may have been blowing in from much lower down the Tees Valley. Hazel, on the other hand, was almost certainly growing within the area. Its frequencies are highest on the WH II and TS I diagrams 80–425 % and 97–201 % respectively, and lowest on DC I 40–70 %. There appears to be a positive correlation between the proximity of limestone soils and a high *Corylus* frequency during zone H, presumably indicating that the hazel was most abundant on the limestone soils at that time.

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(iii) 8000–5770 B.P.

At the beginning of this period, zone O, the *Pinus* frequency is high everywhere and those of *Alnus* and *Quercus* either zero or low. By the end, the *Pinus* frequency has dropped to virtually nothing everywhere and the *Quercus* and *Alnus* frequencies have risen to substantial values. These are, however, but general trends and it is possible to deduce much more than the fact that oak and alder spread at the expense of pine from the differences between the various pollen diagrams. These differences in fact allow us to build up an interesting picture of the way in which the alder and oak spread within the area and even to postulate where the individual species were growing best.

On the diagrams from the reservoir basin, WH I and II, DC I and Foolmire Sike, the tree pollen is at its maximum and, on most of the diagrams, steady throughout, whereas on those from the Fell, TS I and RS I, it rises steadily and reaches a rather more short lived maximum later and in the case of TS I, much later. This establishes that, in very general terms, the trees reached their maximum density in the reservoir basin well before they did so on the higher and more exposed slopes of the Fell.

There is another important general difference between the diagram from WH II and all the others. On the Weelhead Moss diagram the *Pinus* curve falls and the *Quercus* and *Alnus* frequencies rise steadily, giving the impression that the vegetation is changing gradually. On the other diagrams, however, there are several distinct pollen assemblages within the period. For example on the TS I and DC I diagrams the following assemblages, starting with the oldest, can be recognized:

(1) high *Pinus*, low *Quercus* and no *Alnus*, Oa;
(2) high *Pinus*, low *Quercus* and low *Alnus*, Ob;
(3) *Pinus* decreasing, high *Quercus* and *Alnus* increasing, Oc.

On the Foolmire Sike diagram one can again recognize three pollen assemblages although they differ from those at the other two sites:

(1) *Pinus* decreasing slightly, low *Quercus*, low *Alnus*, Oa.
(2) *Pinus* decreasing sharply, high *Quercus*, low *Alnus*, Ob;
(3) *Pinus* decreasing slightly, high *Quercus*, *Alnus* increasing sharply, Oc.

On the Red Sike I diagram there are only two such assemblages:

(1) high *Pinus*, low *Quercus* and rising *Alnus*, Oa;
(2) low *Pinus*, high *Quercus* and *Alnus*, Oc.

The fivefold drop in the *Pinus* frequency between the two at this latter site indicates a hiatus in the peat and the second assemblage is probably best equated with assemblage Oc at the other sites.

The difference in the *Alnus* frequency between the various sites during (1) is interesting. It has already been noted that there was 5% *Alnus* pollen from 8800 to 8000 B.P. on the Foolmire Sike diagram and virtually none on the others. It seems that during (1) this local patch of alder continued to flourish. It also seems to have expanded a little especially around Red Sike and also to some extent around Weelhead Moss. But it still did not expand to the area around Dead Crook or to the area around Tinkler's Sike.

A little later, however, corresponding to stage (2) alder seems to have spread from the Foolmire Sike area onto the slopes around Dead Crook and also onto the Fell near Tinkler's Sike, although it hardly became a serious competitor for the pine there. The only place where the

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pine was not growing so well was on the steep slopes in the vicinity of Foolmire Sike where it seems to have been replaced by oak at this time. This may well have been the first time oak had actually been growing in the area.

Some time later, (3), it seems that the oak together with alder expanded rapidly from around Foolmire Sike gradually replacing the pine everywhere. Even on the limestone areas above Tinkler's Sike where the pine had until then reigned supreme, oak and alder took over until, by the end of the period, well into the fourth millenium B.C., all the pine had gone. It is only at the beginning of this latter stage that the trees on the Fell reached their maximum development.

Thus, although alder and oak replaced pine everywhere between 8000 and 5700 B.P., the rate at which they did so differed at the various sites. First alder and then later oak reached the Foolmire Sike area and established themselves there apparently before spreading elsewhere. This does seem to indicate that they both migrated along the floor of the Tees Valley and into the reservoir basin via Cauldron Snout and from there onto the Fell rather than coming over the higher and more exposed slopes of the Fell from Langdon Beck, along the route of the present road. This fits in with the fact that the trees appear to have reached their maximum development on the Fell later than within the reservoir basin.

It is clear that the pine grew best on the limestone and hung on there for longer than it did elsewhere. As during zone H, its frequencies are statistically higher at the TS I site than at most of the others and they also remain high for longer during zone O there than they do elsewhere. This conclusion is to some extent supported by the fact that *Carex ericetorum*, one of the Teesdale rarities, is now restricted to the sugar limestone. This species grows today in the ground flora of pine woods in European Russia (Kellar 1927), and where it occurs in the grasslands of the East Anglian Breckland, it is thought by Watt (1971) to indicate the former existence of pine woods. It is therefore interesting to note that in Teesdale it is restricted to the sugar limestone, the very areas where it seems pine grew best during much of the post-glacial.

During this period also, peat was just beginning to form on areas which had previously been free from it. The first area to go over to peat, through a stage of *Juncus* dominance, was that around Slapestone Sike. Figure 23 shows that at least 50 cm of peat had formed there before the pine was replaced by oak.

(iv) 5770–5000 B.P.

During this period, the latter part of zone O, very little peat formed on Weelhead Moss, according to the radiocarbon dating evidence only about 10 cm. Also at Tinkler's Sike there is evidence for a long break in peat formation at this time, from sometime before 5000 B.P. until well after 3390 + 90 B.P. On both diagrams the final drop in the *Pinus* frequency occurs at the level of the elm decline, a somewhat unusual feature in British pollen diagrams, and this is also true for most of the other diagrams from the area. It seems that much of Godwin's pollen zone VII a, when one would have expected low *Pinus* and high *Ulmus* frequencies, is missing at these sites and that this was because very little or no peat was forming. This lack of peat growth cannot have been due to a change in the position of the River Tees because that would not have affected Red Sike Moss which is well above river level and was in fact the driest moss of all. Neither is it a peculiar feature of upper Teesdale because Conway (1954) has recorded similar growth of peat during this, the Atlantic period, in her southern Pennine sites, a fact which makes a climatic explanation the most plausible. It seems unlikely that the climate really became

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substantially drier at this time over the entire Pennines, especially as it had been wet enough during the Boreal for peat to form, zones H and O, and wet enough during VII a elsewhere in Britain to support peat growth, for example on many of the lowland mires. Rather more likely is the possibility that peat was unable to accumulate because of the extremely wet climate. This idea was put forward by Kulczynski (1949) and used by Bellamy & Bellamy (1966) to account for the smaller masses of peat in the wetter areas of western Ireland as compared with those on the central plain. Thus the slow growth of peat or lack of peat may have been due to increased erosion of the bog surfaces under an exceptionally high rainfall associated with relatively warm temperatures.

Only on the top of the Fell at Widdybank Moss and on Weelfoot Moss was a little peat forming at this time. Of all the samples counted from sites within the area, only those from 300 to 340 cm on Widdybank Moss (figure 16) and those from 190 to 210 cm on Weelfoot Moss (figure 29) contain a late zone O pollen assemblage with no *Pinus*, but plenty of *Ulmus*, *Quercus*, *Alnus* and *Corylus*. Presumably the oak–alder–hazel woods which had largely replaced the pine, certainly by 5770 B.P., were flourishing throughout the area during this very wet period.

The forest maximum. From about 8000 to 5000 B.P. trees were at their most abundant in the reservoir area and, for the later part of that period, on the Fell; the tree pollen frequency contributing between 30 and 50% to the total pollen spectrum on most of the diagrams. This latter period will subsequently be referred to as the period of the forest maximum. It is the time when the vegetation was most unlike that of either the late-glacial or the present day. If at any time the rare species had difficulty, so to speak, in finding suitable habitats in which to survive then it was during the forest maximum. Even so the pollen assemblages of the forest maximum need to be seen in a wider context because they are quite different from those of lowland diagrams. They contain far less tree and more herbaceous pollen. For example, on Kershaw's lowland diagram from Cranberry moss, Co. Durham (Turner 1970) the herb frequency averages 5% as opposed to the 30 to 40% on our diagrams. This can only mean that the woods were considerably more open than those of the lowlands, open enough to allow a varied herbaceous flora to flourish and contribute approximately a third of the total pollen. Although habitats for the rare species may have been more restricted than during the late-glacial, development of woodland on the Fell could at the most only have decreased the areas available for them, certainly not destroyed them altogether.

(v) 5000 B.P. *to the present*

Peat continued to form on most of the mosses which had begun life during zone J and also for most of the period on Widdybank Moss, Slapestone Sike Moss and on Weelfoot Moss. It also began to form at Dubby Moss. This means that there are more diagrams and a larger number of sites for comparison than during the previous 5000 years. Unfortunately this relatively long period cannot easily be subdivided on the basis of pollen assemblages common to all diagrams. No two diagrams are quite the same and without an unjustifiably large number of radiocarbon measurements attempts at recognizing even broadly synchronous pollen horizons other than that between A and G can only be tentative.

In general terms the open woodland which was covering most of the area at 5000 B.P. was replaced where the soil was becoming waterlogged by blanket peat and where it was better drained by grassland, giving rise eventually to the present-day vegetation. The Gramineae and *Plantago* frequencies tend to rise and fall together and presumably indicate the amount of

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grassland near a particular site. The *Calluna* frequency, however, is a law unto itself and rises and very occasionally falls quite independently of the Gramineae and *Plantago* frequencies. Presumably it indicates the spread of blanket peat at or near a site. The fact that it usually remains high once it has risen means that once established, this blanket peat continued to grow and trees were unable to regenerate on that ground. Woodland to blanket peat seems to have been an irreversible process. This contrasts with the woodlands to grassland change which appears to have been reversed several times.

Three of the diagrams, those from Weelhead Moss, Tinkler's Sike and Slapestone Sike have a series of alternating high and low Gramineae and *Plantago* frequencies near the top. As these changes occur in the 15 cm of peat above the dated level of 2570 ± 80 B.P. on the TS I diagram and above the 3150 ± 100 B.P. level on the Weelhead Moss diagram it seems likely that they represent varying intensities of human occupation in the area from the late Bronze age onwards. We are inclined to regard these periods of human interference as more or less synchronous at all the sites partly because the factors controlling population density are likely to have been operating throughout the whole of the upper dale in much the same way and partly because a similar series of variations in the *Plantago* and Gramineae frequencies has been found on three unpublished diagrams from widely spaced areas in upper Weardale, the dale just to the north of Teesdale, and there is evidence that they were synchronous.

The *Calluna* frequency is high on all three diagrams throughout this period of human interference and there can be little doubt that by this time most of the present-day blanket peat was already there. As discussed on pp. 392 and 393, it must have spread some time before and it appears from the levels at which the *Calluna* frequency rises on the various diagrams, that it did so at different times at each site.

On the Weelhead Moss diagram the *Calluna* frequency is high throughout the whole of the 5000 years under consideration and it seems that in that area a lot of peat started forming relatively early. On the Slapestone Sike diagram the *Calluna* frequency rises slowly and steadily reaching its maximum values at the beginning of the time when the grassland spread. There the spread of blanket peat, which is now extensive in the wide but shallow depression drained by the sike, seems to have been a more gradual process. On the TS I diagram the *Calluna* frequency does not rise to its maximum values until the amount of grassland increases, although there is a smaller peak earlier on. The major spread of blanket peat in that area therefore seems to have been relatively late.

On the other diagrams, the rise in *Calluna* pollen always occurs after the elm decline but well before the first spread of grassland as indicated by the *Plantago* frequency and it tends to be a sharper rise than at Weelhead Moss.

The picture that emerges for this long period therefore is that soon after 5000 B.P. some of the soils gradually became too waterlogged for trees to regenerate on them. Instead, possibly with intermediate stages, bog plants mainly *Calluna vulgaris*, *Eriophorum vaginatum* and *Sphagnum* species began to grow well and eventually to form a blanket peat. More and more ground went over to blanket peat in this way until some time between 3000 and 2500 B.P. most of the present day bog communities had come into existence. From about then onwards the better drained soils on the limestone which still carried open woodland were subjected periodically to interference by man who doubtless grazed his animals there and collected wood for fuel, buildings and eventually for smelting. All this would favour grassland rather than woodland when the population was high and allow regeneration of the trees when it was low. Today's upland sheep

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farming is effectively maintaining these areas as species rich grassland and preventing the growth of trees.

(c) *Pollen records of the rare species*

It is in the nature of pollen analysis that only a limited number of species produce diagnostic pollen. Too often pollen morphology is typical of the genus or even the family of the species concerned. For example, the pollen of *Minuartia stricta* cannot be distinguished from the pollen of *M. verna*, nor indeed from the pollen of most species of *Stellaria* or any species of *Cerastium*. This means it is impossible to say whether the pollen of some of the rare species has been recorded in our analyses or not.

It is perhaps fortunate that of the 75 rare species of flowering plants described by Pigott (1956) 16 have pollen which is diagnostic at species level, or in a few cases, at a level so close to species level that one can be reasonably confident it is the species concerned. The pollen of 11 of these 16 has been recorded in the diagrams. They are marked with an asterisk:

**Armeria maritima* Mill. (Willd).
**Betula nana* L.
**Dryas octopetala* L.
**Gentiana verna* L.
**Helianthemum canum* (L.) Baumg. type
Primula farinosa L.
**Plantago maritima* L.
**Polemonium caeruleum* L.
**Polygonum viviparum* L.
**Rubus chamaemorus* L.
Salix herbacea L.
**Saxifraga azoides* L.
**S. stellaris* L.
S. nivalis L.
Tofieldia pusilla (Michx.) Pers.
Trientalis europaea L.

(i) Armeria maritima (*Mill.*) *Willd.*

A single pollen grain of this species has been recorded from zone O at Farfool Mire. Today *Armeria maritima* grows on Widdybank Fell in the gravel flushes and the pollen record indicates that it was also in the area during the period of the forest maximum.

(ii) Betula nana *L.*

Terasmäe (1951), Walker (1955) and Birks (1968) have discussed the problems involved in distinguishing the pollen of this species from grains of the tree birches. Hewetson's identifications of *B. nana* were based on measurements of the ratio of grain diameter to pore depth on the morphological characters of size, wall thickness and pore protuberance. Grains with a ratio greater than 11.5 were classed as *B. nana*. Pollen of this species was found on Widdybank Moss, Red Sike Moss, RS II and TS I and the frequency at each level counted is shown on the tree pollen diagrams from those sites. They show that it has been present on the Fell throughout the post-glacial and was much more abundant in the past than it is today. It was unknown on the Fell until Hutchinson (1966) found a few small plants of it growing on dry *Calluna* covered peat and demonstrated its presence in the past by finding subfossil leaves in the peat beneath.

(iii) Dryas octopetala *L.*

The pollen of *Dryas octopetala* was recorded from zones O and A at both Weelfoot Moss and Foolmire Sike.

The species does not occur on Widdybank Fell nor within the reservoir basin today but it does grow on Thistle Green on Cronkley Fell on the open sugar limestone soils. Similar habitats exist on Widdybank so it may well have grown there in the past. The pollen records for zone O

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confirm its presence in upper Teesdale, probably on Widdybank Fell, during the period of the forest maximum. Today it grows on base rich stony ground in the Alps and also occurs on the river gravels in the surrounding lowlands. Presumably during the forest maximum in Teesdale it would have grown along the stream edges on the limestone.

(iv) Gentiana verna *L.*

The pollen grains of *Gentiana verna* are reticulate and were distinguished from those of *Gentianella campestris* agg. and *amarella* agg. by their smaller, less coarse granules and from those of *Gentiana pneumonanthe* type by their more clearly defined reticulum.

Pollen of *Gentiana verna* was recorded from zone Od on Widdybank Moss and from zone Oa on Red Sike Moss, RS II and zone G in Basal samples II and III thus confirming its existence in the area during the period of maximum development of forest and afterwards. Today *G. verna* is a member of limestone grassland and calcareous flush communities in Britain and also of alpine meadow and snow patch communities on the European mainland (Elkington 1963). In the Pyrenees it grows along calcareous streams together with a number of species which occur in the calcareous marshy areas in Teesdale. It seems most likely that during the forest maximum it survived in Teesdale along such streams where there was local freedom from the shade of trees.

(v) Helianthemum *sp. Mill and* H. canum (*L.*) *Baumg. type*

The pollen of *Helianthemum canum* is difficult to distinguish from that of other *Helianthemum* species. On most of our diagrams the distinction has not been made and the records are of *Helianthemum* sp. which could reasonably be expected to be either *H. chamaecistus* or *H. canum*. *Helianthemum* pollen has been recorded from zone J (Red Sike Moss, TS I, Dead Crook I and Foolmire Sike), zone HJ (Foolmire Sike), zone H (Red Sike Moss, RS I), zone O (Red Sike Moss, RS II, Widdybank Moss, Weelfoot Moss and Foolmire Sike) and at seven sites during zone A and five during zone G. The genus therefore appears to have been present throughout the late- and post-glacial and to have expanded with the spread of grassland.

Pollen of *H. canum* type, however, has been found in zone O. We are grateful to Miss Robin Andrew for assistance in recognizing it. This indicates that *H. canum*, which today grows only on the top of Cronkley Fell, was probably growing on Widdybank too in the past.

(vi) Plantago maritima *L.*

Pollen grains of this species have been recorded from zone G at Tinkler's Sike, Red Sike, Widdybank Moss and Weelhead Moss and in Basal samples I and III. This concentration of records in zone G indicates that the species has increased with the spread of grassland in the area. It occurs today all over the limestone grassland on Widdybank as well as along the stream edges and in the sedge marshes.

(vii) Polemonium caeruleum *L.*

Pollen grains of this species have been recorded from zone A in Basal samples II and III, from zones O and A at Weelfoot Moss and from zones J, HJ, O, A and G at Foolmire Sike. It appears from these records to have been present in Teesdale since the late-glacial and to have been at its most abundant either at the late- to post-glacial transition or from late zone O

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onwards when the woodland soils were becoming wetter and large areas were going over to blanket peat.

Where *Polemonium caeruleum* occurs in the Pennines it is found on scree slopes and cliffs of Carboniferous limestone as a member of tall herbaceous communities often in woodlands and always where the soils have a high moisture content. In northern and western Germany it also occurs in lowland fens (Pigott 1958). It is therefore quite reasonable to suppose that there were more suitable habitats available for it during late O and A than at any other period during the post-glacial. It does not grow in the region today but apparently did so in the last century for Bell (1843) recorded it from Dun Fell at a site where it can no longer be found.

(viii) Polygonum viviparum *L.*

The pollen of this species is not normally distinguished from that of *Polygonum bistorta* (Faegri & Iversen 1964; Erdtman *et al.* 1963) but it differs from that of other *Polygonum* species. The type has been found fossil at Slapestone Sike, SL I and Dead Crook Moss, DC I in zone G and at Red Sike Moss, TS I in zone J. *P. bistorta* does not occur on Widdybank Fell but *P. viviparum* grows well on the parts of the limestone grassland where the soils are relatively damp and deep. It seems probable therefore that the pollen grains found are of this latter species. Like *Plantago maritima* it appears to have been most abundant in zone G, the time where the limestone grassland spread to its maximum extent.

(ix) Rubus chamaemorus *L.*

The pollen of this species has been found in Zones A and G at Foolmire Sike, in zone A at Red Sike Moss, RS II and in zone G at both Widdybank Moss and Slapestone Sike, SL I. The plant occurs today on the blanket peat of the Fell and its pollen records tally well with the period of blanket bog growth in the area.

(x) Saxifraga axoides *L.*

The pollen of this species closely resembles that of *Saxifraga oppositifolia* L. differing only in that it is more pronouncedly striate (Erdtman *et al.* 1961). We are most grateful to Dr H. J. B. Birks for this specific determination. Grains were found in zones O, A and G at Weelfoot Moss. *S. azoides* is common along the sikes on Widdybank Fell today and these records confirm its presence in the area during the forest maximum.

(xi) Saxifraga stellaris *L.*

The pollen grains of *Saxifraga stellaris*, *nivalis*, *tenuis* and *hieraciifolia* differ from those of other *Saxifraga* species in having a reticulate surface (Erdtmann *et al.* 1963) *S. stellaris* is the only one of these four species which grows in Teesdale today. It does not occur on Widdybank Fell, but is a member of the community found in the bryophyte flushes on Dun Fell. It seems most likely therefore that our subfossil pollen is that of *S. stellaris*. Such grains have been recorded from Red Sike Moss, RS II and Weelhead Moss during zone J, and from Red Sike Moss, RS II and TS I during zone O and from Red Sike Moss, RS II during zone G, thus demonstrating its presence in the area in the late-glacial, at the forest maximum and since the expansion of blanket bog and grassland.

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(xii) Thalictrum *sp. L.*

The pollen of different species within this genus is not usually distinguished although Erdtman *et al.* (1963) describe *T. flavum* L. as having slightly larger grains than *T. alpinum* L. with more distinct and pointed processes. We have not made the distinction, and the records for this pollen type, reasonably substantial amounts from zone J at Weelhead Moss II and zones J and HJ at Foolmire Sike and grains from each of zones P and H at Dead Crook Moss I, from zone Oc at Weelhead Moss I, A at Weelhead Moss II and G at both Dead Crook I and Weelhead Moss I, refer to the genus. *T. alpinum* occurs today on the hummocks of the gravel flushes and on the sugar limestone grassland. If the records are of this species it means that it has been present in the area throughout the post-glacial, though not as abundantly as during the late-glacial.

(xiii) Onobrychis viciifolia *Scop.*

There is also a specific record of *Onobrychis*, presumably *viciifolia*, the only British species of this genus, for zone G from Basal sample III. *Onobrychis* does not occur naturally in Teesdale today. It is found only in southeast England (Perring & Walters 1962) where it is thought to be native in the chalk and limestone grassland (Clapham, Tutin & Warburg 1952). This record indicates either that it was once a member of the Teesdale limestone grasslands, or that it was grown as a fodder crop during prehistoric times in the area.

The records of *Gentiana verna*, *Dryas octopetala*, *Betula nana*, *Saxifraga azoides* and *stellaris*, *Helianthemum canum* and *Thalictrum alpinum* from zone O, the period of the forest maximum, confirm beyond any reasonable doubt that these rare species have indeed been in the area from the late-glacial to the present day and what is true for them is probably true for the others with diagnostic pollen even though they have not yet been recorded. Some such as *Primula farinosa* are insect pollinated and one would not expect their pollen to be released into the atmosphere in sufficient quantity to stand a reasonable chance of being preserved in the very small proportion of the total peat that has been examined. In fact when one considers that within an area of about 6 km^2 we have only looked at a small sample of the pollen falling on as little as 20 cm^2 of peat it is really rather surprising that any rare species pollen has been found at all.

When, as in the case of *Gentiana verna*, only a few pollen grains have been found nothing can be deduced about the species relative abundance during different periods of the post-glacial. But with some species enough grains have been found for this to be done. Some of them show a more or less even distribution during the post-glacial, for example, *Thalictrum* species, but some have a distinct concentration in certain zones. In this later case it is interesting to see how well such concentrations fit in with the general history of the vegetation. For example, *Rubus chamaemorus*, a plant of blanket peat, was at its most abundant in zones A and G when the blanket peat was spreading. And *Polemonium caeruleum* was at its most abundant from A onwards when the woodlands were opening up and their herbaceous communities being replaced by blanket peat. Similarly, for present-day grassland species, *Helianthemum* either *chamaecistus* or *canum*, was more abundant during zones A and G than at any other time during the post-glacial. And *Plantago maritima* has all six of its records in zone G. *Onobrychis viciifolia* has only been recorded from zone G and so has the pollen of *Thymus* species. Pollen of *Linum* and *Gentianella* species has been recorded from zones A and G only. All these records agree fairly well with the evidence for the spread of grassland beginning in A and being particularly extensive in zone G.

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Too little pollen of *Saxifraga stellaris*, *S. azoides* and *Dryas octopetala* has been found to show whether or not they were more abundant at one time than another; the records only prove the presence of these species during the forest maximum.

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