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Studies in the Vegetational History of Scotland. IV. Pine Stumps in Scottish Blanket Peats

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STUDIES IN THE VEGETATIONAL HISTORY OF SCOTLAND

IV. PINE STUMPS IN SCOTTISH BLANKET PEATS

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The palaeoecology of six Scottish blanket peat profiles containing pine stumps was investigated by means of peat stratigraphy, pollen analysis, and radiocarbon dating. In addition, several other pine and birch remains from peat in other areas of Scotland were radiocarbon dated.

Three peat profiles were selected in each of two contrasting regions. The Cairngorm area is within the distributional area of native pine today and pollen analysis has shown that pine has been a major component of the upland forest since about 7000 B.P. The Galloway region in southwest Scotland is south of the native pine area, and pollen analysis has shown that pine has never been a major component of the upland forest.

Despite the limitations of the methods used, it has been established that there were several different circumstances for the growth and death of the pines studied, and that their ages are asynchronous within and between the two areas. Thus little regional climatic significance can be assumed from their occurrence, and they cannot be taken as evidence in support of dry Boreal and sub-Boreal periods in the Blytt and Sernander climatic scheme.

In the northwest Highlands dates from pine stumps and major declines of *Pinus* pollen in pollen diagrams are consistently around 4000 B.P. This overall demise of pine may have a regional climatic cause in this area.

1. Introduction

The remains of trees are commonly preserved in peat deposits including the blanket peats of northern and western Britain. *Salix* and *Betula* wood is frequently found at the base of such peat deposits, representing the forest that once occupied the area before peat development started. Wood interstratified in peat, representing trees that once grew upon the peat surface and were subsequently overwhelmed, is less common. However, when such wood is in the form of pine stumps, these are very conspicuous, and have long attracted the attention of both the population of the area as a source of fuel, and of scientists interested in vegetational and climatic history.

The so-called 'forest beds' in Scottish peat bogs were first brought to scientific notice by F. J. Lewis, who made a very extensive survey (Lewis 1905–7, 1911). He described bogs containing one or two (or sometimes more) layers of interstratified timber, and interpreted his findings in terms of Geikie's (1877) theories of glaciation, in that the peat layers reflected glacial periods, and forest layers reflected interglacials.

In Scandinavia, wood interstratified in peat bogs also occurs, and has attracted scientific attention for many years. Blytt (1876) drew evidence from these forest beds to reconstruct the past climate of Norway, which he then related to the development of Norwegian vegetation. Sernander (1910) extended these views to Sweden. The Blytt and Sernander scheme of climatic periods, as it came to be called, holds that wet oceanic periods alternated with dry continental ones during post-glacial time. The forest beds belonged to the dry Boreal and sub-Boreal periods, while the intervening peat belonged to the Atlantic and sub-Atlantic periods. Samuelsson (1910) applied this interpretation to the data of Lewis from Scotland, and he concluded that the Blytt and Sernander scheme could be applied in Scotland as well as in Scandinavia.

Figure 1 shows the distribution of pine stumps in blanket peat in Scotland, according to the author's knowledge of field and literature records. Pine stumps also occur commonly in Ireland, particularly in the west, but the author is unaware of any occurrences of pine interstratified in blanket peat in England or Wales. When the pine stump distribution (figure 1) is compared with the present distribution of native pine (*Pinus sylvestris* ssp. *scotica*) in Scotland, it is clear that pine stumps extend beyond the present limits of the species. Even when the potential distribution of pine is considered (figure 1; folding map B in McVean & Ratcliffe 1962) pine stumps still occur beyond the limits. This former extent of pine poses problems of vegetational history. When was pine more widespread? What was its status in the forests to the north, south, and west of its present potential range? What caused its reduction in area?

Answers to such questions can be provided by studying the vegetational history of Scotland. General palaeoecological studies of regional vegetation history can be made using pollen analysis to evaluate the role of pine in past forests. The presence of pine stumps in peat bogs can give a false impression of this role, as the local growth of pine in such habitats may be a feature of local environmental changes, particularly moisture. Pine stumps could, however, be useful climatic indicators if the wetness of the bog is directly related to wetness of climate.

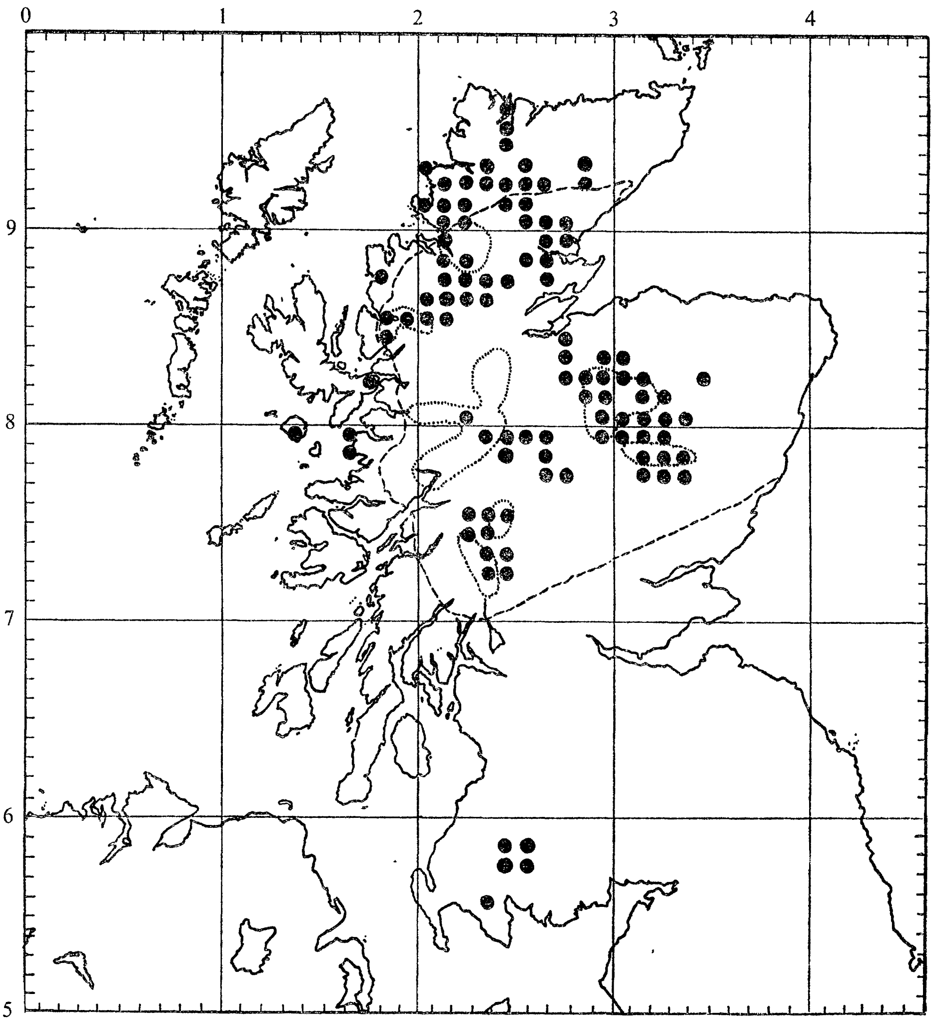

FIGURE 1. The distribution of pine stumps in peat, of native pine at the present day, and the probable limit of native pine had not man been active. ●, Pine stump record in a 10 km × 10 km grid square; ...., present limit; ----, probable limit.

But this need not necessarily be the case, and detailed studies of several sites are therefore required to assess the local circumstances of the growth and death of the pine, and to evaluate its climatic significance.

Accounts of the regional vegetational history of the two areas of Scotland chosen for this pine-stump study were presented by Birks (1970) (referred to subsequently as part I) and

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(1972*a*) (referred to subsequently as part II), and the vegetational history of other parts of Scotland is described in general terms by Birks (1972*b*) (referred to subsequently as part III) and (1969). By using correlations by radiocarbon dating and pollen stratigraphy, any synchroneity of pine growth on peat can be detected, and together with palaeoecological reconstructions, one of the basic premises for the acceptance of the Blytt and Sernander scheme of climatic periods in Britain can be examined. It should be noted that, in a study of past tree lines in Sweden, Lundquist (1959, 1962) radiocarbon dated many pine stumps from the mountains, and his datings were fairly evenly scattered between about 8000 and 2700 B.P. with no distinct aggregations at Boreal or sub-Boreal times, as would be required by the Blytt and Sernander climatic scheme.

This paper presents the results of palaeoecological investigations into the former growth of pine on blanket peats in two areas of Scotland. The first area is the northern Cairngorm region, where pine is still a prominent component of the native forests, and has been so for a considerable time (part I). The second, by contrast, is the Galloway Hills, in southwest Scotland, where pine stumps occur (figure 1), but pine has never had an important role in the regional dry land forest (part II). Both these areas were first investigated by Lewis (1905–7, 1911), and as far as possible, his original sites were used for reinvestigation by means of pollen analysis, peat stratigraphy, and radiocarbon dating. In addition, pine stumps from other areas of Scotland were radiocarbon dated, in case the selected pollen sites perchance gave an atypical age distribution.

Plant nomenclature follows Clapham, Tutin & Warburg (1962), Warburg (1963), Paton (1965), and James (1965) for vascular plants, mosses, liverworts, and lichens respectively. Place names are spelt according to the Ordnance Survey Seventh Series maps.

2. A review of the problem of the growth of pine on peat

In order to interpret the fossil evidence in ecological terms, it is necessary to outline the conditions for the growth of pine on peat today, as far as they are known.

Bog surfaces are one of the many habitats of *Pinus sylvestris* (Carlisle & Brown 1968). The pine-grown bogs of Scandinavia are well known (see, for example, Sjörs 1948, 1950) and there are many examples in Britain of pine colonizing *Sphagnum*-covered bogs. In southeast England, pine is colonizing a *Sphagnum* carpet at Dersingham Bog, near Kings Lynn, Norfolk. Some peat mosses in the West Midland Plain are similarly colonized, for example Wybunbury Moss, Chartley Moss, and Abbot's Moss. Many mosses on either side of the Solway Firth are pine-grown, for example Kirkconnel Flowe, Kirkcudbrightshire. In the Cairngorm area, pine has spread on to many peat-filled hollows within the native pine forests, particularly at Abernethy Forest (McVean 1963*a* and part I). All these places today are within areas of low mean relative humidity and a mean annual rainfall of about 102 cm (40 in) (Climatological Atlas 1952). In wetter parts of Britain, although there are many suitable bogs, pine does not appear to be able to colonize them. Even in the drier parts of Britain, the areal extent of pine-grown bogs is small, unlike that of Scandinavia, owing to the restricted occurrence of suitable bogs in southern Britain, and the universal disturbance by burning and grazing of the wide expanses of bog in Scotland which may otherwise have been suitable for pine colonization (Ratcliffe 1964).

The conditions necessary for the establishment and successful growth of pine on peat have been investigated by McVean (1963*a*, *b*). He demonstrated that colloidal blanket peat formed largely of *Trichophorum cespitosum* or *Molinia caerulea* remains was acutely deficient in phosphorus and that fibrous *Calluna vulgaris* peat was acutely deficient in nitrogen. He also showed that on nutrient-deficient peats, the development of mycorrhiza considerably improved nutrient uptake. However, the colloidal peat was so phosphorus-deficient that mycorrhiza could not develop unless phosphate was added. Other, more mesotrophic peats, such as *Phragmites* peat, contain adequate nutrients for pine growth. The fibrous peat contained a mycorrhizal inhibitor produced by *Calluna* (Harley 1959) which could be destroyed by autoclaving or by a hot burn. In nature, a light burn does not have this effect, and the fertilization by the ash does not release sufficient nutrients, especially nitrogen, to overcome the mycorrhizal dependence. Maximum establishment occurs 3–6 years after a hot burn, when the seedlings are protected to a certain extent by the young heather plants, but when mycorrhizal inhibition has not had time to build up. Thus conditions for colonization after a fire will depend upon the availability of seed, upon the occurrence of a good seed year (once every 4 or 5 years) at an appropriate stage, and also upon the availability of the right mycorrhizal fungus. In old pine stands, parasitic mycorrhiza (DN mycorrhiza, Harley 1959) are present which kill seedlings, and which may be a factor preventing regeneration under a pine canopy.

In addition, McVean showed that waterlogging, while not necessarily unfavourable to young seedlings, retards older seedlings, and may cause their death. However, if sufficient aeration occurs, retarded or checked seedlings may recommence growth, and set seed in conditions unsuitable for further seedling establishment. Waterlogging is also unfavourable for mycorrhizal development. Pine colonization of peat bogs in the more oceanic areas of Britain today is probably inhibited by the prevalence of high water-tables, whereas in the eastern areas, periods of drought are sufficiently common to allow the upper layers of peat to be adequately aerated.

Further experimental work has been done by Brown, Carlisle & White (1966) who showed that pine growth on wet peat was not inhibited as long as the upper layers were not reducing, and that the growth rate was correlated with the depth of oxidizing conditions. Under reducing conditions, nitrogen in the peat is mostly in the rather unsuitable ammonium form. Even though there may be adequate supplies of suitable nitrogen, the ability of the roots to absorb it in any form is severely reduced in anaerobic conditions. Brown *et al.* (1966) did not undertake any investigations on the effect of anaerobic conditions on mycorrhizal development.

Growth is usually slower on wet peat than on mineral soil, and the life span is shorter, although the trees are often of good form (McVean 1963*a*). The root system is shallow, ramifying only in the aerated layer, and consequently the trees are subject to windthrow. Where they are growing on a floating *Sphagnum* mat, as in the mosses in Cheshire and Staffordshire, the density of the peat is important. Often the trees sink under their own weight, and die when their roots become permanently below the water table.

In extrapolating modern ecological observations on the growth of pine on peat to the situation represented by the occurrence of fossil pine stumps, it is important to consider the gross palaeoecological implications of the fossil pine stumps in Scotland.

All the stumps examined in this study stand upright in the peat, and all are well preserved. Only in two instances were trunks observed. The first was revealed by mass peat denudation caused by the formation of the reservoir called Clatteringshaws Loch. The second was in the Inverpolly nature reserve, northwest Scotland, where only the lower side of the trunk was preserved. In general, it can be concluded that the stumps are in the position in which the tree was growing, and that the roots and base of the trunk were in conditions suitable for preservation, whereas, in most cases, the above-ground parts (trunk, needles, cones, etc.) were not preserved.

In view of the present ecological conditions in which pine grows on peat, it would appear that its former growth on peat can be regarded as indicating that the upper layers of peat were sufficiently aerated to be aerobic, due to dry surface conditions, whereas the preservation of the stumps indicates somewhat wetter conditions in the surrounding peat. However, peat has a low biological activity, and the time necessary for the decomposition of a large pine stump already below the surface may have been longer than the time it took for peat growth to raise the water table above the stump and prevent further decomposition. In general, it can be assumed that the preservation of a pine stump indicates somewhat wetter conditions than those prevailing during its life.

Whether such changes in site wetness are a result of local site changes or of regional climatic changes cannot easily be ascertained without a consideration of the regional vegetational history and local development of the peat as deduced from the results of pollen analysis and peat stratigraphy, together with a spatial and temporal analysis of the pine stumps within the area of study.

3. Methods

Six blanket peat sites containing pine stumps were selected for study, three from the Cairngorm area and three from the Galloway area.

At each site a monolith of peat was extracted from a cleaned vertical face adjacent to a pine stump. Mineral ground could not always be reached by digging, owing to flooding and collapse, so the basal parts of some of the profiles were collected with a Hiller peat borer modified to take removable liners. The monoliths and Hiller cores were sampled in the laboratory for pollen and sediment analysis. The level of the pine stump was recorded as that level just above the roots where it was estimated that the ground surface would have been during its life. The positions of any other large wood remains in the profiles were also recorded, and samples taken for radiocarbon dating.

The peat stratigraphy was described in the field, but because the peat was usually very humified, microscopic examination of the peat residues retained by a fine sieve during the preparation of pollen samples was made in the laboratory, and the abundance of the variou macroscopic components noted on a 5-point scale. Little attempt was made to identify plant cuticles, but those of *Eriophorum vaginatum* were distinctive enough to be recorded.

Samples were prepared for pollen analysis by Erdtman's acetolysis, with the addition of hydrofluoric acid treatment to remove silicates when necessary (Faegri & Iversen 1964). The preparations were mounted in glycerine jelly, and the pollen grains identified and counted with the equipment described in part I.

Pollen identifications were made to the lowest possible taxonomic level within the native British flora (Clapham *et al.* 1962). Unusual or critical pollen types are described in appendix III.

Standard pollen diagrams (figures 4, 6, 8, 12, 14 and 16) were prepared as described in part I. Local pollen diagrams (figures 5, 7, 9, 13, 15 and 17) were also prepared by using a pollen sum of all undoubtedly local pollen types. Types which may or may not be local (e.g.

Betula) or that are very erratic and may unduly influence the pollen sum (e.g. *Sphagnum*) are presented as percentages of local pollen + taxon concerned. Macrofossils and peat components are shown to the right of the local pollen diagrams as abundant, occasional, frequent, rare, absent. On the left side of all the diagrams, the peat stratigraphy is diagrammatically represented, the density of the symbols approximating to the abundance of the components. Stratigraphic symbols are shown in figure 2. The data are on file at the Botany School, University of Cambridge, and are available on request to the author.

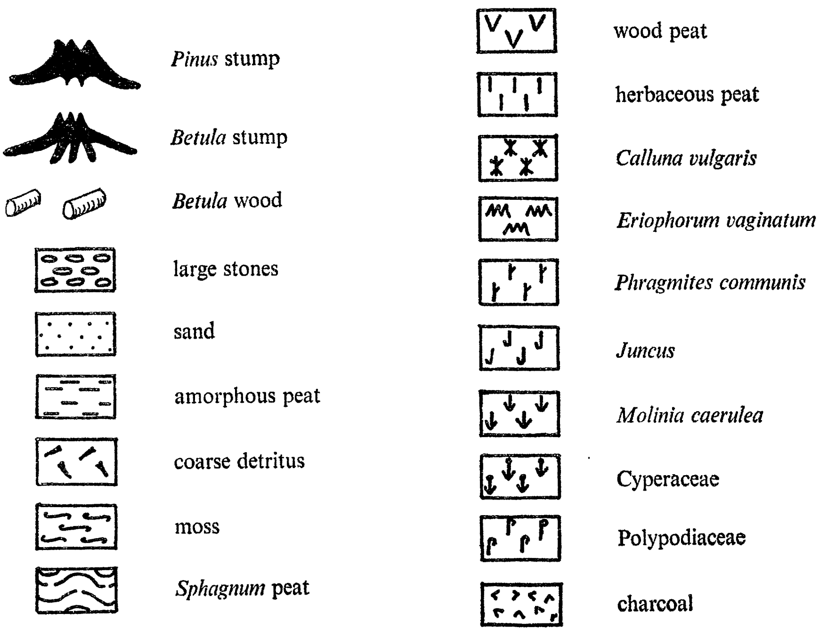

FIGURE 2. Stratigraphic symbols used to represent the sediments of the profiles in the column at the left side of the pollen diagrams. Abundance of the element is indicated approximately by the density of the symbol.

The pollen diagrams are divided into local pollen zones, according to the regions of homogeneity within them. These zones are given site designations and are numbered from the base upwards. They can be accommodated within the regional pollen assemblage zones defined in part I for the Cairngorm region, and in part II for the Galloway region, and these regional zones have been marked on the standard diagrams. Being rather broadly defined, and taking little or no account of local pollen types, a regional pollen zone may contain more than one local pollen zone.

More radiocarbon dates are required before it can be certain that the regional zones are time correlative within the areas concerned. However, the areas covered are relatively small, and the pollen diagrams within them are considered to be sufficiently consistent, with the possible exception of Coire Bog.

4. Sites in the Cairngorm region

Three pine stump sites shown in figure 3 were investigated in the Cairngorm region. The pollen diagram from Abernethy Forest in the Spey Valley (part I) showed that the Flandrian vegetational history of the area started with herbaceous vegetation, containing much *Empetrum* locally, and this was then successively colonized by *Juniperus*, *Betula*, and *Corylus*. Later at about 7000 B.P. *Pinus* became the dominant dry-land tree, and remained so until the present day, except where man has removed it during forest clearances. The pollen diagrams from other nearby sites and from the pine stump sites confirm this picture. However, the pollen diagram from Coire Bog, 70 km (44 miles) north of Allt na Feithe Sheilich, is somewhat different, possibly due to local influences of the peat vegetation, or because the regional history of the area, as yet unknown, is different. The regional pollen assemblage zones are not applied to the lower part of this sequence (figure 8).

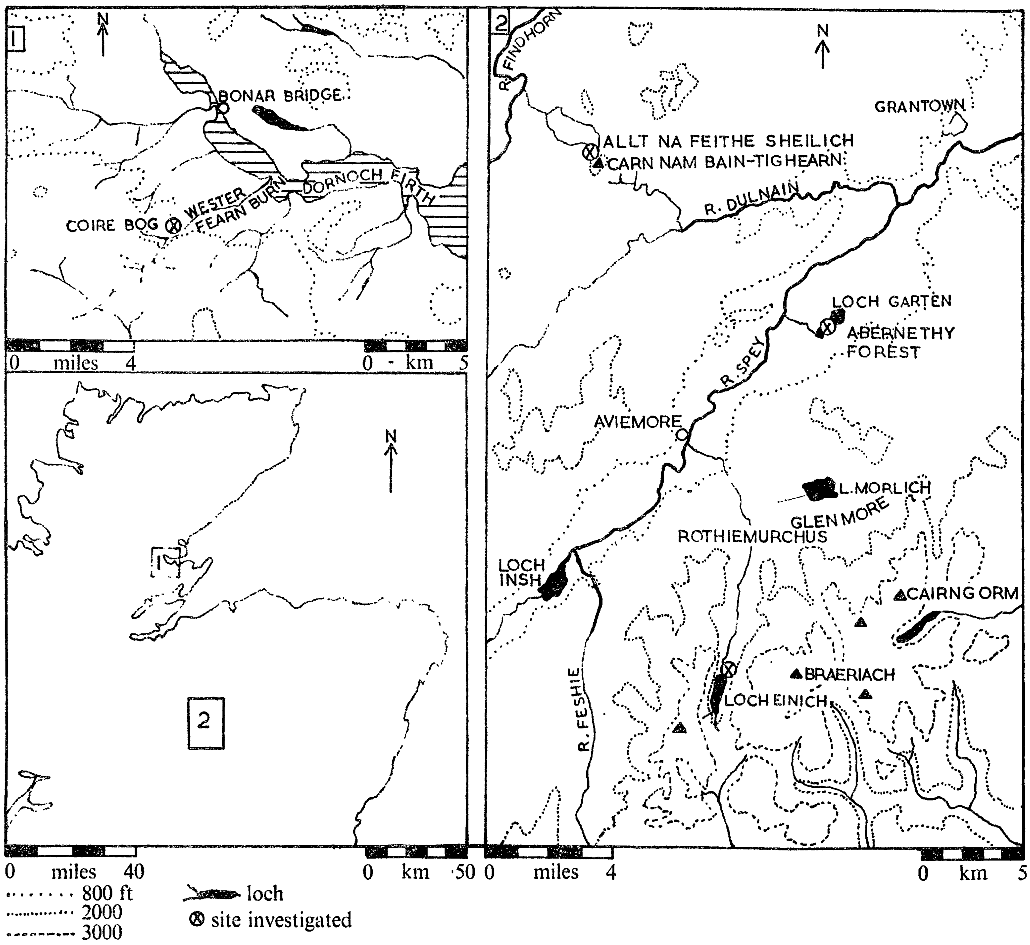

FIGURE 3. Map of the Cairngorm area to show the positions of the sites investigated.

(*a*) *Allt na Feithe Sheilich*

(i) *Site description*

The site of Allt na Feithe Sheilich is situated north of the Cairngorms on the Monadhliath plateau near the summit of Carn nam Bain Tighearn (Nat. Grid Ref. 28/8526; lat. 57° 19′ N; long. 3° 54′ W; altitude 595 m (1950 ft) O.D.).

The source of the stream (Allt) is in a large area of blanket bog on the watershed, which is currently being eroded by back cutting of the stream channels. The site corresponds to the site called 'Spey-Findhorn Watershed' by Lewis (1906). He recorded two layers of pine stumps with birch below in two sections, and one layer of pine stumps with birch below in a third.

Samuelsson (1910) disagreed with his observations, as he only found one layer of pine stumps. In the present investigation, only one layer of pine stumps was found, mixed with birch, and an indistinct birch-*Calluna* horizon above.

The blanket bog vegetation is typical Calluneto-Eriophoretum (Pennine blanket bog, McVean & Ratcliffe 1962) with both lichen-rich and *Sphagnum*-rich facies. Dwarf-shrub communities occur on steeper slopes, and *Rhacomitrium lanuginosum* dominates exposed rocky ground. Heavy sheep grazing is reflected in the relatively scarcity of *Calluna* heaths on the lower slopes, their place being taken by species-poor *Agrostis-Festuca* grasslands. The Allt na Feithe Sheilich descends from the plateau in a steep-sided valley. Juniper scrub is locally common in the area in spite of burning and grazing pressures. Below about 350 m (1000 ft) the stream passes remnants of birch wood with *Sorbus aucuparia*, until flatter ground is reached, where the richer alluvial soil has been enclosed as pastures.

On the plateau, erosion has cut channels in the peat up to about 4 m depth in flat areas, shallowing to 2 m and less as the slope increases. A discontinuous layer of pine stumps mixed with birch remains is revealed, with a more indistinct layer above of birch and heather twigs. The stratigraphy of the profile examined is shown diagrammatically on the left side of the pollen diagrams (figures 4, 5) and the estimates of the macroscopic components on figure 5. A general description of the stratigraphy follows:

cm	
0–70	highly humified peat penetrated by modern rootlets and containing *Sphagnum* leaves, *Eriophorum vaginatum* and *Trichophorum cespitosum* leaves, and *Calluna* stems
70–150	dark brown, highly humified *Sphagnum-Eriophorum vaginatum* peat, within a matrix of fungal mycelium
150–155	indistinct layer of birch and *Calluna* twigs
155–170	humified *Sphagnum* peat containing *Betula* wood fragments and *Eriophorum vaginatum* leaves
170–180	pale amorphous humified peat with wood fragments and occasional *Calluna* stems
180–195	dense wood peat containing pine and birch stumps
195–230	humified *Sphagnum-Eriophorum vaginatum* peat containing a few wood fragments of *Betula* and *Salix*
230–325	humified *Sphagnum-Eriophorum vaginatum* peat with wood fragments of *Betula* and *Salix*, some of them carbonized, becoming abundant downwards, mixed with monocotyledonous detritus. Trigonous nut of *Carex* sp. at 320 cm
325–	gravel

(ii) *Local vegetational development at Allt na Feithe Sheilich*

The standard pollen diagram is presented in figure 4, and the local pollen diagram in figure 5. Local pollen zones have been designated AFS- and numbered from the base upwards. The regional pollen assemblage zones for the Cairngorm region are also marked on figure 4.

Zone AFS-1; 310–325 cm

Tree pollen, dominated by *Betula*, is about 20–30 % of the total. *Salix* and *Juniperus communis* pollen values are high, and *Empetrum* pollen is abundant. Cyperaceae and Gramineae are the dominant herb pollen types, but there is a wide variety of other herbs including *Rumex acetosa* type, *Potentilla* type, and other taxa of damp soil, and several pollen types from plants of open ground.

The peat started to accumulate on stony mineral ground, presumably in poorly-drained hollows. The relatively high values of *Juniperus* pollen suggest that flowering juniper occurred near the site, perhaps associated with birch. However, open, fairly species-rich grasslands also occurred, as suggested by the pollen and spores of Gramineae, *Rumex acetosa* type, *Ranunculus acris* type, *Saussurea alpina*, *Campanula* type, *Lotus*, *Thalictrum*, *Botrychium lunaria*, and *Lycopodium clavatum*. More acid, heathy communities may be represented by *Empetrum* and *Potentilla* type pollen.

In the waterlogged hollow, a fen carr community developed with *Salix* and possibly *Betula*, and with an understorey rich in *Sphagnum*, possibly shade tolerant species such as *S. fimbriatum*, *S. palustre*, *S. squarrosum*, and *S. recurvum*. Such *Sphagna* often fruit freely under open shade. The community was mesotrophic, as shown by the finds of pollen of many fen plants: *Filipendula*, *Epilobium*, *Caltha* type, *Ranunculus trichophyllus* type, *Stellaria* type, *Lotus*, *Silene dioica* type, *Angelica* type, *Vicia* type, and *Valeriana officinalis*. High values of Cyperaceae pollen could have been produced by *Eriophorum vaginatum* or more likely by *Carex* spp., as a nut of *Carex* was recovered. In surface samples from wet birch woods, Cyperaceae pollen can be abundant, usually produced by sedges such as *Carex remota* or *C. sylvatica* (H. J. B. Birks 1973).

Zone AFS-2; 275–310 cm

Betula continues as the major pollen type, but the principal feature of the zone is the very high *Empetrum* pollen values. Most of the herb pollen taxa of zone AFS-1 are absent, and *Salix* pollen values are low.

Size measurements of the *Empetrum* pollen fall within the range of modern reference material of *Empetrum nigrum* (Birks 1969). Such high values of *Empetrum* pollen imply the local presence of *Empetrum*. In surface pollen spectra from Scotland, it is found that *Empetrum* spp. in bog communities produce relatively little pollen, and that it is not dispersed far in any quantity (Birks 1969). Similarly, although high pollen values are found in surface samples from *Empetrum* heath communities in Greenland and arctic Canada, the pollen is not dispersed far, in spite of *Empetrum* being wind pollinated (Fredskild 1967; Bartley 1967). The high *Empetrum* pollen values at Abernethy Forest in the Spey Valley probably originated from communities of mineral soil (part I). However, *Empetrum* can grow in a relatively wet *Sphagnum* carpet under shade, as seen until a recent flooding at Wybunbury Moss, Cheshire, where it grew abundantly under pines in a *Sphagnum* mat. At Allt na Feithe Sheilich, the high *Empetrum* pollen values are associated with a peak of *Calluna vulgaris* pollen (most distinct on the local diagram, figure 5), the pollen of mesotrophic plants being absent or at a minimum. Perhaps a community similar to that which occurred at Wybunbury Moss developed, with *Empetrum* and *Calluna* growing in a *Sphagnum* carpet under birches and willows.

Zone AFS-3; 215–275 cm

Betula remains the dominant pollen type. *Empetrum* and *Calluna* pollen values are low and herb pollen values are high, the most abundant being Gramineae, Cyperaceae, and *Melampyrum*, but with many other taxa also being well represented.

Although herb pollen becomes abundant once more in this zone, the amount ascribable to open ground taxa, such as those found in zone AFS-1, is very small, indicating that peat or forest had covered most of the landscape near the site, thereby restricting the occurrence of shade intolerant herbs and also juniper.

The declining values of *Calluna* and *Empetrum* pollen are replaced by a wide range of pollen representing mesotrophic fen plants, including all those present at the beginning of peat formation, and with the addition of *Viburnum opulus* in the canopy, and of *Cirsium* type, *Lychnis flos-cuculi*, *Melampyrum*, and *Menyanthes trifoliata* in the understorey. The peat stratigraphy indicates that *Eriophorum vaginatum* may have been important in producing the Cyperaceae pollen, although in surface samples from bogs, its representation appears to be relatively poor (Birks 1969). *Molinia caerulea* or *Deschampsia cespitosa* may have contributed to the high Gramineae pollen values. *Melampyrum* is the most abundant pollen type among the other herbs, constituting up to 30 % of the local pollen sum (figure 5). It probably originated from *Melampyrum pratense* growing abundantly in the *Sphagnum*-rich fen-wood. It is found in such situations at the present day, for example at Biglands Bog, Cumberland in a *Sphagnum magellanicum* carpet under birches (D. A. Ratcliffe, personal communication), and at Wybunbury Moss, Cheshire in a *Sphagnum recurvum* carpet under pines, where a form with a red-tinted corolla occurs (Smith 1963). In surface pollen samples from contemporary *Melampyrum pratense* communities, *Melampyrum* pollen is nearly always recorded, and presence of more than one or two grains always indicates local presence of the plant (Birks 1969).

This assemblage from Allt na Feithe Sheilich closely resembles 'lagg' communities described by Sjörs (1948) from Sweden. He records an open canopy of *Betula pubescens* and *Salix aurita* or *S. pentandra* with occasional *Pinus sylvestris*. In the species-rich facies *Calluna vulgaris*, *Cirsium heterophyllum*, *Drosera anglica*, *D. rotundifolia*, *Empetrum nigrum*, *Epilobium palustre*, *Eriophorum angustifolium*, *E. latifolium*, *E. vaginatum*, *Filipendula ulmaria*, *Galium palustre*, *Menyanthes trifoliata*, *Molinia caerulea*, *Potentilla erecta*, *P. palustris*, *Succisa pratensis*, *Valeriana sambucifolia*, and *Viola palustris* occur together in the understorey. The moss layer is dominated by *Sphagnum recurvum* or *S. warnstorfianum*. In more acid situations, the community is more species poor, and constant members include *Empetrum nigrum*, *Vaccinium oxycoccus*, *Carex pauciflora*, *Eriophorum vaginatum*, *Sphagnum magellanicum*, *S. recurvum*, *S. robustum*, *Aulacomnium palustre*, and *Acrocladium stramineum*. Other common components include *Calluna vulgaris*, *Melampyrum pratense*, and *Carex nigra*. Similar communities are fragmentary in the British Isles today, but examples can be seen at Abbots Moss, Cheshire, Flitwick Moor, Bedfordshire, Malham Tarn Moss, Yorkshire, and Unity Bog, Cumberland. Perhaps such communities were once considerably more widespread in upland Britain, and they have either been destroyed by man's activities, or buried by the growth of blanket peat in antiquity, leaving little trace except wood of birch and willow at the bottom of the peat profiles. Examples of this process are described by Pennington (1965) from the English Lake District, and by Moore (1973) from mid-Wales.

Zone AFS-4; 190–215 cm

Pinus sylvestris pollen is abundant, exceeding the *Betula* pollen values which, however, remain high. *Salix* pollen frequencies are reduced. Herb pollen, particularly *Melampyrum*, is almost absent. However, *Calluna* pollen frequencies are high and *Empetrum* is well represented. *Sphagnum* spore values are relatively low.

Calluna remains occur in the peat of this zone, and at the top there is a pine stump with associated birch remains, dated to 6960 ± 130 B.P. (K-1419).

The changes in the pollen diagram indicate that the mire community had become more

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acid, eliminating the fen herbs of zone AFS-3, and also drier, allowing *Calluna* with some *Empetrum* to dominate the understorey. Pine had occupied the landscape at the beginning of the *Pinus* regional pollen assemblage zone (AFS-4), and it colonized the peat surface shortly afterwards. The pine-*Sphagnum*-dwarf shrub dominated bog may have been similar to the communities described by Poore and Walker (1959) from Wybunbury Moss, Cheshire, to communities at Chartley Moss, Staffordshire, and to the pine-grown bogs of Scandinavia (see, for example, Sjörs 1948). Poore & Walker (1959) suggest that the invasion of the pine on to Wybunbury Moss caused acidification and drying out, thereby allowing *Empetrum nigrum* to flourish. However, in view of the peat stratigraphy at Allt na Feithe Sheilich, it is more likely that acidification and drying, favouring *Empetrum* and *Calluna*, produced conditions suitable for pine colonization. The lower *Betula* pollen values apparent at this time (figure 4) are an artefact of the sum AP method of calculation, for in figure 5 they remain high. Birch still grew on the peat, as birch logs are found at the same level as the pine stumps. However, no large birch remains were found below this level, either due to poor growth of the trees, or to decay of the wood in the mesotrophic environment.

Zone AFS-5; 169–190 cm

Pollen of *Pinus* and *Betula* remain abundant, but values of *Empetrum* and *Calluna* are relatively low. The herb pollen proportion increases, and its composition is similar to that of zone AFS-3. However, values of *Valeriana officinalis* and *Silene dioica* type are very low, and those of *Filipendula*, Cyperaceae, *Melampyrum*, and *Salix* are lower than in zone AFS-3. The values of Gramineae and *Menyanthes trifoliata* pollen are about the same, and those of *Potentilla* type pollen and *Sphagnum* spores are much higher. In addition, pollen of *Sparganium* type and *Succisa pratensis* are present for the first time.

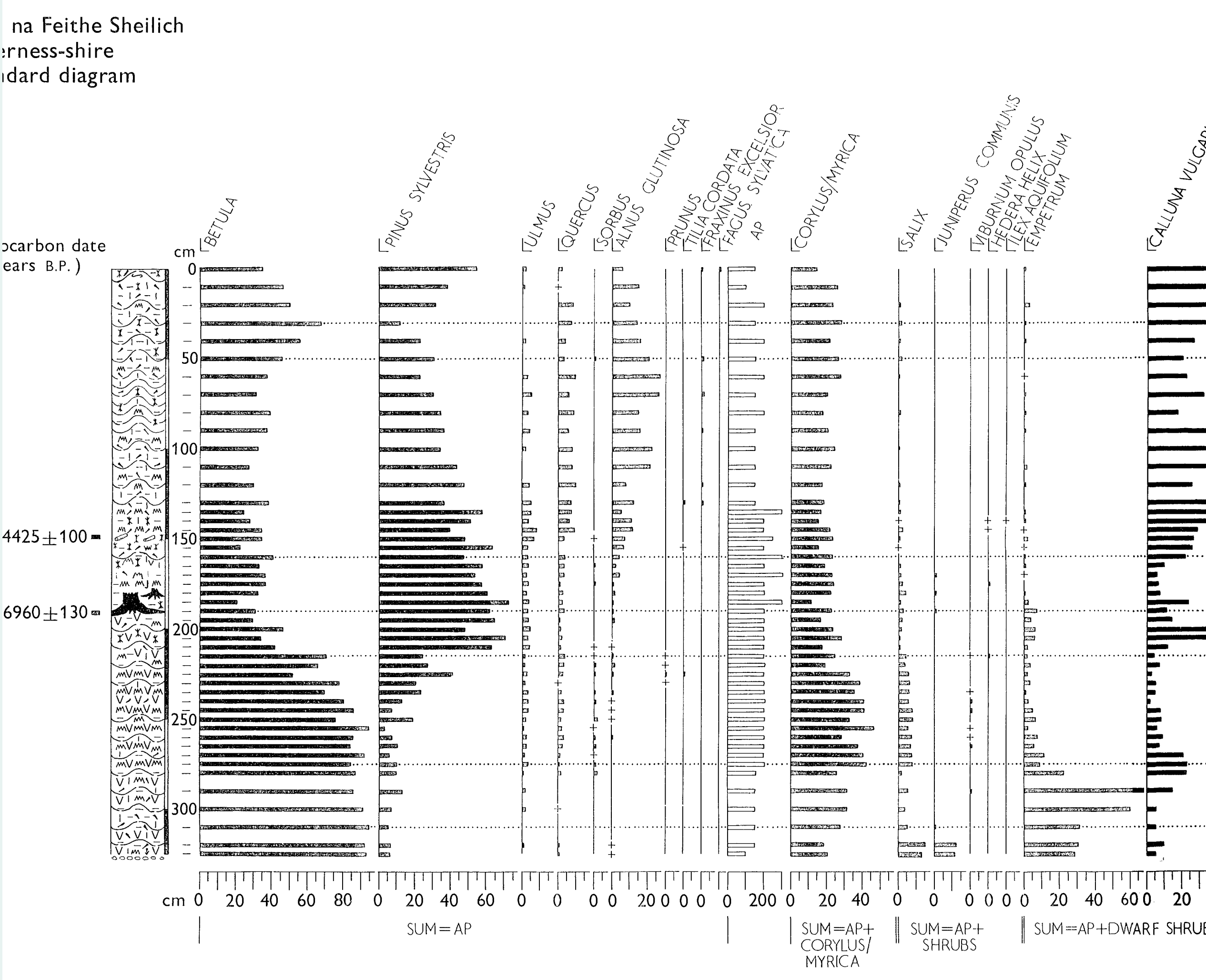
These changes above the layer of pine and birch timber suggest that the mire surface became wetter, killing the trees. Perhaps the increased light encouraged the fruiting of *Sphagnum*, together with its fungal parasite, *Tilletia sphagni*. The reappearance of pollen of fen plants indicates the development of a community similar to that of zone AFS-3, but perhaps of a more acid nature with an increased abundance of *Potentilla* type (possibly *P. erecta* or *P. palustris*) and with the addition of *Succisa pratensis*.

Zone AFS-6; 50–160 cm

Betula and *Pinus* are the dominant tree pollen types, but *Alnus* frequencies increase. *Calluna* pollen values are high throughout, but those of *Empetrum* are very low. Herb pollen values are low, except for a small peak of Cyperaceae, and the total number of taxa is small.

A rather indistinct layer of birch and *Calluna* remains, dated to 4425 ± 100 B.P. (Q-886), occurs in the peat at 150–155 cm, associated with a peak of carbonized fragments. This suggests that the peat surface became drier, and was perhaps burned, or at least exposed to aerial oxidation. Although *Calluna* and birch grew on the surface, pine did not recolonize the site. Perhaps the substrate was unsuitable for pine seedling establishment, or perhaps seed sources were too far away for colonization to occur.

Just above the woody layer *Eriophorum vaginatum* remains are common in the peat, associated with a peak of Cyperaceae pollen. Wood remains cease to be present. *E. vaginatum* probably dominated the peat vegetation, and was associated with *Drosera*. The presence of *Sparganium* type pollen is ecologically inexplicable unless *Sparganium minimum* or *S. angustifolium* were



...na Feithe Sheilich
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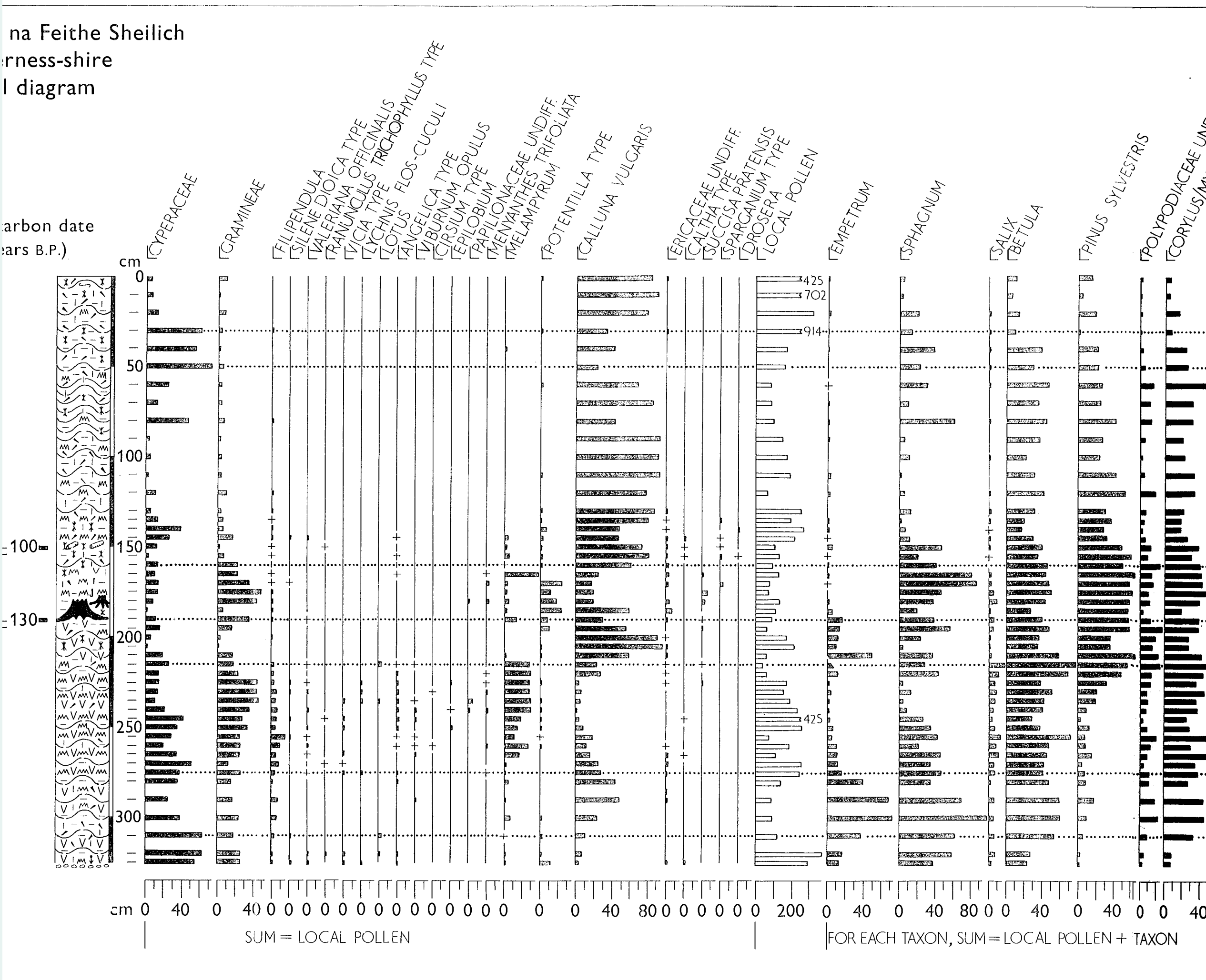
4425±100
6960±130
cm
BETULA
PINUS SYLVESTRIS
ULMUS
QUERCUS
SORBUS
ALNUS GLUTINOSA
PRUNUS
TILIA CORDATA
FRAXINUS EXCELSIOR
FAGUS SYLVATICA
AP
CORYLUS/MYRICA
SALIX
JUNIPERUS COMMUNIS
VIBURNUM OPULUS
HEDERA HELIX
ILEX AQUIFOLIUM
EMPETRUM
CALLUNA VULGAR...
SUM=AP
SUM=AP+CORYLUS/MYRICA
SUM=AP+SHRUBS
SUM=AP+DWARF SHRUB...



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cm
CYPERACEAE
GRAMINEAE
FILIPENDULA
SILENE DIOICA TYPE
VALERIANA OFFICINALIS
RANUNCULUS TRICHOPHYLLUS TYPE
VICIA TYPE
LYCHNIS FLOS-CUCULI
LOTUS
ANGELICA TYPE
VIBURNUM OPULUS
CIRSIUM TYPE
EPILOBIUM
PAPILIONACEAE UNDIFF.
MENYANTHES TRIFOLIATA
MELAMPYRUM
POTENTILLA TYPE
CALLUNA VULGARIS
ERICACEAE UNDIFF.
CALTHA TYPE
SUCCISA PRATENSIS
SPARGANIUM TYPE
DROSERA
LOCAL POLLEN
EMPETRUM
SPHAGNUM
SALIX
BETULA
PINUS SYLVESTRIS
POLYPODIACEAE UN...
CORYLUS/M...
425
702
914
SUM = LOCAL POLLEN
FOR EACH TAXON, SUM = LOCAL POLLEN + TAXON

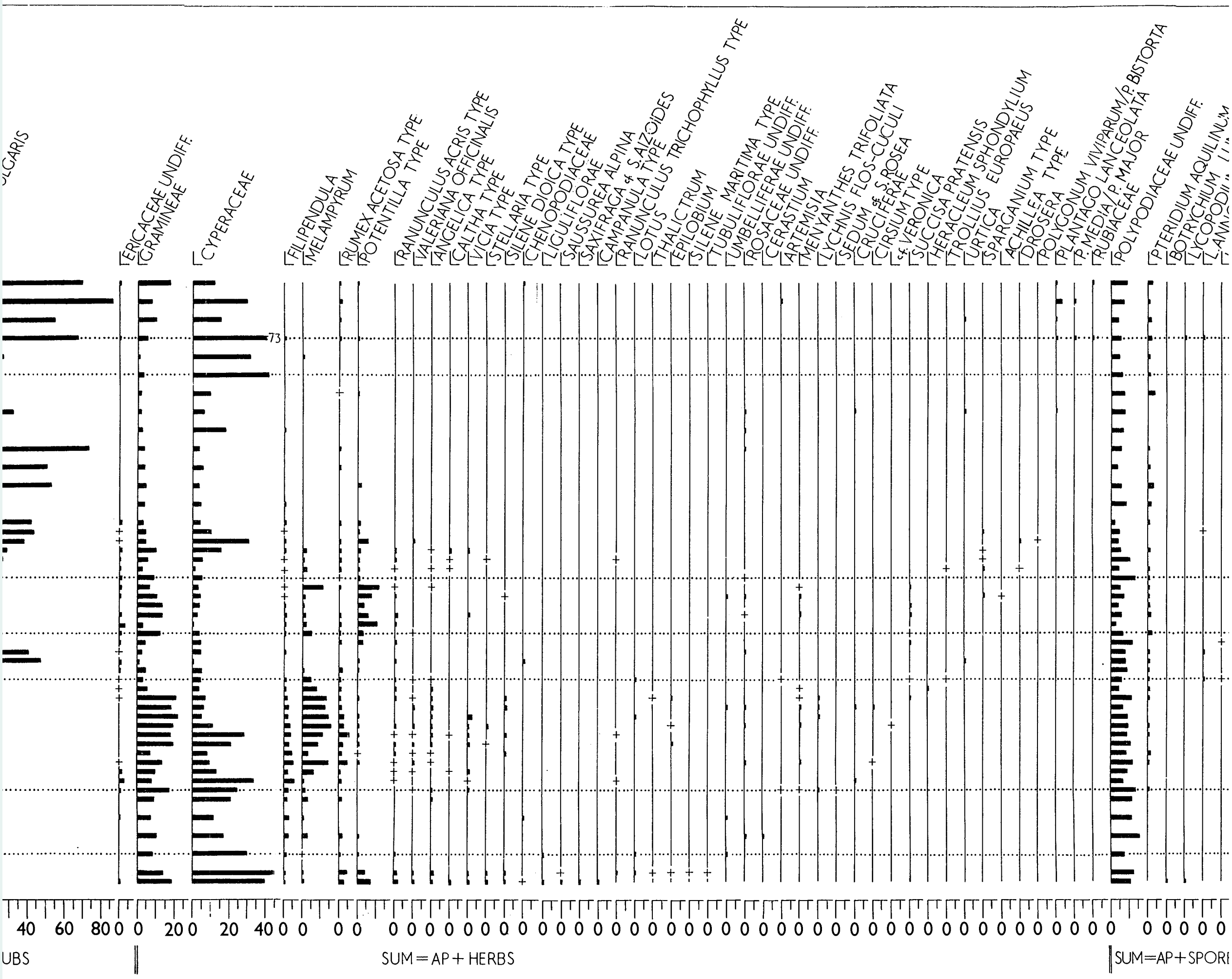

FIGURE 4. Standard pollen d
pollen (AP). For the su
dophyte spores = 100 %
symbols see figure 2.

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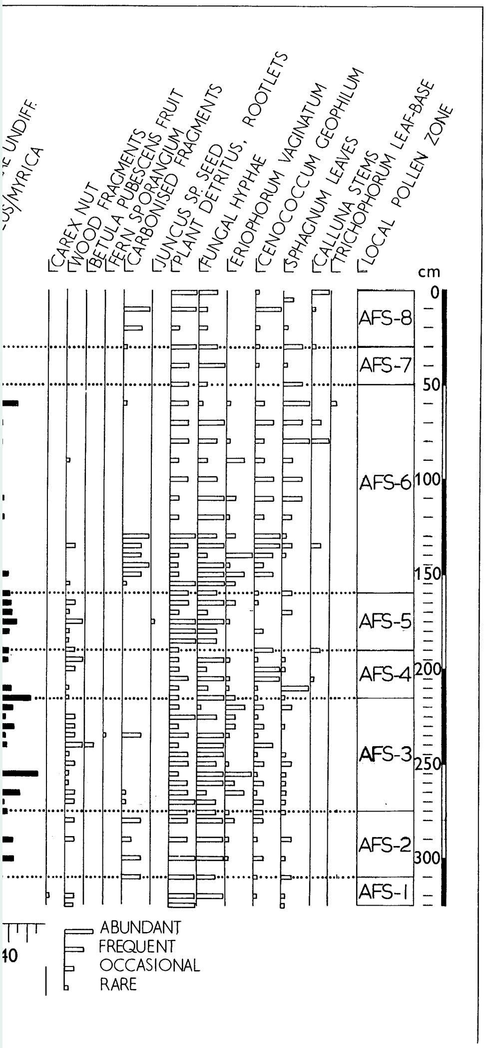

FIGURE 5. Local pollen diagram from Allt na Feithe Sheilich, Inverness-
pollen, which includes the types indicated. Abundance of macrofossil
ferentiated. For key to stratigraphic symbols see figure 2.

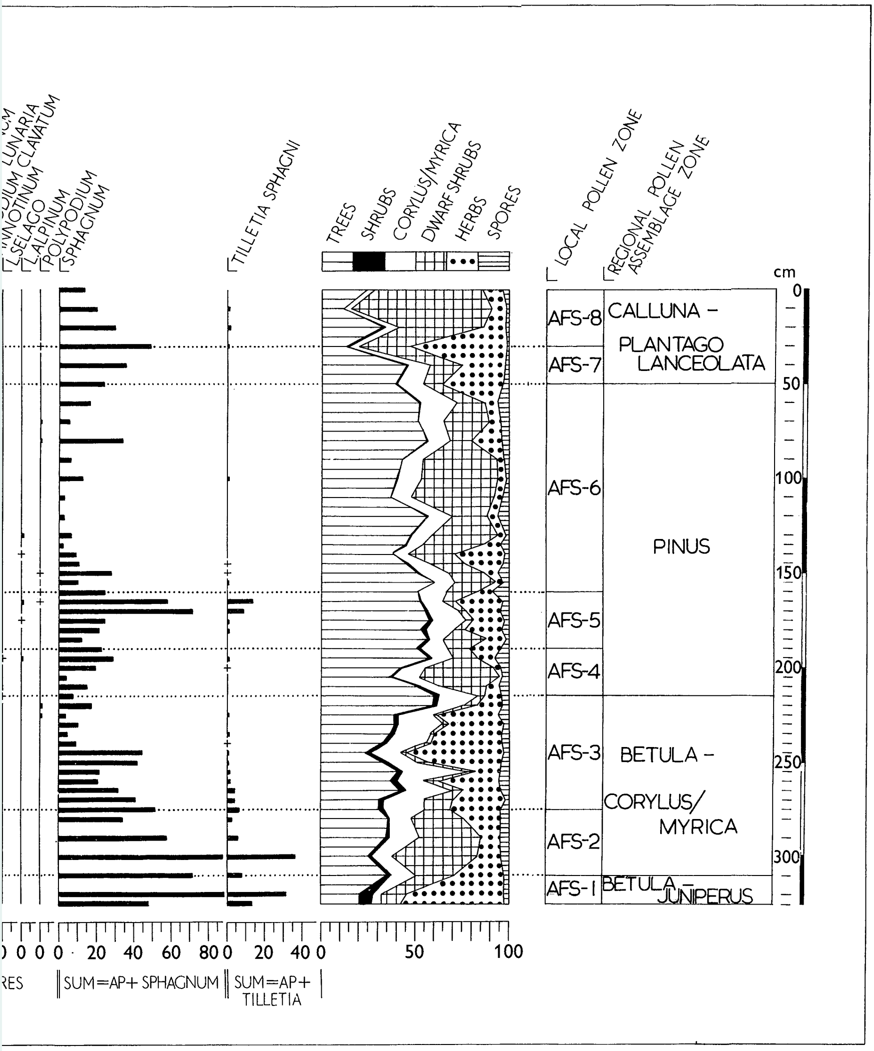

diagram from Allt na Feithe Sheilich, Inverness-shire. Calculation base is sum of tree
ımmary diagram, sum of AP + shrubs + *Corylus*/*Myrica* + dwarf shrubs + herbs + pteri-
%. Undiff., Undifferentiated; B.P., before present (i.e. 1950). For key to stratigraphic

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-shire. Calculation base is sum of local
ils shown as white bars. Undiff., Undif-

och Einich
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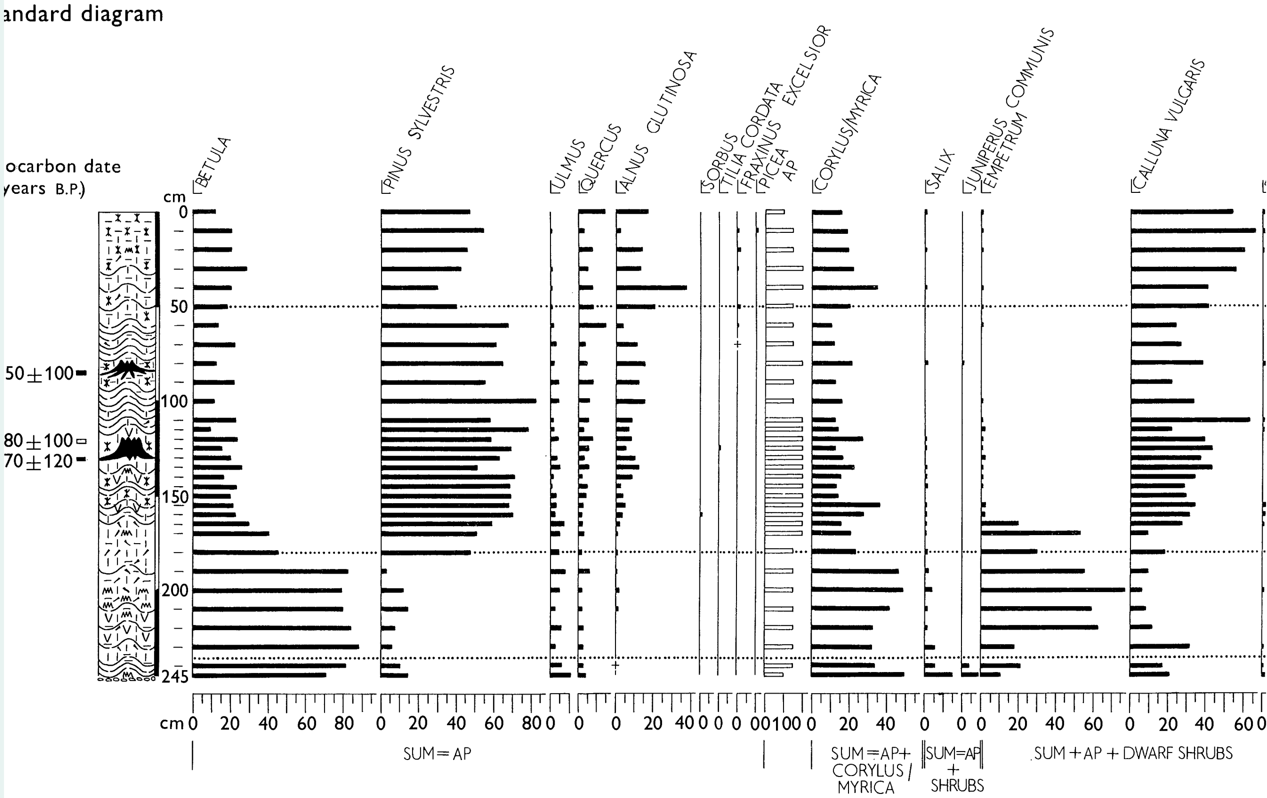
andard diagram



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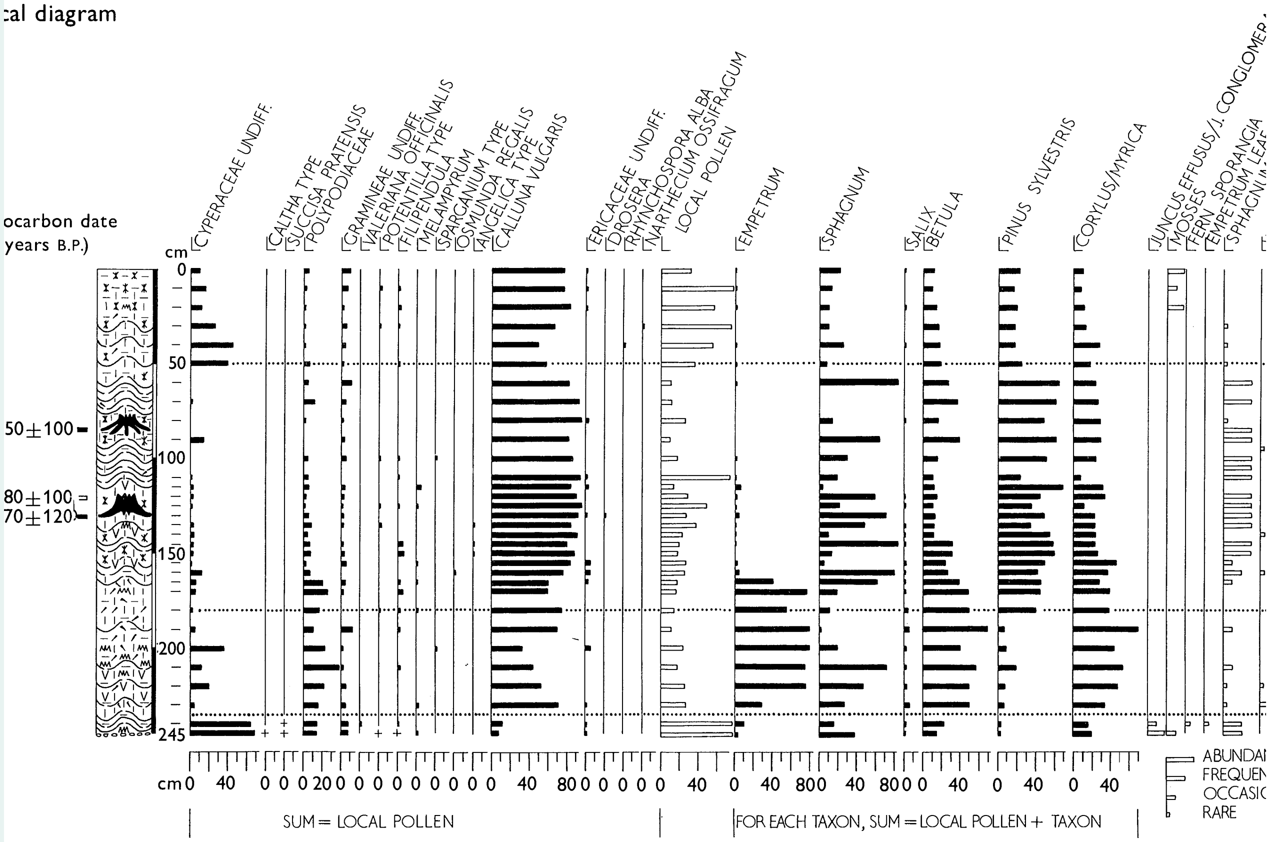

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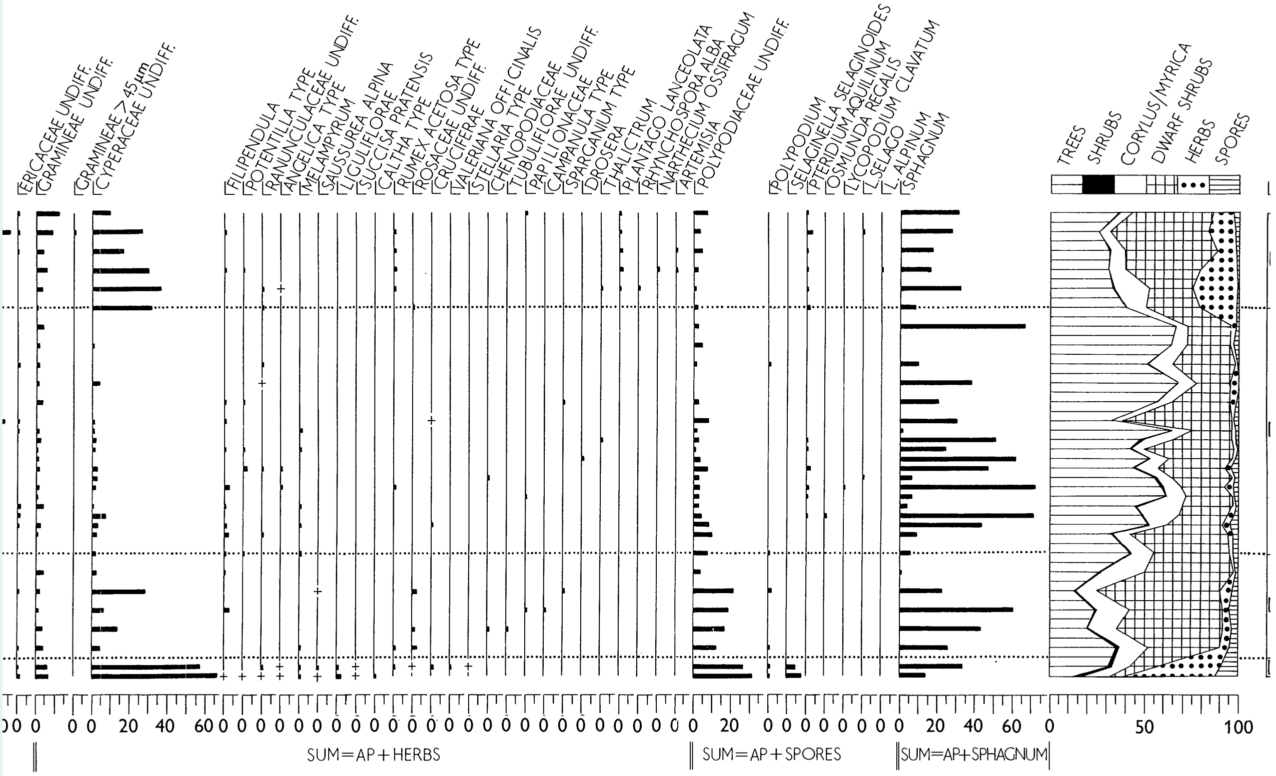


Figure 6. Standard pollen diagram from Loch Einich, Inverness-shire. Calcula (AP). For the summary diagram, sum of AP + shrubs + *Corylus*/*Myrica* + dwar spores = 100 %. Undiff., Undifferentiated; B.P., before present (i.e. 1950). F see figure 2.

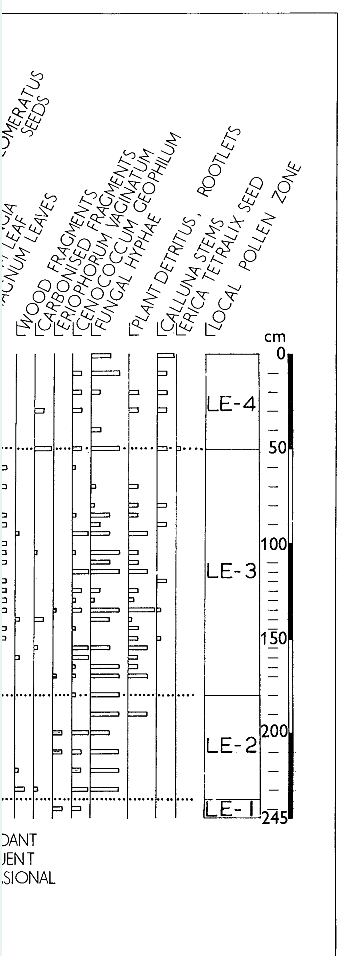
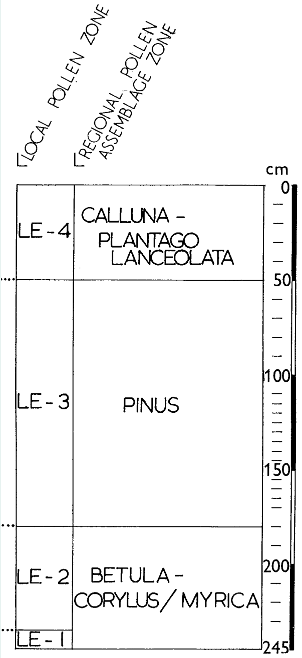


Figure 7. Local pollen diagram from Loch Einich, Inverness-shire. Calculation base is su includes the types indicated. The abundance of macrofossils is shown by white ba tiated. For key to stratigraphic symbols see figure 2.



lation base is sum of tree pollen
arf shrubs + herbs + pteridophyte
For key to stratigraphic symbols

um of local pollen, which
ars. Undiff., Undifferen-

growing in some nearby peaty pools. *Sparganium* type pollen is known to be well dispersed in Scotland (H. J. B. Birks 1973), but its stratigraphic restriction here suggests that it may not have been a part of the regional pollen rain. Pollen of a few fen herbs, such as *Angelica* type, *Caltha* type, *Filipendula*, and *Silene dioica* type suggest that mesotrophic fen communities occurred not far from the site, but were unlikely to have been present at the sampling point. Tree growth had ceased on the bog surface, perhaps due to the increased wetness of the peat, and pollen of such taxa may have been dispersed from nearby sources. Similarly the relative representation of more distant pollen sources increased, for example *Alnus glutinosa* which was probably growing in waterlogged mesotrophic sites in the valleys below.

After the phase of *E. vaginatum* abundance, ombrotrophic peat growth commenced, formed by a community dominated by *Calluna*, *Sphagnum*, and *E. vaginatum* which may have resembled modern Calluneto-Eriophoretum bogs. This community is common today in plateau situations in the Eastern Highlands (McVean & Ratcliffe 1962) and is the bog community of the Allt na Feithe Sheilich watershed today.

Zone AFS-7; 30–50 cm

Tree pollen values fall, Cyperaceae is the dominant pollen type, and *Calluna* values are high.

Pollen of weed species, such as *Plantago lanceolata*, appear during this zone, suggesting that the forests in the vicinity were being cleared by man. However, peat growth was not affected, although it may have been deteriorating, as high values of Cyperaceae pollen in surface samples from bogs often occur where *Trichophorum cespitosum* is common (Birks 1969), and a leaf base of *Trichophorum* was recovered from the peat at 60 cm.

Zone AFS-8; 0–30 cm

Tree pollen values are very low. *Calluna* is the dominant pollen type, Cyperaceae values having decreased considerably, especially when calculated on a local pollen sum. *Sphagnum* spore values are also lower than in zone AFS-7, and pollen of weeds and *Rumex acetosa* type are present.

The bog surface probably dried out during this zone to its present condition, as indicated by the abundance of *Calluna* pollen and also the presence of carbonized fragments, probably resulting from direct burning or blowing from moor-burning nearby. The increase of Gramineae pollen and presence of *Rumex acetosa* type indicate that the dwarf-shrub heaths were being converted to grasslands by excessive burning, a process still occurring in the area. The peat sequence may not reach the present day due to the erosion which is occurring largely as a result of man's activities.

(*b*) *Loch Einich*

(i) *Site description*

The site here called Loch Einich is situated at the north end of Loch Einich (Nat. Grid Ref.: 28/919001; lat. 57° 05′ N; long. 3° 48′ W; altitude 502 m (1650 ft) O.D.), in the Cairngorms National Nature Reserve (figure 3). Glen Einich is a glacial valley, about 3.8 km (6 miles) long, cut deep into the western Cairngorm massif between Braeriach and Carn Ban Mor. The floor of the lower part of the Glen contains extensive fluvioglacial terraces, commented upon by Sissons (1967). Loch Einich itself occupies the upper end of the valley, lying between the ferocious 610 m (2000 ft) cliffs of Sgorr Gaoith to the west, and the lesser cliffs and corries of Braeriach to the east.

The vegetation of Glen Einich reflects the acid soils developed from the till and granitic bedrock. The native pinewoods of Rothiemurchus ascend to 412 m (1350 ft). This is not the natural tree limit, for, on Creag Fiachlach in Glen Feshie to the west, pine shows a more or less natural tree line at about 610 m (2000 ft). McVean (1963*a*) has constructed a map of Glen Einich to show the broad distribution of vegetation types if man had never affected the area. He suggests that the whole glen would have been wooded, with open bog forest on the valley floor, and dense pine forest on the steeper slopes round the Loch and on the northwest flank of Braeriach. Pears (1968) estimates that the present day natural tree-line would lie between 610 and 686 m (2000 and 2250 ft).

However, man has been cutting and clearing the forest for a very long time, and today the upper valley is treeless. Flat ground is covered by Trichophoreto-Callunetum bog, and better drained slopes bear a mosaic of Callunetum vulgaris and species-poor *Agrostis-Festuca* grassland. At higher altitudes other dwarf-shrub heaths or grass heaths are found, depending upon exposure, snow-lie, or the brokenness of the ground.

The cliffs at the head of Loch Einich are basic metamorphosed moine schist, and their flora and vegetation are a striking contrast to the surrounding granite with abundant basiphilous tall herbs and montane willows. Several rare mountain plants occur (Birks 1969), and together with the basic cliffs in Glen Feshie, the whole area is of considerable floristic and vegetational interest.

In the hummocky, ill-drained topography around the outflow of Loch Einich, deep blanket-peat has developed. This is extensively eroded at present, and a layer of pine stumps, with an upper layer of birch remains, is exposed. A peat profile was sampled adjacent to a pine stump. The peat composition, as assessed by microscopic examination of peat residues from pollen samples, is shown on the left side of the pollen diagrams (figures 6, 7). Estimates of the various macroscopic components are shown in figure 7. A general description of the stratigraphy follows:

cm	
0–80	highly humified blanket peat penetrated by modern rootlets at the top; the components are very decayed, and include *Calluna* stems and leaves, *Sphagnum* leaves, and *Eriophorum vaginatum* leaves; *Rhacomitrium lanuginosum* abundant at surface
80–85	layer of birch twigs and branches surrounded by a black humus 'soil'
85–130	humified *Sphagnum* peat with occasional *Calluna* stems
130–140	layer of pine stumps surrounded by a black humus 'soil'
140–235	humified, paler brown, *Sphagnum* peat, with occasional *Eriophorum vaginatum* and wood fragments
235–245	humified *Sphagnum* peat with *Eriophorum vaginatum* rhizomes and leaves and *Juncus effusus* or *J. conglomeratus* seeds, moss fragments of *Mnium* cf. *M. pseudopunctatum* and cf. *Pleurozium schreberi*, one leaf of *Empetrum*, and a few fern sporangia
245–	gravel

(ii) *Local vegetational development at Loch Einich*

The pollen diagrams are divided into local pollen zones, designated LE- and numbered from the base upwards. They are shown on the standard pollen diagram (figure 6) and the local pollen diagram (figure 7), and the regional pollen assemblage zones are shown on the standard diagram (figure 6).

The Loch Einich site differs from Allt na Feithe Sheilich in that it is a valley site rather than a plateau site. Peat began to form at the time of the *Betula-Corylus/Myrica* regional pollen assemblage zone in waterlogged hollows in the till at the north end of Loch Einich.

Zone LE-1; 235–245 cm

At the base of the peat, *Sphagnum* remains and *Juncus effusus/J. conglomeratus* seeds are common, and are accompanied by moss remains of cf. *Pleurozium schreberi* and *Mnium* cf. *M. pseudopunctatum*. Cyperaceae is the most abundant pollen type, and several mesotrophic fen herbs are represented. *Juniperus communis* and *Salix* pollen have their highest percentages in this zone when calculated on the basis of AP (figure 6).

The local peat-forming community may have resembled the *Juncus effusus-Sphagnum* mire (Sphagneto-Juncetum effusi) of McVean & Ratcliffe (1962). Characteristic components of this community are *Juncus effusus*, *Sphagnum recurvum*, *Carex nigra*, *Galium saxatile*, *Potentilla erecta*, and *Polytrichum commune*. Occasional species include *Eriophorum vaginatum*, *Ranunculus acris*, *Rumex acetosa*, *Stellaria alsine*, *Succisa pratensis*, *Leontodon autumnalis*, *Pleurozium schreberi*, and other *Sphagnum* spp.

Pollen of other mesotrophic fen herbs in zone LE-1 may have originated from plants growing locally, in which case the community may have no close modern analogue, or from plants in other habitats nearby. Similarly, the *Salix* pollen may have been produced by plants growing locally in the mire, or by streamsides and on the nearby cliffs. Juniper probably grew with birch on well-drained mineral ground on ridges and slopes. *Selaginella selaginoides* occurred nearby, probably in open flushes, from where its spores could have been water-transported into the soligenous *Juncus* community.

Zone LE-2; 180–235 cm

Betula is the dominant tree pollen type, and values of *Corylus/Myrica* are also high. However, *Empetrum* and *Calluna* are the most abundant pollen types on a total pollen basis (figure 6, summary diagram). Cyperaceae values are low and erratic, and *Salix*, Gramineae undiff., and other herb pollen types have very low values.

The peat composition indicates that the *Juncus* mire became overgrown by *Sphagnum*, possibly because water flow was impeded by peat growth downslope. Wood remains in the peat and the abundance of *Betula* pollen indicate that birch grew on the site. The pollen assemblage, with high values of *Empetrum* pollen (size measurements by Birks (1969) indicate that the pollen was produced by *E. nigrum*) together wih *Calluna* could have been produced by a similar community to that envisaged during zone AFS-2 at Allt na Feithe Sheilich, with *Empetrum* and *Calluna* growing under birches on the mire surface, as well as on the surrounding drier slopes.

Zone LE-3; 50–180 cm

Pinus sylvestris is the dominant pollen type, with a reduction in *Betula* and *Corylus/Myrica* pollen. *Calluna* is the dominant local pollen type. *Empetrum* decreases sharply near the beginning of the zone. *Sphagnum* spores have high values.

Pine colonized the area at the beginning of the zone, which corresponds with the *Pinus* regional pollen assemblage zone, and probably occupied all available habitats, at the expense of birch and hazel on the drier slopes up to its altitudinal limit.

During zone LE-3, the bog appears to have been growing actively, with *Sphagnum* playing an important role. For some reason, *Empetrum* ceased to grow in abundance on the bog, leaving *Calluna* as the dominant dwarf-shrub. Perhaps the present pattern of communities had become established at this time, implying that *Empetrum* would have its greatest abundance above the altitudinal limit of *Calluna*. However, *Empetrum hermaphroditum* is the most abundant species at these altitudes today, and Empetreto-Eriophororetum blanket bog does not occur below about 763 m (2500 ft) in the Cairngorms. *Empetrum nigrum* occurs locally at lower altitiudes as a component of dwarf-shrub heaths. It is disappointing that the pollen diagram from 918 m (3010 ft) on the plateau at the head of Glen Einich by Pears (1968; figure 4) does not differentiate within 'Ericaceae' pollen. Many unanswered questions remain about the Flandrian *Empetrum* pollen record in the Cairngorm area, particularly the nature of the very high values, and the reason for their abrupt decline at different times in different places.

At about 6000 B.P. conditions became favourable for colonization of the bog surface by pine. There is little change in the pollen spectra of figures 6 or 7 to indicate the special nature of these conditions, or any reason why pine should not have colonized the bog earlier. The pine stump is in a layer of highly humified black peaty 'soil' which may represent the surface of the bog upon which it grew. The peat may have become oxidized by aeration and may have also been altered by the addition of pine needles. However, no evidence could be obtained from examination of the very decayed peat. The pine stump is dated to 5970 ± 120 B.P. (K-1418) and the black 'soil' to 5880 ± 100 B.P. (Q-881). There can be little doubt that the 'soil' was being formed during the life of the pine tree.

The reason for the death of the pine and its subsequent overgrowth by peat is unclear. The overlying peat is composed largely of *Sphagnum*, and *Sphagnum* spore values are high, so it is possible that the bog surface became wetter, and the pine died from anaerobic conditions round its roots. Similarly, regeneration would have been prevented. Pine remained abundant in the area, as there is no decrease in its pollen values.

Higher in the zone, the layer of birch wood and *Calluna* stems is dated to 4150 ± 100 B.P. (Q-883). Presumably a drier bog surface was colonized by birch, but a subsequent change in local conditions killed the trees. The overlying peat is rich in *Sphagnum* suggesting that the bog became wetter once more. However, there is little indication in the pollen record of any changes in the local plant community. The 50 cm of peat between the two timber layers took about 2000 years to accumulate, an average rate of 1 cm in about 40 years. No doubt the rate was not constant, fast rates alternating with static periods, or even periods of erosion, which are not detectable in the profile.

Zone LE-4; 0–50 cm

There is a large increase in the proportion of herb pollen (mostly due to an increase in Cyperaceae values) at the expense of tree pollen. Pollen of the weeds *Plantago lanceolata* and *Artemisia* appear together with *Rumex acetosa* type and spores of *Pteridium aquilinum*. *Calluna* remains the overall dominant pollen type.

The decrease in tree pollen is probably due to forest clearance, and the gradual artificial lowering of the tree-line by grazing and felling to its present level of about 412 m (1350 ft) in Rothiemurchus forest. There was little or no cultivation above the tree-line, the upper slopes being used for summer sheep grazing. The forests were felled to provide timber and fuel, and regeneration was prevented by sheep and deer grazing, and increased wind exposure.

The peat of the profile is much more oxidized in this zone, and *Sphagnum* ceases to be an important component. The high values of Cyperaceae pollen are indicative of the presence of *Trichophorum cespitosum* in the bog community (Birks 1969). This would suggest that the bog surface was disturbed, which favours *Trichophorum* at the expense of *Sphagnum*. Erosion may also have commenced at this time, accelerating the drying out process. The treeless conditions allowed the representation of weed pollen in the regional pollen rain, and the grain of Gramineae > 45 μm probably represents a cereal grain blown from the lower valleys. There are a few crofts today at the bottom of Glen Einich and also Glen Feshie, as well as more extensive cultivation in the Spey valley.

Scattered throughout the profile are pollen grains of plants which may have been growing on the basic cliffs a mile away at the head of the Glen, for example *Thalictrum*, Ranunculaceae undiff., Rosaceae, and Cruciferae. However, they are disappointingly scarce.

(*c*) *Coire Bog*

(i) *Site description*

Coire Bog is an extensive blanket bog in an area of gently undulating morainic topography surrounded by low hills, in the valley of the Wester Fearn Burn, near Bonar Bridge, Ross and Cromarty (figure 3). The part of the bog investigated (Nat. Grid Ref.: 28/592857; lat. 57° 51′N; long. 4° 25′ W), lies on the north side of the Abhainn a' Choire Bhuig at an altitude of 259 m (850 ft O.D.). This area is described by Lewis (1906). He reported that pine stumps were absent at 427 m (1400 ft) at the head of the valley, but were present at 381 m (1250 ft) and below as one layer. Further east down the valley, two layers of pine stumps were present, with birch below. In the area examined in the present study, only one layer of pine stumps was discovered, overlain by two birch layers.

The rocks of the area are siliceous Moine schists and schists metamorphosed by the Carn Chuinneag granitic intrusion (Phemister 1960). They give rise to acidic soils, supporting acidophilous vegetation, except in some areas where the schists are more basic, such as the ravine near the mouth of the Wester Fearn Burn. The valley above is moraine-covered, with bog vegetation on flat areas, and species-poor *Agrostis-Festuca* grassland on slopes, and on river gravel and alluvial banks. The vegetation of Coire Bog itself is affected by grazing and burning, and is rather dry, with *Trichophorum cespitosum* and *Calluna vulgaris* as the dominant plants. There are large *Rhacomitrium lanuginosum* hummocks, and lichens, principally *Cladonia* spp., are prominent. *Sphagnum* cover is poor. The community corresponds closely to the 'fire climax' of Trichophoreto-Callunetum (Ratcliffe 1964). The peat is not extensively hagged, but where stream courses are cutting back, up to 3.1 m (10 ft) of peat are exposed above stony till, and the whole bog seems to be in a state of incipient erosion.

The stratigraphy of the profile examined is shown diagrammatically on the left side of the pollen diagrams (figures 8, 9). Estimates of the macroscopic components are shown in figure 9. A general description of the stratigraphy follows:

cm	
0–90	highly humified amorphous blanket peat containing *Calluna* stems and *Sphagnum* leaves in a matrix of fungal hyphae and plant detritus
90–145	humified *Sphagnum-Eriophorum vaginatum* peat within a matrix of fungal hyphae

145–160	layer of birch twigs and *Calluna* stems
160–190	humified *Sphagnum-Eriophorum vaginatum* peat containing fragments of birch wood and *Calluna* stems
190	birch stump
190–200	*Eriophorum vaginatum* peat with birch wood fragments
200–230	decayed *Sphagnum-Eriophorum vaginatum* peat with birch wood fragments
230–235	indistint horizon containing charcoal fragments
235–255	pine stump
255–265	soft, highly humified peat, with monocotyledonous remains, *Juncus* seeds, and wood fragments
265–280	very compact birch wood peat, containing *Carex* and *Juncus effusus/J. conglomeratus* seeds
280–	gravel

(ii) *Local vegetational development at Coire Bog*

The standard pollen diagram (figure 8) and the local pollen diagram (figure 9) are divided into local pollen zones, which are designated CB-, and numbered from the base upwards. The relation between the upper local pollen assemblage zone and the *Calluna-Plantago lanceolata* regional pollen assemblage zone is shown in figure 8.

Zone CB-1; 265–280 cm

Betula and *Corylus/Myrica* are the dominant pollen types, and Polypodiaceae undiff. spores are very abundant. The herb pollen is rich in taxa, but *Empetrum* values, although at their highest in the profile, are relatively low.

Peat began to accumulate on the gentle slope down to the Abhainn a' Choire Bhuig. The peat-forming community was some kind of wet birch carr, with an undergrowth of *Juncus effusus* or *J. conglomeratus*, abundant ferns, *Carex*, *Equisetum*, and fen herbs, including *Valeriana officinalis*, *Filipendula*, *Menyanthes trifoliata*, *Epilobium*, and *Melampyrum*. *Salix* bushes also occurred in the carr, and the community must have been mesotrophic, with some soligenous influence. The other herb pollen types could all have originated from plants growing in such a community.

Zone CB-2; 247.5–265 cm

Pinus is the dominant tree pollen type. *Betula* pollen values remain high and fern spores remain abundant.

Pine must have grown in the vicinity of Coire Bog at this time. The mire community was largely unchanged, but the loss of some of the herb taxa may indicate that it was becoming more acid as peat growth prevented the penetration of base-rich drainage water.

Zone CB-3; 227.5–247.5 cm

Pinus and *Alnus* are the major tree pollen types, although *Betula* is equally abundant on a local pollen basis (figure 9).

The pine-stump is situated in this zone and is dated to 6980 ± 100 B.P. (Q-887). The addition of pine to the mire community had little effect on its composition, and the vegetation may have resembled that of the marginal laggs of oligotrophic mires in Scandinavia and N. Germany

(Sjörs 1948; Steffan 1931), but with an abundance of ferns, reflecting the greater oceanicity of Scotland.

The sharp rise in the frequencies of *Alnus* pollen indicates that alder grew nearby, perhaps in the mire community itself, or else further downslope in somewhat richer sites near the Abhainn a' Choire Bhuig.

Abundant charcoal and carbonized fragments in the peat above the pine stump are evidence of fire, which may have caused the death of the tree. There may have been some peat disturbance or redeposition due to the fire, as the curves on figure 8, especially of *Pinus*, *Alnus*, *Betula*, and Polypodiaceae undiff. are rather erratic. However, the local pollen diagram (figure 9) shows no fluctuations in *Alnus* values, suggesting that it was not affected by the fire, and was therefore not growing on the site, but in a wetter area immune from burning.

Zone CB-4; 202.5–227.5 cm

The dominant tree pollen type is *Alnus*, and the most abundant herb pollen types are Cyperaceae and *Rumex acetosa* type. Polypodiaceae undiff. spores fall sharply during the zone.

Peat growth continued after the fire, with *Betula* probably still growing on the peat surface. The community was colonized by *Eriophorum vaginatum* and *Rumex*. Pollen of both *Rumex acetosella* s.l. and *R. acetosa* are present, the latter being more abundant. *Melampyrum* is the only other herb pollen type likely to have originated locally. Presumably this zone represents the colonization of the peat surface after the fire, and no modern analogues to the community can be envisaged.

Zone CB-5; 175–202.5 cm

Betula is the most abundant tree pollen type, and *Pinus* values increase as those of *Alnus* decrease. Values of *Corylus/Myrica* also rise, and Gramineae is the most abundant herb pollen type. *Sphagnum* spores are abundant.

A large birch stump, dated to 6731 ± 100 B.P. (Q-888) occurs in the peat of this zone, showing that birch colonized the site. Pine also recovered its abundance in the region but failed to recolonize the peat locally. The declining *Alnus* values indicate that alder was becoming more restricted as peat spread over its former habitats.

The local community had become more acid, allowing the invasion of *Sphagnum* and grasses, possibly *Molinia caerulea*. The community may have resembled the Scandinavian acid wooded lagg communities described by Sjörs (1948).

The rate of peat growth between the pine stump at 235 cm and the birch at 190 cm is approximately 1 cm in 5.5 years. This rapid rate suggests that the fire did not cause a great hiatus in peat growth. However, if the rate is assumed to be constant, the peat of zone CB-4 took about 137 years to accumulate. This shows that the transitory community represented by the zone lasted a surprisingly long time and that the change to the mire community of zone CB-5 occurred relatively suddenly. However, the rate of peat growth cannot be assumed to have been constant without a very detailed study with many radiocarbon dates. The rate of peat growth between the two radiocarbon dated birch remains is about 1 cm in 24 years. It is unlikely that the rate of peat growth changed at the level of the lower birch stump, and it is more probable that it fluctuated throughout, depending upon local hydrological conditions and the nature of the peat-forming vegetation.

PHILOSOPHICAL TRANSACTIONS OF THE ROYAL SOCIETY B BIOLOGICAL SCIENCES

Zone CB-6; 150–175 cm

Betula and *Pinus* are the dominant tree pollen types, and *Calluna vulgaris* reaches moderate values, replacing Gramineae pollen. *Sphagnum* spore values remain high. Birch twigs at 160 cm were radiocarbon dated to 5005 ± 100 B.P. (Q-889).

The mire community was colonized by *Calluna*, which replaced the grasses, presumably as the peat became more acid. Birch again colonized the sampling site, and the birch remains correspond with low *Sphagnum* spore values. These values may indicate a dryness of the surface, or perhaps only the effects of shading, as *Sphagnum* remained the principal peat-former, and finally overgrew the birch remains.

Zone CB-7; 0–150 cm

Betula is the major tree pollen type, but the total proportion of tree pollen is low (figure 8, summary). *Calluna* and Cyperaceae are the most abundant pollen types, and there are consistent values of Gramineae, *Rumex acetosa* type, and *Plantago lanceolata* pollen, and *Pteridium aquilinum* spores. *Sphagnum* spores value remain high until near the top of the profile.

The low tree pollen values indicate the reduction of the forests of the area. The spread of bog may have been an important factor, the treeless conditions allowing the representation of weed pollen from cultivation in the lowlands, where cairns and chambered tombs of Neolithic origin are abundant. Daniel (1962) tentatively brackets the Neolithic Period in Scotland between 2700 and 1300 B.C. (4650 and 3250 B.P.). The people were farmers and hunters, growing barley and keeping sheep, cattle, and pigs, hunting red deer and wildfowl, and fishing. It is conceivable that the relatively large population of the Dornoch Firth area affected the forests of more remote areas, such as Coire Bog. Because of soil degeneration and incipient peat formation, forest regeneration did not occur, leading to the present treeless landscape.

The bog surface was little affected at this time. An abundance of *Calluna vulgaris* and moderate values of Cyperaceae pollen combined with the presence of *Eriophorum vaginatum* in the stratigraphy suggest that the surface community was Calluneto-Eriophoretum. The relative proportions of *Sphagnum* and *E. vaginatum* vary with time. This may be a local effect produced by the tussocky nature of *E. vaginatum*, or may reflect cycles of *Sphagnum* abundance, possibly related to changes in the water table or pool formation. The records of *Drosera* and *Narthecium ossifragum* pollen correspond with abundant *Sphagnum* remains in the peat. At 30 cm there is a marked increase in Cyperaceae pollen with no associated *E. vaginatum* remains, suggesting that *Trichophorum cespitosum* may have become locally abundant. This could result from burning and drying out, as the peat is much more humified and structureless at this level. There is little evidence for peat cutting on the present surface, and hagging is not extensive. However, the surface vegetation is degraded at present due to frequent burning, and is on the point of erosion. The disturbance of the surface may correspond to moor burning practices introduced when the region was converted from crofting communities to sheep-walk during the Highland Clearances of the early nineteenth century (Mackenzie 1946).

(*d*) *Summary of the Cairngorm region sites*

The chart in figure 10 shows the three blanket peat profiles in relation to the regional pollen assemblage zones. The boundary between the *Pinus* zone and the *Calluna-Plantago lanceolata* zone is probably not synchronous, as shown by the available radiocarbon dates. The curves for proposed basicity and wetness at each site are schematic, and have no actual values.

It is clear that the pine and birch remains do not form synchronous horizons. The pine stumps at Allt na Feithe Sheilich and Coire Bog are about the same age, and a stump from Carn Mor in the northern Cairngorms reported by Pears (1969) although somewhat younger, just falls within the same age range if the standard errors of the dates are considered. However, the stump from Loch Einich is about 1000 years younger, and further pine stumps studied by Pears are considerably younger.

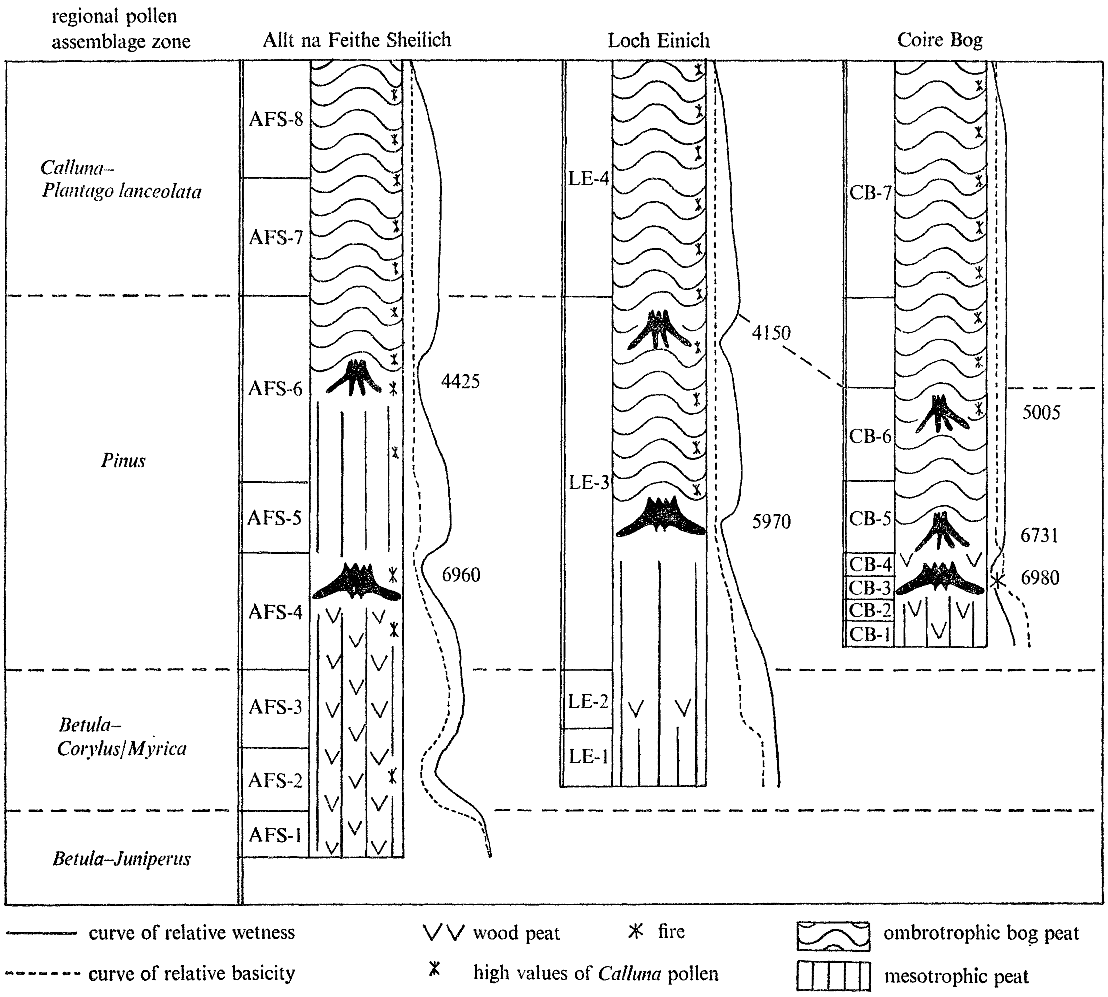


FIGURE 10. Summary of postulated changes in wetness and basicity in the Cairngorm area sites. The curves are relative, not quantitative. Radiocarbon dates of the wood remains are indicated.

Similarly, there is no synchronous pattern in the birch remains, even when they are considered in relation to the pine stumps. The lower birch stump at Coire Bog is within the age range of the older pine stumps, but the upper is about 1000 years younger than the Loch Einich pine stump. The birch remains at Allt na Feithe Sheilich and Loch Einich are about 600 and about 850 years younger respectively than the upper Coire Bog birch stump, the ones at Loch Einich corresponding in age with a pine stump from Sgor Mor reported by Pears (1969) (see figure 21).

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If climatic changes were solely responsible for the occurrence of tree horizons in blanket bogs, a very complicated climatic regime would have to be postulated for the Cairngorm region from about 7000 B.P. to about 4000 B.P. However, when the palaeoecological evidence from pollen analysis and peat stratigraphy is considered, some insights can be gained into the factors affecting tree establishment, growth, and death.

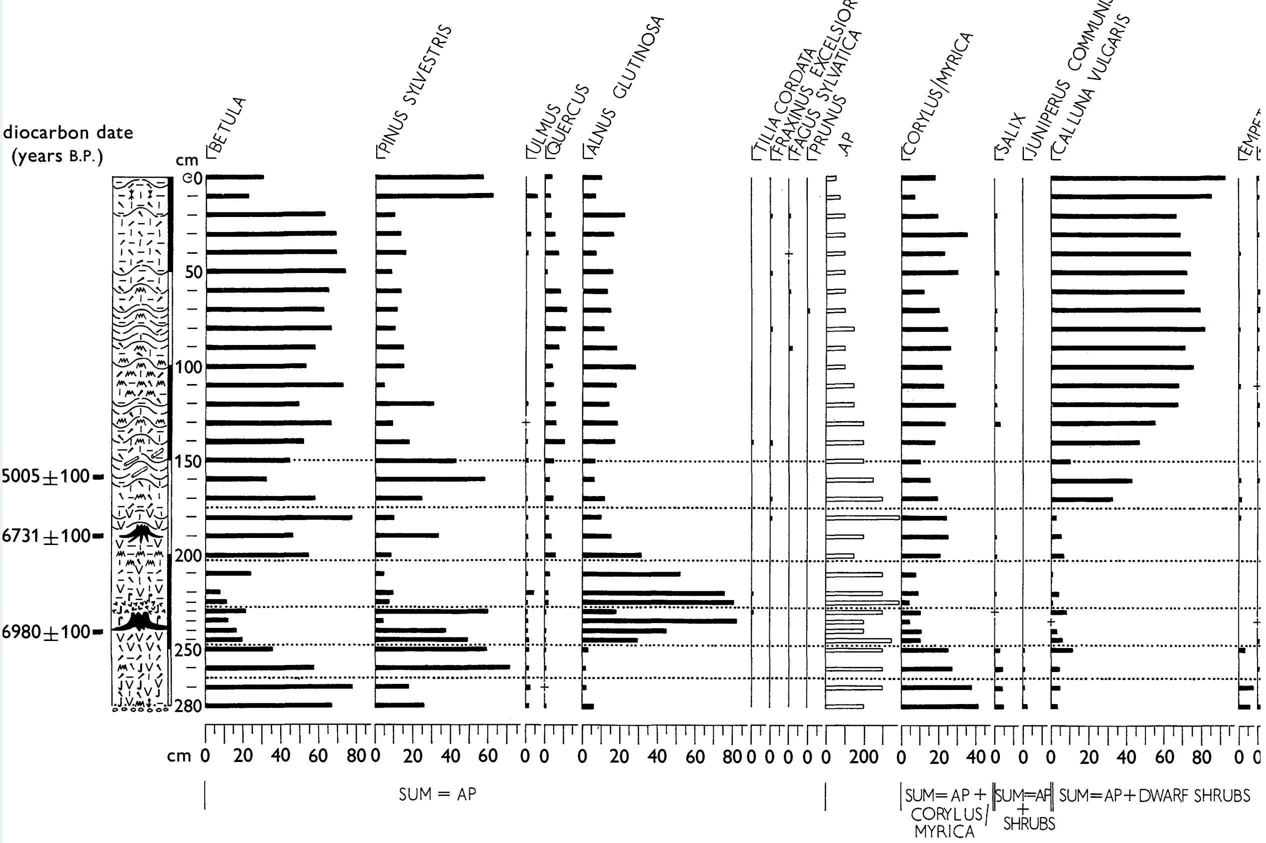
Presumably, at the time of pine colonization, the peat surfaces were sufficiently dry to allow seedling establishment and subsequent healthy growth. At all three sites, the base status of the peat-forming community was low. *Sphagnum* had become a prominent part of the vegetation except at Coire Bog, where a community resembling an oligotrophic lagg community had developed. *Calluna* pollen is virtually absent at Coire Bog, but is common at Allt na Feithe Sheilich and Loch Einich. At Allt na Feithe Sheilich, *Calluna* was present for only a short time before pine colonization, so concentrations of its mycorrhizal inhibitor may not have attained importance. At Loch Einich, the community was *Sphagnum*-dominated with probably fairly scattered *Calluna* plants producing abundant pollen. Fibrous *Calluna* peat, which seems to contain the greatest amounts of mycorrhizal inhibitor (McVean 1963*b*) was not formed, and indeed, the peat may have been sufficiently nutrient-rich at Loch Einich to preclude the necessity of developing mycorrhiza at all, for there are scattered pollen grains present of mesotrophic fen herbs.

Increased waterlogging appears to have been the cause of death of the pine trees at Allt na Feithe Sheilich and Loch Einich, and also the reason for the lack of regeneration. There could have been two rather wetter climatic phases at these times in the Cairngorm region, but only one prolonged wet season may have been necessary to kill the trees in the particular hydrological situation in which they were growing (McVean 1963*a*), and it is not necessary to postulate an overall climatic change. At Coire Bog, the tree appears to have been killed by a fire, indicating that conditions were very dry at this site. For some reason, pine was unable to recolonize the peat, perhaps through lack of a nearby seed source, or adverse competition from the peat vegetation.

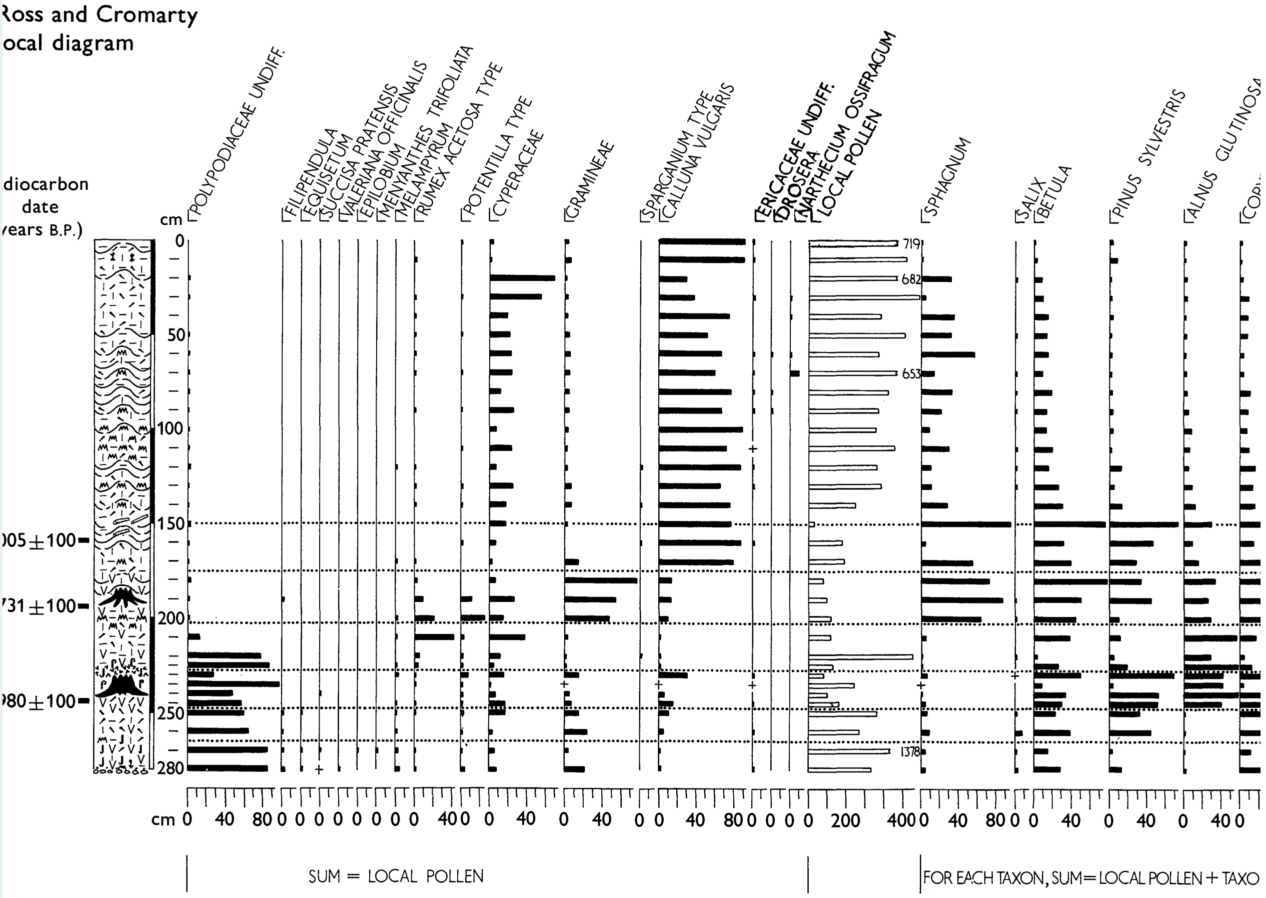
The general asynchroneity of tree growth in the Cairngorm region sites and the varied causes of death of the trees suggests that there were no overriding climatic changes controlling bog development. In the case of timber remains dated to after about 5000 B.P. it is possible that man influenced vegetational events. However, in the Cairngorm region it is proposed (part I) that the influence of man is reflected by the *Calluna-Plantago lanceolata* assemblage zone, whose lower boundary appears to be markedly asynchronous. The only wood in this zone is the upper birch wood at Coire Bog, dated to 5005 ± 100 B.P. (Q-889), and here it is possible that early Neolithic man affected the bog, at this time.

The growth and death of trees on the peat may have been controlled by small climatic fluctuations, to which one ecosystem may have been sensitive at one particular time, but not others nearby, depending upon the stage in the vegetational succession, and factors of aspect, altitude, and local topography (see, for example, Pears 1969). Pine colonization also depends upon the vegetational conditions of the mire. In general, it seems to become established after the peat has become acid, but before the establishment of *Calluna*-dominated ombrotrophic bog growth. This generalization is borne out by the work of Pears (1968), who presents pollen diagrams from two pine stump sites in the Cairngorms. Although the diagrams are not very detailed, they show the general features of the region. The pine stumps appear to be situated in mesotrophic peat shortly before the period of Ericaceae (*Calluna*) pollen abundance, associated with ombrotrophic peat growth.

Coire Bog
Ross and Cromarty
standard diagram



Coire Bog
Ross and Cromarty
ocal diagram



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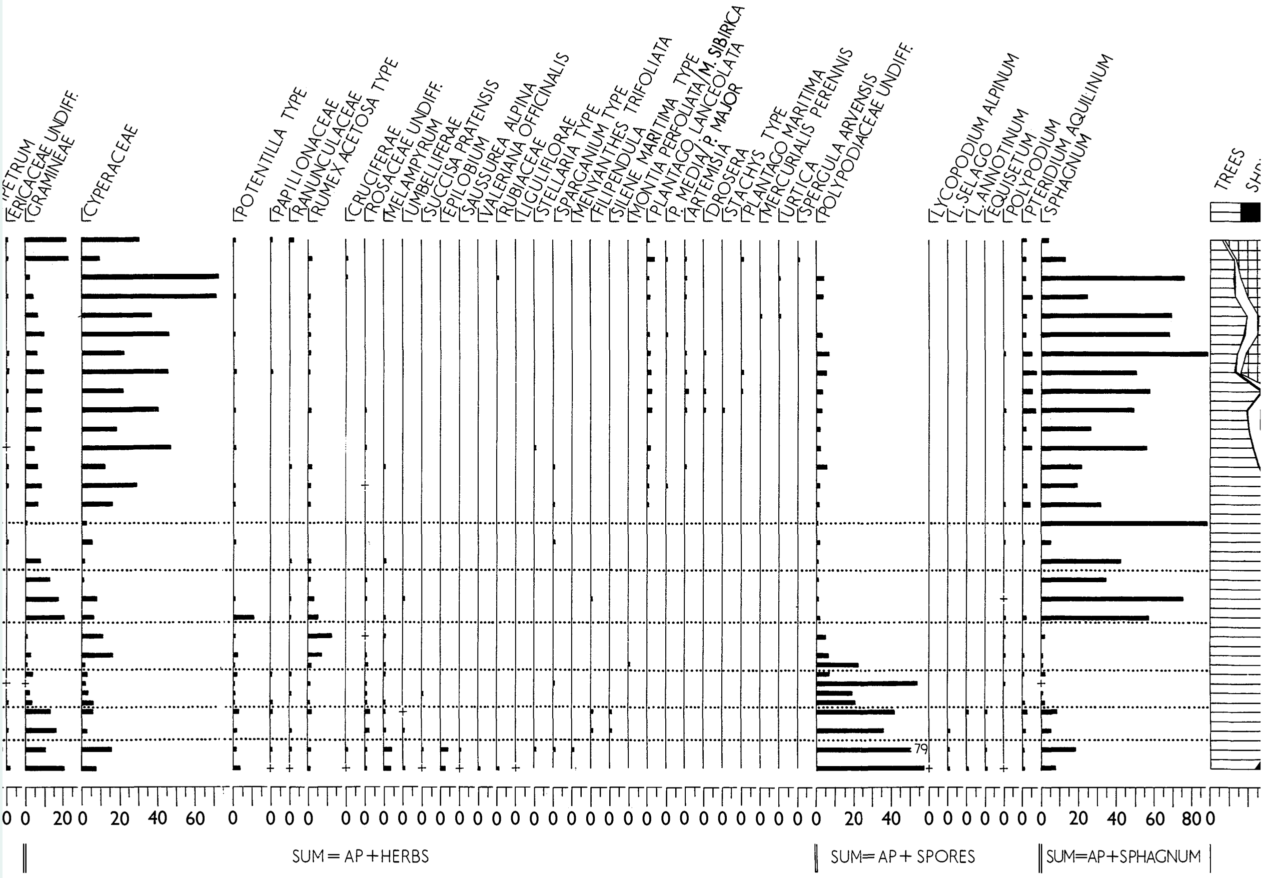

FIGURE 8. Standard pollen diagram from Coire Bog, Ross and Croma (AP). For the summary diagram, sum of AP + shrubs + *Corylus*/*M* spores = 100%. Undiff., Undifferentiated; B.P., before present (see figure 2.

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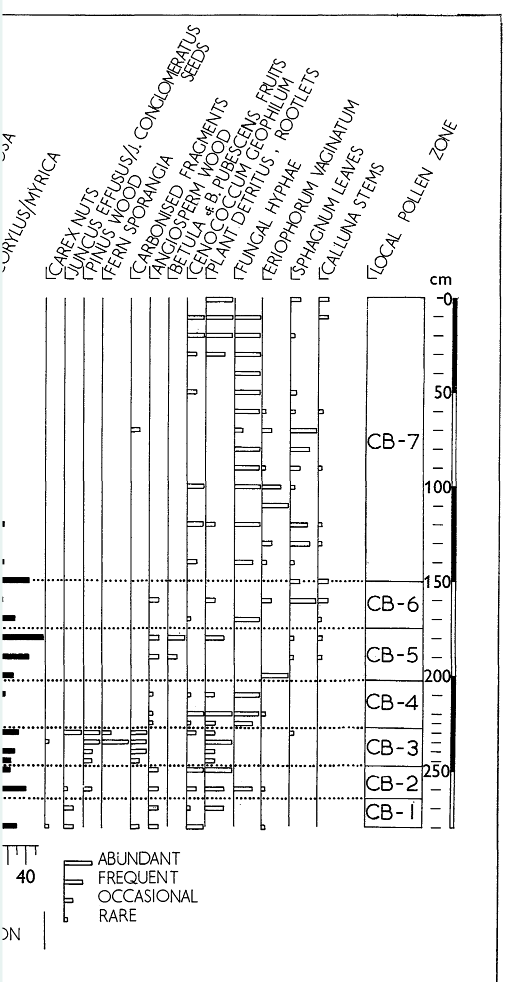
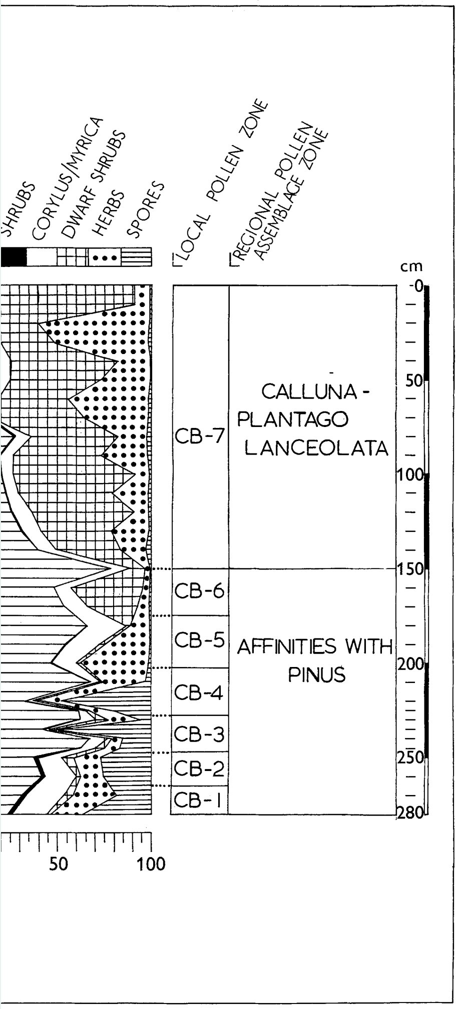


FIGURE 9. Local pollen diagram from Coire Bog, Ross and Cromarty. which includes the types indicated. The abundance of macrofo Undifferentiated. For key to stratigraphic symbols see figure 2.



ıarty. Calculation base is sum of tı ee pollen
Myrica + dwarf shrubs + herbs + pteridophyte
(i.e. 1950). For key to stratigraphic symbols

. Calculation base is sum of local pollen,
fossils is shown by white bars. Undiff.,

ooran Lane
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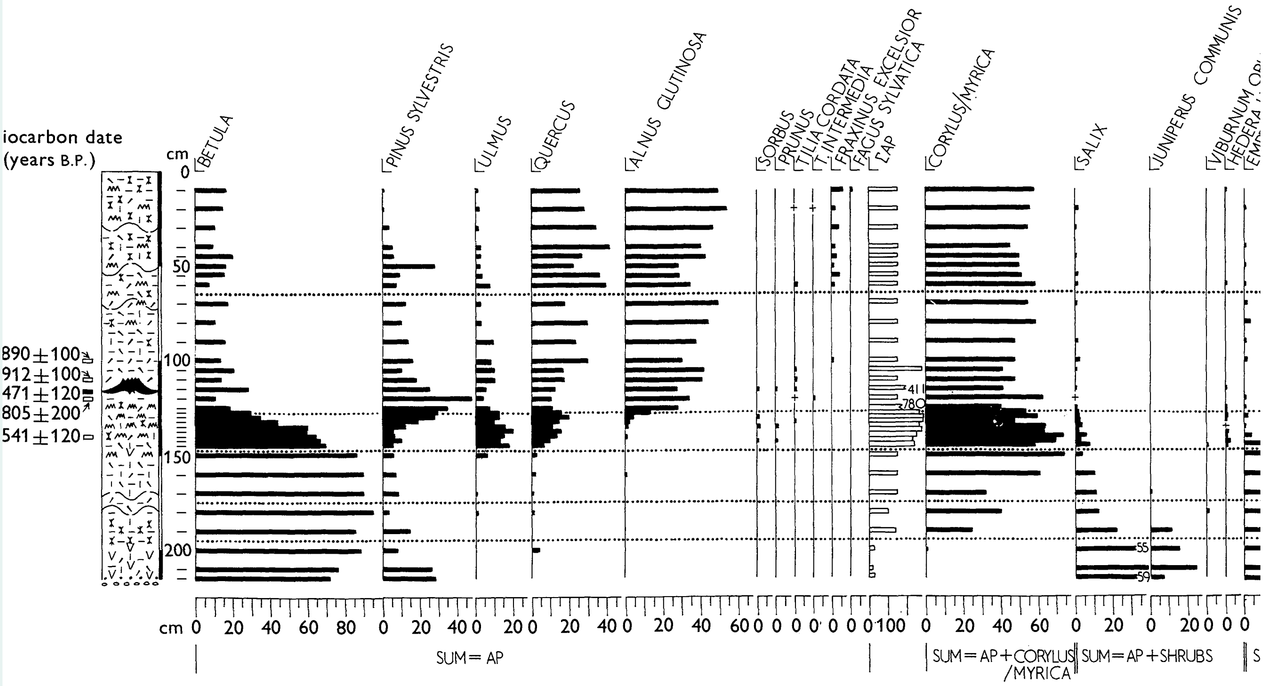
andard diagram



Cooran Lane
Kirkudbrightshire
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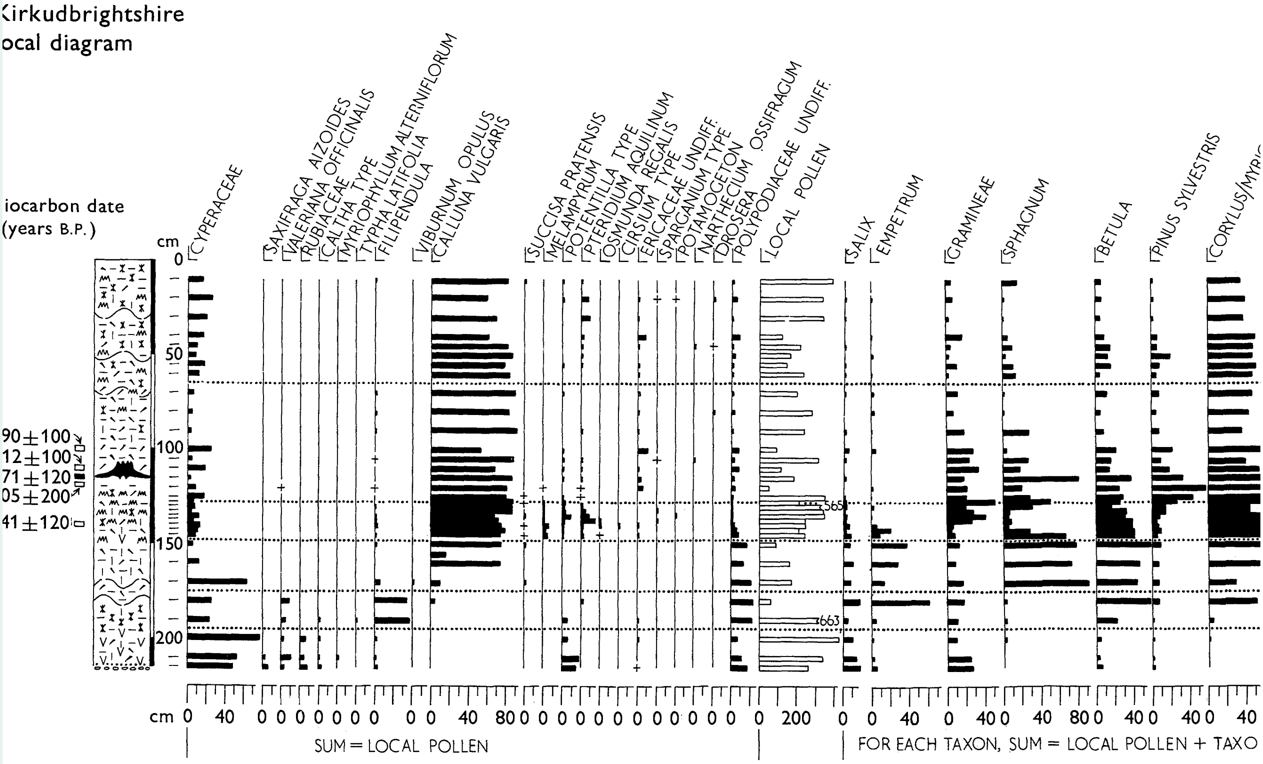


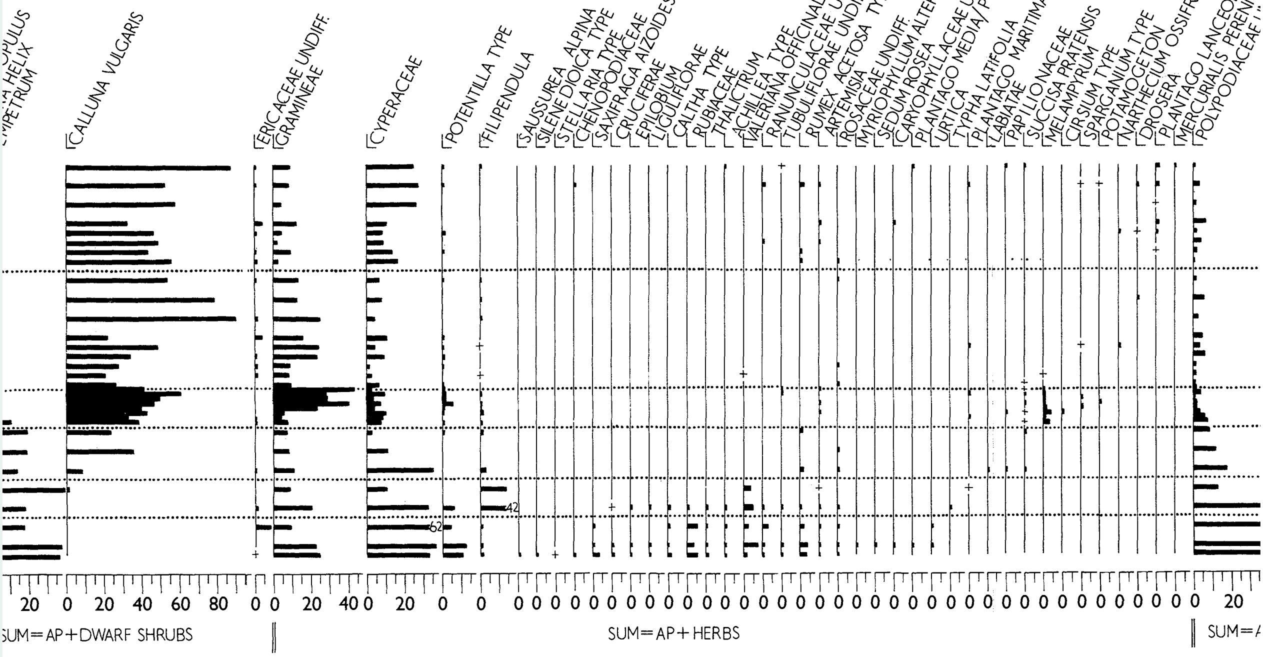


FIGURE 12. Standard polle
pollen (AP). For the
pteridophyte spores =
graphic symbols see fi

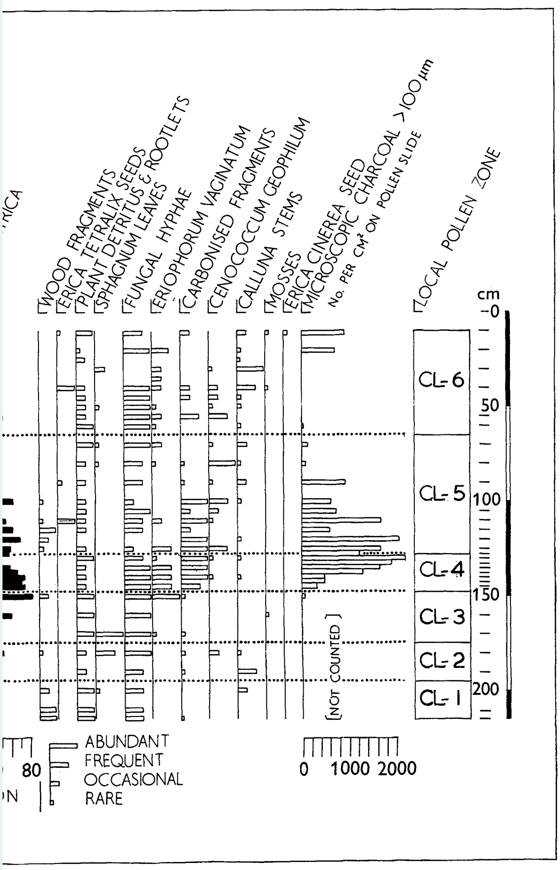
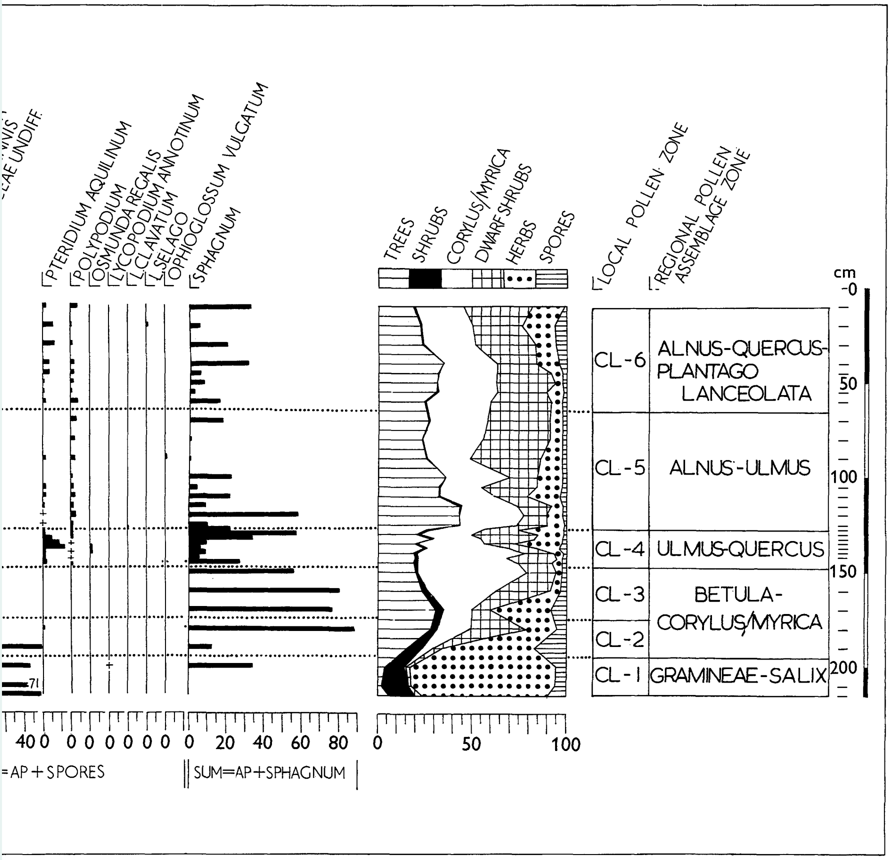


FIGURE 13. Local pollen diagram from Cooran Lane, Kirkcudbrig
which includes the types indicated. Abundance of macrofossil
tiated. For key to stratigraphic symbols see figure 2.

PHILOSOPHICAL TRANSACTIONS OF THE ROYAL SOCIETY B BIOLOGICAL SCIENCES



len diagram from Cooran Lane, Kirkcudbrightshire. Calculation base is sum of tree
ie summary diagram, sum of AP + shrubs + *Corylus*/*Myrica* + dwarf shrubs + herbs +
= 100 %. Undiff., Undifferentiated; B.P., before present (i.e. 1950). For key to strati-
figure 2.

ghtshire. Calculation base is sum of local pollen,
ils is shown by white bars. Undiff., Undifferen-

5. Sites in the Galloway region

Three pine stump sites were investigated in the Galloway Hills (figure 11). Part II demonstrated that the vegetational history of the region as a whole was generally similar to that of northwest England (see, for example, Walker 1966; Pennington 1964). The deglaciated landscape was colonized by herbaceous vegetation, closely followed by birch and hazel. These were superseded by elm and oak forests on dry ground and willow followed by alder in wet areas. Human influence on the vegetation began in Neolithic times and continued to the present day. Virtually all the native woodland has now been destroyed, and conifers planted extensively in the hills.

(a) *Cooran Lane*

(i) *Site description*

The valley of the Cooran Lane and the Gala Lane was investigated by Lewis (1905). He discovered one layer of pine stumps, with a layer of *Empetrum* stems below. In the present

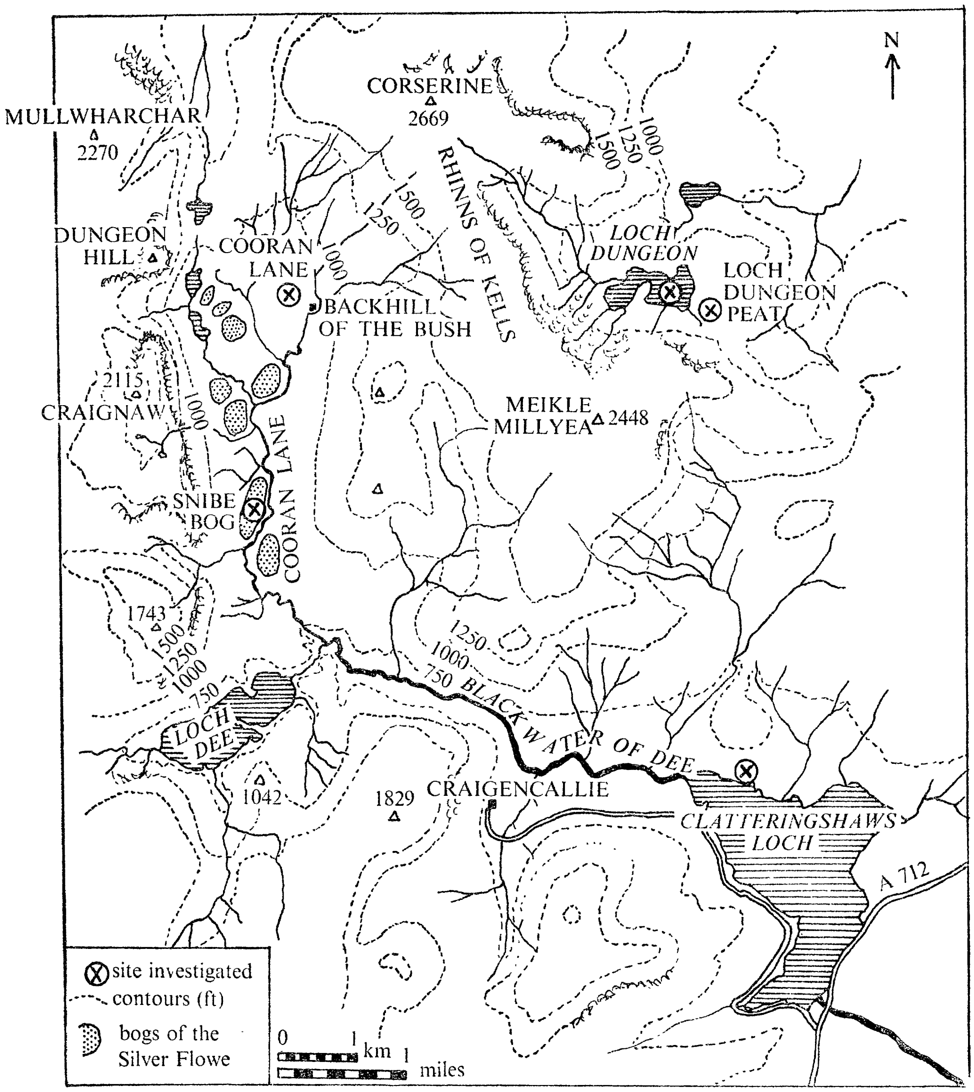


Figure 11. Map of the Galloway area to show the position of the sites investigated.

investigation, one layer of pine stumps was found, but the *Empetrum* layer was not detected in the field. (However, it is represented in the pollen diagrams.)

The Cooran Lane site lies between the Backhill of the Bush and the Saugh Burn (Nat. Grid Ref.: 25/479845; lat. 55° 7′ N; long. 4° 24′ W; altitude 274 m (900 ft) O.D.), 2.4 km (1.5 miles) from Snibe Bog (part II). On fairly level ground near the watershed, at the head of the Cooran Lane valley, blanket bog covers the ground. It is best developed on the Long Loch and Round Bogs of the Silver Flowe series, where a pool pattern has developed in the Trichophoreto-Eriophoretum (Ratcliffe & Walker 1958). The thickness of the peat is variable, and pine stumps are widespread, being exposed in peat hags and Forestry Commission drains. The Forestry Commission have recently ploughed, drained, fertilized, and planted most of the blanket peat and lower slopes of the valley, destroying all trace of the natural vegetation pattern.

The stratigraphy of the profile examined is shown diagrammatically on the left side of the pollen diagrams (figures 12, 13) and the estimates of the various macroscopic components in figure 13. A general description of the stratigraphy follows:

cm	
0–80	highly humified, very decayed *Calluna-Eriophorum vaginatum* peat with occasional *Sphagnum* leaves in a matrix of fungal hyphae
80–110	paler, highly humified amorphous peat with occasional *Calluna* stems in a matrix of fungal hyphae
110	pine stump; seeds of *Erica tetralix* abundant in a very thin blacker layer at the level of the stump
110–150	highly humified *Eriophorum vaginatum* peat with many carbonized fragments, and pine wood fragments
150–190	highly humified amorphous *Sphagnum* peat with a few ericaceous twigs.
190–215	highly humified amorphous wood peat of *Salix* or *Betula*
215–	gravel

(ii) *Local vegetational development at Cooran Lane*

The standard pollen diagram is shown in figure 12, and the local pollen diagram in figure 13. Both diagrams are divided by local pollen zones, designated CL- and numbered from the base upwards. The regional pollen assemblage zones are shown on figure 12.

Zone CL-1; 195–215 cm

Herb pollen, mostly Gramineae and Cyperaceae, is dominant, and there is a large number of taxa. *Empetrum*, *Salix*, and *Juniperus* pollen are moderately abundant. Tree pollen values are very low.

The presence of wood fragments of *Salix* or *Betula* in a matrix of plant detritus and rootlets, coupled with high pollen values of Cyperaceae, *Salix*, and fen herbs, such as *Caltha* type, *Epilobium*, *Potentilla* type, Rubiaceae (possibly *Galium palustre*), and *Valeriana officinalis* (figure 13), suggest that the earliest peat-forming community was a willow-grown sedge swamp occupying a shallow hollow in the drift covering the valley floor. A grain of *Myriophyllum alterniflorum* suggests the presence of open water nearby. *M. alterniflorum* seems to flower best today in slow-moving shallow streams. The relative abundance of *Saxifraga aizoides* pollen together with *Thalictrum* is suggestive of open gravel-flushes on gentle slopes nearby, the moving water carrying the pollen from there to the fen. The occurrence of *Saxifraga aizoides* is of phytogeographical interest, as it is absent from the whole of the Southern Uplands at the present day, its nearest stations being in Lakeland. The appearance of the Cooran Lane site at this time may have been similar to subalpine sites described by Nordhagen (1927, Fig. 169) from Sylene, Norway.

At the beginning of zone CL-1, the better drained mineral-ground nearby supported open treeless vegetation. *Empetrum* and juniper with ferns probably formed shrub communities, and plants of treeless habitats recorded include *Artemisia*, Chenopodiaceae, *Lycopodium annotinum*, *Plantago media/P. major*, *Saussurea alpina*, *Sedum rosea*, and *Thalictrum*. Later, *Betula* invaded the area, and formed open birchwoods at first, on the dry ground around the fen, with an understorey of juniper and *Empetrum*, an assemblage reminiscent of the 'heathy facies' of the subalpine birchwoods of the Åbisko region of Swedish Lappland. The open ground herbs were eliminated from the area, but *Sedum rosea* and *Saussurea alpina* still survive at the present day on the ungrazed crags of Merrick, and other mountain plants persist above Loch Dungeon (part II). Post-glacial refuges for base-demanding mountain plants were very rare in Galloway, an area of predominantly acid rocks, in contrast to the more basic Moffat Hills, where colonies of several base-demanding mountain plants are more common today.

Zone CL-2; 175–195 cm

The proportion of tree pollen (largely *Betula*) and of *Corylus/Myrica* pollen increases, while that of herb pollen decreases. Values of *Filipendula* are relatively high, as are those of *Empetrum* and Cyperaceae. *Juniperus* pollen values decline to zero.

During this zone, the fen became drier. *Betula* invaded it, and *Filipendula* became common (figure 13). A grain of *Typha latifolia* may have originated in the fen, but it is more likely to have come from plants growing in calm stretches of the Cooran Lane nearby. The fen also became more acid, probably due to the decreasing influence of ground water, which encouraged the increase of *Sphagnum*. The high values of *Empetrum* pollen may indicate that *Empetrum* was abundant on the dry ground nearby, but the occurrence of ericaceous stems (probably *Empetrum*, as *Calluna* pollen is virtually absent) indicates that it was growing on the mire. These stems were originally recorded as *Calluna* stems, and appear as such on figure 13. They correspond to the layer of *Empetrum* stems discovered in the field by Lewis (1905). The mire during zone CL-2 may have resembled the vegetation envisaged at Allt na Feithe Sheilich in zone AFS-2, and at Loch Einich in zone LE-2, but was probably somewhat more basic, with *Filipendula* present in the understorey, and the tree layer consisting mostly of willows with some birch.

Zone CL-3; 147.5–175 cm

Betula is the main tree pollen type, and *Corylus/Myrica* pollen is very abundant. *Empetrum* pollen values remain high, and those of *Calluna* increase. The values of Cyperaceae pollen decline, and pollen of fen taxa is virtually absent. *Sphagnum* spore values remain high.

During this zone, *Sphagnum* was the prominent peat-forming plant, and the mire must have become sufficiently acid to cause the decline of fen herbs. The absence of wood remains indicates a reduction in the cover of *Salix* and *Betula*. However, the *Sphagnum* carpet remained a suitable habitat for *Empetrum*, and later *Calluna*.

The record of a pollen grain of *Viburnum opulus* may suggest that this species was growing in the mire community, but it is more likely to have originated from more base-rich communities nearby, perhaps on the banks of the Cooran Lane. At the end of the zone, *Eriophorum vaginatum* becomes abundant in the peat, and this, together with low Cyperaceae and high *Calluna* pollen values, suggests that the bog community resembled Calluneto-Eriophoretum.

Zone CL-4; 127.5–147.5 cm

Betula pollen values fall, and are replaced by increasing values of *Pinus*. Values of *Ulmus* and *Quercus* are high, and *Alnus* pollen is present in low amounts. *Hedera* pollen is relatively abundant. Gramineae pollen becomes abundant, and pollen of *Melampyrum*, *Potentilla* type, *Succisa pratensis*, and spores of *Pteridium aquilinum* reach relatively high values. The *Sphagnum* spore curve shows a minimum. Large numbers of charcoal fragments were encountered on the slides, and an attempt at counting them is shown on figure 13.

These features in the local pollen curves are interpreted as evidence for a fire. The bog surface must have become sufficiently dry for accidental burning to occur during a particularly dry period. Similar features in a pollen diagram from southeast Sweden have been ascribed to a fire by Berglund (1966). His diagram showed a maximum of *Melampyrum* pollen, together wih *Vicia* type, Umbelliferae, and *Rumex acetosella*. Florin (1957) found similar fire effects in central south Sweden, where *Melampyrum*, Gramineae, and *Pteridium* all increased in response to burning. This fire was interpreted as an attempt at forest clearance by Neolithic man. At Cooran Lane, there is no evidence that the fire was a result of human interference. Peat from this level was radiocarbon dated to 7541 ± 120 B.P. (Q-874). It is possible that Mesolithic man may have been responsible. However, no evidence of occupation has been found in the hills, although Mesolithic remains have been found on the Galloway coast.

The fire at Cooran Lane favoured *Melampyrum* and *Pteridium* and probably *Potentilla erecta* (*Potentilla* type) on the burned peat surface. Spores of *Osmunda regalis* may indicate that it colonized the disturbed surface, as it does in recent peat cuttings in the west of Ireland today. The occurrence of *Hedera* pollen in continuous amounts (figure 12) may reflect an opening of the forest on mineral ground, allowing *Hedera* pollen to be dispersed further. The high Gramineae values may represent *Molinia caerulea*, as this grass is favoured by burning at the expense of other bog plants, and its flowering is stimulated by the high temperature during a fire (Ratcliffe 1964).

The high charcoal frequencies continue throughout the zone, together with high values of *Melampyrum*, *Potentilla* type, and *Pteridium*, and it is thus possible that a whole series of fires burned the bog surface, but not sufficiently strongly to affect peat formation. The main peat-forming plants appear to have been *Calluna* and *Eriophorum vaginatum*.

Zone CL-5; 65–127.5 cm

Alnus is the predominant tree pollen type, and *Quercus* values are higher than those of *Ulmus* or *Betula*. *Pinus* percentages reach a maximum at the beginning of the zone. *Corylus/Myrica* and *Calluna* maintain high values throughout. The variety of herb pollen is small, and Gramineae is the most abundant type.

A pine stump occurs in the peat of this zone, and was radiocarbon dated to 7471 ± 120 B.P. (Q-871). Pine may not have colonized the peat previously because of the build-up of mycorrhizal inhibitors and acute nitrogen deficiency in the *Calluna* peat. The burning of the peat presumably destroyed the inhibition and also released some nutrients in the ash, and pine seedlings were able to become established. There are signs of burning on the pine stump, so the tree may have been killed by a further fire. Another pine stump, about 20 m away, and at about the same horizontal level (checked by levelling), was radiocarbon dated to 6564 ± 120 B.P. (Q-875). Perhaps further fires destroyed the humus built up under the original pines, which would otherwise be unfavourable for regeneration (McVean 1963*a*), and another stand grew upon the peat. There were no noticeable signs of burning on the second stump, so this tree may have therefore died a natural death. Pine subsequently died out from the bog surface.

The pine stump in the Cooran Lane profile, and also those in the other two Galloway peat profiles are slightly higher than the corresponding peaks of pine pollen. This may possibly be due to compaction of the peat, leaving the incompressible stump with its widespread roots higher in the profile than its true stratigraphic position (see, for example, Kaye & Barghoorn 1964).

Radiocarbon dating of the peat containing the pine pollen maximum gave the result 6805 ± 200 B.P. (Q-873). This is 666 radiocarbon years younger than the adjacent pine stump, but could be contemporary with the second pine stump, dated at 6564 ± 120 B.P. The discrepancy in the dates may be due to dating two different materials, the peat appearing younger owing to contamination by down-growing roots and percolating humic acids. However, if the dates are true, they suggest that the pine pollen maximum was produced by the second generation of trees, and that the high values of pine pollen expected to have been produced by the first generation may well have been destroyed by peat oxidation or burning, which left a hiatus in the profile.

A radiocarbon date of 5912 ± 100 B.P. (Q-1148) from peat above the pine stump at 110–115 cm suggests that there was a period of very slow peat accumulation after the deposition of the peat containing the high values of *Pinus* pollen. The date may be an artefact due to disturbance of the peat as it sank around the pine stump. However, if it is true, it indicates that peat growth was not active after the death of the younger pine, which therefore may have died of old age rather than by increased waterlogging leaving an environment unsuitable for further seedling establishment.

A radiocarbon date 10 cm above at 100–105 cm of 5890 ± 100 B.P. (Q-872) is virtually synchronous with the date from 110–115 cm. This overlap may be due to disturbance but it may also indicate a rapid resumption of peat growth. If the top of zone CL-5 is assumed to occur at 5000 B.P. the average rate of peat accumulation for the upper part of this zone is 1 cm in about 25 years. This is in contrast to the average rate of peat accumulation for zone CL-4 of 1 cm in about 37 years, and for the lower part of zone CL-5 of 1 cm in about 46 years. There may be several short hiatuses during zone CL-4 and early CL-5 caused by fire or dry periods of no peat growth, especially as zone CL-4 is narrow (20 cm) compared to the width of the same regional pollen assemblage zone at other sites in the area.

The peat-forming vegetation of the upper part of zone CL-5 was composed of blanket bog species, principally *Calluna* and *Eriophorum vaginatum*, and probably also *Myrica*, as values of *Corylus/Myrica* pollen remain high throughout. *Sphagnum* appears to have been rare.

Zone CL-6; 0–65 cm

Alnus, *Quercus*, and *Betula* are the dominant tree pollen types, *Pinus* and *Ulmus* values being low, except for a small peak of *Pinus* pollen near the base of the zone. *Fraxinus* pollen is continuously present. *Corylus/Myrica*, *Calluna vulgaris*, Gramineae, and Cyperaceae are the other major pollen types. Pollen of *Plantago lanceolata* and spores of *Pteridium aquilinum* are continuously present in small amounts, and there is a wider variety of herb pollen taxa than in zone CL-5.

Peat growth continued during this zone with little change in the bog vegetation. The increase in Cyperaceae pollen values may reflect the increase in *Eriophorum vaginatum*, whose remains become abundant in the peat, and also perhaps of *Trichophorum cespitosum*.

The small peak of *Pinus* pollen probably reflects the growth of pine on the peat around Clatteringshaws, further down the valley (figure 11), where a pine stump was radiocarbon dated to 5080 ± 100 B.P. (Q-878). The average rate of peat growth during zone CL-6 is very slow (1 cm in about 79 years). This is probably due to recent peat erosion, which has caused the peat to become hagged to the mineral ground. Burning by man will also have reduced the peat thickness, and accelerated the erosion.

(*b*) *Loch Dungeon Peat*

(i) *Site description*

This site is in the area of blanket peat covering the flat top of the spur coming northward from Meikle Millyea to Mid Hill, on the east side of Loch Dungeon (Nat. Grid Ref.: 25/5284; lat. 55° 7′ N; long 4° 19′ W; altitude 396 m (1130 ft) O.D.) (figure 11). The peat is hagged and subject to sheet erosion at present, exposing a layer of large pine stumps. The peat vegetation is discontinuous. It gives way on more sloping ground to Callunetum, Molinietum, or species-poor *Agrostis-Festuca* grassland. The slightly basic nature of the bedrock is reflected by small stony flushes at the edge of the blanket peat, which contain *Pinguicula vulgaris*, *Drepanocladus revolvens*, *Riccardia pinguis*, and *Scorpidium scorpoides*. The land around Loch Dungeon, apart from the blanket peat and steep ground below the cliffs has been ploughed and planted with conifers.

A pollen diagram from the sediments of Loch Dungeon has been discussed in part II.

The stratigraphy of the peat profile studied is shown diagrammatically on the left side of the pollen diagrams (figures 14, 15) and estimates of the various macroscopic components are shown in figure 15. A general account of the stratigraphy follows:

cm	
0–25	highly humified dried blanket peat matted with roots of *Calluna* and *Vaccinium myrtillus*
25–110	highly humified *Eriophorum vaginatum-Calluna* peat with occasional *Sphagnum* leaves in a matrix of fungal hyphae
110–122	similar to above, but with rare *Phragmites* rhizomes
122–124	black humus ‘soil’ or mor humus, with carbonized fragments, around or just above a pine stump
124–145	amorphous, humified light brown peat with abundant pine root fragments and occasional *Phragmites* and *Eriophorum vaginatum* rhizomes
145–200	*Phragmites-Carex*-wood peat with abundant *Juncus* seeds from 180–190 cm, and *Eriophorum vaginatum* remains
200–260	*Phragmites-Carex* peat with *Carex* sp. seeds
260–265	*Sphagnum* peat with abundant leaves of *Sphagnum magellanicum*, and also *S. acutifolium* agg. and *S. palustre;* moss stems (*Acrocladium giganteum* and *Scorpidium scorpioides*) also abundant; also present are seeds of *Carex panicea* or *C. dioica*, *Potamogeton polygonifolius*, and a fruit of *Sparganium* sp.
265–	gravel

(ii) *Local vegetational development at Loch Dungeon Peat*

The standard pollen diagram is shown in figure 14 and the local pollen diagram in figure 15. The diagrams are divided into local pollen zones, designated LDP- and numbered from the base upwards. The regional pollen assemblage zones are shown in figure 14.

Zone LDP-1; 245–265 cm

Corylus/Myrica is the dominant pollen type and *Betula* is the major tree pollen type. *Salix*, Gramineae, and Cyperaceae pollen, and *Sphagnum* and Polypodiaceae undiff. spores are frequent, and there are low values of *Potentilla* type, *Melampyrum*, *Succisa pratensis*, *Menyanthes trifoliata*, and *Filipendula* pollen.

Together with the associated mosses and other macrofossils at the base of the profile, the assemblage is suggestive of a base-rich fen community resembling *Carex lasiocarpa* communities of shallow water. However, the peat stratigraphy shows that this community soon became overgrown with sedges and *Phragmites*, with relatively few associated herbs, and with the elimination of the moss carpet.

Zone LDP-2; 215–245 cm

Ulmus and *Quercus* are prominent components of the tree pollen. There is little difference in the other pollen frequencies from zone LDP-1.

During this zone, the *Carex-Phragmites* fen continued to develop. It contained relatively few associated plants, chiefly small amounts of *Filipendula*, *Potentilla*, and *Menyanthes trifoliata*. The vegetation may have resembled the mixed *Phragmites/Carex* fen communities described by Spence (1964).

Zone LDP-3; 182.5–215 cm

Tree and shrub pollen frequencies are similar to those of zone LDP-2. In the herb pollen, Gramineae values exceed those of Cyperaceae, and there is an abundance of fen herb taxa, such as *Filipendula*, *Succisa pratensis*, *Osmunda regalis*, *Angelica* type, *Polygala*, *Cirsium* type, and *Valeriana officinalis*. There are relatively high frequencies of *Melampyrum* and *Potentilla* type pollen and Polypodiaceae undiff. spores.

The large variety of herbs probably appeared in response to the infilling of the hollow and relative lowering of the water table. Successions from *Phragmites/Carex* communities of open water to *Phragmites/Carex* fens rich in herbs and mosses are described by Spence (1964) from Scottish lochs. Pollen types at Loch Dungeon Peat representing plants found in such mesotrophic fens include *Angelica* type (*A. sylvestris*), *Cirsium* type (*C. heterophyllum*), *Corylus/Myrica* (*Myrica gale*), *Epilobium* (*E. palustre*), *Filipendula* (*F. ulmaria*), *Menyanthes trifoliata*, *Potentilla* type (*P. palustris*), *Ranunculus trichophyllus* type (*R. flammula*), Rubiaceae (*Galium palustre*, *G. uliginosum*), *Succisa pratensis*, and *Valeriana officinalis*. The relative abundance of *Osmunda regalis* spores indicates that *Osmunda* was a member of the fen community. The royal fern is rare in Galloway today, due probably to drainage and cultivation of suitable habitats, and possibly as a result of gross collecting. A pollen grain of *Cladium mariscus* is also recorded (figure 14), and *Cladium* may have been growing locally, although its rhizomes were not observed in the peat. *Cladium* is also very rare in Galloway at present, occurring mainly near the coast. Hafsten (1965) shows that the Flandrian restriction of *Cladium* in Norway is a result of edaphic factors, acidification, and infilling of lakes and resulting bog development. Its extinction in the Galloway Hills is undoubtedly for the same reasons.

The abundance of *Eriophorum vaginatum* in the peat suggests that local conditions had become acid in zone LDP-3. *Juncus effusus/J. conglomeratus* seeds and *Sphagnum* spores are common, and pollen of *Melampyrum* and *Potentilla* type reach relatively high values. The site may also have become drier during this zone, as *Juncus effusus* is commonly found in dry fen communities. The peak of Polypodiaceae undiff. spores, indicating the local growth of ferns, together with the associated local taxa also suggest a drying of the mire. Any irrigation by base-rich water would decrease as the peat accumulated, and the increase of carbonized fragments may be due to increased peat oxidation under drier conditions.

Throughout the development of the fen, *Salix* pollen is relatively abundant, and *Salix* species may have been part of the mire community, as they commonly are in Scandinavian fens today. *Myrica gale* may also have been growing in the mire, as values of *Corylus/Myrica* pollen are high throughout.

Zone LDP-4; 102.5–182.5 cm

Alnus is a major component of the tree pollen, and *Pinus* pollen is also frequent. *Calluna vulgaris* pollen reaches relatively high values, particularly in the local diagram (figure 15), and pollen of fen herb taxa are low or absent. Gramineae pollen values decline throughout.

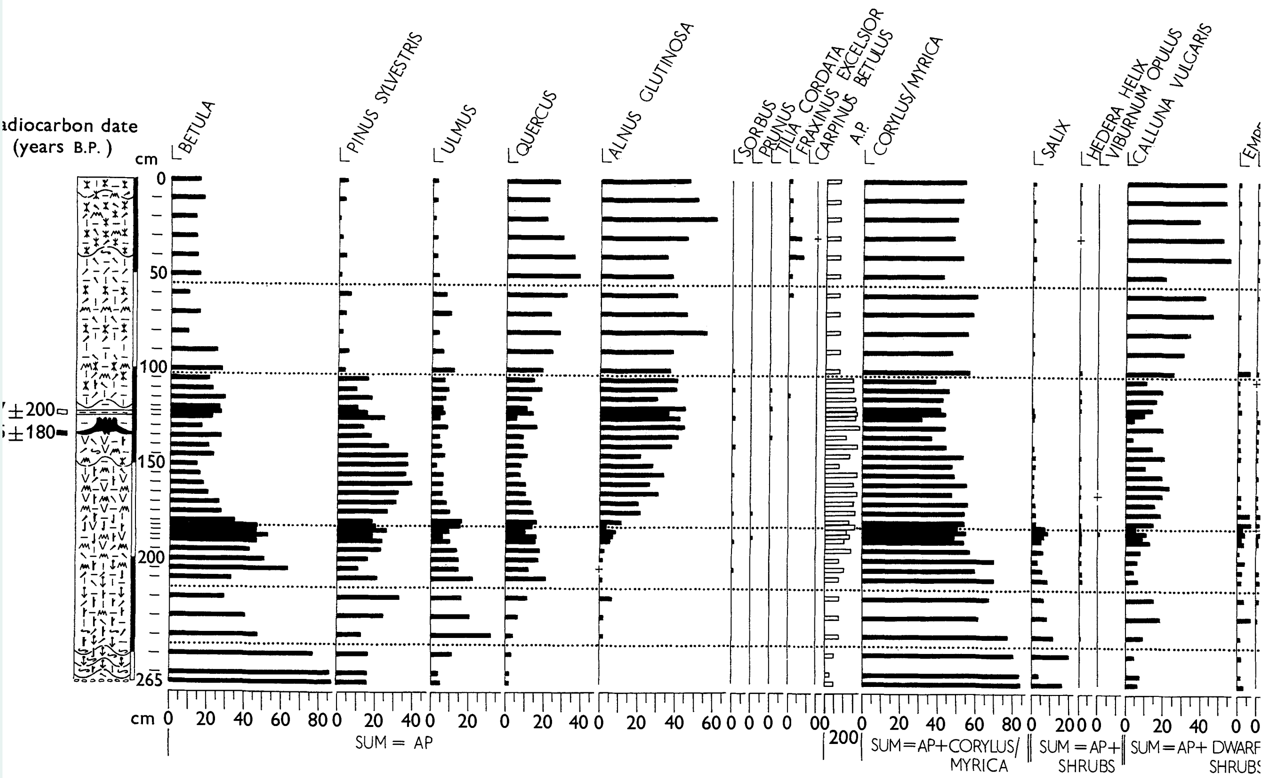
Acidification of the mire continued with the increase of *Calluna* and *Sphagnum*, and also of Ericaceae undiff. pollen associated with the occurrence of *Erica tetralix* seeds (figure 15). *Phragmites* persisted, but the decline in Gramineae pollen values probably reflects its decreasing vigour. *Myrica* was probably also present in the mire community.

Pinus pollen increases at the beginning of the zone, and pine must have grown near the site. Pine was also present on the other side of the Kells range, as the Cooran Lane pine stump is dated 300 years older than the one at Loch Dungeon. Eventually, the peat at Loch Dungeon became suitable for pine colonization. About 10 cm above the level of the pine stump, there is a black amorphous layer in the peat, containing no recognizable remains other than carbonized fragments. The pine stump is dated to 7165 ± 180 B.P. (Q-876) and the black layer to 6787 ± 200 B.P. (Q-877). There is sufficient overlap in the uncertainty of the measurements that the dates could be contemporary, especially when the unknown errors of sampling and of younger root penetration into the peat sample are taken into account, and also any differences due to the dating of two different materials. There is no sign of burning on the bark of the pine stump in contrast to the older stump at Cooran Lane, so it is unlikely that fire killed the tree, or was responsible for the formation of the blackened peat. It is more likely that the black layer was formed during the growth of the pine, perhaps by the deposition of pine needles. The pollen deposition from the mire community appears to be unaffected by the presence of pine. *Pinus* pollen values continue to be high through the black layer, only decreasing above it at the end of the zone. However, *Sphagnum* spores decline markedly above the layer, and *Calluna* becomes a major peat component.

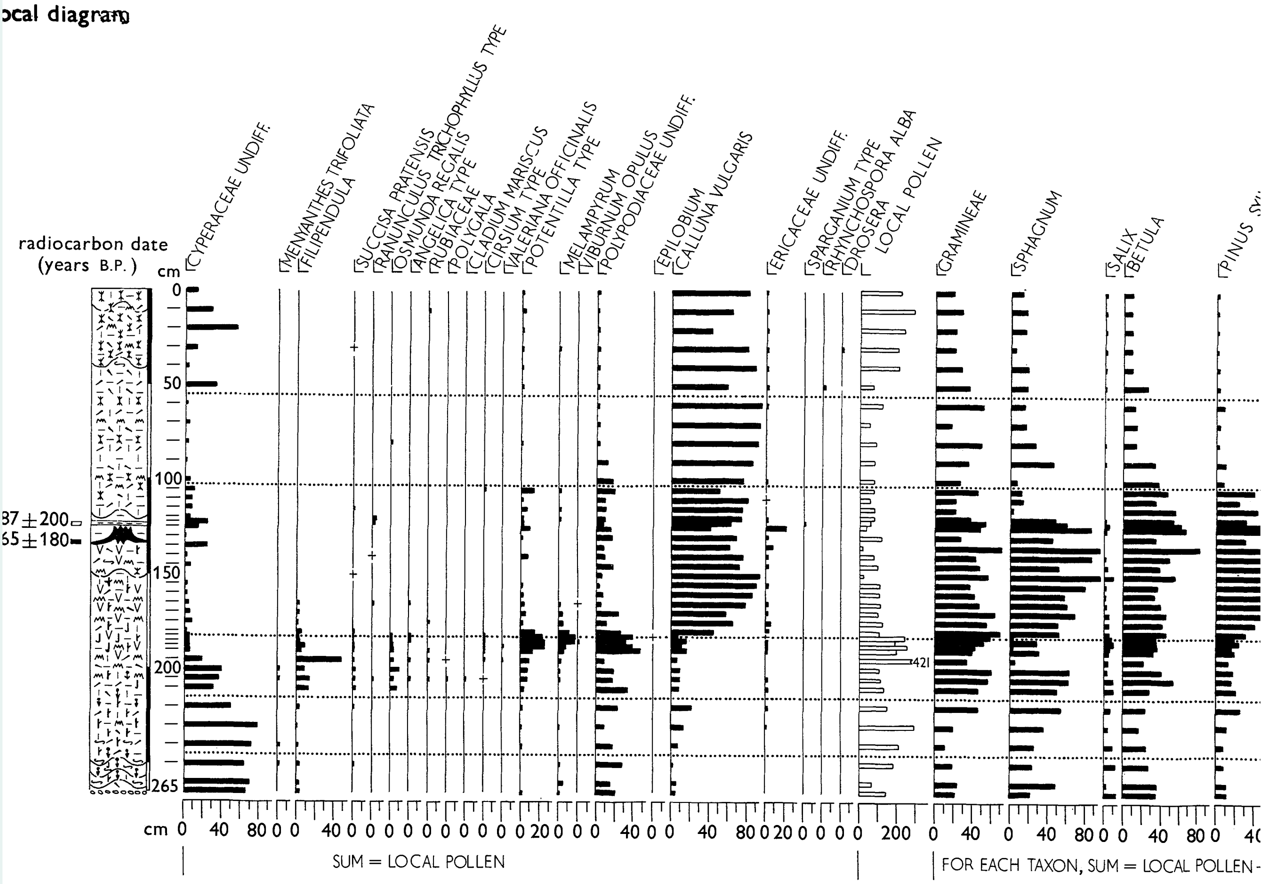
The cause of death of the pine stump is uncertain. It was unlikely to have been killed by fire, and there is no good evidence in the pollen diagrams or the peat stratigraphy for a rise in the water table, which would lead to an anaerobic root environment inhibiting regeneration. It is possible that the bog became completely ombrotrophic, and dominated by *Calluna* and *Eriophorum vaginatum*. Pine regeneration may have been prevented by the formation of

PHILOSOPHICAL TRANSACTIONS OF THE ROYAL SOCIETY B BIOLOGICAL SCIENCES

Loch Dungeon Peat
Kirkudbrightshire
standard diagram



Loch Dungeon Peat
Kirkudbrightshire
local diagram



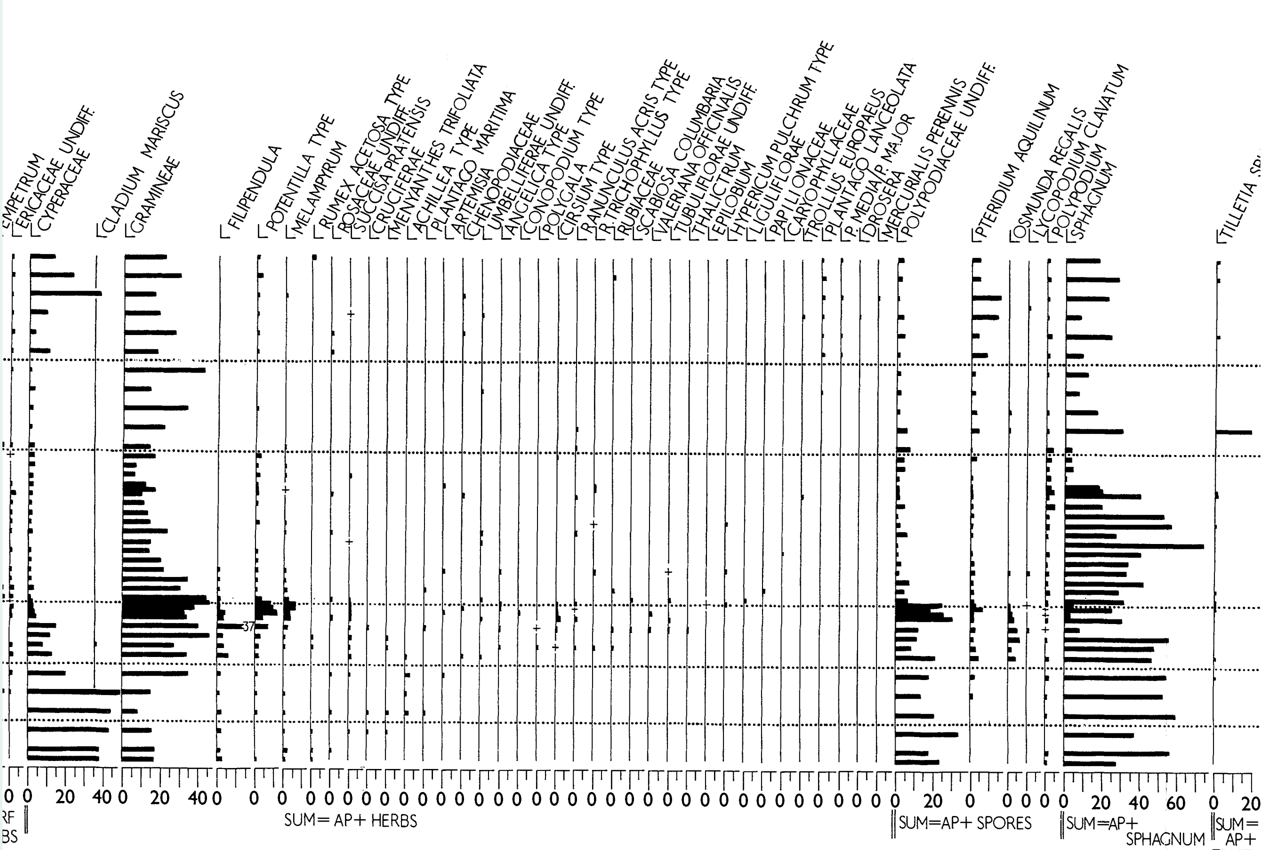


FIGURE 14. Standard pollen diagram
tree pollen (AP). For the summ
pteridophyte spores = 100 %. U
graphic symbols see figure 2.

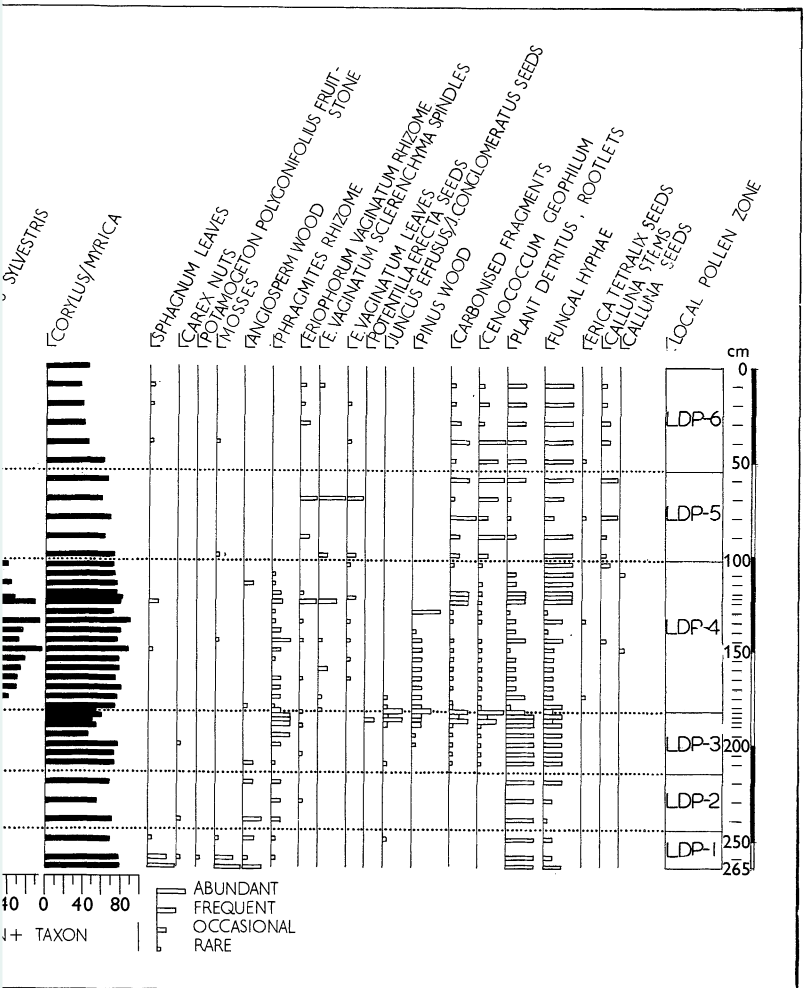
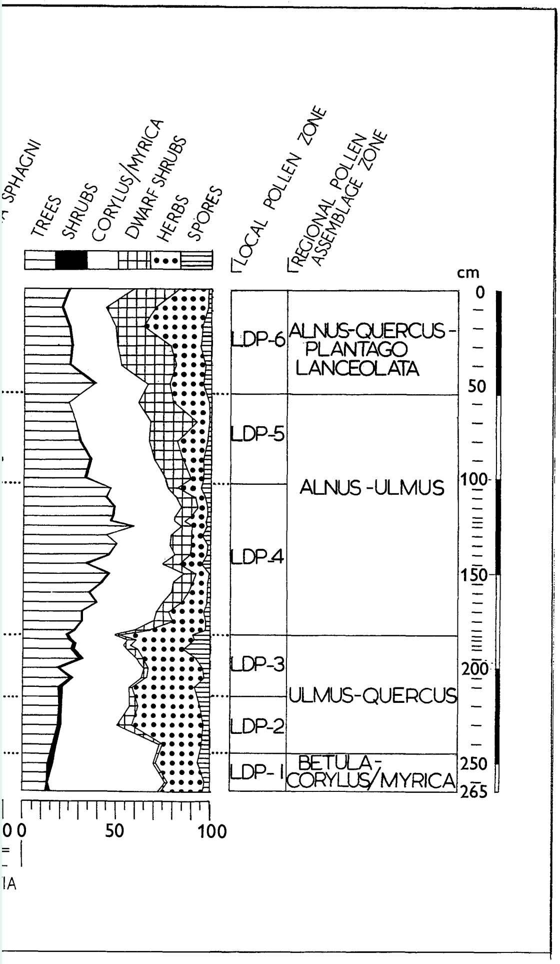


FIGURE 15. Local pollen diagram from Lo
pollen which includes the types ind
Undifferentiated. For key to stratigr

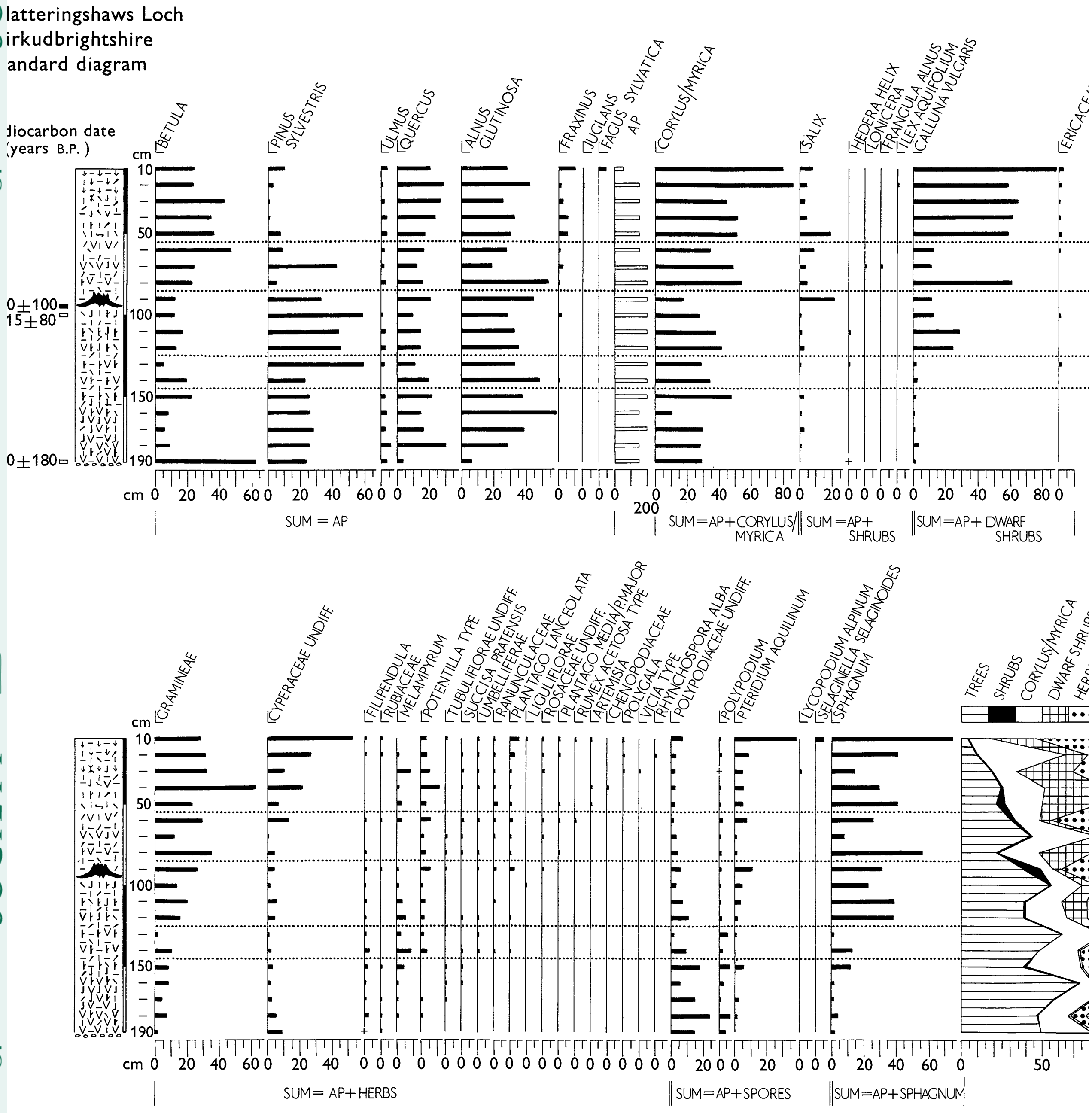


m from Loch Dungeon Peat, Kirkcudbrightshire. Calculation base is sum of
mary diagram, sum of AP + shrubs + *Corylus*/*Myrica* + dwarf shrubs + herbs +
Undiff., Undifferentiated; B.P., before present (i.e. 1950). For key to strati-

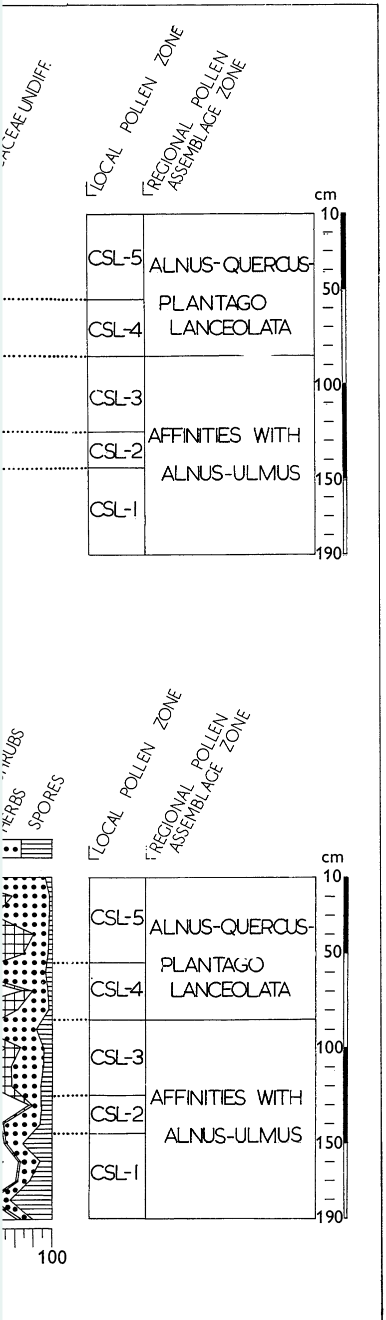
och Dungeon Peat, Kirkcudbrightshire. Calculation base is sum of local
dicated. Abundance of macrofossils is shown by white bars. Undiff.,
raphic symbols see figure 2.

(*Facing p.* 210)

PHILOSOPHICAL TRANSACTIONS OF THE ROYAL SOCIETY B BIOLOGICAL SCIENCES



URE 16. Standard pollen diagram from Clatteringshaws Loch, Kirkcudbrightshire. Calculation base is sum of tree pollen (AP). For the summary diagram, sum of AP + shrubs + *Corylus*/*Myrica* + dwarf shrubs + herbs + pteridophyte spores = 100 %. Undiff., Undifferentiated; B.P., before present (i.e. 1950). For key to stratigraphic symbols see figure 2.



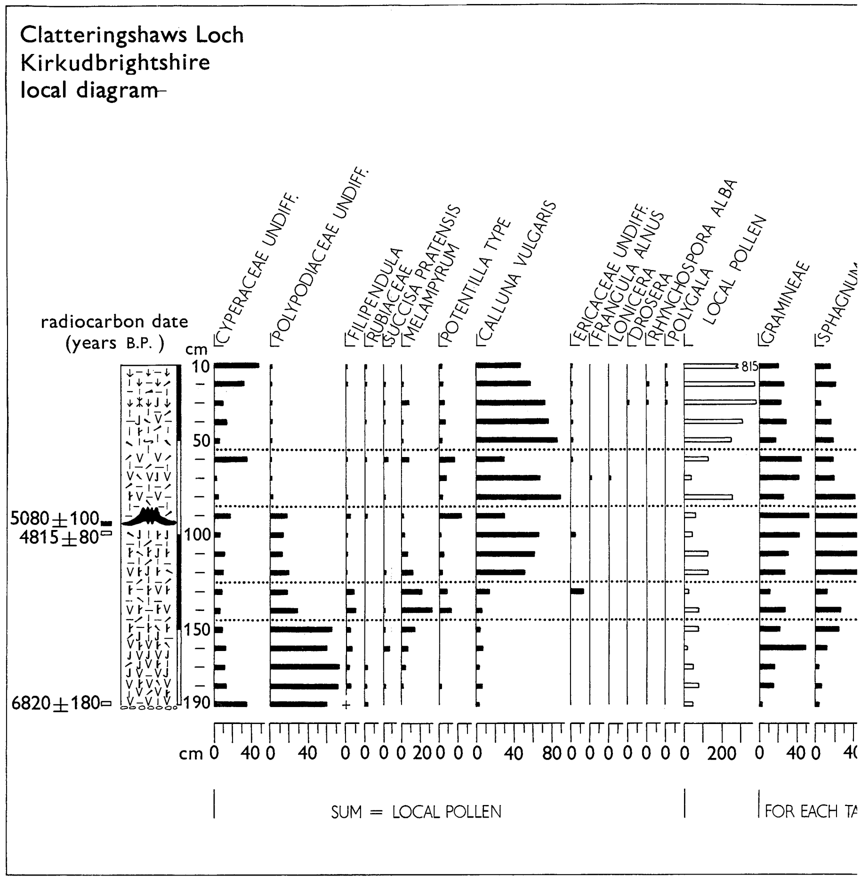
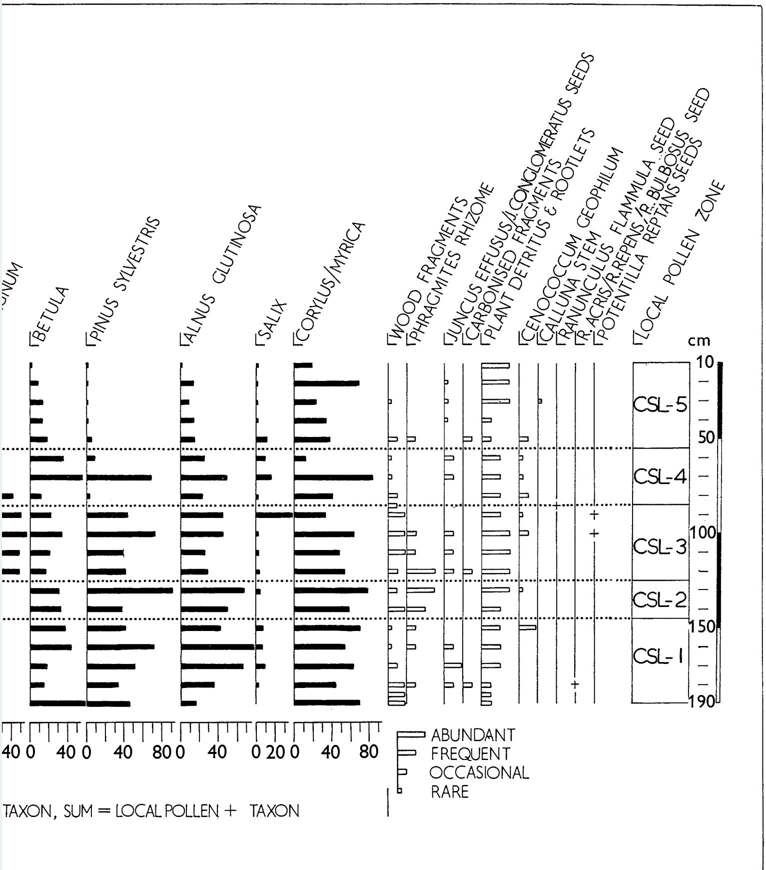


FIGURE 17. Local pollen diagram from Clatteringshaws Loch, Kirkcudbrightshire
local pollen, which contains the types indicated. Abundance of macrofossils is s
Undifferentiated. For key to stratigraphic symbols see figure 2.



'e. Calculation base in sum of
shown by white bars. Undiff.,

unsuitable humus by the parent trees or by the ombrotrophic conditions and abundance of *Calluna*. The parent trees would have died a more or less natural death, and their remains would then have been overgrown by the bog community.

Zone LDP-5; 55–102.5 cm

Pinus pollen values are low, and the proportion of tree pollen gradually falls throughout. *Calluna* pollen is abundant, and gradually increases.

The bog continued its growth, and little difference in the local community is detectable in this zone from zone LDP-4. The low *Pinus* pollen values indicate that pine became rare in the area, presumably because it could not compete with the deciduous trees on dry ground, and was thus restricted to cliffs and the few remaining suitable mire habitats, for example beside the River Dee at Clatteringshaws (figure 11). Although pollen from the Clatteringshaws pines is detectable in the Cooran Lane diagram, it is not discernible at Loch Dungeon Peat, probably owing to the greater distance, and the intervening mountain range.

LDP-6; 0–55 cm

Tree pollen values are low, and pollen of weeds appears in small quantities. Cyperaceae and *Calluna* pollen values are high, and pollen of *Drosera* and *Rhynchospora alba* are present.

These differences from zone LDP-5 suggest that the bog surface became wetter, possibly owing to increased run-off from deforested slopes. Overall peat accumulation was very slow, for the beginning of the *Quercus-Alnus-Plantago lanceolata* zone is dated to about 5000 B.P. During this zone, the surface of the bog became disturbed, and erosion started, preventing further peat growth. Erosion is severe at the present day, large areas of the peat being devoid of vegetation.

(*c*) *Clatteringshaws Loch*

(i) *Site description*

Clatteringshaws Loch is a reservoir created in 1937 by damming the Black Water of Dee. Its level fluctuates considerably depending upon the needs of the Hydroelectric Board. The valley was once peat covered, and the rising water has washed most of it away, leaving a peat cliff at its highest extent. At times of low water, pine stumps can be seen deposited on the gravelly bottom and a trunk and several branches were found. In several places, stumps have been exposed *in situ* in the peat cliff. The site investigated, on the northeast shore, was of this nature (Nat. Grid Ref.: 25/5477; lat. 55° 4′ N; long. 4° 17′ W; altitude 210 m (600 ft) O.D.). The vegetation of the valley has been largely destroyed by ploughing and planting for forestry. There was some kind of raised bog at Raploch Moss, at the southeast corner of the Loch, but this has been drained and planted. Presumably the area was covered by blanket bog and heather moor, with *Molinia* grassland in wetter areas, and species-poor *Agrostis-Festuca* grassland in more heavily grazed areas.

The pine stumps at the site studied are very large, and root anastomoses can be seen between them. They are in one layer (checked by levelling data) and lie over about 1 m of peat.

The stratigraphy of the profile investigated is shown diagrammatically on the left side of the pollen diagrams (figures 16, 17), and estimates of the various macroscopic components shown on figure 17.

A general account of the stratigraphy of the profile follows:

cm	
0–28	dark brown, highly oxidized structureless peat penetrated by modern *Molinia* roots from the turf above; *Juncus* sp. seeds are present
28–45	dark brown, amorphous, moister peat with occasional carbonized fragments and *Salix* twigs
45–90	very dark brown moist rooty peat with many monocotyledon remains and twig fragments of *Salix* and *Alnus*, and *Alnus* root nodules; *Juncus* sp. seeds are rare; one seed each of *Ranunculus flammula* and *Potentilla reptans*
87	top of pine stump adjacent to profile
90–110	almost black, moist peat with many roots and wood fragments of *Pinus*, *Alnus*, and *Salix*; monocotyledonous rhizomes abundant and *Phragmites* rhizomes occasional; seeds of *Juncus effusus/J. conglomeratus* and *Potentilla reptans*
110–171	large pine root at 120 cm; almost black *Phragmites*-monocotyledonous peat with abundant wood fragments and occasional *Juncus effusus/J. conglomeratus* seeds
171–190	wood peat with *Phragmites* rhizomes containing seeds of *Ranunculus acris* type (*R. acris*, *R. bulbosus*, or *R. repens*) and *Juncus effusus/J. conglomeratus*
190–	gravel

(ii) *Local vegetational development at Clatteringshaws Loch*

The standard pollen diagram is shown in figure 16, and the local pollen diagram in figure 17. The diagrams are divided into local pollen zones, designated CSL-, and numbered from the base upwards. The regional pollen assemblage zones are shown in figure 16.

Zone CSL-1; 145–190 cm

Tree pollen is abundant, and *Pinus*, *Alnus*, and *Quercus* are the principal tree pollen types, and *Corylus/Myrica* pollen is frequent. *Calluna* pollen is rare, and herb pollen frequencies are low, with relatively few taxa. Polypodiaceae undiff. spore values are high, especially on a local pollen basis (figure 17).

The peat at the base of the profile is radiocarbon dated to 6820 ± 180 B.P. (Q-880), a little later than the pine stump at Loch Dungeon, and the older pine stump at Cooran Lane. However, it is close in age to the younger pine stump at Cooran Lane. It is postulated that active peat growth did not restart at Cooran Lane until about 5900 B.P., so the onset of peat growth at Clatteringshaws Loch probably does not reflect a regional change to a more humid climatic regime, but may result from changes in local hydrological factors, such as a change in the course of the River Dee, or the obstruction of drainage by local peat development.

The initial peat-forming community was probably a birch-alder fen carr. The understorey was rich in ferns, including *Polypodium* which may have been growing epiphytically. As peat accumulated, the site was colonized by *Juncus effusus* or *J. conglomeratus* and *Phragmites*, and *Salix* became a member of the canopy. The relatively low amounts of Gramineae pollen indicate that the *Phragmites* was not growing sufficiently vigorously under the shade of the canopy to flower abundantly (Björk 1967). The abundance of *Alnus* pollen indicates that it was growing locally (Jonassen 1950), and high values of *Corylus/Myrica* pollen may have originated from *Myrica gale* in the understorey. Other understorey species are represented by pollen of

Cyperaceae, *Filipendula*, Rubiaceae (? *Galium palustre*), *Succisa pratensis*, *Melampyrum*, and *Potentilla* type, and a seed of *Ranunculus acris* type (includes *R. acris*, *R. bulbosus*, and *R. repens*). The low amounts of *Calluna* pollen probably originate from outside the Clatteringshaws fen, but the high values of *Pinus* pollen may indicate that *Pinus* may have already been growing on the peat nearby, for it is unlikely to have formed extensive forests on the surrounding upland.

Zone CSL-2; 125–145 cm

This is a short zone of similar pollen composition to zone CSL-1, but with lower values of Polypodiaceae undiff. spores, and higher values of *Melampyrum* and *Potentilla* type pollen.

The abundance of *Phragmites* rhizomes in the peat indicate that *Phragmites* became an important member of the understorey of the fen carr, largely at the expense of ferns. The increases in *Melampyrum* and *Potentilla* type pollen may reflect a decrease in base status. Birch and alder were still the major components of the canopy, and *Salix* was reduced in abundance.

Zone CSL-3; 85–125 cm

Tree pollen values remain high, the dominant types being *Pinus*, *Quercus*, and *Alnus*. *Corylus*/*Myrica* and *Calluna* pollen values are high, as are values of *Sphagnum* spores. Herb pollen values are dominated by Gramineae, and there are relatively high values of *Potentilla* type and *Melampyrum*.

Phragmites rhizomes decrease in abundance through the zone, and there is a large pine stump in the peat at the top of the zone.

The peat became more acid, and birch and alder decreased in abundance. The understorey became bog-like, dominated by *Calluna* and *Sphagnum*, and possibly also *Myrica gale*, and containing decreasing amounts of *Phragmites* and *Juncus*. The increasing amounts of Gramineae pollen may originate from *Molinia caerulea*, *Deschampsia cespitosa*, or *D. flexuosa* in the acid fen carr. Eventually conditions became suitable for pine to colonize the site. The pines became large, and were sufficiently close for root anastomoses to occur between them. Seeds of *Potentilla reptans* were recovered from the peat at the level of the pine stump, suggesting that this plant grew in association with the pines, and accounting for the high values of *Potentilla* type pollen at this level.

Pine was probably already growing on the peat near the site as its growth at the site had little effect on the already high values of *Pinus* pollen in the local pollen diagram (figure 17). However, *Pinus* becomes the most abundant pollen type in the tree pollen diagram (figure 16) at the expense of all the other major tree pollen types. The pine stump was radiocarbon dated to 5080 ± 100 B.P. (Q-878). This corresponds with the estimated age of the lower boundary of the *Quercus-Alnus-Plantago lanceolata* assemblage zone, established from Snibe Bog (part II). However, although changes in the Clatteringshaws diagram above this level correspond to changes associated with the *Quercus-Alnus-Plantago lanceolata* zone, local pollen influences the diagram sufficiently that the definition cannot be strictly applied, and thus the sequence above 85 cm cannot be assigned to a regional pollen assemblage zone.

The peat below the pine stump at 100 cm, at the level of the maximum values of *Pinus* pollen in the standard diagram (figure 16) was radiocarbon dated to 4815 ± 100 B.P. (Q-879). The date of the pine stump, and its conformity with the regional pollen picture combine to suggest that this date is slightly anomalous. It is probable that the peat has been grown through by younger roots, thus destroying the true age. The average rate of peat accumulation from the base of the peat up to the pine stump was moderate (1 cm in about 20 years), but was very much slower above the pine stump to the surface (1 cm in about 50 years). This slow rate of accumulation would have given ample opportunity for much younger roots to grow down through the peat. This illustrates once again the difficulties encountered in interpreting radiocarbon dates from slow growing peat deposits, and the differences encountered when dating different materials of the same age.

Zone CSL-4; 55–85 cm

Betula, *Alnus*, and *Quercus* have high pollen values, but those of *Pinus* are relatively low. *Salix* pollen values are relatively high, *Calluna* values are moderate, and Gramineae and *Potentilla* type are the most abundant herb pollen types. Pollen of *Fraxinus* and weed taxa are present in low amounts.

The presence of wood remains in the peat and the high values of *Betula* and *Salix* pollen suggest that the peat became flooded by relatively base-rich water, allowing the establishment of a birch-willow fen carr. Other members of the community are represented by pollen grains of *Lonicera* and *Frangula alnus*, and *Alnus glutinosa* was probably present, but not in its former abundance.

This rise in water table was probably responsible for the death of the pines. *Pinus* pollen has low values in this zone, suggesting that most of the pollen of previous zones had originated from trees growing locally on the peat, and that once they had been killed, pine was rare in the area, probably being restricted to open forest or cliff habitats.

The renewed fen wood was still acid, as *Calluna* and *Sphagnum*, grasses, and possibly *Myrica* continued to flourish in the understorey. *Potentilla* and *Juncus effusus* or *J. conglomeratus* were also associated. A seed of *Ranunculus flammula* just above the pine stump is associated with Ranunculaceae pollen. This plant would have flourished in the wet acid conditions associated with a rise in water table.

Zone CSL-5; 0–55 cm

Tree pollen frequencies fall very low. *Calluna*, *Corylus/Myrica*, and Gramineae are the dominant pollen types, although Cyperaceae pollen becomes abundant towards the top of the zone. *Fraxinus* pollen and *Pteridium* spores are frequent and there is a variety of herb pollen taxa, including pollen of weeds such as *Plantago lanceolata* and *Artemisia*.

Local tree growth on the peat ceased at the beginning of this zone, as shown by the decrease in local tree pollen (*Betula*, *Alnus*, *Salix*), and the scarcity of wood fragments. A relatively treeless landscape resulted, both from the spread of bog and the activities of man. The vegetation of the site became *Calluna*- and *Sphagnum*-dominated bog, possibly with *Myrica*. Pollen of Ericaceae undiff. probably represents *Erica* spp. in the community. Later the bog surface may have become wetter, allowing the growth of *Rhynchospora alba* and *Drosera*. However, these may have been growing on bare disturbed peat. The increase of Cyperaceae pollen may be due to the presence of *Trichophorum*, and the high amounts of Gramineae and the grain of *Polygala* may result from grazing pressure converting the vegetation to acidic grasslands, such as Molinietum. The peat community possibly resembled Calluneto-Trichophoretum (McVean & Ratcliffe 1962) as *Sphagnum* spore values are very low, and *Eriophorum vaginatum* rhizomes were not recorded, although the peat was very humified. Peat growth became minimal, and peat may have been removed for fuel. Its present surface is dry and dominated by *Molinia*, as a result of drainage and fertilization by the Forestry Commission, and drainage and erosion by the formation of the reservoir.

(*d*) *Summary of the Galloway region sites*

The chart in figure 18 represents the three pine stump profiles and that from Snibe Bog (part II) in relation to the regional pollen assemblage zones. The proposed curves for wetness and basicity are schematic and have no actual values.

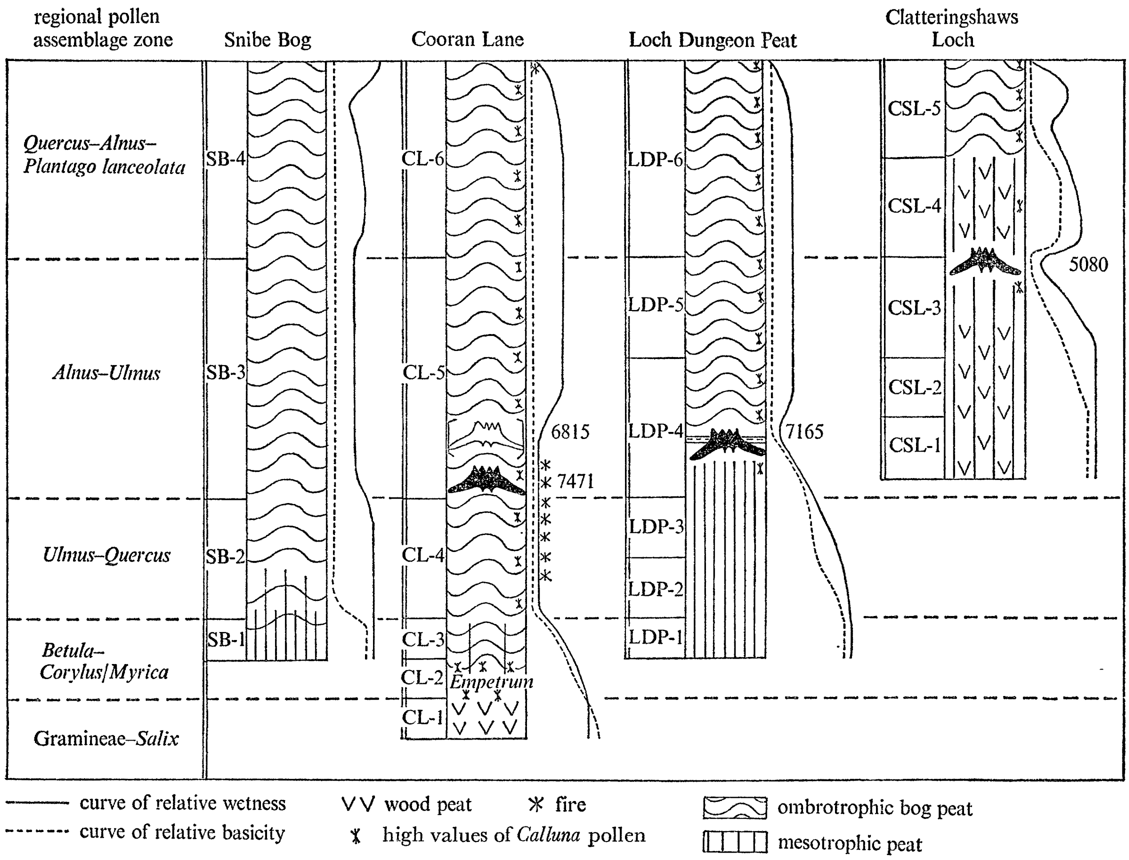


FIGURE 18. Summary of postulated changes in wetness and basicity in the Galloway area sites. The curves are relative, not quantitative. Radiocarbon dates of the wood remains are indicated.

The chart shows that the conditions for pine colonization of the peats were similar to those at the Cairngorm sites. The sites became sufficiently dry for seedling establishment, and the pine grew on acid, but still relatively mesotrophic peat, in which *Calluna* was rare. However, at Cooran Lane, *Calluna* was well established on the peat before pine colonization, and pine only became established after a series of fires, which presumably created a favourable seed bed, free from mycorrhizal inhibitors. The second stump at the site grew after another fire or fires which destroyed the first generation of trees, and presumably once again created a favourable humus for seedling establishment. Pine growth ceased at the Cooran Lane and Loch Dungeon sites when the pines died of old age, perhaps hastened by waterlogging, leaving unfavourable conditions for further regeneration. Ombrotrophic peat growth, dominated by *Calluna*, then commenced at both sites, and this probably prevented further pine colonization. At Clatteringshaws Loch, the pine tree was killed by a rise in water table and re-establishment of an acid fen carr. Conditions were probably too wet for further seedling establishment, and subsequently *Calluna*-dominated blanket bog developed, and pine became rare in the area.

The pine stumps at Cooran Lane and Loch Dungeon span a period of about 650 years, but the stump dated at Clatteringshaws is nearly 2000 years younger. Both the Loch Dungeon and Cooran Lane sites were dry at the time of pine colonization, with fires at Cooran Lane. At Snibe Bog, a relatively dry type of bog community was forming the peat at this time (part II). It is unlikely that sudden waterlogging killed the pines, although increased wetness may have hastened their death and prevented further regeneration. At Snibe Bog, there is no evidence for increased wetness at this time. However, at Clatteringshaws Loch, peat started to accumulate, possibly reflecting either wetter climatic conditions or, more probably, local hydrological changes.

There would therefore seem to be reasonably good evidence for a period of climatic dryness in the Galloway region at about 7400–6800 B.P. However, there is no conclusive evidence for a subsequent great increase in wetness, but rather a gradual change to somewhat wetter conditions.

The peat at Clatteringshaws Loch dried out sufficiently at about 5000 B.P. to support pine growth. Here there is good evidence that the pines were killed by a rise in water table. At Snibe Bog, at the beginning of the *Alnus-Quercus-Plantago lanceolata* assemblage zone, there is also a change to a wetter bog vegetation. The remaining two sites show little evidence for any change at this time, and peat growth was slow at both. Thus there may have been a regional increase in wetness at about 5000 B.P., but the evidence is not conclusive. This is the time of the start of forest clearance by man, and run-off may have been increased onto Snibe Bog, thus affecting its water regime. Clatteringshaws Loch may also have been affected by local drainage changes, due to man or other causes.

Today, the blanket bog sites are all very dry, while Snibe Bog is extremely wet. This demonstrates how factors other than climate can influence bog growth at the present day. Forest clearance, grazing, and burning have culminated in the drying out and erosion of the blanket peats, but have also increased run-off from the uplands, which collects in the valley bottom and has increased the wetness of Snibe Bog. The formation of pools on the bog is quite a recent event (Ratcliffe & Walker 1958), and is correlated with total forest clearance of the surrounding hills (part II).

6. Other pine stump sites studied in Scotland

Samples of pine stumps from other blanket peat sites in Scotland have been obtained by the author (figure 19) and dated by Dr V. R. Switsur and his colleagues (see appendix I). In addition radiocarbon dates from pine stumps collected by other workers have been published, and details of these are listed in appendix II.

Several pollen diagrams have been published from Scotland with radiocarbon dates for a major decline in the values of *Pinus* pollen. Details of these dates are also listed in appendix II.

All the dates are shown in relation to their geographical location on figure 20. They fall into three main groups: the Galloway area, the Cairngorm area, and the northwest Highlands. The dates from Rannoch Moor, Coire Bog, and Rogart are intermediate in geographical position.

The dates are plotted in relation to their position in time in figure 21. They fall into two main groups.

(1) The most striking group of dates falls between about 4000 and 4500 B.P. They correspond closely to the northwest Highland geographical group, with the addition of pine stump dates from Rannoch Moor, from Rogart, and from Sgor Mor and Jean's Hut in the Cairngorms. Two dates from birch wood remains also fall within this range from the Cairngorm area. Studies on the vegetational history of the northwest Highlands (part III; Pennington, Haworth, Bonny & Lishman 1972; Moar 1969) show that pine dominated the upland forest at least as far north as Loch Sionascaig, and perhaps further north, but with considerable amounts of birch at Duartbeg. It was certainly widespread on blanket bogs up to the north coast of Sutherland (figure 1). Between 4500 and 4000 B.P. the radiocarbon dates from both pine stumps and from substantial declines in pine pollen in pollen diagrams from lochs indicate a widespread decrease of pine, both in bog habitats and in the upland forest. Pennington *et al.* (1972) and Pennington (1973) comment upon this horizon, and consider that, although man was active in the area,

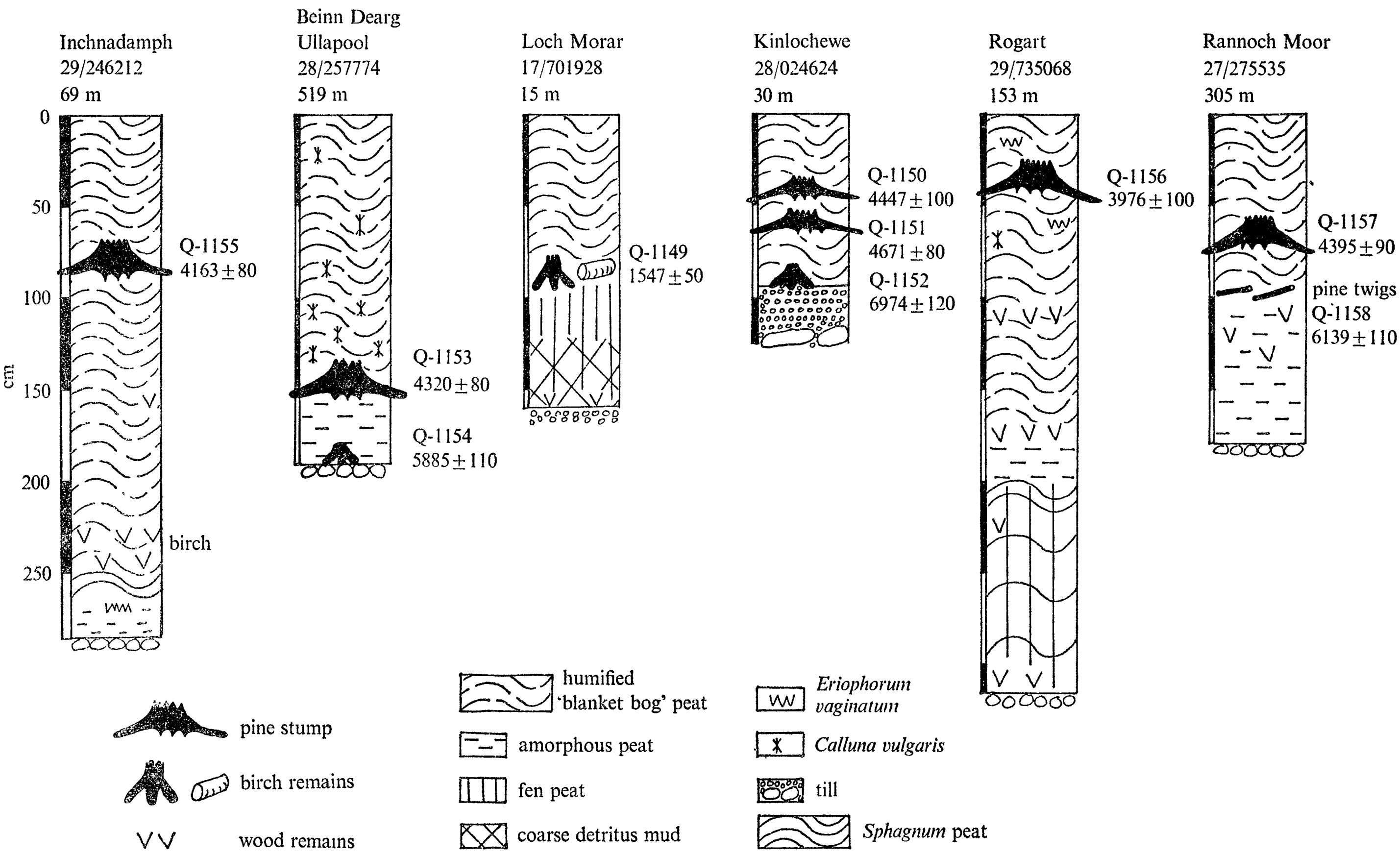


FIGURE 19. Stratigraphy of blanket peat sites containing wood remains which were radiocarbon dated.

widespread deforestation on both upland and bog situations was unlikely. Similarly, there is little palaeoecological evidence for a widespread period of fires which could have destroyed the forest. The pollen diagrams and chemical profiles from loch sediments generally record the increase of pollen of blanket bog taxa from 6000 B.P., which accelerated at 5000 B.P. Pennington *et al.* (1972) suggest that pine and birch grew on blanket peat as it was relatively dry, but that a climatic deterioration about 4500 B.P. led to increased wetness, resulting in inhibition of regeneration of pine, and swamping by the increased growth of blanket bog. Birks (part III) considers the ecological implications of the *Pinus* decline at Loch Maree, and comes independently to similar conclusions. Here it was suggested that the forests had reached a critical threshold, due to continued leaching and podsolization, and waterlogging of soils and any slight adverse change such as an increase in climatic oceanicity, with stronger winds associated with increases in humidity and cloudiness, or disturbance of the ecosystem by man would tip the balance towards the death of pine and its replacement by ombrotrophic blanket bog. The wet, extremely acid, blanket bogs of the west of Scotland today are unsuitable for the growth of pine (see §2) although birch may colonize them in somewhat drier situations which are sheltered and protected from grazing.

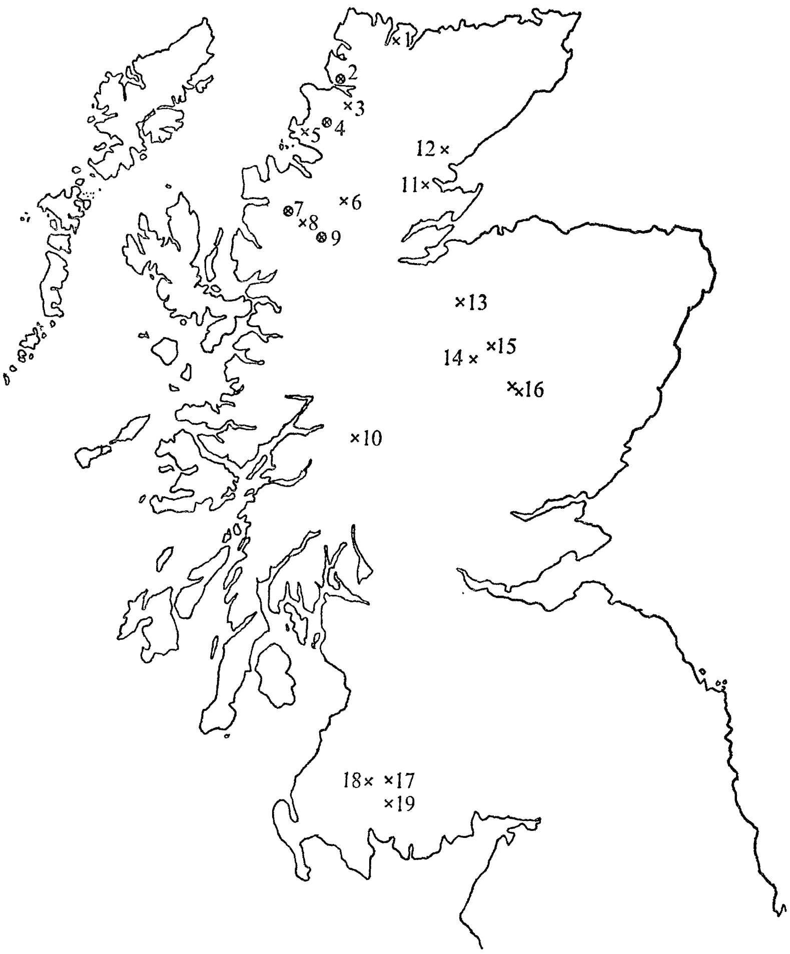


Figure 20. Map to show location of sites with radiocarbon dated wood remains and pollen diagrams with radiocarbon dated *Pinus* pollen declines in Scotland. 1, A'Mhoine; 2, Duartbeg; 3, Inchnadamph; 4, Loch Sionascaig and Inverpolly; 5, Achiltibuie; 6, Beinn Dearg, Ullapool; 7, Loch Maree; 8, Kinlochewe; 9, Loch a'Chroisg; 10, Rannoch Moor; 11, Coire Bog; 12, Rogart; 13, Allt na Feithe Sheilich; 14, Loch Einich; 15, Jean's Hut; 16, Carn Mor and Sgor Mor; 17, Loch Dungeon Peat; 18, Cooran Lane; 19, Clatteringshaws Loch. ×, Timber site, ⊗, pollen diagram site.

The demise of pine at around 4000 B.P. is not restricted to Scotland. Nine dates from north-east Ireland demonstrate a clear horizon between about 4400 and 3600 B.P. (Smith & Pilcher 1973). Pilcher (1973) discusses the *Pinus* pollen decline at Slieve Gallion, Co. Tyrone. Beaker people extensively cleared the forests of this area at about this time. This was followed by blanket bog growth in many places. He suggests that man may therefore be partially responsible, but that a climatic cause cannot be ruled out. Mitchell (1972) discusses the initiation and growth of blanket peat in Ireland, and concludes that Neolithic or Bronze Age agriculture depleted the soil and impeded drainage by iron pan formation, which allowed the growth of peat in areas of suitable climate. He presents evidence that blanket peat began to form at about 4000 B.P. and that it has continued to spread since then, as further areas were cultivated and abandoned. Further palaeoecological work using pollen and peat stratigraphic studies in conjunction with radiocarbon dating may provide more insight into the ecological factors which led to the death of pines on both the uplands and on blanket peat in Scotland and in northern Ireland.

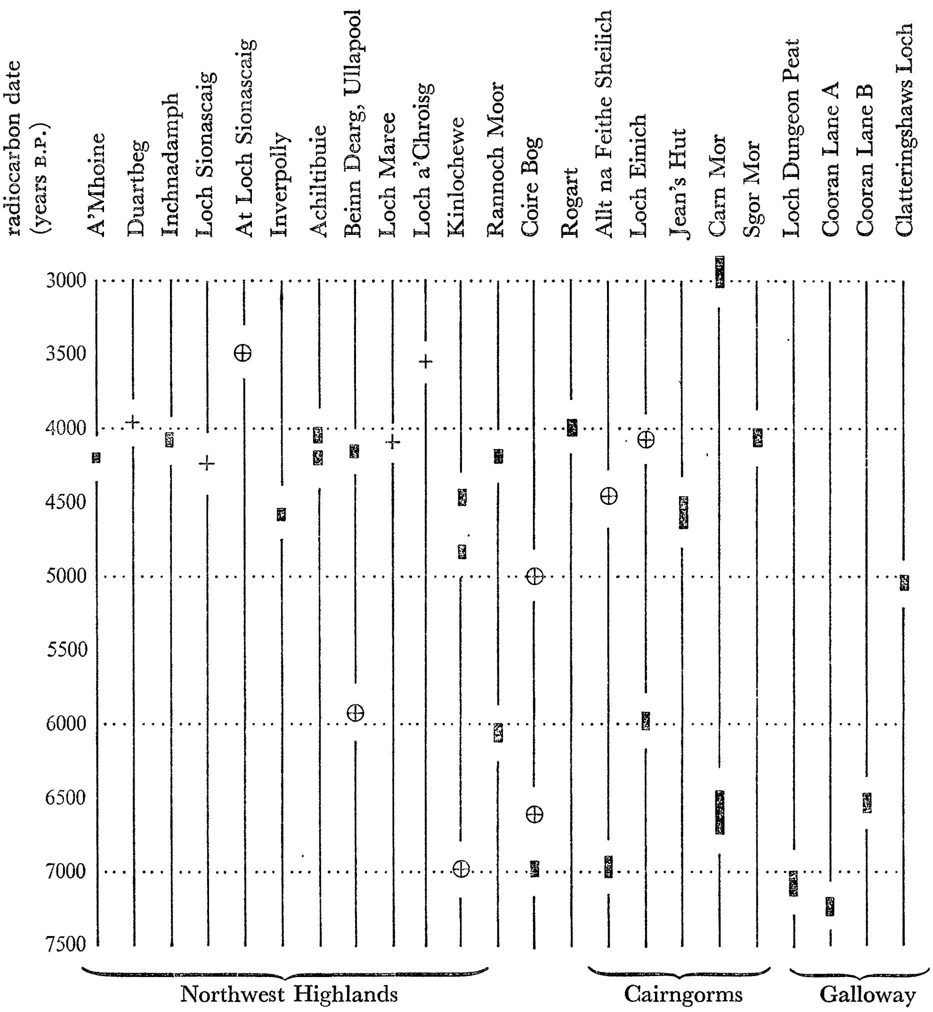


FIGURE 21. Table of radioacarbon dates in relation to their ages. The sites are arranged in geographical order with the northernmost at the left. The height of the symbol represents one standard deviation. ▮, Pine stump; ⊕, birch wood; +, pollen diagram.

The dates of pine stumps at Rannoch Moor and Rogart between 4500 and 4000 B.P. suggest that the factors influencing pine at this time extended as far south and east as these sites. However, the intermediate nature of the sites is emphasized by other dates from Rannoch Moor and from Coire Bog (near Rogart (figure 20)) which fall into the second group of dates.

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(2) The second group of dates are between about 6000 and 7500 B.P. This is a much larger time range than that covered by the first group. The dates are from the Cairngorm and Galloway areas, except for the two from Rannoch Moor and Coire Bog. The lack of striking synchroneity within the group precludes any single widespread cause, and the palaeoecological investigations in these areas presented in this paper have revealed various reasons for the growth and death of the pines.

(3) Dates outside the ranges of the two groups are recorded from all the geographical areas. Those from the northwest Highlands are from birch remains, a tree which is capable of growing on blanket peat. The birch remains at Beinn Dearg, Ullapool and Kinlochewe are old, and represent trees that grew on the site before bog development, or trees which grew in the mesotrophic wooded fen community which developed before pine colonized the sites. Johansen in Pennington *et al.* (1972) suggests that the birch on the bog near Loch Sionascaig dated to 3470 ± 100 B.P. (K-1302) was killed as a result of human interference with an already deteriorating and unstable forest ecosystem. The dates from the birch remains by Loch Morar are very young, and although no pollen analyses have yet been undertaken in this area, it is likely that birch colonized a disturbed bog surface, and was subsequently killed either by human activity or by an increased rate of bog growth.

In the Galloway area, the date of the pine at Clatteringshaws Loch falls outside the range of the other dates. Here it is likely that pine colonized locally suitable conditions. In the Cairngorm area, three of the dates of Pears (1969) are younger than the majority. Those from pine stumps at Sgor Mor and Jean's Hut fall within the range of the first group of dates, and so do the dates from birch remains at Loch Einich and Allt na Feithe Sheilich. It may be that the change in climate tentatively postulated in the northwest Highlands also affected the Cairngorms to some degree, causing trees growing on relatively dry bogs to be killed by renewed peat growth. However, pine was not eliminated from the area, and was able to colonize a bog on Carn Mor at 2880 ± 220 B.P. Because pine was abundant in the upland forest, there was presumably a seed source available to colonize any bog that became suitable. More dates are required to determine whether there are any clusters of dates at certain time intervals and therefore if it was likely that climatic changes were sufficiently great to start any rapid changes in the vegetation of the area.

7. General conclusions

As far as is known, pine stumps have a distinct geographical distribution in Scotland (figure 1). With the exception of the stumps in southwest Scotland, they all occur in, or to the north of areas of potential native pine forest. Pollen analytical studies indicate that pine was a prominent component of mid-Flandrian forests in the eastern Grampians and in the northwest Highlands, at least as far north as Loch Sionascaig (as far as is known at present).

Radiocarbon dates divide the stumps into two main groups, which correspond to geographical areas. Those in the northwest Highlands are dated between about 4500 and 4000 B.P.; those to the east and south are much more heterogeneous in age, but most are some 2000 years older. The lack of synchroneity at the Boreal/Atlantic and sub-Boreal/sub-Atlantic boundaries of Blytt and Sernander (about 7000 and 2500 B.P. respectively) implies that the occurrence of pine stumps cannot be taken as evidence in support of their climatic scheme, as it has been in the past (see, for example, Samuelsson 1910).

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This does not mean to say that pine stumps do not reflect climatic changes. The remarkable synchroneity of stump ages and dates for the *Pinus* pollen decline in pollen diagrams from northwest Scotland and northeast Ireland may well be a result of increased climatic wetness. If the climate was relatively dry before about 4500 B.P. pine growth on bogs would be encouraged, and pine would also be able to grow on soils which had been leached, acidified, and podsolized during the previous 5000 years since the beginning of the Flandrian, particularly in areas of base-deficient rocks. A marked increase in climatic wetness would lead to changes in the vegetation of existing bogs, and encourage the spread of bog communities over acid, ill-drained mineral soils. Pine would probably be the commonest tree on such soils, and would therefore suffer from paludification more than oak and elm on richer soils.

The pine stumps in the south and east of Scotland show a much wider age range, from about 7400 to 6000 B.P. and there are several stumps dated from these areas which are much younger (between about 5000 and 2000 B.P.). Any simple explanation for their occurrence in terms of climatic change cannot be upheld. Palaeoecological investigations of six pine stump sites reveal that there are several possible causes for the growth and death of the trees. In all cases, pine colonized mire communities which had become acid, owing to the reduction in the influence of ground water as peat accumulated. Presumably the mires were all sufficiently dry to permit seedling establishment and maturation of the trees. In most cases, blanket bog communities had not developed with *Calluna* as a prominent component, and fibrous *Calluna* peat, unfavourable for seedling establishment was not being formed. The mires were either dominated by *Sphagnum*, or were oligotrophic wooded mires, with willows and birch. At the site of Cooran Lane, *Calluna* had become important in the mire, but the occurrences of fire prepared suitable seed beds.

The death of the pines seems to be due to various causes. Most commonly, some increase in wetness of the mire surface is postulated to have killed the trees. This need not necessarily be due to a large climatic change, as McVean (1963*a*) has indicated that a single wet season may be sufficient to kill pines growing in a situation marginal to their survival. In most cases, *Calluna*-dominated ombrotrophic blanket bog developed, a habitat which is generally unsuitable for pine regeneration. The pine at Clatteringshaws Loch was killed by a flooding of the peat surface sufficient to allow the re-establishment of the acid wooded mire, which then gradually developed into a blanket bog community. At Coire Bog north of the Cairngorms, the pine appears to have been killed by a fire. At no site is there conclusive evidence that man was directly responsible for the death of any of the trees. Most of the pines are pre-Neolithic in age, but some of the birches could have been affected by the activities of Neolithic man.

Little evidence can be drawn from the palaeoecological studies for the hypothesis that large scale climatic changes are reflected by the occurrence of forest beds. However, the methods used have many methodological and interpretative limitations and difficulties; the peat is usually very highly humified and decayed, with few recognizable macroscopic remains preserved; pollen analysis has limitations at all stages of the method, particularly in pollen identification as far as palaeoecological reconstruction is concerned: and there are difficulties in obtaining a true age of peat by radiocarbon dating due to contamination by younger roots and percolating humic acid. These limitations should therefore be borne in mind in assessing the validity of the palaeoecological conclusions.

In general, the palaeoecological evidence is inconclusive in climatic terms, although it is possible that the period of the older pine stumps in the Galloway region was a time of relative

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climatic dryness. However, it is felt that no simple climatic model can be proposed to explain the geographical and temporal distribution of the pine stumps studied during this investigation, and that tree remains, particularly pine stumps, cannot be used as direct evidence of climatic change without a detailed investigation of their palaeoecological circumstances.

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Appendix 1. Radiocarbon dates of samples from sites in Scotland provided by H. H. Birks

By V. R. Switsur

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The ages of the samples are shown in the table. They were calculated by using the 'Libby' half-life of 5568 years for radiocarbon and the statistical uncertainty is quoted as one standard deviation calculated from the proper combination of measurements on the samples and international standards. They are thus reported as 'conventional radiocarbon dates' uncorrected for any effects except the normal laboratory variations. Conversion to the more recently measured half-life of 5730 may be performed by multiplication of the B.P. age by 1.03.

laboratory number	site	sample	depth cm	age (B.P.)	age (B.C.)	uncertainty ±
Q-871	Cooran Lane site A	pine stump	110	7471	5521	120
Q-872	Cooran Lane site A	peat	100	5890	3940	100
Q-1148	Cooran Lane site A	peat	110	5912	3962	100
Q-873	Cooran Lane site A	peat	120	6805	4855	200
Q-874	Cooran Lane site A	peat	140	7541	5591	120
Q-875	Cooran Lane site B	pine stump	—	6564	4614	120
Q-876	Loch Dungeon peat	pine stump	125	7165	5215	180
Q-877	Loch Dungeon peat	humus	125	6787	4837	200
Q-878	Clatteringshaws Loch	pine stump	87	5080	3130	100
Q-879	Clatteringshaws Loch	peat	100	4815	2865	80
Q-880	Clatteringshaws Loch	peat	—	6820	4870	180
Q-881	Loch Einich	'humus'	120	5880	3930	100
K-1418	Loch Einich	pine stump	120	5970	4020	120
Q-883	Loch Einich	birch twigs	80	4150	2200	100
Q-886	Allt na Feithe Sheilich	birch twigs	150	4425	2475	100
K-1419	Allt na Feithe Sheilich	pine stump	180	6960	5010	130
Q-887	Coire Bog	pine bark	235–255	6980	5030	100
Q-888	Coire Bog	birch	190	6731	4781	100
Q-889	Coire Bog	birch	145–160	5005	3055	100
Q-1149	Loch Morar	birch branch	80	1547	A.D. 403	50
Q-1123	Loch Morar	birch branch	80	1530	A.D. 420	50
Q-1150	Kinlochewe	pine stump	45	4447	2497	100
Q-1151	Kinlochewe	pine stump	70	4671	2721	80
Q-1152	Kinlochewe	birch twigs	95	6974	5024	120
Q-1153	Beinn Dearg, Ullapool	pine	140	4320	2370	80
Q-1154	Beinn Dearg, Ullapool	birch	180	5885	3935	110
Q-1155	Inchnadamph	pine stump	70	4163	2213	80
Q-1156	Rogart	pine	30	3976	2026	100
Q-1157	Rannoch Moor	pine stump	60	4395	2445	90
Q-1158	Rannoch Moor	pine twigs	95	6139	4189	110
Q-1031	Inverpolly	pine trunk	—	4674	2724	60

The table includes two dates that were obtained by Dr H. Tauber of the Copenhagen Radiocarbon Dating Laboratory. In view of the surprisingly late date obtained for the sample Q-1149 from Loch Morar, a second part of the sample Q-1123 was treated and combusted to obtain a check date, which confirmed the earlier determination.

A description of the pretreatment and methods of preparation of the samples will be published elsewhere.

Appendix 2. Radiocarbon dates from Scottish tree remains obtained by other workers and dates from pollen diagrams for the decline of *Pinus* pollen

site	grid ref.	source	material	conventional radiocarbon date (B.P.)	age (B.C).	uncertainty ±	quoted by
			(*a*) *tree remains*				
A'Mhoine, Eriboll	29/487605	Q-1121	pine	4393	2443	50	H. H. Lamb (personal communication)
At Loch Sionascaig	29/129128	K-1302	birch twigs	3470	1520	100	J. Johansen in Pennington *et al.* (1972)
Badentarbert Achiltibuie	29/103101	NPL-13	pine wood	4420	2470	102	Lamb (1964)
Achiltibuie	29/013101	NPL-14	pine roots	4220	2270	105	Lamb (1964)
Carn Mor	37/028907	Gak-2006	pine stump	6700	4750	300	Pears (1969)
Carn Mor	37/028907	Gak-2003	pine stump	2880	930	220	Pears (1969)
Sgor Mor	37/004908	Gak-2004	pine stump	4140	2190	220	Pears (1969)
		Birm-134		4130	2180	110	Pears (1969)
Jean's Hut	28/995052	Gak-2005	pine stump	4630	2680	210	Pears (1969)
Duartbeg	29/166384	Q-741	lake mud	3900	1950	105	Moar (1969)
Loch Sionascaig	29/120134	SRR-12	lake mud	4485	2535	100	Harkness & Wilson (1973)
Loch Maree	18/919709	Q-1005	lake mud	4206	2256	55	part III
Loch a'Chroisg	28/1158	SRR-54	lake mud	3583	1633	75	Pennington (1973)

A pollen diagram by J. Johansen accompanies the date from 'At Loch Sionascaig', and pollen diagrams for the Cairngorm sites, Carn Mor, Sgor Mor, and Jean's Hut are presented by Pears (1968).

Appendix 3. Pollen identifications

So that the reader may assess the floristic and ecological implications of the names of the pollen curves on the pollen diagrams, the taxa included in each pollen type are listed below. References and short notes on identification of unusual pollen types are given where necessary.

Achillea type. Includes *Achillea* (2 spp.), *Anthemis* (2 spp.), *Chamaemelum nobile*, *Chrysanthemum* (4 spp.), *Matricaria recutita*, *Otanthus maritimus*, and *Tripleurospermum maritimum* (Birks 1973).

Angelica type. Includes *A. sylvestris*, *Carum verticillatum*, *Ligusticum scoticum*, *Meum athamanticum*, *Peucedanum officinale*, *Selinum carvifolia*, and *Silaum silaus* (Birks 1973).

Caltha type. Includes *Aconitum anglicum*, *Aquilegia vulgaris*, and *Caltha palustris* (Faegri & Iversen, 1964; Birks 1973).

Campanula type. Includes *Campanula* (5 spp.), *Jasione montana*, *Legousia hybrida*, *Phyteuma* (2 spp.), and *Wahlenbergia hederacea* (Birks 1973).

Cirsium type. Includes *Carduus* (3 spp.) and *Cirsium* (8 spp.) (Birks 1973).

Conopodium type. Includes *Anthriscus sylvestris*, *Conopodium majus*, and *Pimpinella major* (Birks 1973).

Hypericum pulchrum type. Includes *H. montanum*, *H. pulchrum*, and some grains of *H. tetrapterum* (Birks 1969; part II).

Lychnis flos-cuculi. Very similar to pollen of *L. alpina* and *L. viscaria* (Andersen 1961) but distinguished by the ratio of pore diameter to inter-pore distance (Birks 1969).

Montia perfoliata/M. sibirica. Similar to pollen of *M. fontana* but differs in being tricolpate rather than pericolpate.

Potentilla type. Includes *Potentilla* (11 spp.), *Fragaria vesca*, and *Sibbaldia procumbens*. May also include some grains of *Geum* (2 spp.) (Faegri & Iversen 1964).

Ranunculus acris type. Includes *R. acris*, *R. auricomus*, *R. bulbosus*, *R. ficaria*, *R. lingua*, *R. parviflorus*, *R. repens*, *R. sardous*, and *Clematis vitalba* (Birks 1973, *R. acer* type of Andersen 1961).

Ranunculus trichophyllus type. Includes *R. aquatilis*, *R. baudotii*, *R. circinatus*, *R. flammula*, *R. fluitans*, *R. hederaceus*, *R. omiophyllus*, *R. ophioglossifolius*, *R. peltatus*, *R. reptans*, *R. sceleratus*, *R. trichophyllus*, and *R. tripartitus* (Andersen 1961; Birks 1973).

Rumex acetosa type. Includes *R. acetosa*, *R. acetosella*, and *R. tenuifolius*.

Sedum cf. *S. rosea*. See Birks (1973).

Silene dioica type. Includes *S. alba*, *S. conica*, *S. dioica*, and *S. noctiflora* (*Melandrium* of Andersen 1961; Birks 1973).

Silene maritima type. Includes *S. gallica*, *S. maritima*, *S. nutans*, *S. otites*, and *S. vulgaris* (Birks 1973).

Sparganium type. Includes *Sparganium* (4 spp.), *Typha angustifolia*, and monads of *T. latifolia* (Birks 1973).

Spergula arvensis. See Birks (1973).

Stachys type. Includes *Ajuga* (2 spp.), *Ballota nigra*, *Galeobdolon lutea*, *Lamium* (4 spp. excluding *L. album*), and *Stachys* (4 spp. excluding *S. arvensis*).

Stellaria type. Includes *S. alsine*, *S. graminea*, *S. media*, *S. neglecta*, and *S. nemorum*. (*Stellaria* undiff. of Birks 1973).

cf. *Veronica*. See Birks (1973) and Andersen (1961).

Vicia type. Includes *Lathyrus* (8 spp.), and *Vicia* (11 spp.).

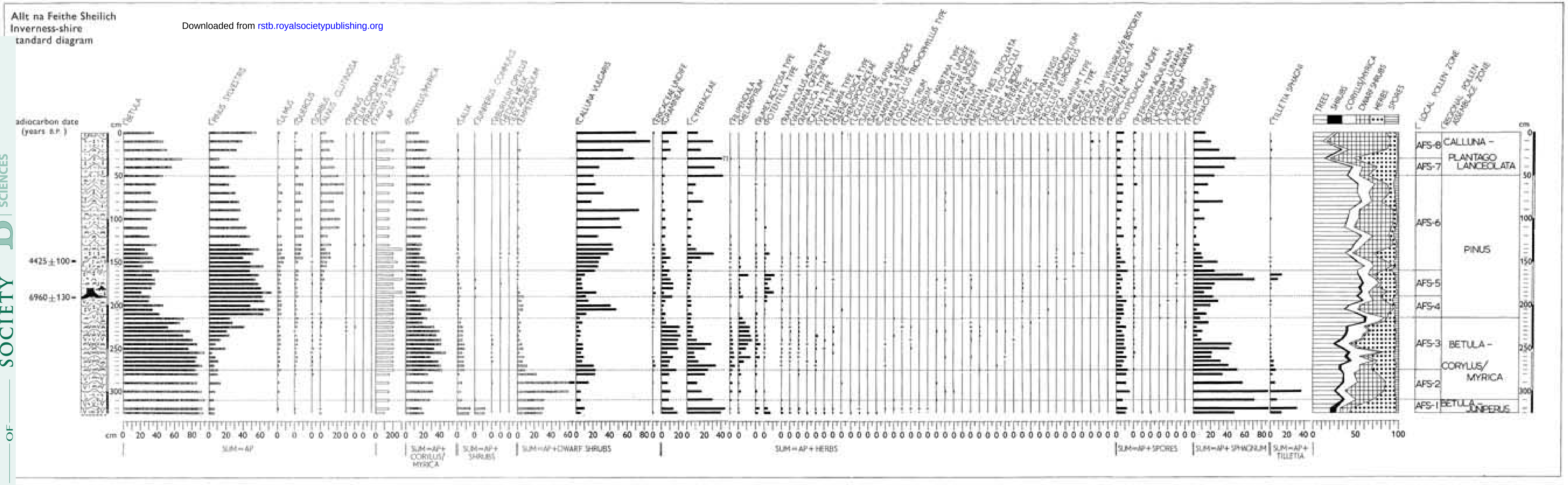

FIGURE 4. Standard pollen diagram from Allt na Feithe Sheilich, Inverness-shire. Calculation base is sum of tree pollen (AP). For the summary diagram, sum of AP + shrubs + *Corylus*/*Myrica* + dwarf shrubs + herbs + pteridophyte spores = 100%. Undiff., Undifferentiated; B.P., before present (i.e. 1950). For key to stratigraphic symbols see figure 2.

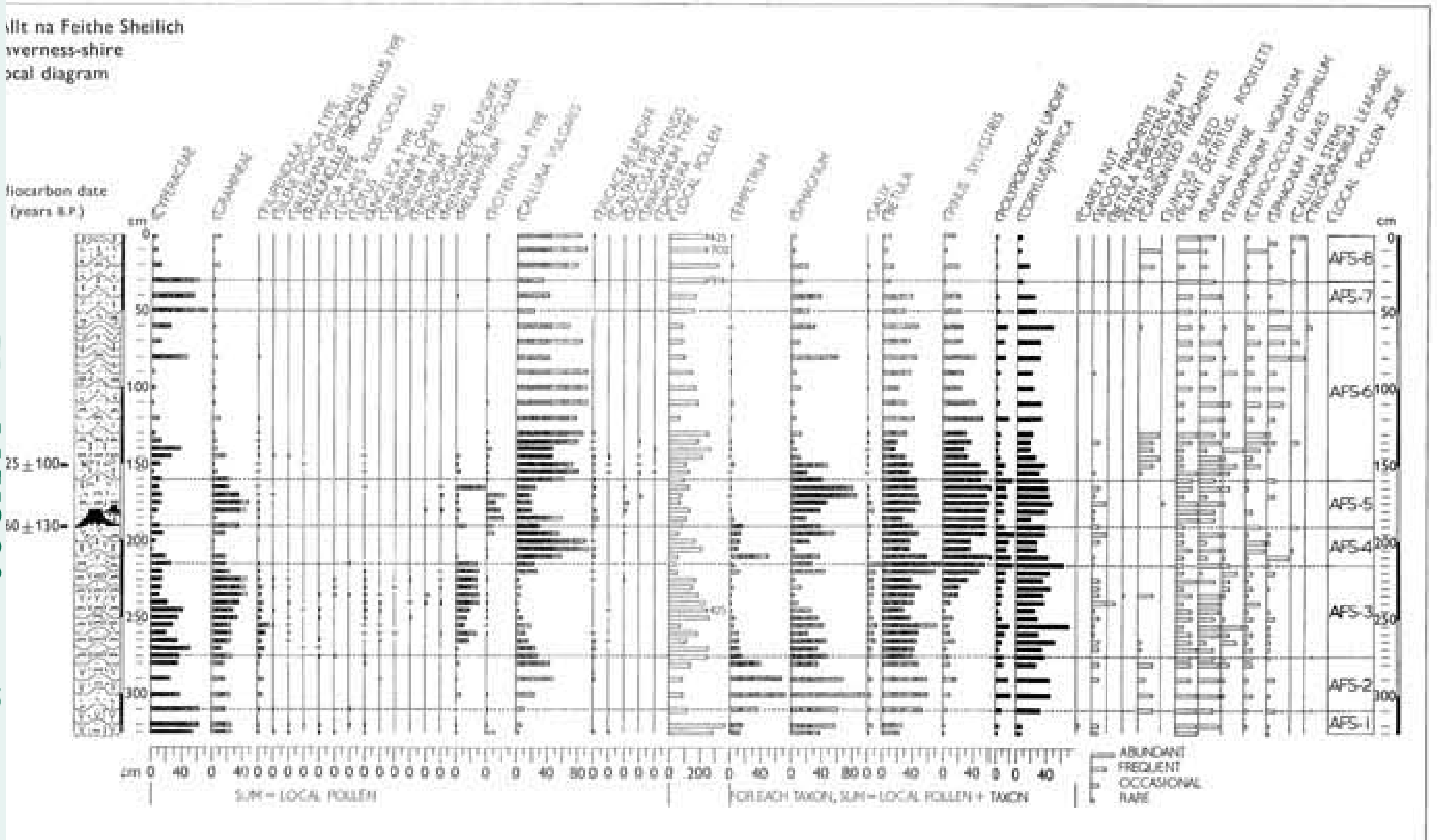

FIGURE 5. Local pollen diagram from Allt na Feithe Sheilich, Inverness-shire. Calculation base is sum of local pollen, which includes the types indicated. Abundance of macrofossils shown as white bars. Undiff., Undifferentiated. For key to stratigraphic symbols see figure 2.

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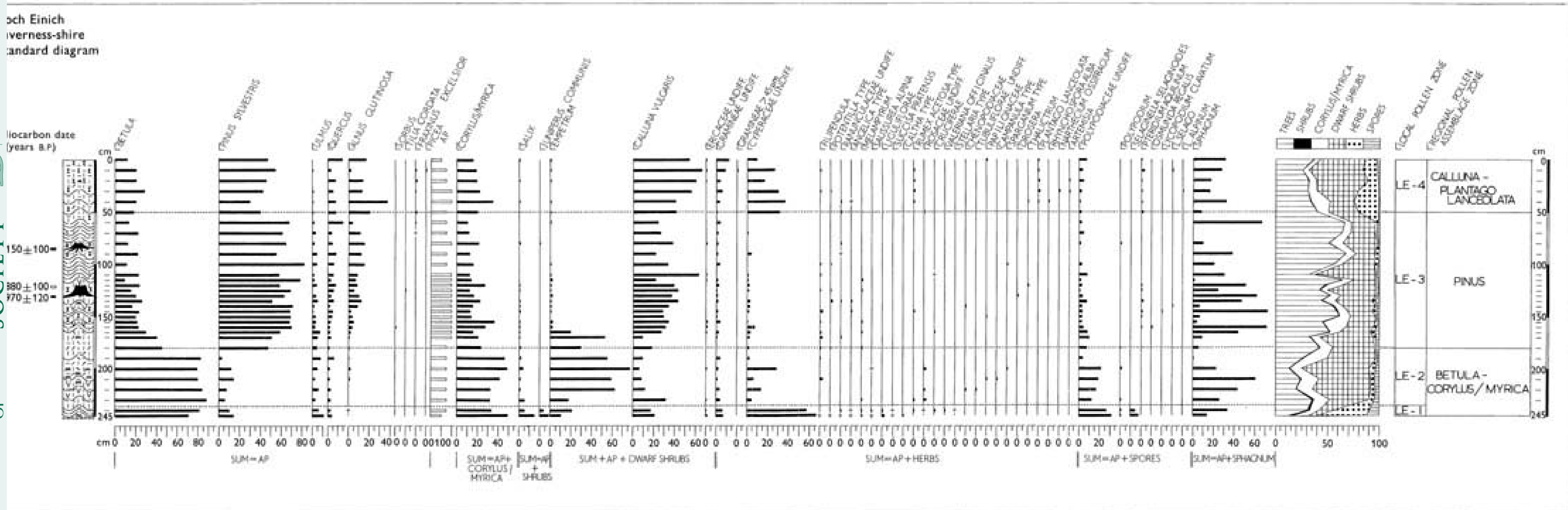

FIGURE 6. Standard pollen diagram from Loch Einich, Inverness-shire. Calculation base is sum of tree pollen (AP). For the summary diagram, sum of AP + shrubs + *Corylus/Myrica* + dwarf shrubs + herbs + pteridophyte spores = 100 %. Undiff., Undifferentiated; B.P., before present (i.e. 1950). For key to stratigraphic symbols see figure 2.

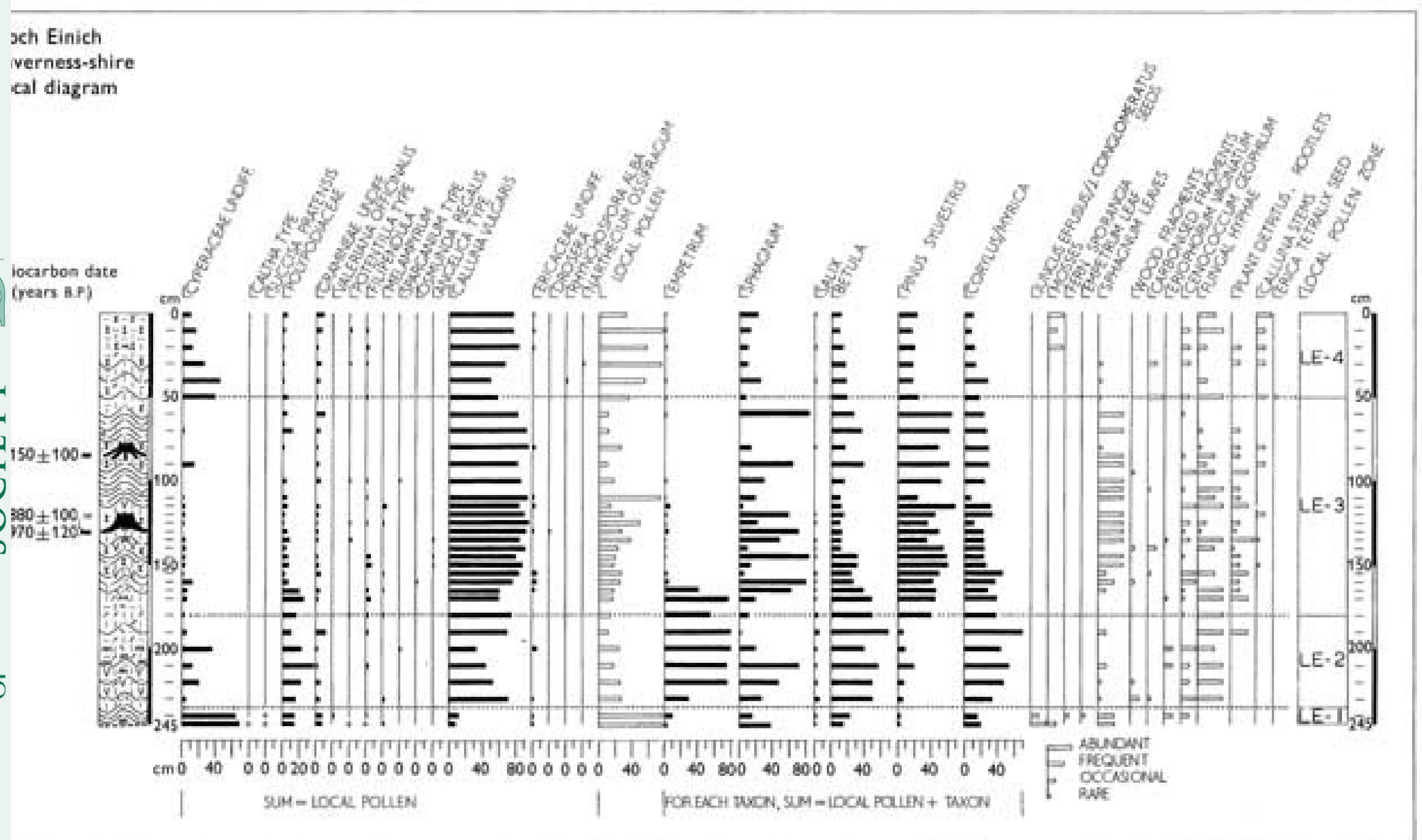

FIGURE 7. Local pollen diagram from Loch Einich, Inverness-shire. Calculation base is sum of local pollen, which includes the types indicated. The abundance of macrofossils is shown by white bars. Undiff., Undifferentiated. For key to stratigraphic symbols see figure 2.

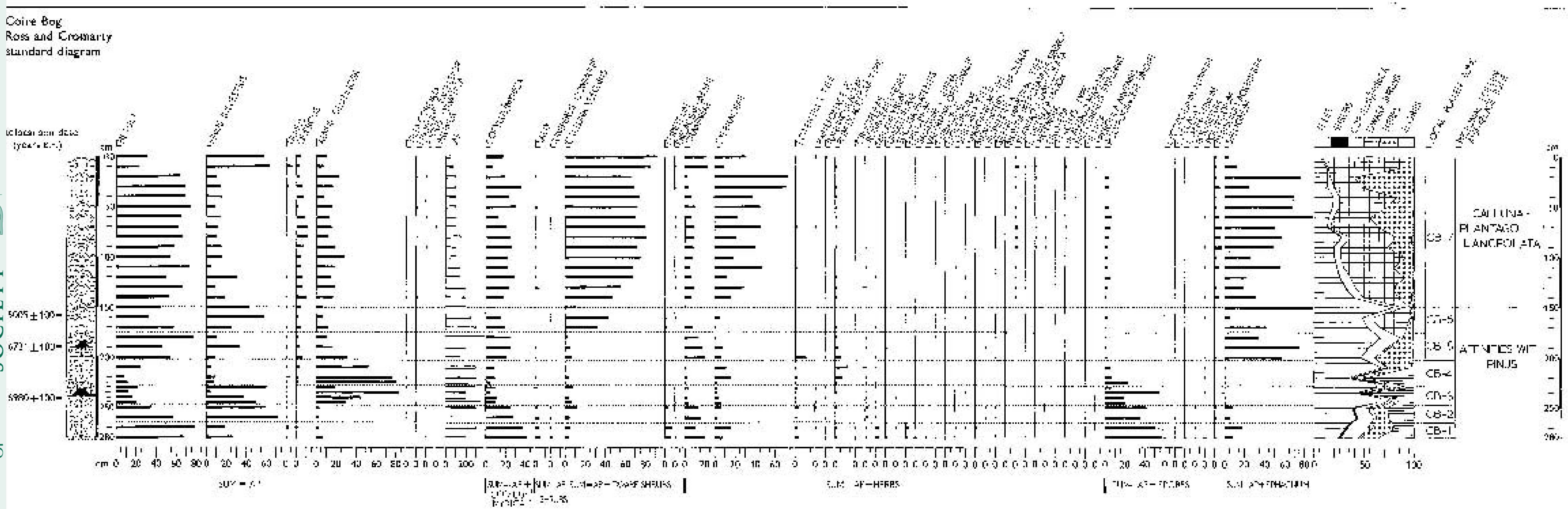

Figure 8. Standard pollen diagram from Coire Bog, Ross and Cromarty. Calculation base is sum of tree pollen (AP). For the summary diagram, sum of AP + shrubs + *Corylus*/*Myrica* + dwarf shrubs + herbs + pteridophyte spores = 100%. Undiff., Undifferentiated; B.P., before present (i.e. 1950). For key to stratigraphic symbols see figure 3.

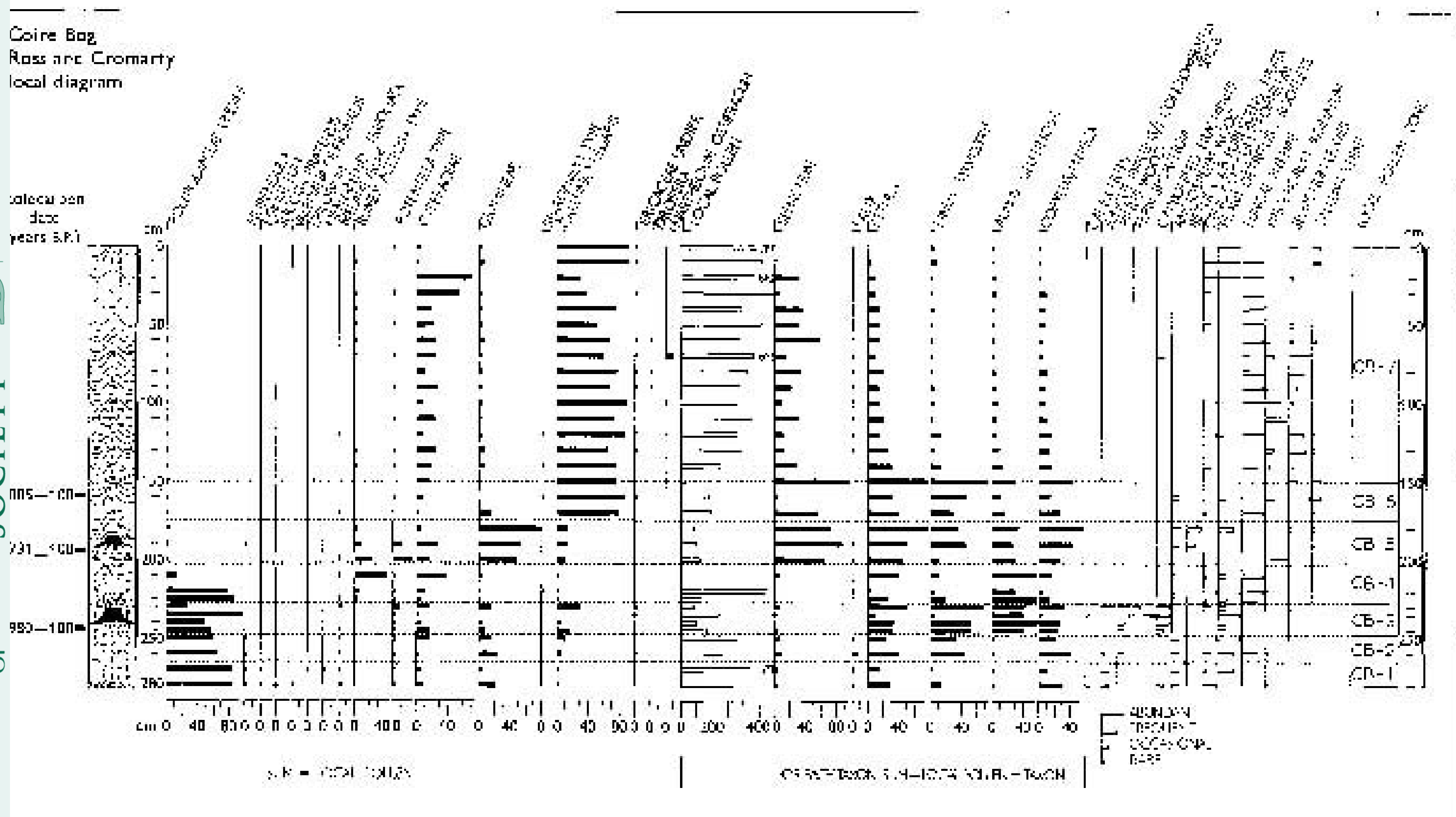

Figure 9. Local pollen diagram from Coire Bog, Ross and Cromarty. Calculation base is sum of local pollen, which includes the types indicated. The abundance of macrofossils is shown by white bars. Undiff., Undifferentiated. For key to stratigraphic symbols see figure 2.

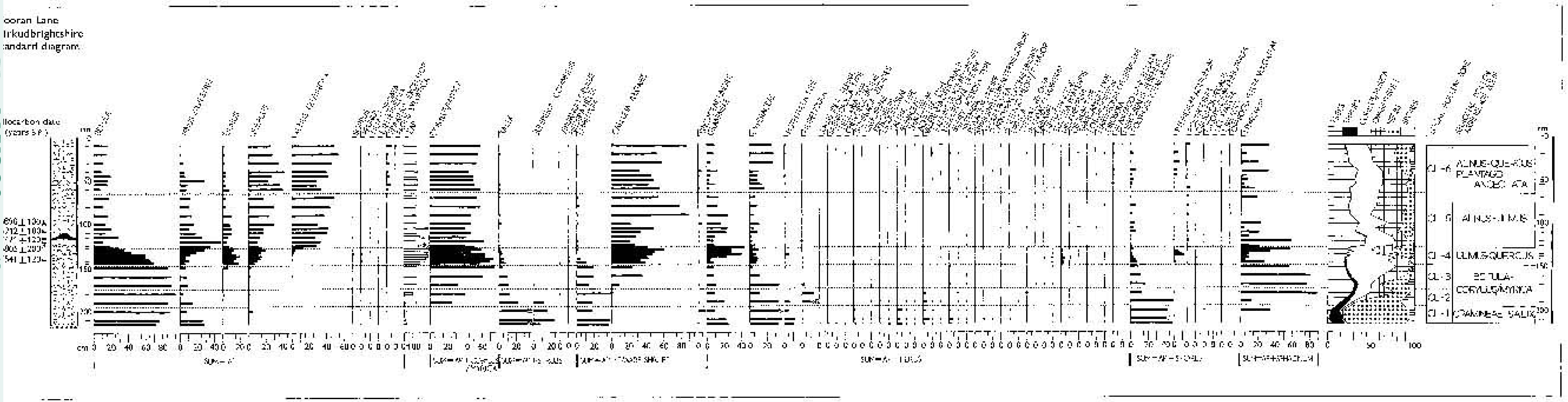

FIGURE 12. Standard pollen diagram from Cooran Lane, Kirkcudbrightshire. Calculation base is sum of tree pollen (AP). For the summary diagram, sum of AP + shrubs + *Corylus*/*Myrica* + dwarf shrubs + herbs + pteridophyte spores = 100%. Undiff., Undifferentiated; B.P., before present (i.e. 1950). For key to stratigraphic symbols see figure 2.

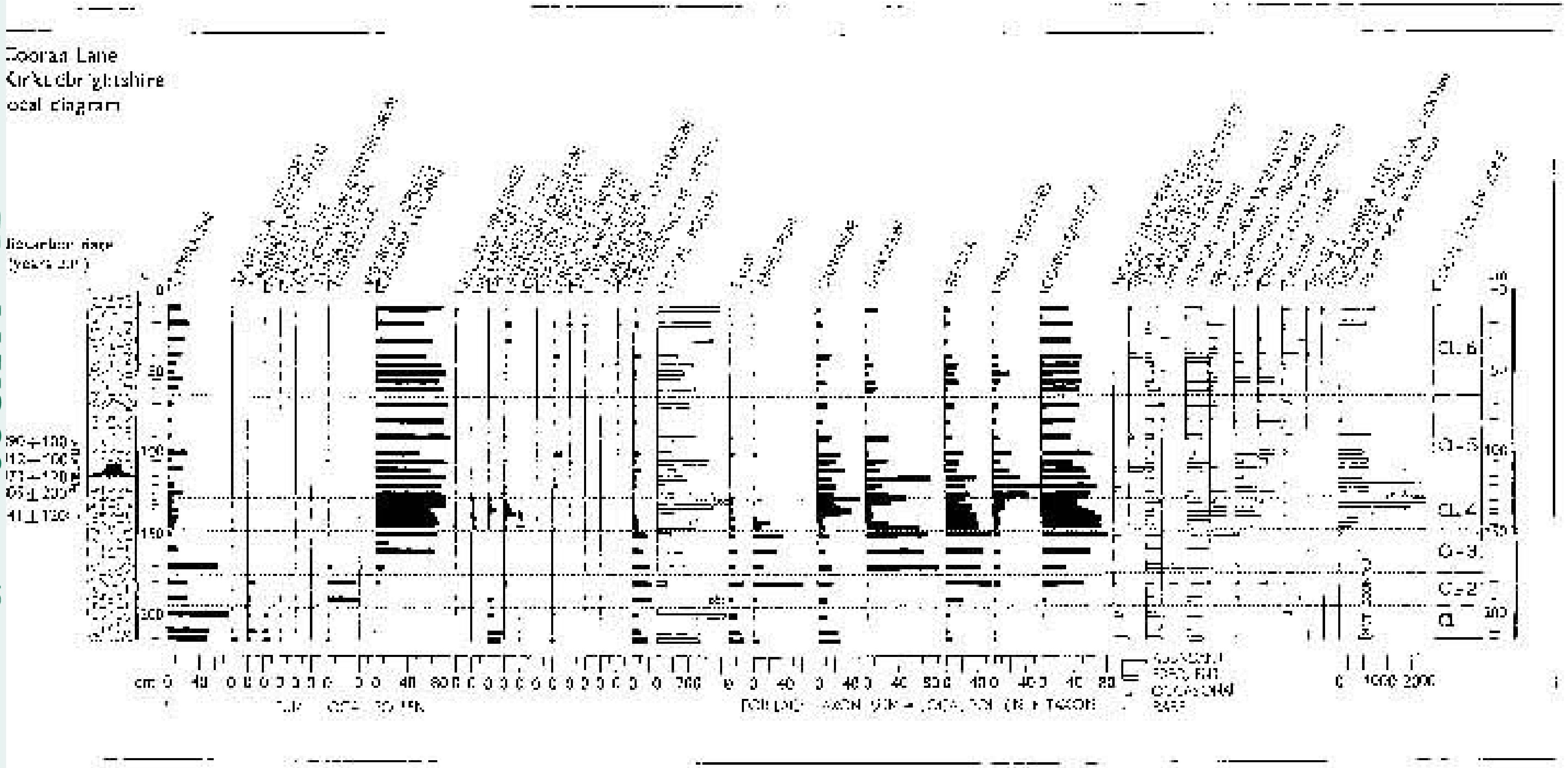

FIGURE 13. Local pollen diagram from Cooran Lane, Kirkcudbrightshire. Calculation base is sum of local pollen, which includes the types indicated. Abundance of macrofossils is shown by white bars. Undiff., Undifferentiated. For key to stratigraphic symbols see figure 2.

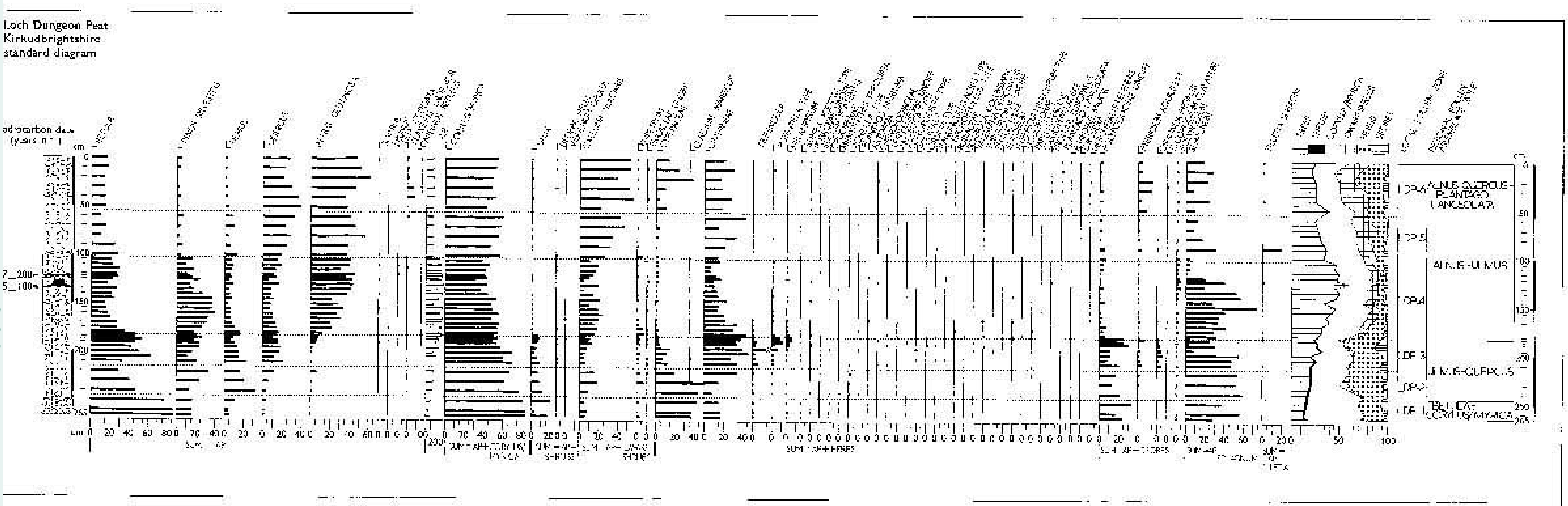

FIGURE 14. Standard pollen diagram from Loch Dungeon Peat, Kirkudbrightshire. Calculation base is sum of tree pollen (AP). For the summary diagram, sum of AP + shrubs + *Corylus*/*Myrica* + dwarf shrubs + herbs + pteridophyte spores = 100 %. Undiff., Undifferentiated; B.P., before present (i.e. 1950). For key to stratigraphic symbols see figure 2.

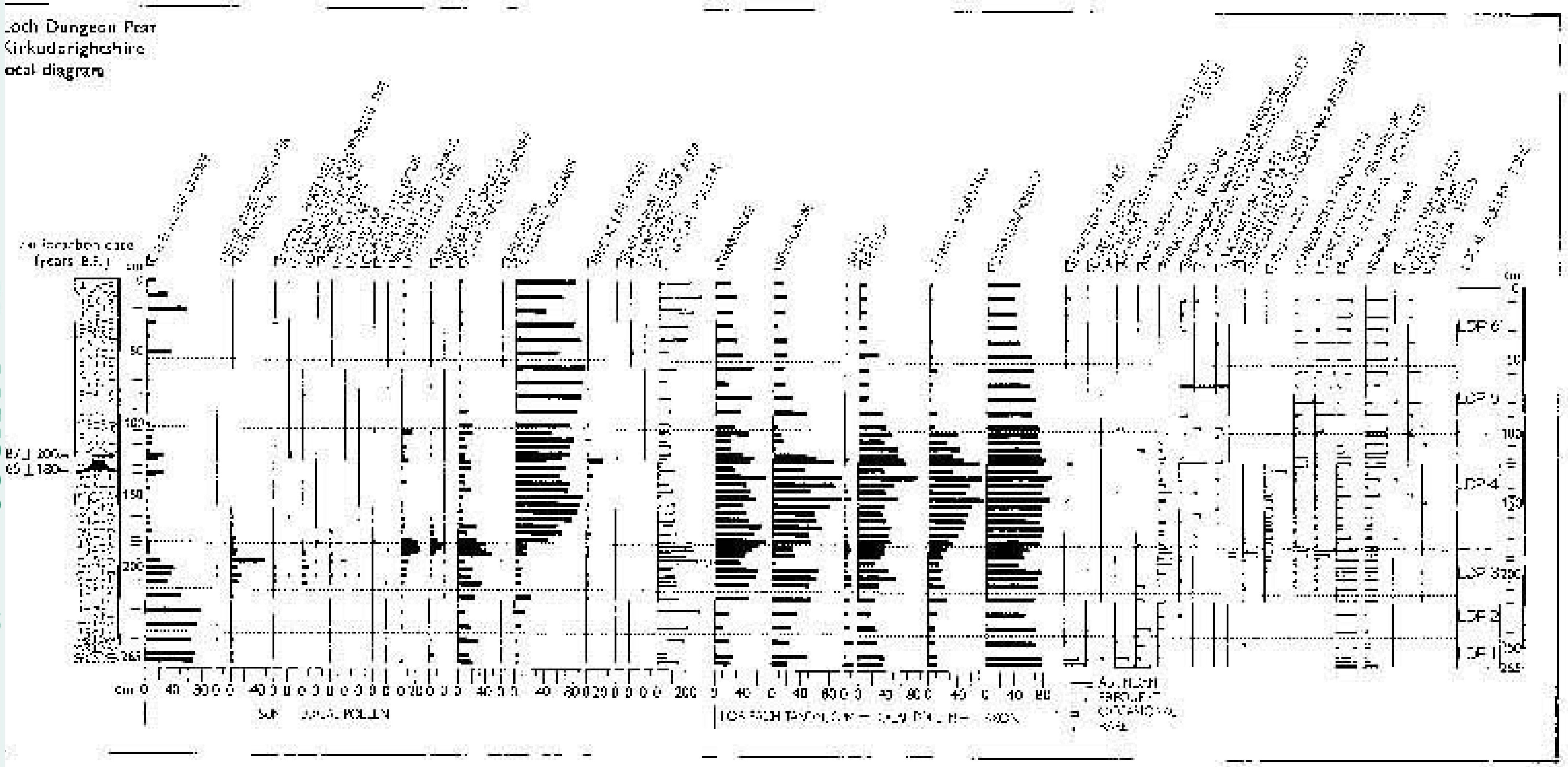

FIGURE 15. Local pollen diagram from Loch Dungeon Peat, Kirkudbrightshire. Calculation base is sum of local pollen which includes the types indicated. Abundance of macrofossils is shown by white bars. Undiff., Undifferentiated. For key to stratigraphic symbols see figure 2.

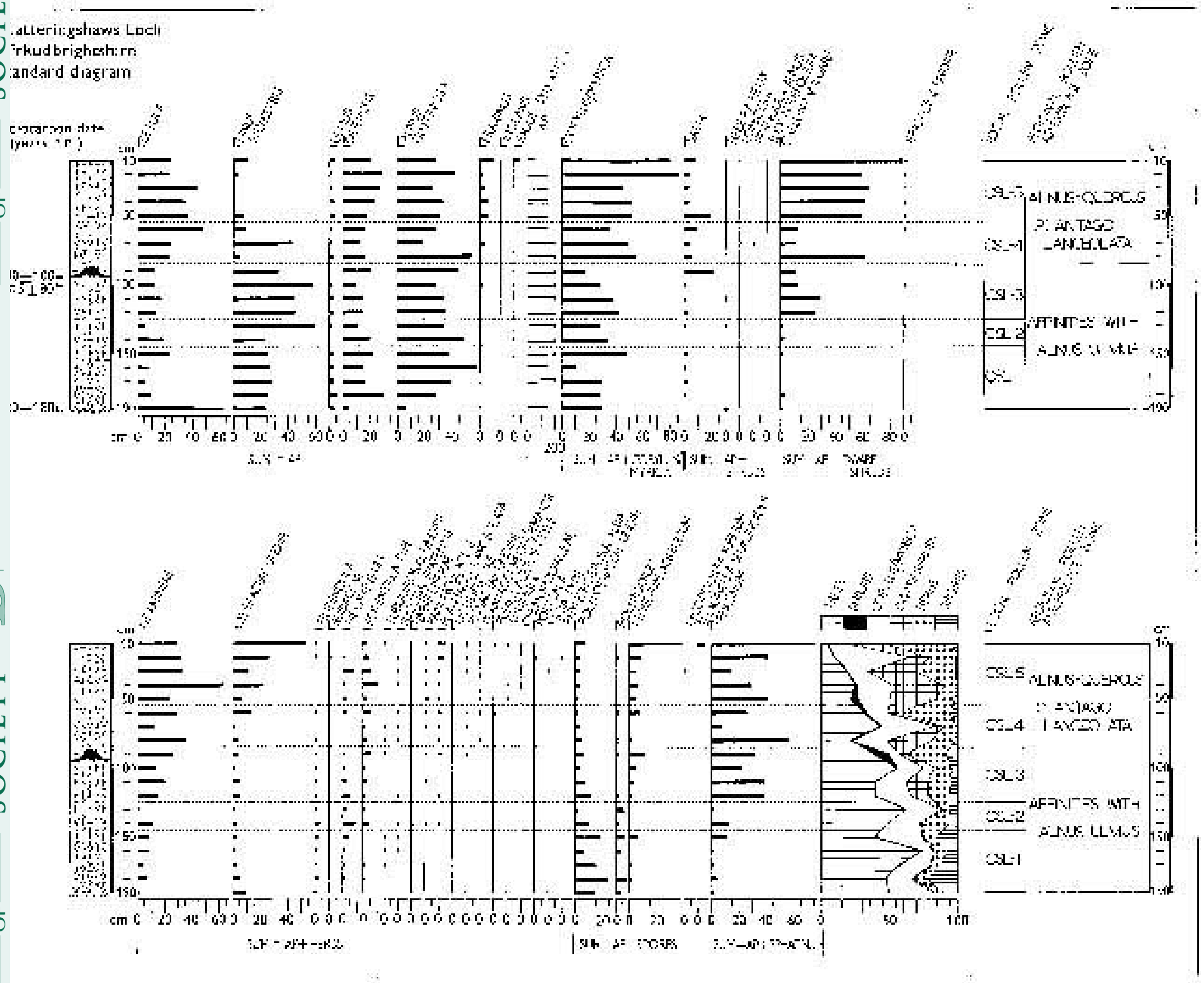

FIGURE 18. Standard pollen diagram from Clatteringshaws Loch, Kirkcudbrightshire. Calculation base is sum of tree pollen (AP). For the summary diagram, sum of AP + shrubs + *Corylus/Myrica* – dwarf shrubs + herbs – pteridophyte spores = 100%. Undiff., Undifferentiated; B.P., before present (i.e. 1950). For key to stratigraphic symbols see figure 2.

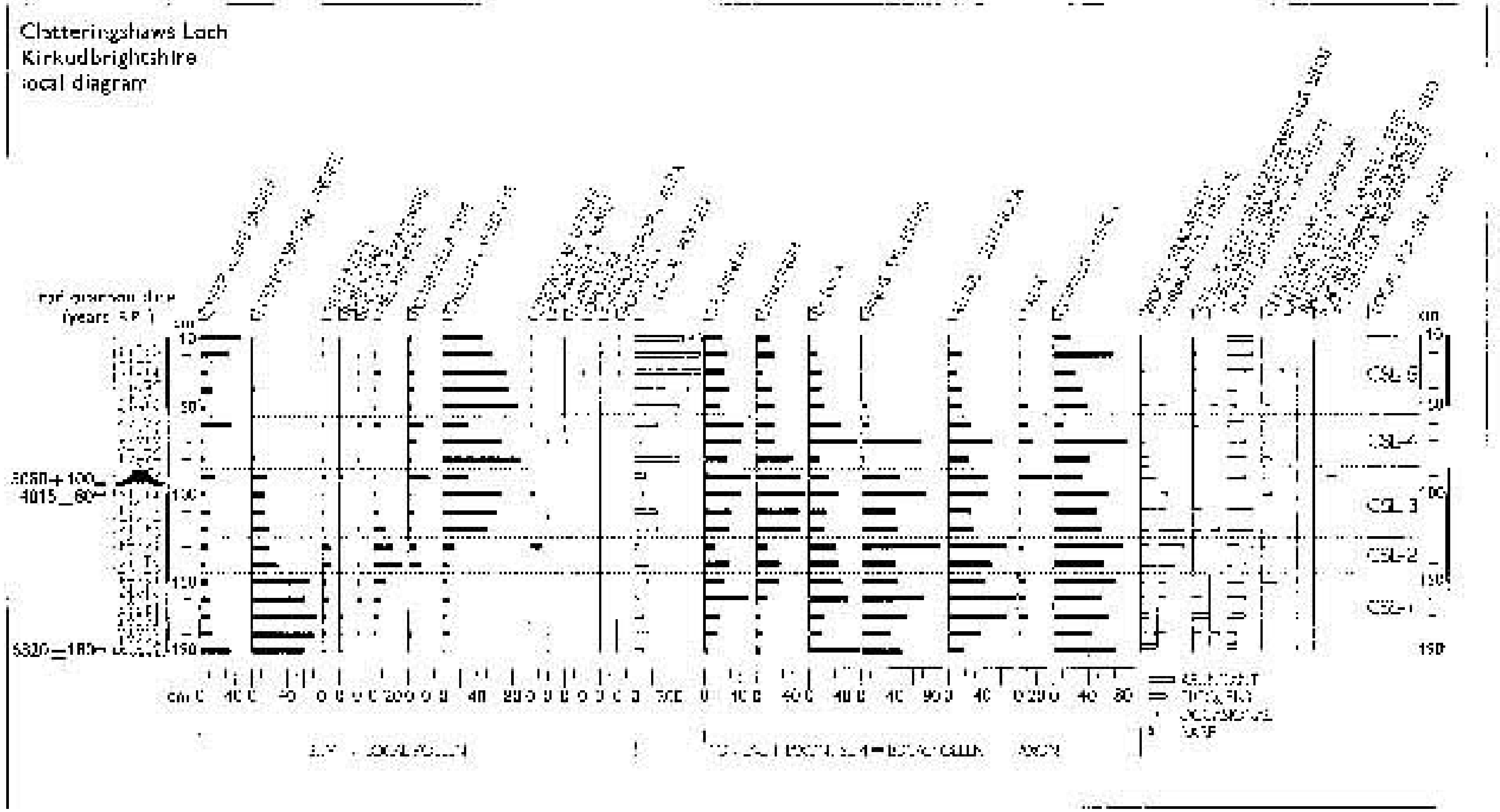

FIGURE 17. Local pollen diagram from Clatteringshaws Loch, Kirkcudbrightshire. Calculation base in sum of local pollen, which contains the types indicated. Abundance of macrofossils is shown by white bars. Undiff., Undifferentiated. For key to stratigraphic symbols see figure 2.